PAVUDI:
Patch-based vulnerability discovery using Machine Learning

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Introduction

Vulnerability Discovery

- Classical Static Vulnerability Detection
  - Manually crafted rules
  - Often high false positive rate
  - For example
    - Flawfinder, CPPCheck
    - Coverity, Clang Analyzer

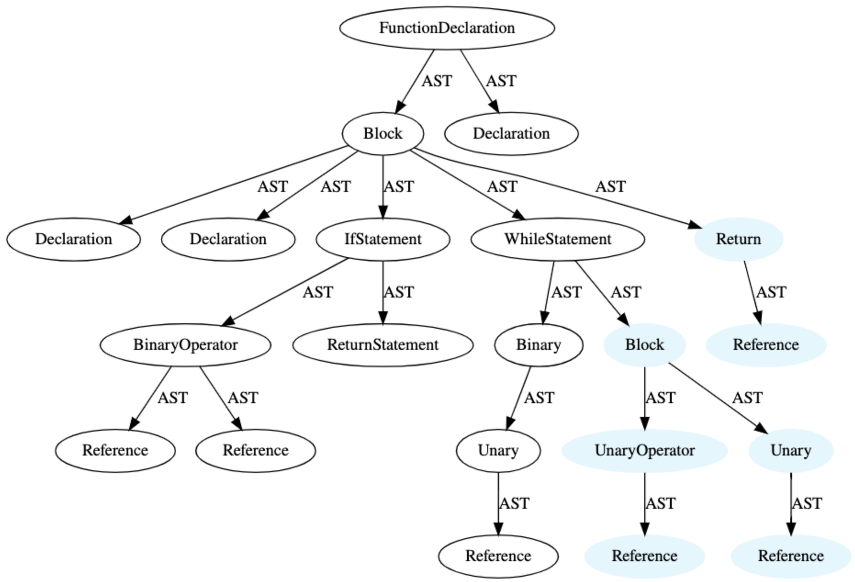
- Definition of a Vulnerability Detector

A method for **static vulnerability discovery** is a decision function $f : x \mapsto P(\text{vuln} \mid x)$ that maps a piece of code x to its probability of being vulnerable.

Learning-based Vulnerability Discovery

```
...
value = *name;
value <<= 5;
if (len > 10) {
    value += name[len - (plen + 1 + 1)];
...
```

- Learning-based Static Vulnerability Detection
  - – Learns rules
  - – Requires dataset
  - – Adjustable threshold
  - – Representation learning



- Definition of a Learning-based Vulnerability Detector

A static **learning-based vulnerability discovery method** is a parametrized hypothesis function $f_\theta : x \rightarrow P(vuln|x)$ that extracts a representation x and maps it to a probability of being vulnerable.

Problem Setting

- Apply vulnerability detector on each patch (CI/CD)
- Problems with patches:
  - Context-sensitive changes
  - Non-coherent changes
  - Evolution of Software

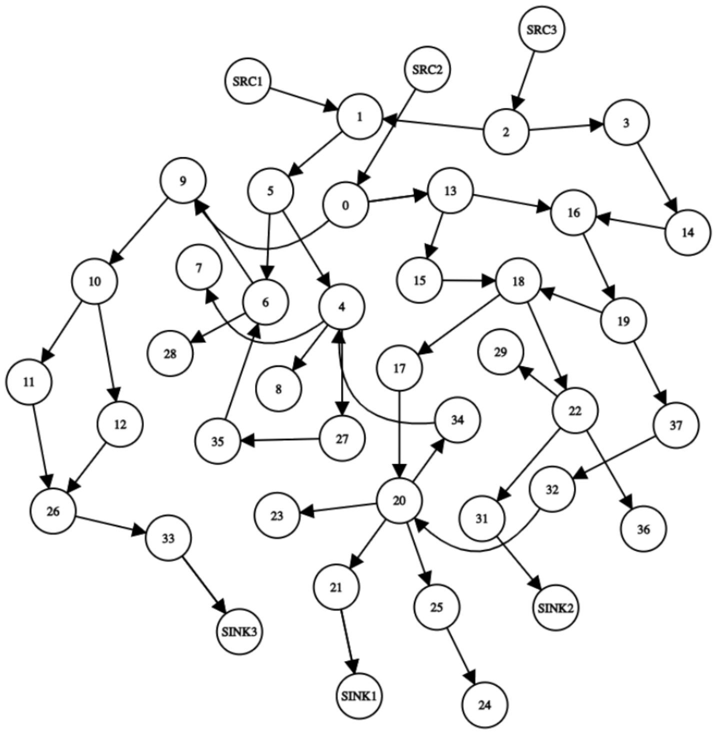
- Example: Heartbleed Bug
- Commit introducing the bug:
  - Touches 12 Files
  - 5 Header Files
  - In 2 different packages

```c
if (hbtype == TLS1_HB_REQUEST)
    {
    unsigned char *buffer, *bp;
    int r;

    /* Allocate memory for the response, size is 1 byte
     * message type, plus 2 bytes payload length, plus
     * payload, plus padding
     */
    buffer = OPENSSL_malloc(1 + 2 + payload + padding);
    bp = buffer;

    /* Enter response type, length and copy payload */
    *bp++ = TLS1_HB_RESPONSE;
    s2n(payload, bp);
    memcpy(bp, pl, payload);
```

