Vulnerability Detection in Source Code via Subgraph Isomorphism Analysis

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ABSTRACT

Vulnerability detection is crucial for ensuring, the security, reliability, and privacy of software systems. By representing **source code as a property graph**, where nodes represent code elements and edges represent relationships between them, we are able to perform a comprehensive vulnerability assessment. With the source code represented as a graph, we can leverage graph-based algorithms, and machine-learning techniques to identify potential vulnerabilities. In this study, we introduce two things: a **novel graph representation** of source code based on the **Abstract Syntax Tree (AST)** and a novel approach to **estimating subgraph isomorphism**. We demonstrate the effectiveness of using graph analysis of source code for vulnerability detection. It indicates that such methods can be particularly valuable for **detecting well-understood and documented vulnerabilities**.

RELATED WORK

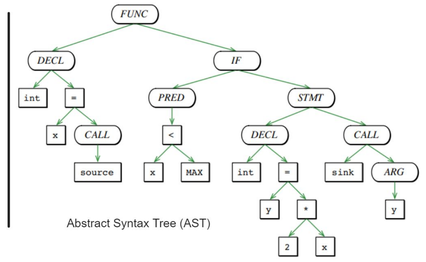
The research paper titled "Modeling and Discovering Vulnerabilities with Code Property Graphs" by Fabian Yamaguchi et al. [1] presents a **novel method for representing source code known as a code property graph**. This graph consolidates traditional program analysis concepts into a single data structure. While effective, this approach may face **scalability issues** when dealing with large code bases. In the paper "Abstracting Program Dependencies using the Method Dependence Graph" by Haipeng Cai et al. [2], a new dependence abstraction called the **method dependence graph (MDG)** is introduced. It **approximates the traditional fine-grained software dependence model** at the method level. "Source Code Vulnerability Detection: Combining Code Language Models and Code Property Graphs" by Ruitong Liu et al. [3] proposes a **unified model combining pre-trained code language models with code property graphs for vulnerability detection**. However, this method might **underestimate code semantics** and encounter challenges capturing long-distance contextual information. The work on "Source Code Vulnerability Detection Using Deep Learning" [4] focuses on **static security vulnerability detection** in C# code using **deep learning algorithms**. Lastly, "An Analytical Review of the Source Code Models for Exploit Analysis" [5] investigates a new approach for detecting vulnerabilities that can be **exploited in cyber attacks**.

ABSTRACT SYNTAX TREE

An **Abstract Syntax Tree (AST)** represents the **structure of a program** in a tree format. Each node in the tree represents a part of your code. For example, a function could be a parent node, and the statements inside that function could be its children. It's called **"abstract" because it simplifies the code** by leaving out some details like punctuation and brackets. ASTs are used in many areas of computer science, such as compilers and code analysis tools.

```
void foo()
{
    int x = source();
    if (x < MAX)
    {
        int y = 2 * x;
        sink(y);
    }
}
```

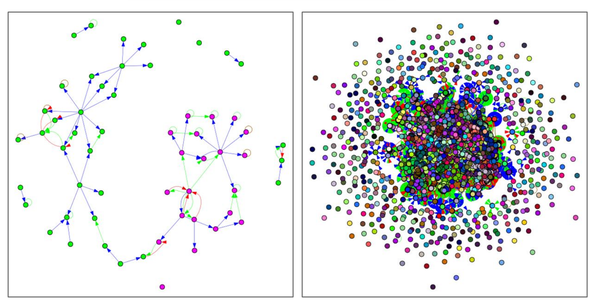
Source Code



Abstract Syntax Tree (AST)

