NAVEX: Precise and Scalable Exploit Generation for Dynamic Web Applications

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Web Applications

- **Common Characteristics**
  - Content generated on the fly to improve usability and responsiveness
  - Tasks require a series of steps to accomplish
    - e.g., online shopping: view → select → add to cart → checkout
  - Dependencies among them
- **However**
    - **Increase** application **complexity**
    - **Increase analysis difficulty**

Web Application Example

view.php → addToCart.php → checkout.php

- **How to Exploit?**
  - Find a vulnerability
  - Craft an exploit string for that vulnerability
  - Find a navigation path to the vulnerability
    - e.g.: http…view.php → http…cart.php → http..checkout.php
- **Exploit is:**

1. http://localhost../view.php?item_quant=3&item_name=book
2. http://localhost../addToCart.php?type=order
3. http://localhost.../checkout.php?delivery_desc=nothing'; DROP table TB- -&submit=yes

Problem & Challenges

- **Problem: How to automatically construct exploits for large and complex web application?**
- **Challenge #1: Scalability:**
    - Large code base consisting of hundreds of modules with large number of intra-module execution paths
- **Challenge #2: Sinks reachability:**
    - Have to derive inputs that reach ‘deep sinks’
    - Exploit input has to
        - navigate through the complex dependencies among modules
        - satisfy module and path constraints

Challenges

- **Challenge #3: Dynamic features of web applications**
  - dynamically generated content may drive the navigation of the application to vulnerable sinks
    - Forms, links, JavaScript content
- **Challenge #4: handling multiple vulnerability classes**
  - e.g., injection vulnerabilities (SQLI, XSS, etc.) and logic vulnerabilities (e.g., EAR)
  - minimal changes to the analysis

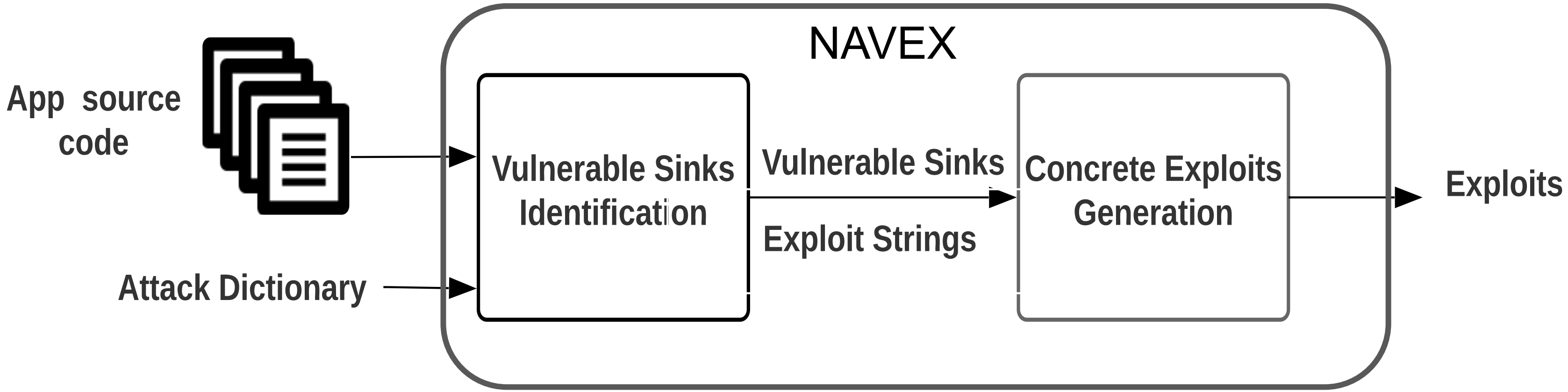
➡ **Goal: Automatic exploit generation approach that addresses these challenges**

Our Main Contribution: NAVEX, a system that has identified over two hundred exploits in modern PHP web applications