Naive Solution

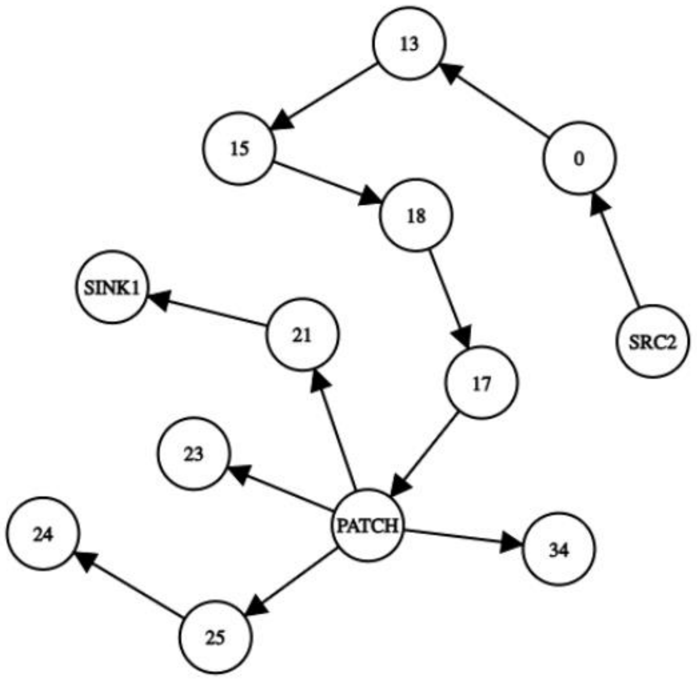
Use Existing Learning-based Discovery Methods:

- Feed them Inputs with Patch Context
- Problem: Feature Space explodes



Better Idea:

