Security by the Analytic: A Framework for Automatic Mapping of Vulnerabilities to Attack Patterns using Artificial Intelligence

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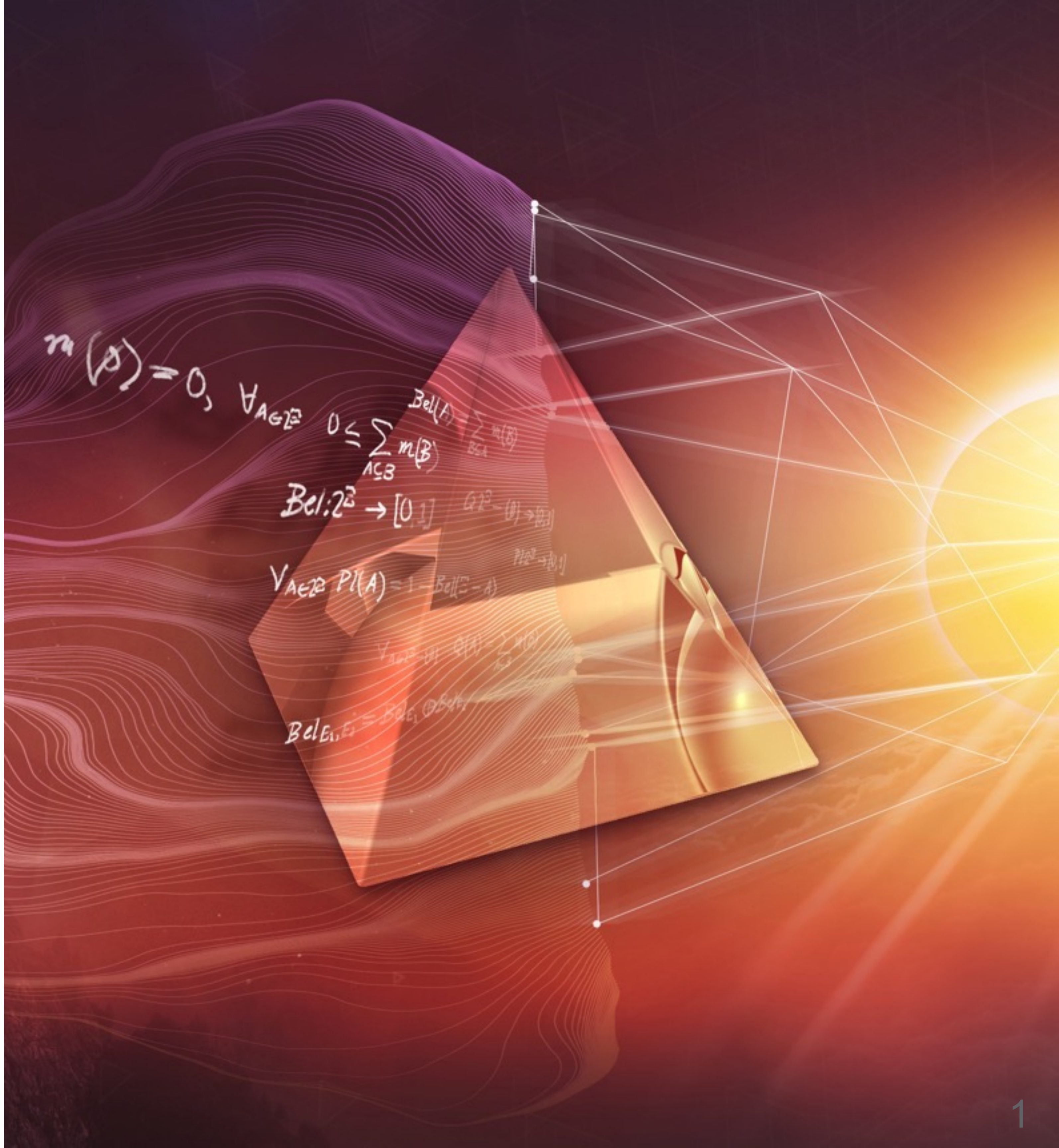

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Programming must be…

"If ***debugging*** *is the process of removing software bugs, then* ***programming*** *must be the process of putting them in."*

