THE UNIVERSITY OF TEXAS AT DALLAS

# DeepVD: Toward Class-Separation Features for Neural Network Vulnerability Detection


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- Vulnerability detection is the task of analyzing a given code example to predict whether it is vulnerable (i.e., possesses vulnerabilities such as Denial of Service, Memory Corruption, etc.), or benign.

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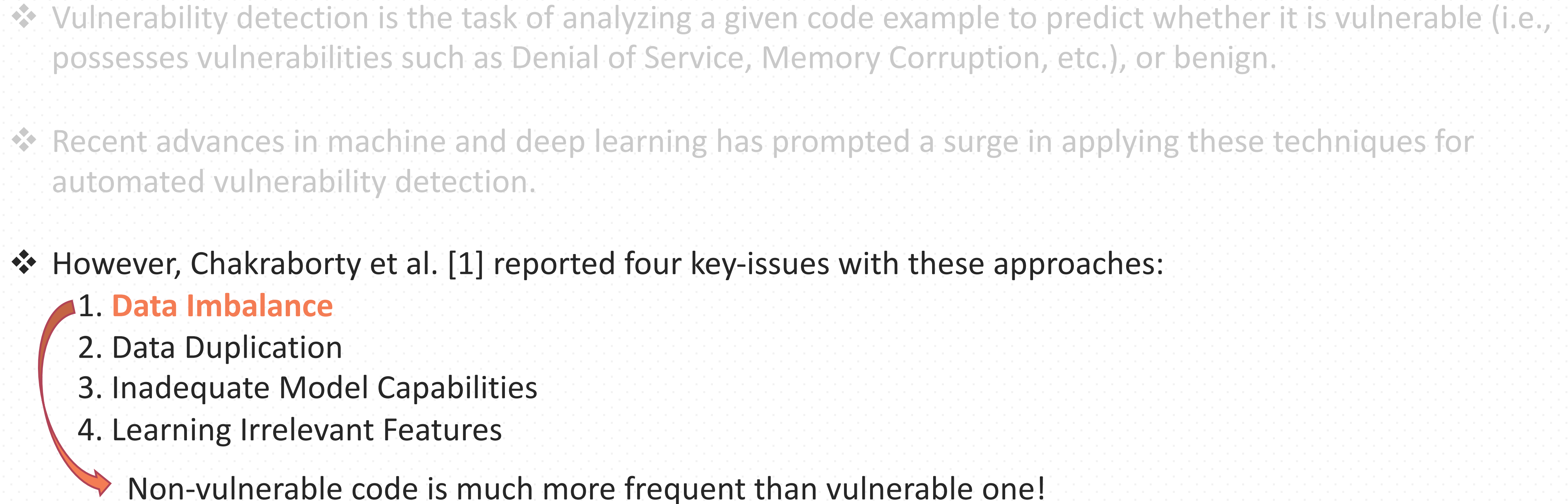

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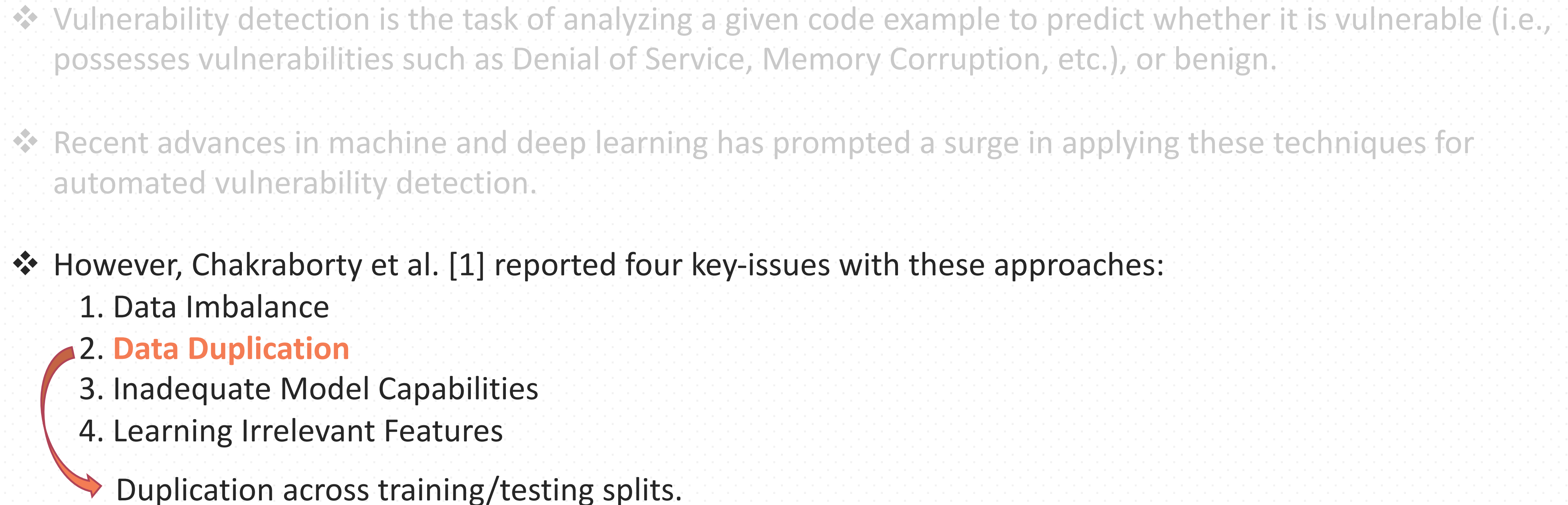