- Identify security relevant Paths
- Only consider those intersecting Changes



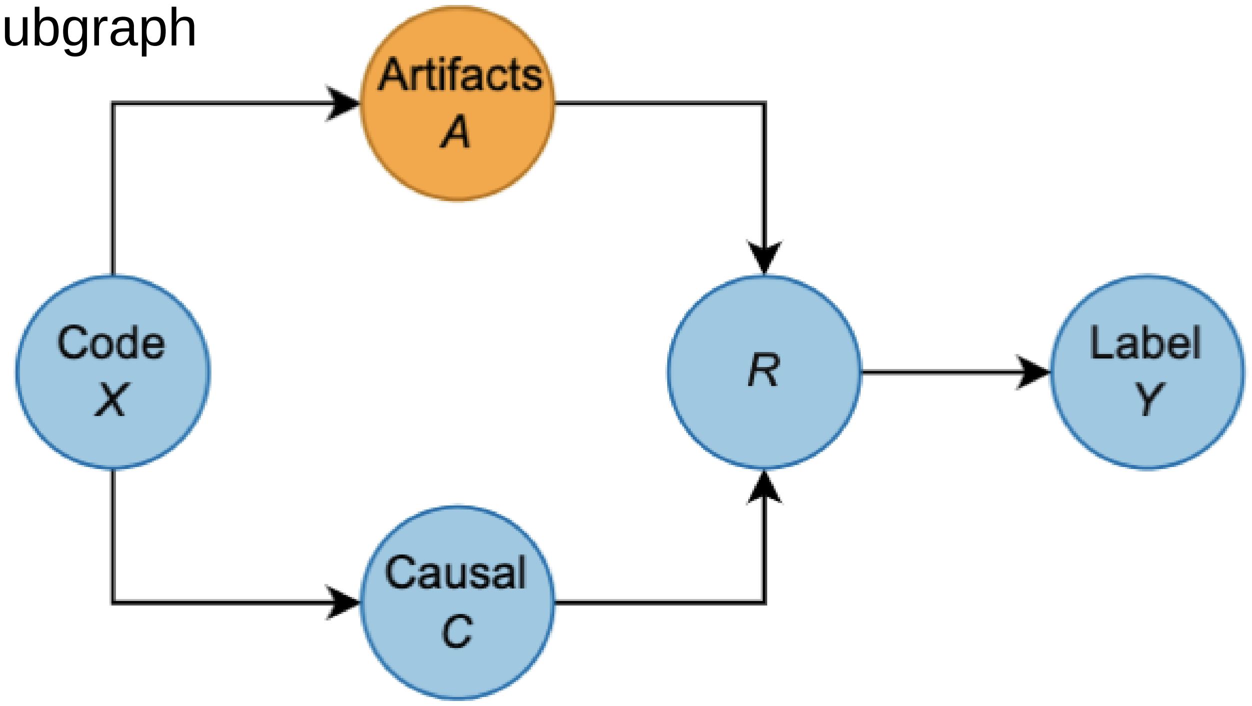
Methodology

Representation

1. Obtain composite code graph
2. Insert call edges
3. Insert interprocedural data flow
4. Perform value-set analysis
5. Create security-relevant slices

Causal Graph Neural Network

- Graph separated into Artifacts and causal Subgraph
- Separation learned by network
- Prediction only on causal Subgraph



Training dataset

- Previous datasets contain only vulnerability-fixing patches
- We try to find vulnerability-introducing patches
  - Very difficult to collect
- Instead: Find patches that touch vulnerable code
  - From vulnerability-fixing patches, go back in time
  - Patches on same methods are vulnerable
  - Patches on other methods are assumed to be clean

Experiments

Research Questions

- RQ1 How do other strategies compare to PAVUDI?
- RQ2 How does the size of a commit affect the performance?
- RQ3 How does PAVUDI behave after training and deployment?
- RQ4 How do the individual components of PAVUDI contribute to the detection capability?

Model Baselines

- Learning-based Graph Vulnerability Detectors
  - DeepWuKong
  - ReVeal
  - Devign
  - BGNN4VD
- Learning-based Token Vulnerability Detectors
  - SySeVR
  - VulDeePecker
- Heuristics-based Vulnerability Detector
  - VUDDY

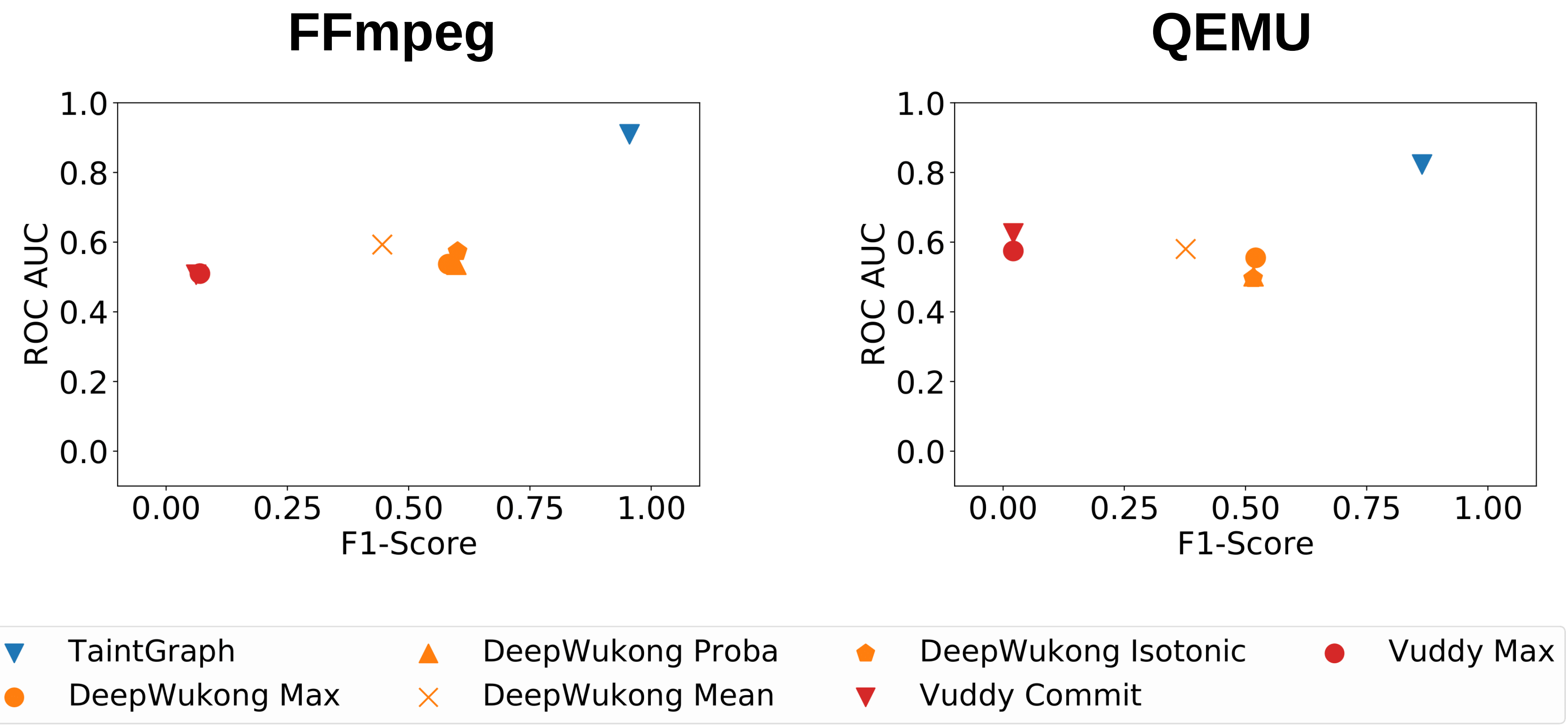
Not Applicable to Patches!