1972 ACM A.M. Turing Award winner Edsger W. Dijkstra.

Photo Credit: The University of Texas at Austin

#1 Rule in cybersecurity: "*Treat Everything Like It's Vulnerable*"

Our Goal: Feed the Good Wolf

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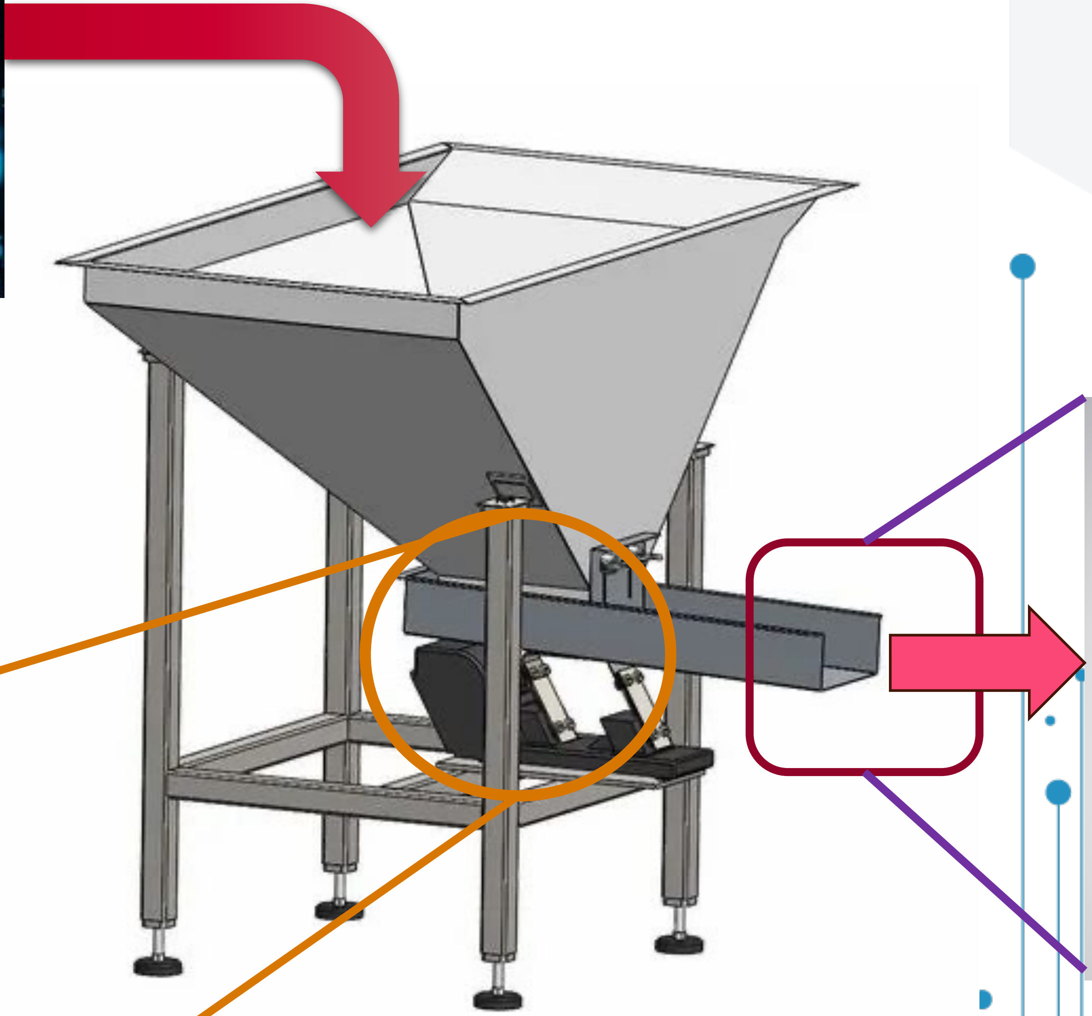
- Minimize the time between vulnerability discovery and mitigation by linking vulnerabilities to mitigation actions
- Enhance threat intelligence and exploratory research
- Eg., The "Log4Shell" flaw was widely exploited -- ~40,000 attempted attacks within two hours of it becoming public, and >830,000 attempts within the first three days.*