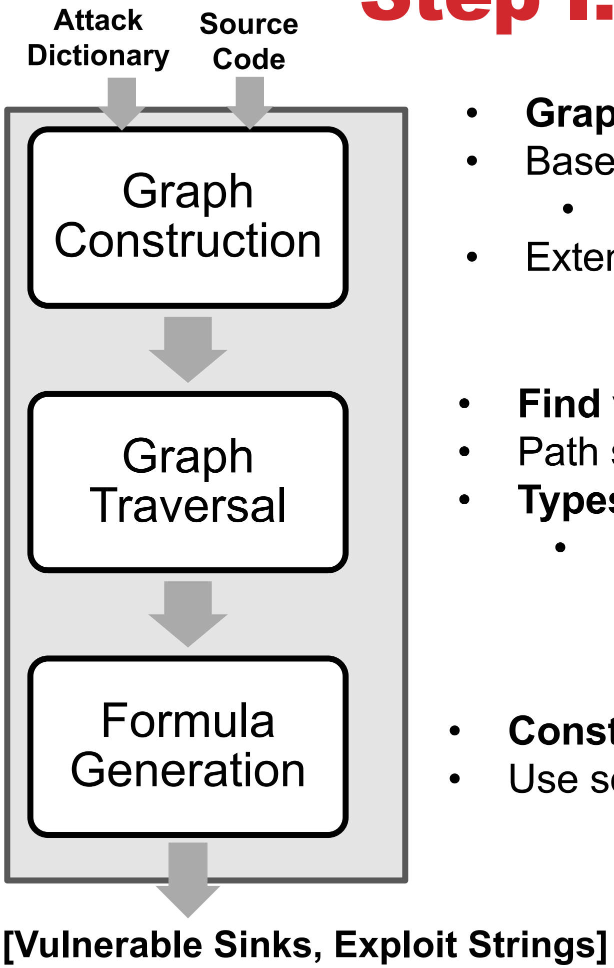
Approach Overview

- Find vulnerable sinks using static analysis methods
- Build a graph representation of navigation structure of applications dynamically
- Find navigation paths to the identified vulnerabilities
- Final exploit construction

NAVEX Architecture



Step I: Vulnerable Sinks Identification

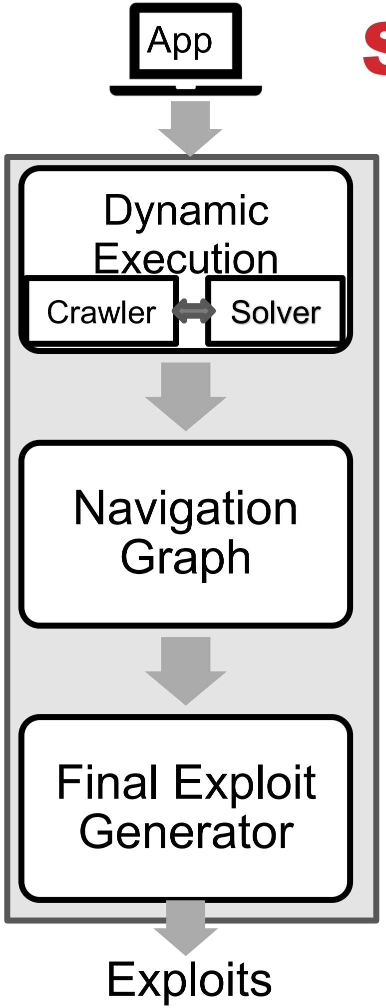


- **Graph model of source code**
- Based on Code Property Graphs (CPGs)
  - CPG = AST+CFG+ call graph+DDG
- Extend CPGs with ***sanitization* and *database constraints* tags**

- **Find vulnerable paths to sensitive sinks**
- Path sensitive analysis
- **Types: Forward** and **backward** traversals based on vulnerability type
  - E.g., **backward** search for **injection vulnerabilities**

- **Construct formulas** from **vulnerable path statements**
- Use solver to generate **exploit strings**