Application Strategies

Apply Models to Fragments of the Patch and aggregate prediction score

- Max
- Mean
- Probability
- Isotonic
- Commit

RQ1 How do other strategies compare to PAVUDI?



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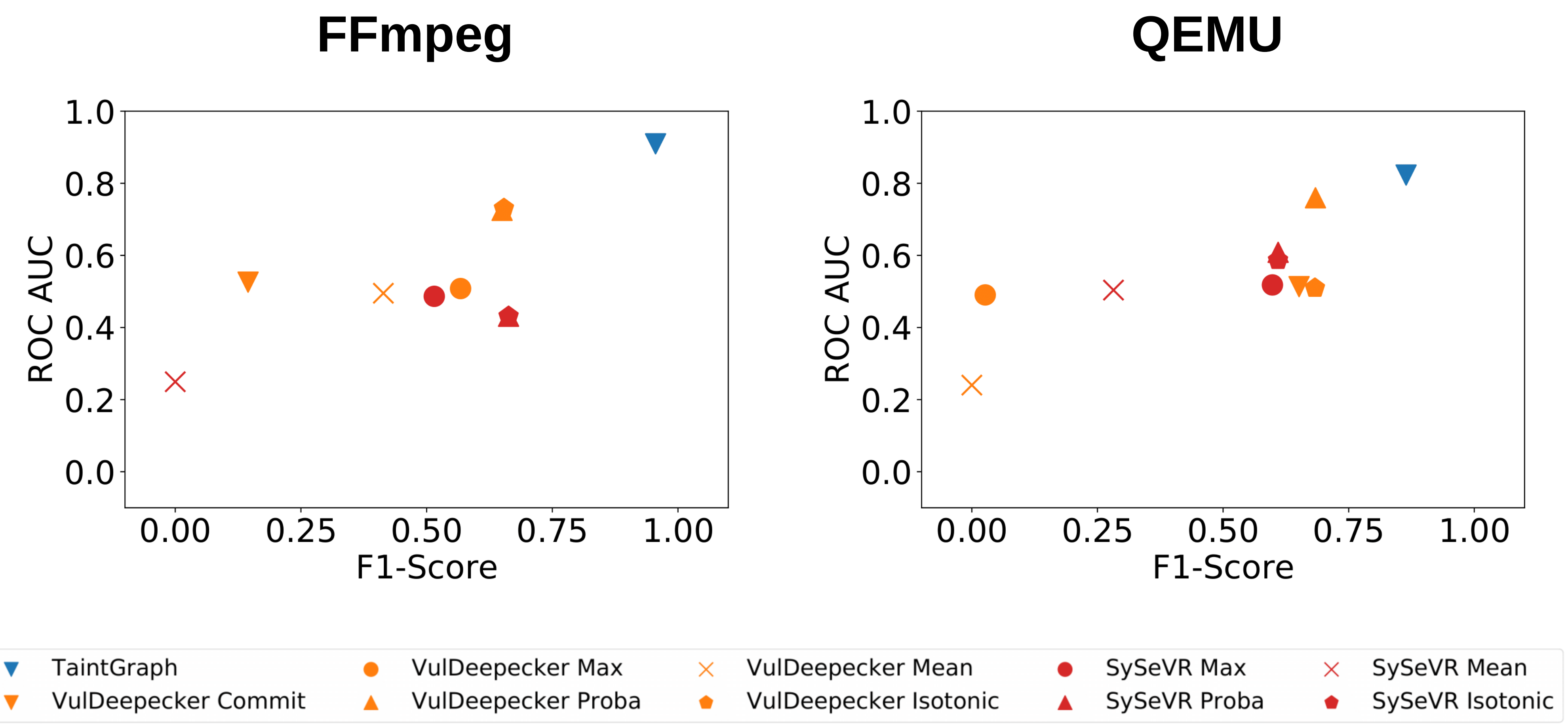