Image source: https://theevidenceisplain.blogspot.com/2014/07/a-tale-of-two-wolves-battle-between.html

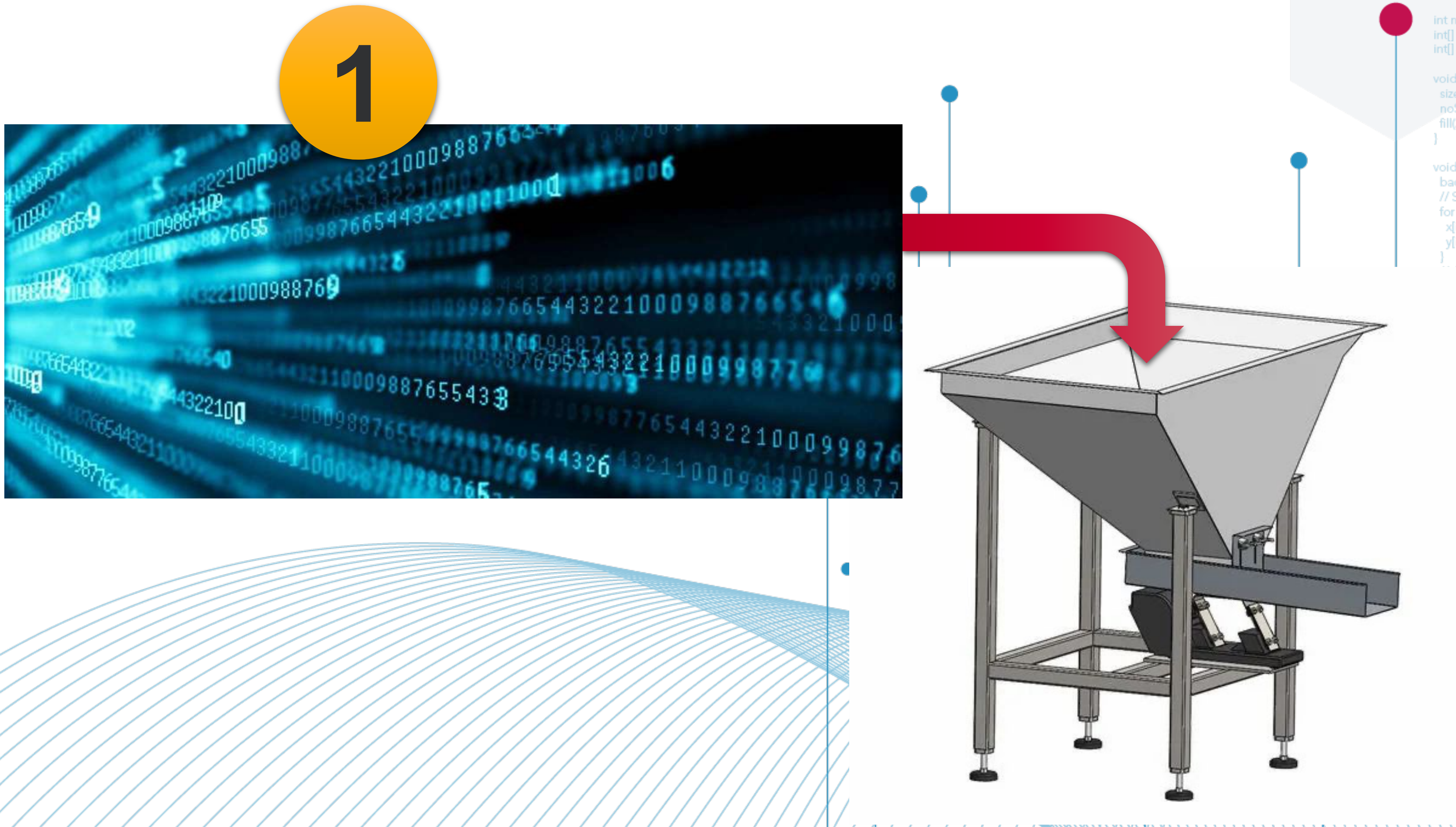
* https://www.checkpoint.com/cyber-hub/cyber-security/what-is-cybersecurity/biggest-cybersecurity-challenges-in-2022/