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→ Treat code as sequence of tokens and DO NOT consider semantic dependencies..

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Training Process & Model Design (issues 1–3)

We focus on identifying “*Class-Separation*” features

# Motivating Examples

**Figure 1.** CVE-2020-18899: Denial of Service (DoS) from an Uncontrolled Memory Allocation in Exiv2 0.27

```
1  void Jp2Image::printStructure(...) {
2    ...
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Value of 0 for `subBox.length` results in Integer Overflow

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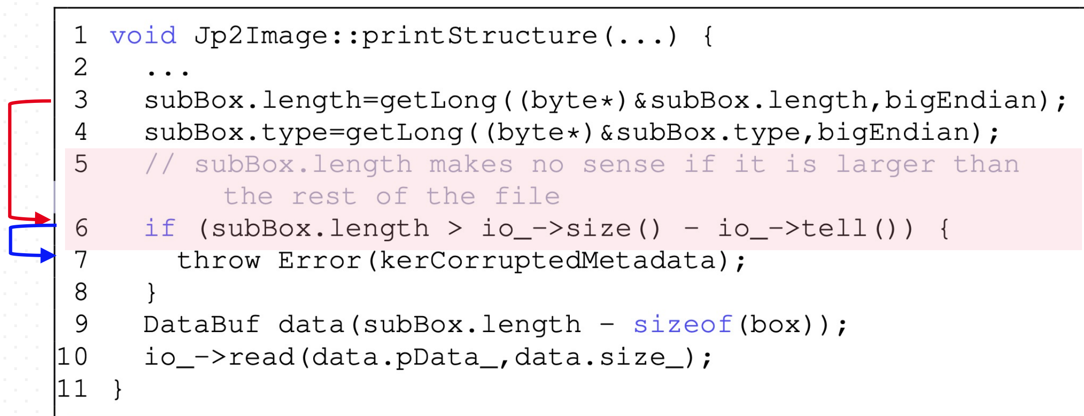

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We can observe a data dependency (**red**) from line 3 to line 6, and a control dependency (**blue**) from line 6 to line 7.

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**Observation 1**

*A model could investigate the* data and control flows toward the exception/error-handling points to detect a potential vulnerability.

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**Figure 2.** CVE-2020-19155: Improper Access Control in `Jfinal`