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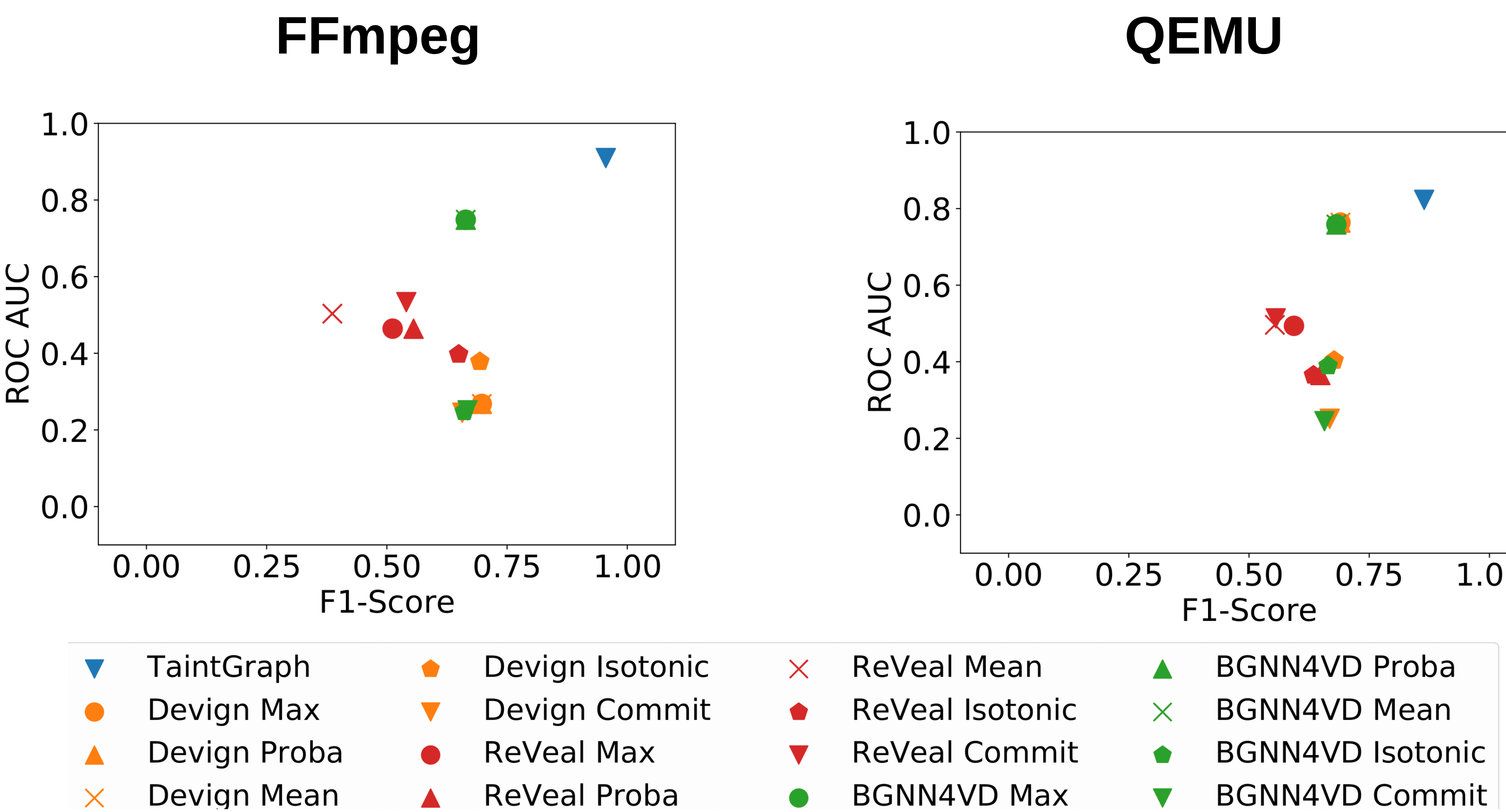