Overview

Security by the Analytic

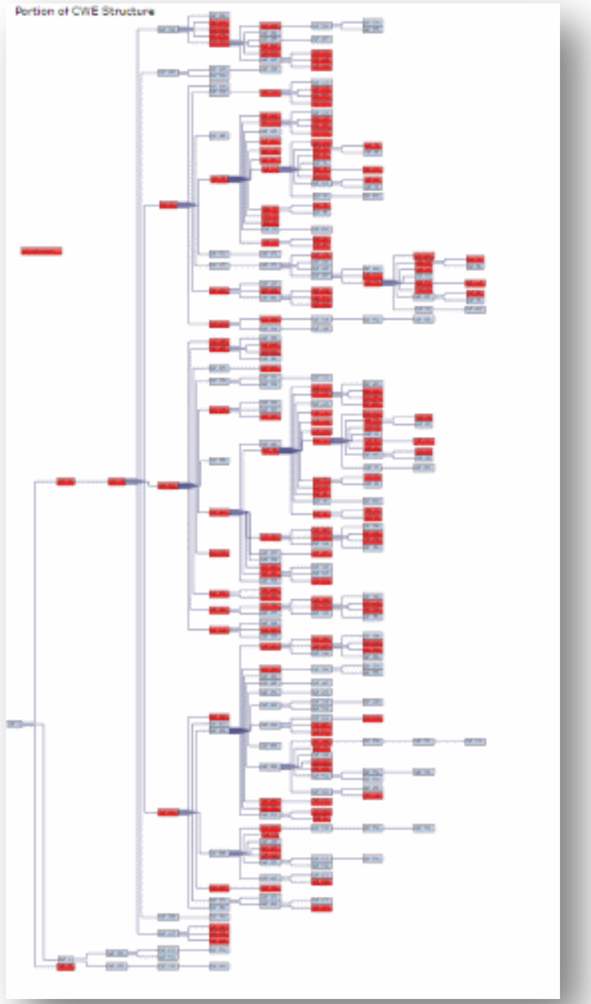


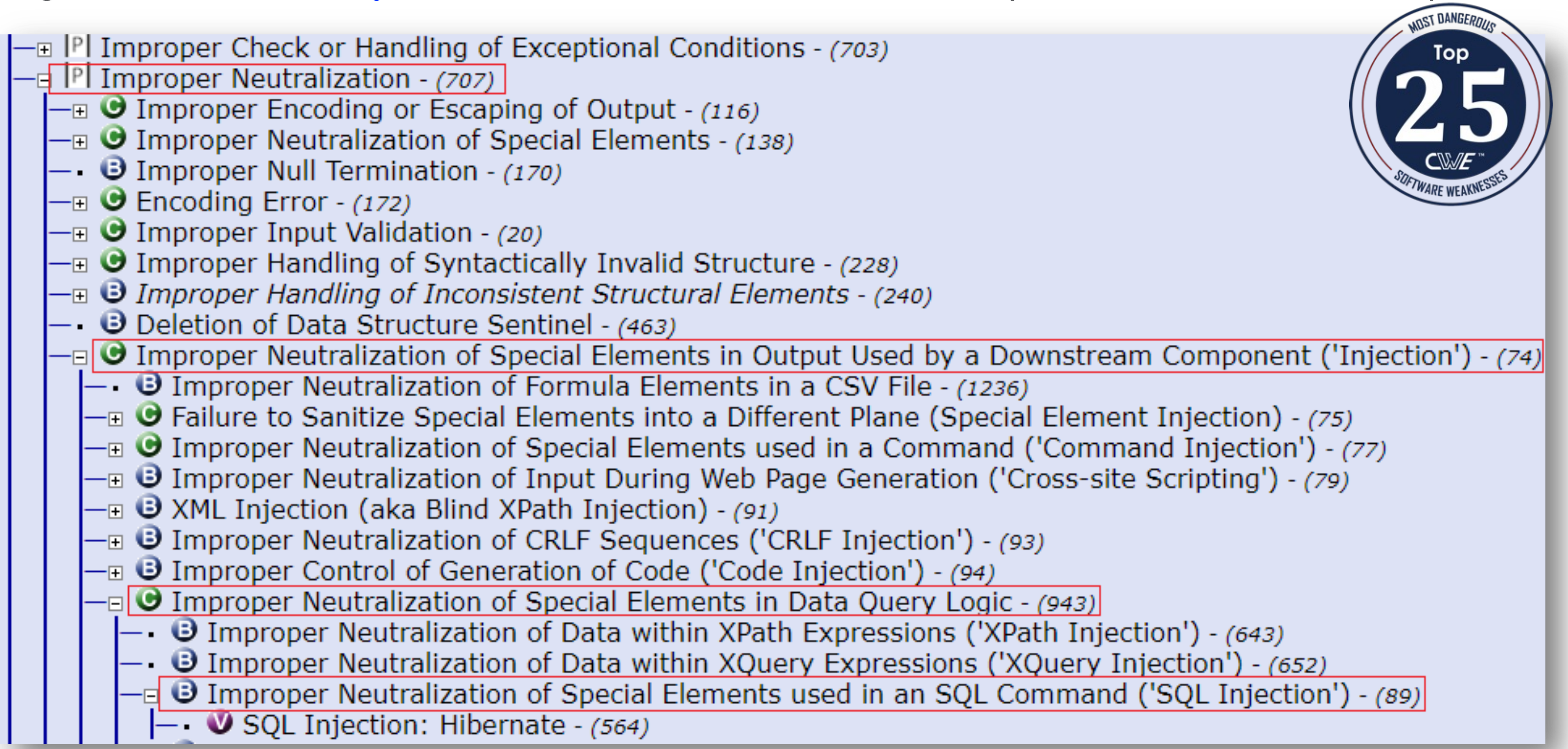
1. Data & Problem Setting



Common Weakness Enumeration (CWE)

A blueprint for understanding software flaws and their impact through a hierarchically designed dictionary of software weaknesses (934 Weaknesses)

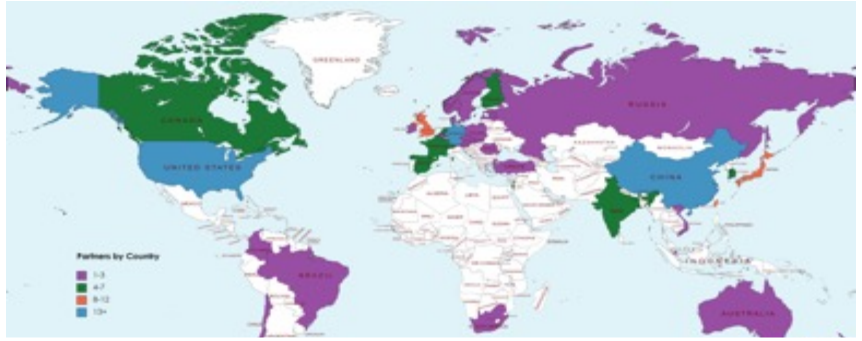




https://cwe.mitre.org

Common Vulnerabilities & Exposures (CVE)

- Bugs: Mistakes happen in the process of building and coding a system
- Vulnerabilities: Bugs that can be exploited to induce unintended behavior from software/protocol/hardware
- A bug is determined to be a vulnerability is registered by MITRE as a CVE
  - Publicly known information-security vulnerabilities and exposures
  - TOTAL CVE Records: **215,715**. (https://cve.mitre.org/) on 10/31/2023
- Some Examples:
  - Broken Authentication
  - SQL Injection
  - Cross-Site Scripting