```
1 public JSONObject rename() {
2   String oldFile = this.get.get("old");
3   String newFile = this.get.get("new");
4   oldFile = getFilePath(oldFile);
5   ...
6   String path = oldFile.substring(0, pos + 1);
7   File fileFrom = null;
8   File fileTo = null;
9   try {
10    fileFrom = new File(this.fileRoot + oldFile);
11    fileTo = new File(this.fileRoot + path + newFile);
12    if (fileTo.exists()) {
13     if (fileTo.isDirectory()) {
14      this.error(sprintf(lang("DIRECTORY_ALREADY_EXISTS");
15      error = true;
16     } else { // fileTo.isFile
17      this.error(sprintf(lang("FILE_ALREADY_EXISTS").));
18      error = true;
19     }
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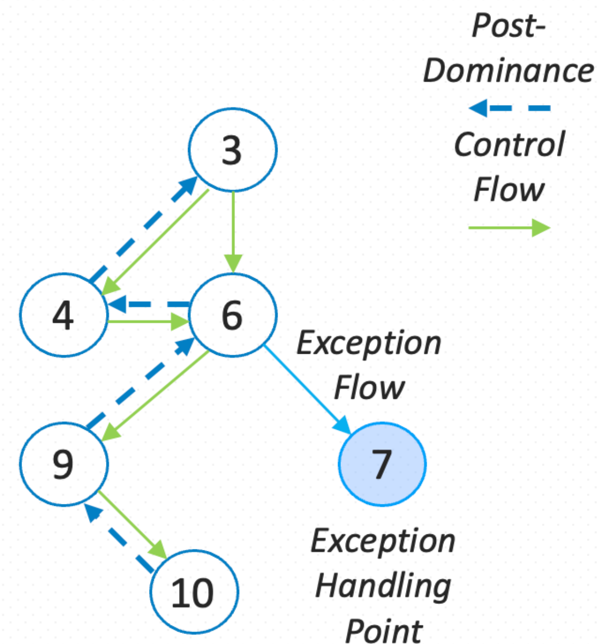

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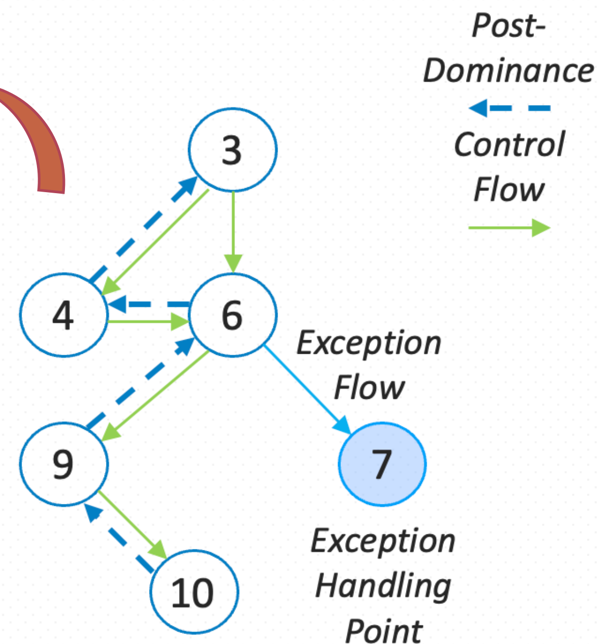
Statement ***d*** is considered as a *post-dominator* of another statement ***s*** if all the paths to the exit point of the method starting at ***s*** must go through ***d***.



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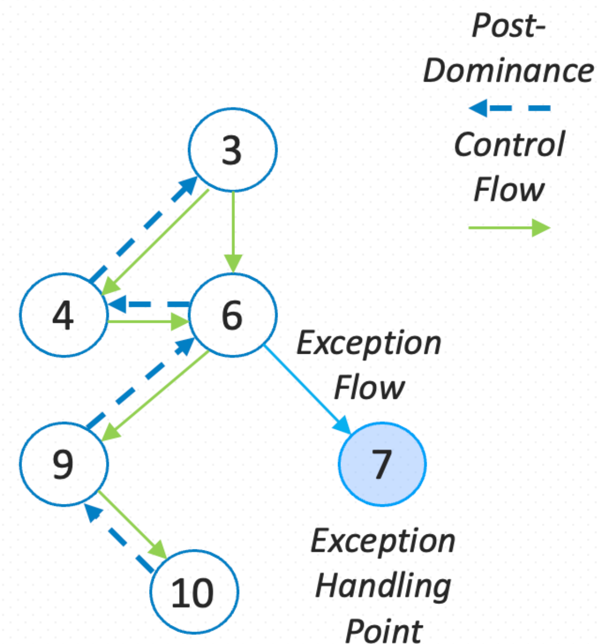