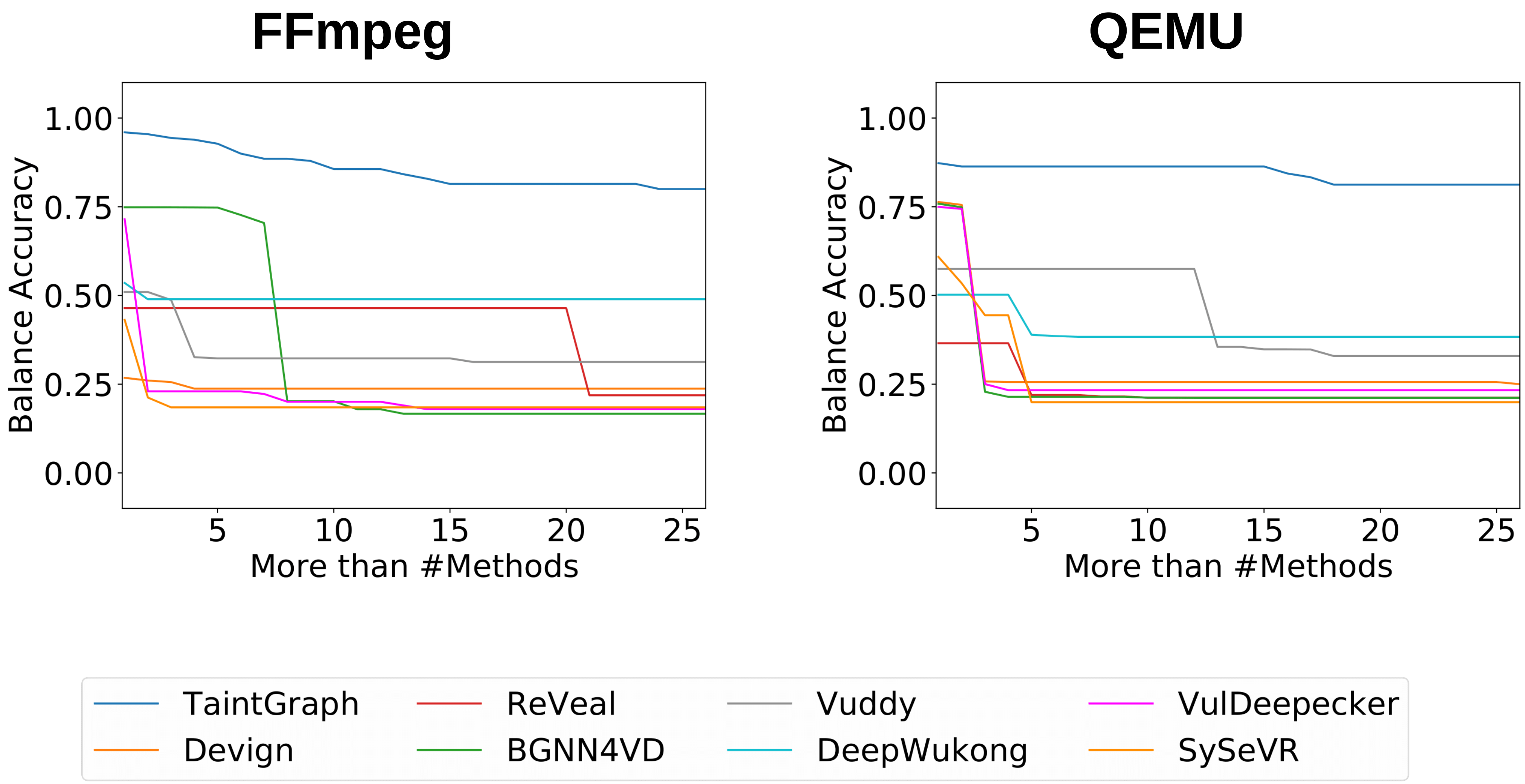
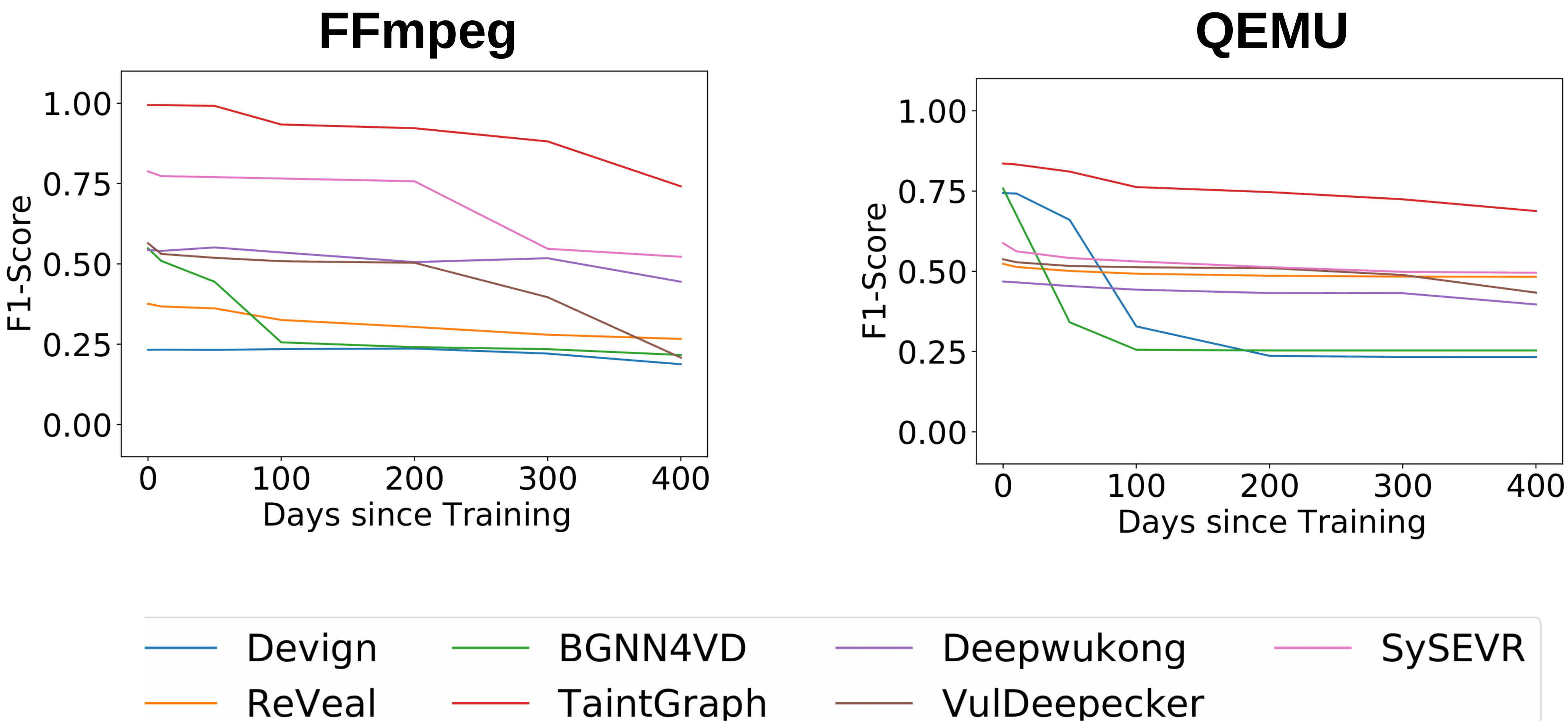