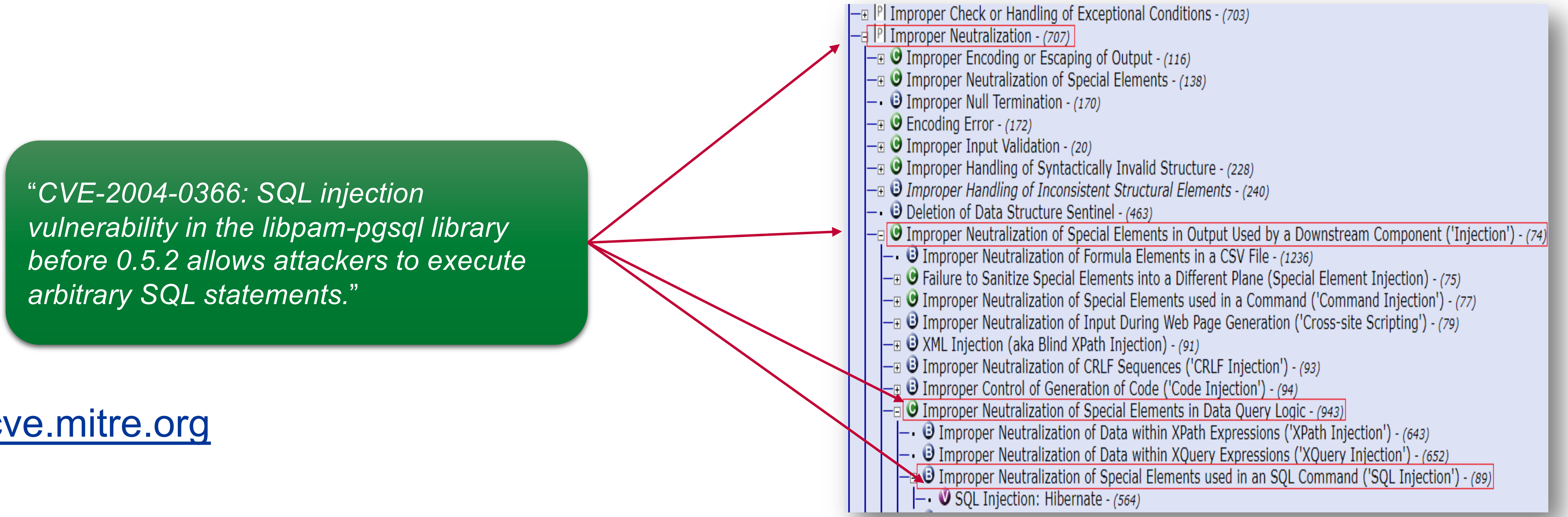


330 CVE Numbering Authorities

Example description: "*CVE-2004-0366: SQL injection vulnerability in the libpam-pgsql library before 0.5.2 allows attackers to execute arbitrary SQL statements.*"

Mapping CVEs to CWEs

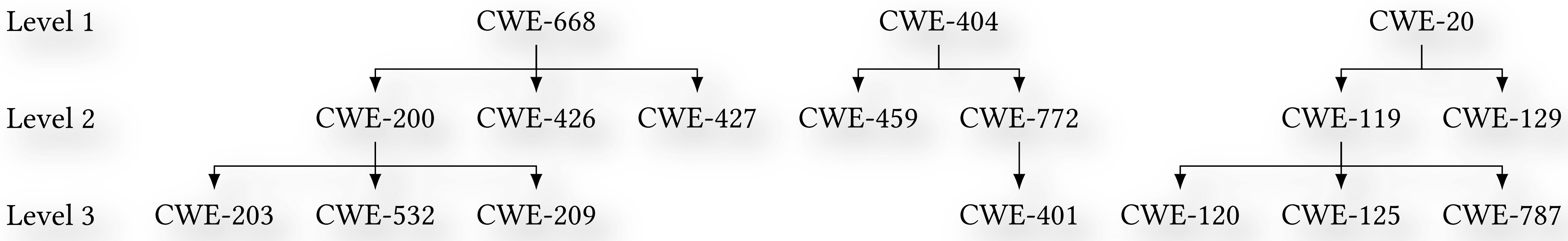
- CVE reports are uniquely identified computer security vulnerabilities, where a vulnerability is defined as a set of one or more *weaknesses* in a specific product or protocol that allows an attacker to exploit the behaviors or resources to compromise a system
- Example: "*CVE-2004-0366: SQL injection vulnerability in the libpam-pgsql library before 0.5.2 allows attackers to execute arbitrary SQL statements.*"