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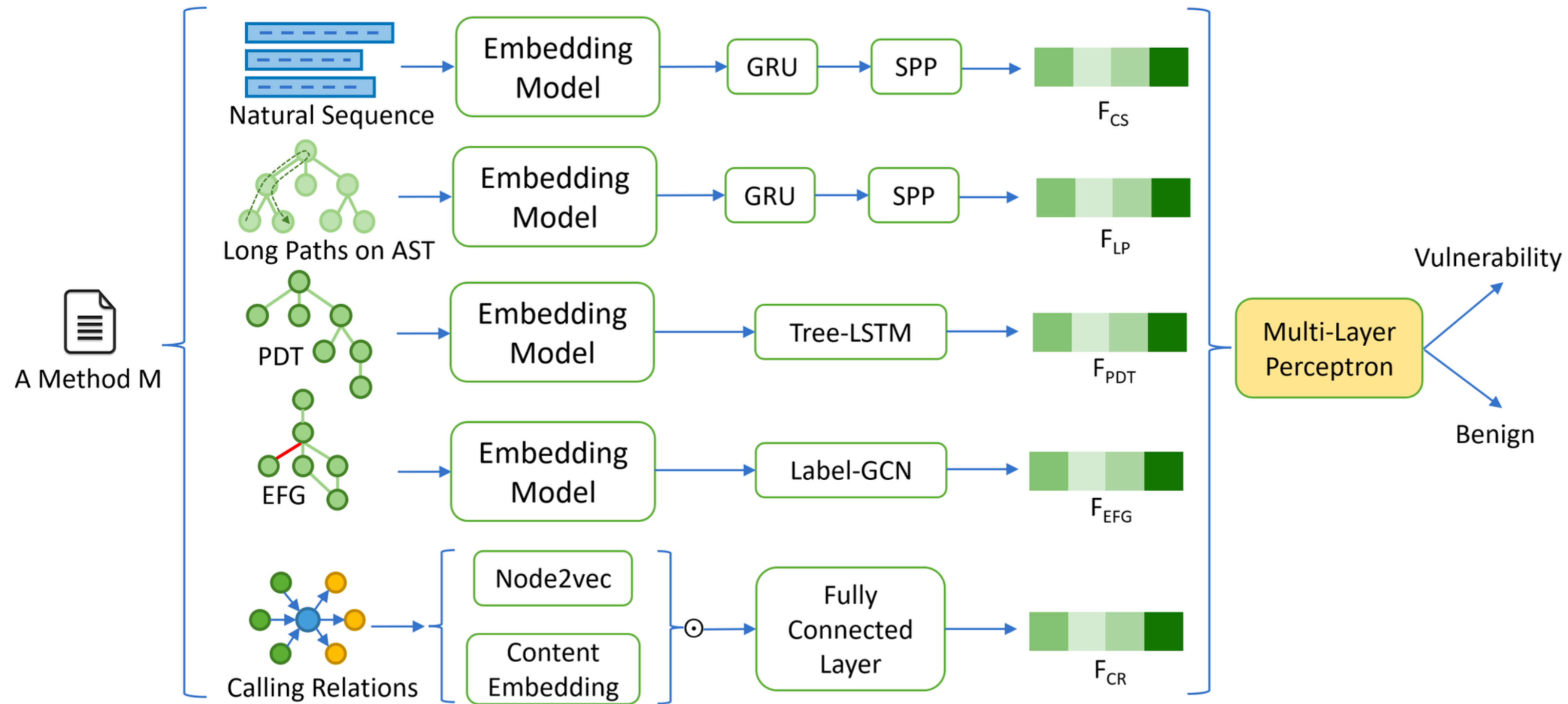
- To capture the global context, we consider the caller/callee relations.

# Architecture Overview



# Empirical Evaluation

**Table 1:** Comparison with other DL-Based VD Approaches

| Approach | Precision | Recall | F-score |
|---|---|---|---|
| VulDeePecker | 0.55 | 0.77 | 0.64 |
| SySeVR | 0.54 | 0.74 | 0.63 |
| Russell *et al.* | 0.54 | 0.72 | 0.62 |
| Devign | 0.56 | 0.73 | 0.63 |
| Reveal | 0.62 | 0.69 | 0.65 |
| IVDetect | 0.54 | 0.77 | 0.67 |
| DeepVD | **0.70** | **0.89** | **0.78** |

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| DEEPVD | **0.70** | **0.89** | **0.78** |

*Overall, DEEPVD* relatively improves over the baseline models from **13%– 29.6%** in Precision, from **15.6%–28.9%** in Recall, and from **16.4%–25.8%** in F-score.