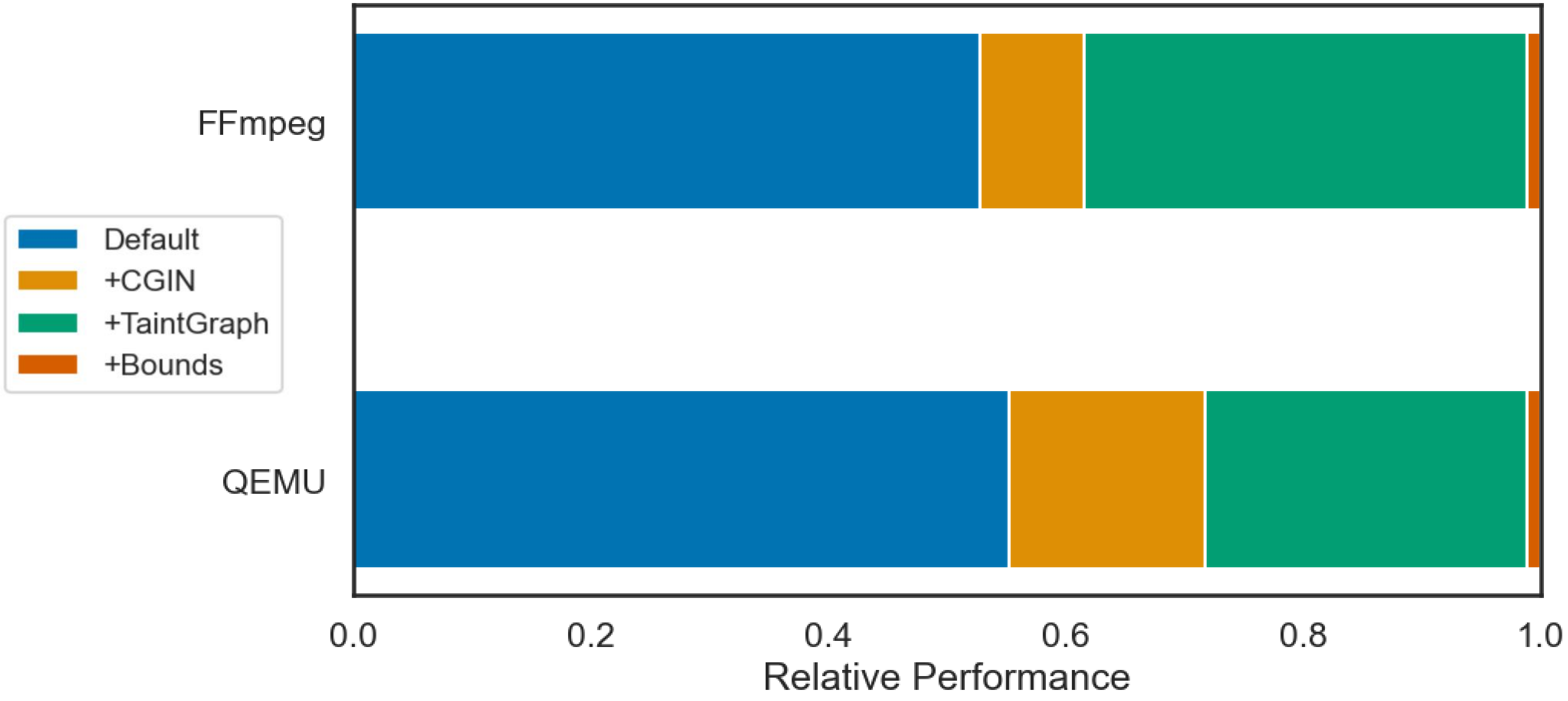
RQ2 How does the size of a commit affect the performance?