https://cve.mitre.org

CVE to CWE Mapping

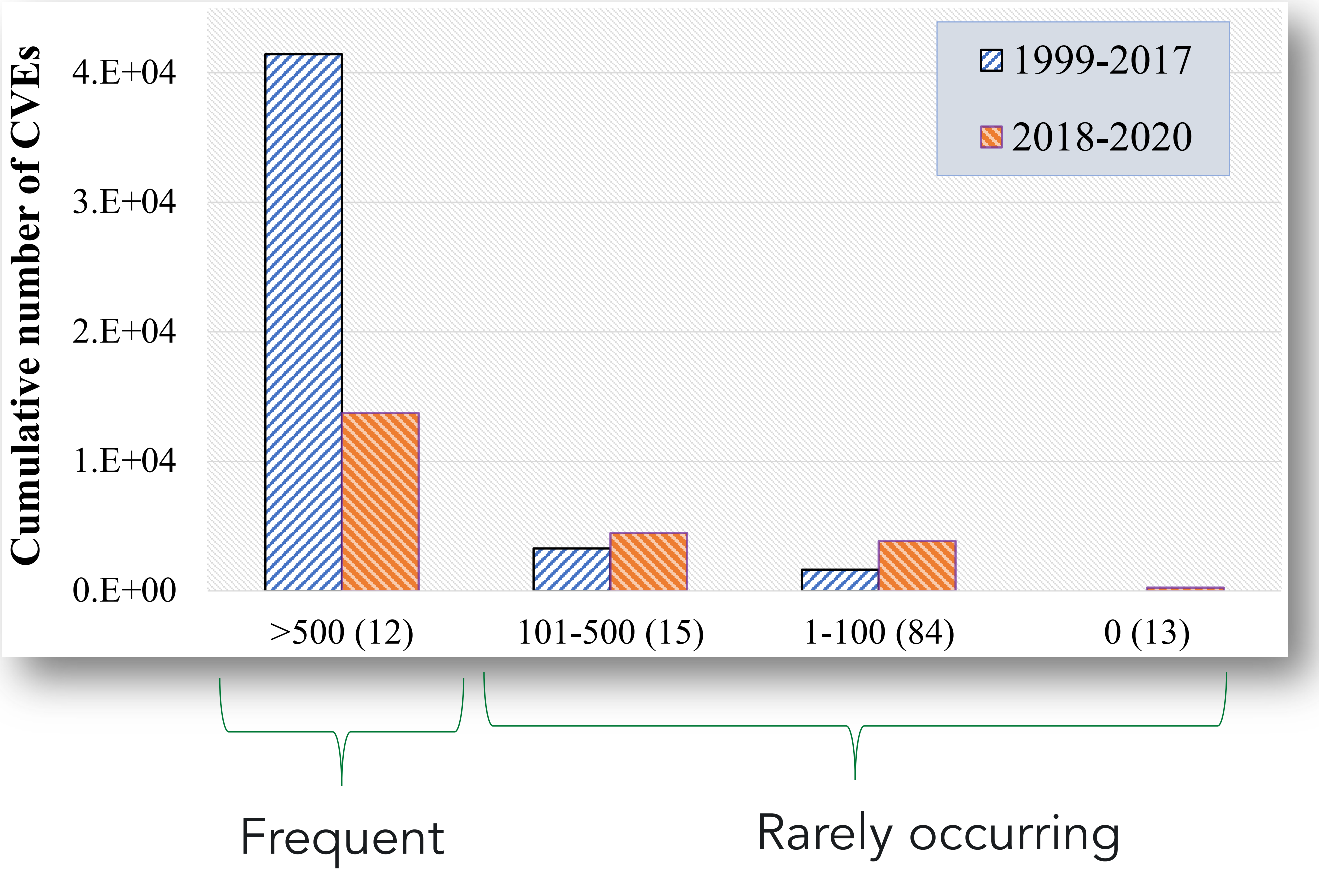
- We considered 933 CWE classes from MITRE (circa 2021)
- About 124 types of CWEs are classified in National Vulnerability Dataset (NVD)
- CVE to CWE mapping is done manually, requires human expertise, and error prone



Partial hierarchy of CWE extracted from MITRE to demonstrate how precise and relaxed predictions are performed. We consider **124** CWEs that are distributed in three levels in the hierarchy, with **34** in the first level, **78** in the second level, and **16** in the third level.

CVE to CWE Mapping: Challenges

- Distribution of the number of CVEs per CWE in NVD, bucketed into four categories
- Data partitioned into two time periods to simulate testing for CVEs observed in the future
- 1999-2017 (used for training) and 2018-2020 (used for testing).