Step II: Concrete Exploits Generation

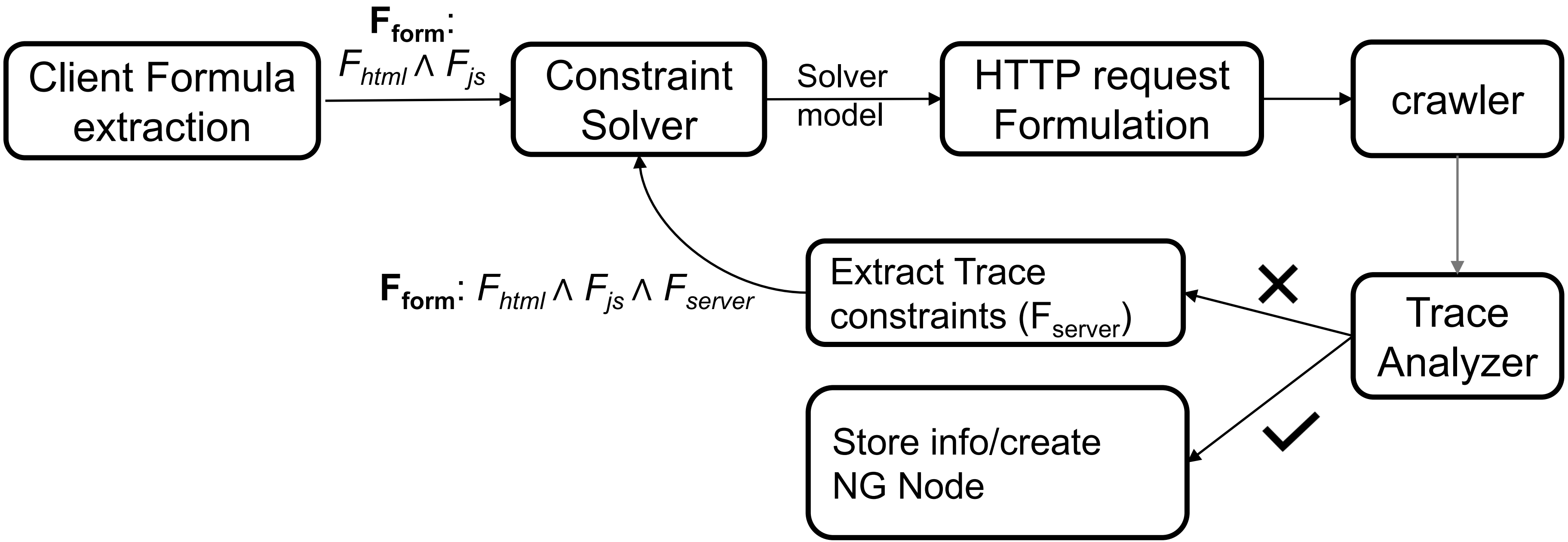


- **Links:** stored and used as new URLs to crawl
- **Forms:** Generate **form inputs automatically**
  - Extract constraints from forms
- **JavaScript :** concolic execution based on NoTamper (Bisht et al.,CCS'10)

- An **application-wide navigation graph**
  - represents possible sequences of module executions
- Directed graph
  - ***node***: HTTP request
  - **edge:** navigation between nodes (type is *link* or *form)*

- Search the NG to **find navigation paths to vulnerable sinks**

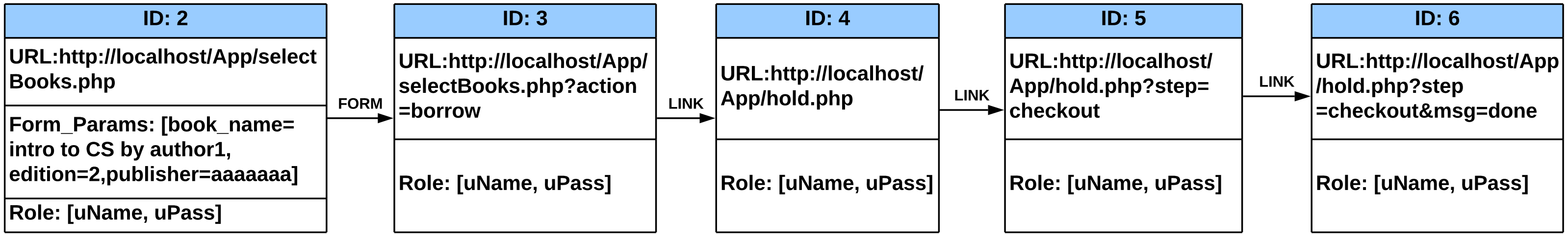
Input Generation



Combining Static & Dynamic Results

- **Example:**
  - vulnerability in **PathToApp/App/checkout.php, checkout.php is included** by **hold.php** (no direct access)
  - Navigation Graph: **no node of a URL = "….checkout.php"**
- **Problem:** combining the results produced by the step of vulnerable sink identification (static analysis) with the Navigation Graph (dynamically generated).
- **Solution: Inclusion Map**
  - Constructed statically, [Parent file -> included files]