GRAPH REPRESENTATION

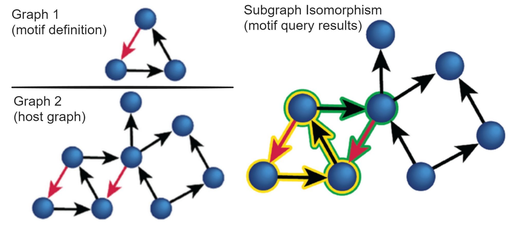
1. **Graph nodes = Classes/Functions**
2. **For each node:**
   a. **Get edges**
      i. **Child (node defined "under" it)**
      ii. **Call (node that it "calls")**
      iii. **Return (if node explicitly returns, then edge to match each 'Call' to it)**
   b. **Build node "profile" for each node**
      i. **Whether *CLASS* or *FUNCTION***
      ii. **Whether is *ASYNCHRONOUS***
      iii. **Whether explicitly *RETURNS***
      iv. **Number of *PARAMETERS***
      v. **Number of *CALLS***
      vi. **Number of *CHILDREN***



Extracted graphs from files of the 'Torch' package colored by file. Left is 2 arbitrary files, right is the entire package.

SUBGRAPH ISOMORPHISM (SI)

Subgraph isomorphism is a concept in **graph theory** that deals with the **structural relationship** between two graphs. Two graphs are considered **isomorphic** if there is a **one-to-one correspondence** between their vertices and edges that preserves the connectivity of the graphs. A graph G is a **subgraph isomorphic** to another graph H if a subgraph of H is isomorphic to G. This means there's a way to **map each vertex in G to a unique vertex in H** and each edge in G to a unique edge in H, **preserving connectivity**.



Graph 1: smaller graph that defines structure to look for. **Graph 2:** larger graph that defines structure to look over. **Results:** Set of subgraphs of Graph 2 that are isomorphic Graph 1.

SI ESTIMATION

Given **profile embeddings** for each node in the graph, we can **calculate distances** between nodes in Graph 1 and Graph 2. We then create a **ranking of node correspondence candidacy** for all pairs of nodes. Using these lists, we generate unique node-to-node correspondences and **evaluate their connectivity**. These checks can be **parallelized**, but we compute a **bounded solution** due to the lack of guaranteed results with large graphs.

Compute node profile distances

For each motif node profile C versus host node profile A.

C = [0, 0 , 0, 0, 2, 4] **A = [1, 0 , 1, 0, 0, 1]** **A = [0, 0 , 0, 0, 7, 16]**

i. 1 for each of first three not equal

A = [1, 0 , 1, 0, 0, 1] **A = [0, 0 , 0, 0, 7, 16]**

ii. Euclidean for last three

A = [1, 0 , 1, 3.60555…] **A = [0, 0 , 0, 13]**

iii. Normalize Euclideans (let max = 87.057…)

A = [1, 0 , 1, 0.04140…] **A = [0, 0 , 0, 0.14932…]**

iv. Matrix multiplication w/ weights (let weights = [0.5, 0.1, 0.1, 0.3])

A = 0.61242… **A = 0.04479…**

Therefore results "distances" are 0.61242… and 0.04479…

Node Correspondence Combination

Component nodes

0 1 2 3 4 5 6 7 8 9 10

Application candidate nodes

47 48 49 50 51 52 53 54 55 56 57

Connectivness Evaluation

A47 as C0: matches 100% each specified by component

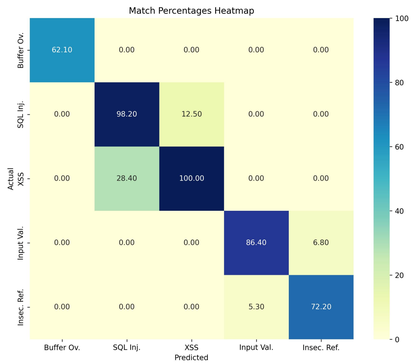
46,347:call
48,47:call → 1,0:call
47,48:return → 0,1:return
73,47:call
47,73:return

MITRE CWE & CVE

MITRE's Common Weakness Enumeration (CWE) is a community-developed list of common software weaknesses. **MITRE's Common Vulnerabilities and Exposures (CVE)** is a list of known security vulnerabilities.

RESULTS

We created a **motif** graph for **five classic vulnerability** types defined under CWE. Then, the same **vulnerability is inserted** somewhere in a **larger code file**, and host graphs are created. Each host graph is then **checked for the presence of each motif**, and only the best-found result above at least 5% match is reported.



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