**Figure 4.** CVE-2019-1563: A vulnerable code example in OpenSSL.

```
1  BIO *PKCS7_dataDecode(PKCS7 *p7, EVP_PKEY *pkey, BIO
       *in_bio, X509 *pcert) {
2    ...
3    if (evp_cipher != NULL) {
4      ...
5      if (pcert == NULL) {
6        for (i = 0; i < sk_PKCS7_RECIP_INFO_num(rsk); i++) {
7          ri = sk_PKCS7_RECIP_INFO_value(rsk, i);
8          if (pkcs7_decrypt_rinfo(&ek, &eklen, ri, pkey) < 0)
9            goto err;
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```

- Has 186 lines of code after removing comments and empty lines.
- PDG with 145 nodes and 477 edges, and the CPG with 622 nodes and 1,393 edges.
- In contrast, EFG + PDT has 145 nodes and 295 edges.

# Empirical Evaluation

**Table 2:** Comparison on different vulnerability types

| | Vulnerability Type | TN | FP | FN | TP | Total | **Precision** | **Recall** | **F-score** |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Denial Of Service | 424 | 490 | 64 | 658 | 1,636 | 0.57 | 0.91 | 0.70 |
| 2 | Overflow | 225 | 371 | 28 | 340 | 964 | 0.48 | 0.92 | 0.63 |
| 3 | Execute Code | 129 | 279 | 11 | 202 | 621 | 0.42 | 0.95 | 0.58 |
| 4 | Memory corruption | 102 | 190 | 9 | 162 | 463 | 0.46 | 0.95 | 0.62 |
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*Leveraging EFG+PDT particularly also helped with identifying the popular **DOS-based vulnerabilities**, that are majorly identified with improper exception/error-handling.*

# Conclusion

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Items 1–3: Training Process & Model Design

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3    subBox.length=getLong((byte*)&subBox.length,bigEndian);
4    subBox.type=getLong((byte*)&subBox.type,bigEndian);
5    // subBox.length makes no sense if it is larger than
         the rest of the file || 0
6    if (subBox.length == 0 ||
7        subBox.length > io_->size() - io_->tell()) {
8      throw Error(kerCorruptedMetadata);
9    }
10   DataBuf data(subBox.length - sizeof(box));
11   io_->read(data.pData_,data.size_);
12 }
```

**Observation 1**

*A model could investigate the* data and control flows toward the exception/error-handling points to detect a potential vulnerability.

## Key Ideas

Focused on improving ***class-separability***, we consider the following:

- **Exception-Flow Graph (EFG)**, which helps distinguish the key characteristics in the proper/improper handling of exceptions and error cases, a key aspect of vulnerabilities.
- While EFG accommodates the exception-flows, **Post-Dominator Tree (PDT)** considers the regular flows.
- With each node, we associate a **Statement Type** (i.e., the root of the sub-AST corresponding to the statement) which is analogous to the POS-tags in natural language.
- To capture the syntactic structure, we consider the **Long Path** between two leaf nodes.
- To capture the global context, we consider the caller/callee relations.

## Background

❖ Vulnerability detection is the task of analyzing a given code example to predict whether it is vulnerable (i.e., possesses vulnerabilities such as Denial of Service, Memory Corruption, etc.), or benign.

❖ Recent advances in machine and deep learning has prompted a surge in applying these techniques for automated vulnerability detection.

❖ However, Chakraborty et al. [1] reported four key-issues with these approaches:

1. Data Imbalance
2. Data Duplication
3. Inadequate Model Capabilities
4. Learning Irrelevant Features

(1–3: Training Process & Model Design)

We focus on identifying "*Class-Separation*" features

## Key Ideas

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## Motivating Examples

**Figure 1.** CVE-2020-18899: Denial of Service (DoS) from an Uncontrolled Memory Allocation in Exiv2 0.27

```
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2    ...
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## Empirical Evaluation

**Table 1:** Comparison with other DL-Based VD Approaches

| Approach | Precision | Recall | F-sc [No Title] |
|---|---|---|---|
| VulDeePecker | 0.55 | 0.77 | 0.64 |
| SySeVR | 0.54 | 0.74 | 0.63 |
| Russell *et al.* | 0.54 | 0.72 | 0.62 |
| Devign | 0.56 | 0.73 | 0.63 |
| Reveal | 0.62 | 0.69 | 0.65 |
| IVDetect | 0.54 | 0.77 | 0.67 |
| DEEPVD | **0.70** | **0.89** | **0.78** |

*Overall, DEEPVD* relatively improves over the baseline models from **13%– 29.6%** in Precision, from **15.6%–28.9%** in Recall, and from **16.4%–25.8%** in F-score.

# EXTRA SLIDES