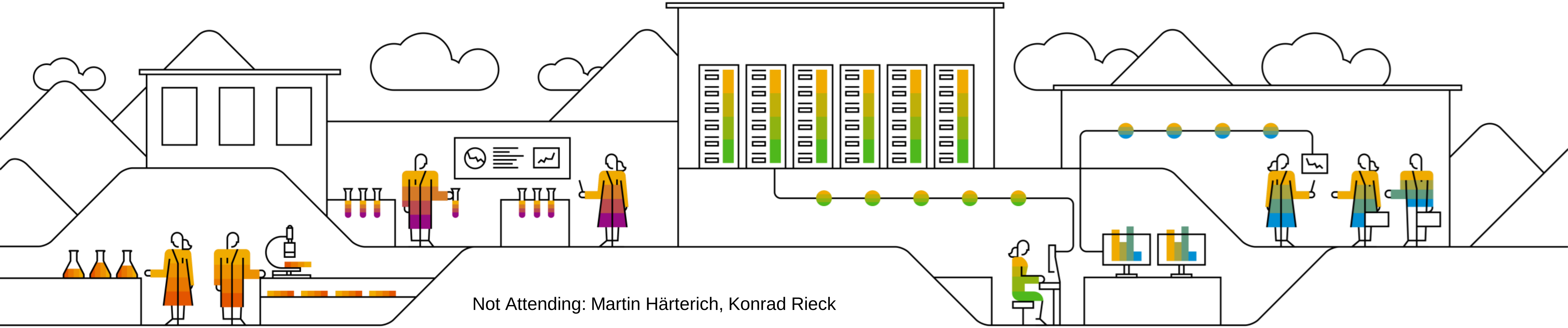
RQ3 How does PAVUDI behave after training and deployment?



RQ4 How do individual components of PAVUDI contribute to its capabilities?



Conclusion



Not Attending: Martin Härterich, Konrad Rieck

Conclusion

- Patches are the atomic unit of modern software development
- Existing vulnerability detectors are badly suited to patches
- Identified five previously undisclosed bugs
- We introduce a patch-based vulnerabiliyt discovery (PAVUDI)
  - With a new interprocedural code representation
  - An explainable graph neural network
- Our solution
  - has more than 50% increased detection performance
  - is twice as robust against concept drift
- Public Implementation: https://github.com/SAP-samples/security-research-taintgraphs

Thank you.

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Intelligente Verfahren zur Aufdeckung von Software - Hintertüren

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