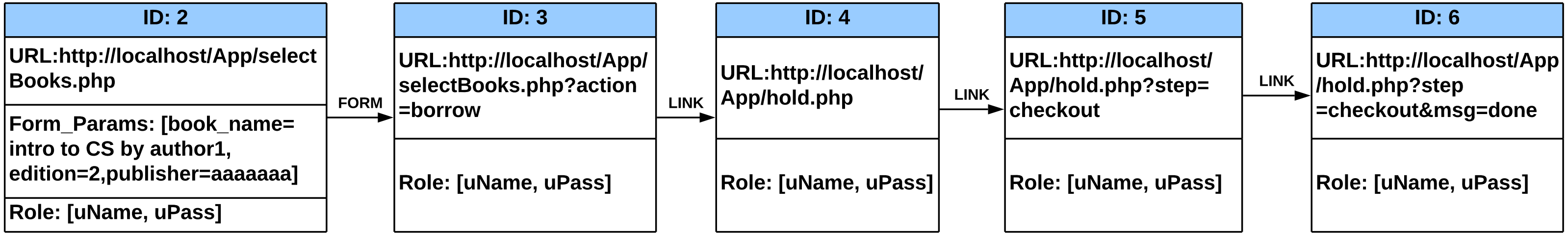
Searching Navigation Graph



- **Input :**
  - **vulnerable sink (destination URL)** = http://localhost/App/hold.php
  - **exploit string** is msg =<script>alert(”XSS”);</script> (GET)
  - **Public URL (source URL)** = http://localhost/App/selectBooks.php

- **Search Results:**
  - nodes of [id=2, id=3, id=4, id=5, id=6]
    - http://localhost/App/hold.php?step=checkout&**msg=done**
    - http://localhost/App/hold.php?step=checkout&**msg=<script>alert(”XSS”);</script>**

Final Exploit



1. **http://localhost/App/index.php**
2. **http://localhost/App/selectBooks.php**

   POST params:[book name=intro to CS by author1, edition=2,publisher=aaaaaaa]
3. **http://localhost/App/selectBooks.php?action=borrow**
4. **http://localhost/App/hold.php**
5. **http://localhost/App/hold.php?step=checkout**
6. **http://localhost/App/hold.php?step=checkout&msg=<script>alert(”XSS”);</script>**

EVALUATION

Dataset

- **26 real-world** open-source **PHP** web applications
- Total of **3.2M SLOC** and **22K PHP files**
- Applications selection criteria
  - **Popular and large** PHP apps
    - Such as **WordPress**, **OpenConf, HotCRP, Drupal, Gallery, Joomla, LimeSurvey, Collabtive**, and **MediaWiki**
  - **Comparison** with **state-of-the-art work** in exploit generation (e.g., Chainsaw (Alhuzali et al., CCS'16)) and vulnerability analysis (e.g., RIPS (Dahse and Holz, NDSS'14))

Results Summary

- NAVEX constructed a total of **204 exploits**
  - **195** are on **injection vulnerabilities (SQLI and XSS)**.
  - **9** are on **logic vulnerabilities (EAR).**
- The **enhanced CPG reduced FPs by 87%** on average.
- **Client-side code analysis** for building the navigation graph **enhanced the precision of exploit generation by 54%** on average.
- Drill down **as deep as 6 HTTP requests** to stitch together **exploits.**

SQLI Exploits

- Reported **155 SQLI exploitable sinks**
- **No false positives**
- Constructed **105 concrete SQLI exploits**
- **Vulnerable** web apps
    - **osCommerce (2.3.3)**
    - **phpBB (2.0.23)**
    - **myBloggie, Scarf, Dnscript, WeBid, Eve, SchoolMate, geccbblite, FAQforge, and WebChess**

XSS Exploits

- Found **133 XSS exploitable sinks**
- 5 false positives
- Generated **90 XSS exploits**
- **Vulnerable** web apps
  - **HotCRP (2.60)**
  - **osCommerce (2.3.4)**
  - **osCommerce (2.3.3)**
  - **CPG**
  - **MediaWiki**
  - **phpBB (2.0.23)**
  - **myBloggie, Scarf, Dnscript, WeBid, Eve, SchoolMate, FAQforge, and WebChess**

EAR EXPLOITS (LOGIC EXPLOITS)

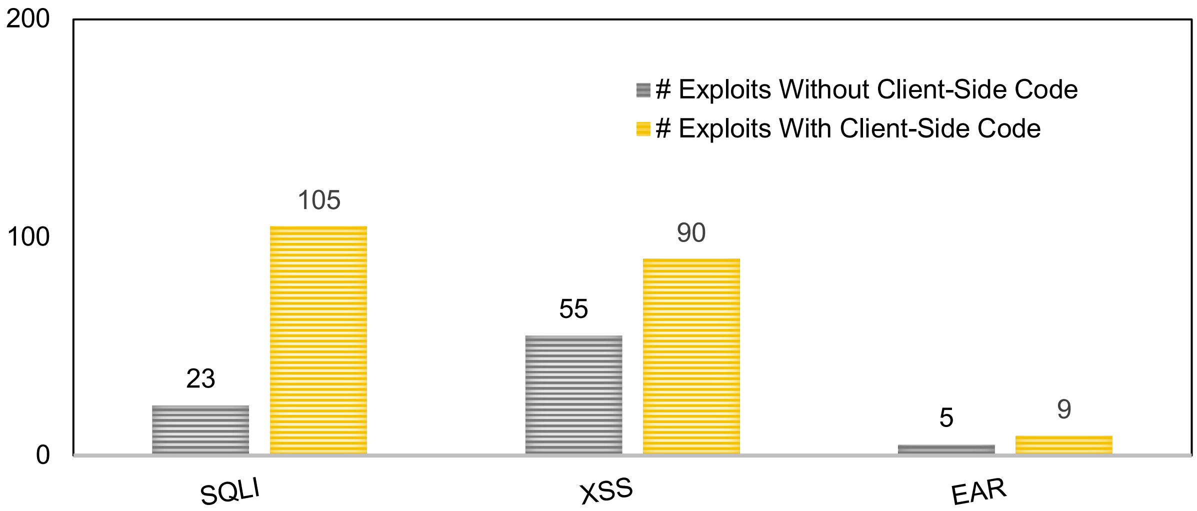
- Found **22 EAR** vulnerabilities
- 3 false positives
- Generated **9 EAR exploits**
- **Vulnerable** web apps
  - **HotCRP (2.100)**
  - **HotCRP (2.60)**
  - **OpenConf**
  - **osCommerce (2.3.4)**
  - **osCommerce (2.3.3)**
  - **LimeSurvey**
  - **Collabtive**
  - **MediaWiki**
  - **myBloggie, WeBid**, and **Eve**

Performance and Scalability

- **Performance**: **total time** to **find exploitable sinks** and to **generate exploits** per vulnerability type.
  - **Vulnerability identification** from **17.28** to **109.27** minutes.
  - **Exploit generation** from **1.38** to **40.20** minutes.

Effect of Client-side Code Analysis

- **Forms are common**
  - **Number of unique forms** ranges from **3 to 186** (average of 45 form/application).
- **Input generation and constraints extraction from client-side code → improve the crawling coverage.**
- **NAVEX constructed more exploits.**



Conclusion

- NAVEX is an automatic exploit generation system that considers
  - **dynamic features** and **the navigational complexities** of modern web applications
- NAVEX constructed **204 exploits**
  - **195** are on **injection vulnerabilities**
  - **9** are on **logic vulnerabilities**
- **Outperform prior work** on the precision, efficiency, and scalability of exploit generation.

THANK YOU FOR YOUR ATTENTION
QUESTIONS?

NAVEX is available at
https://github.com/aalhuz/navex

GitHub

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