Common Attack Pattern Enumeration and Classification (CAPEC)

CAPEC™

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- An "exploit" makes a "weakness" a "vulnerability"
- "Attack Patterns" are descriptions of the common attributes and approaches employed by adversaries to exploit known weaknesses in cyber-enabled capabilities
- CAPEC is a dictionary of common identifiers for attack patterns

Some Well-Known Attack Patterns:

- HTTP Response Splitting (CAPEC-34)
- Session Fixation (CAPEC-61)
- Cross Site Request Forgery (CAPEC-62)
- SQL Injection (CAPEC-66)
- Cross-Site Scripting (CAPEC-63)
- Buffer Overflow (CAPEC-100)
- Clickjacking (CAPEC-103)
- Relative Path Traversal (CAPEC-139)
- XML Attribute Blowup (CAPEC-229)

1000 - Mechanisms of Attack

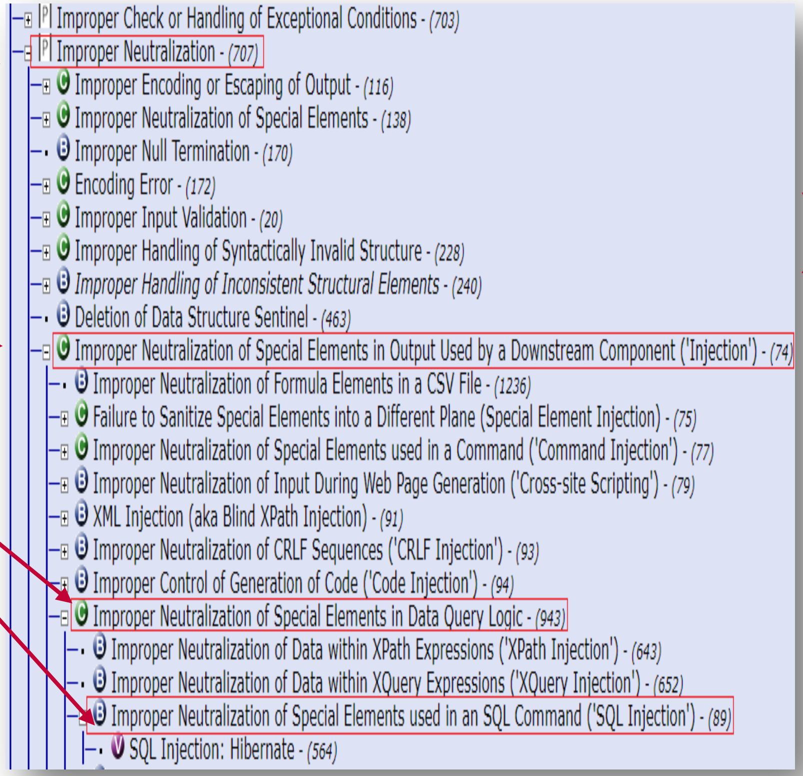
- C Engage in Deceptive Interactions - *(156)*
  - M Content Spoofing - *(148)*
  - M Identity Spoofing - *(151)*
    - S Fake the Source of Data - *(194)*
    - S Principal Spoof - *(195)*
    - S Signature Spoof - *(473)*
    - S Pharming - *(89)*
    - S Phishing - *(98)*
  - M Resource Location Spoofing - *(154)*
  - M Action Spoofing - *(173)*
  - M Manipulate Human Behavior - *(416)*
- C Abuse Existing Functionality - *(210)*
  - M Interface Manipulation - *(113)*
  - M Flooding - *(125)*
  - M Excessive Allocation - *(130)*
  - M Resource Leak Exposure - *(131)*
  - M Functionality Misuse - *(212)*
  - M Communication Channel Manipulation - *(216)*
  - M Sustained Client Engagement - *(227)*
  - M Protocol Manipulation - *(272)*
  - M Functionality Bypass - *(554)*
- C Manipulate Data Structures - *(255)*
- C Manipulate System Resources - *(262)*
- C Inject Unexpected Items - *(152)*
- C Employ Probabilistic Techniques - *(223)*
- C Manipulate Timing and State - *(172)*
- C Collect and Analyze Information - *(118)*

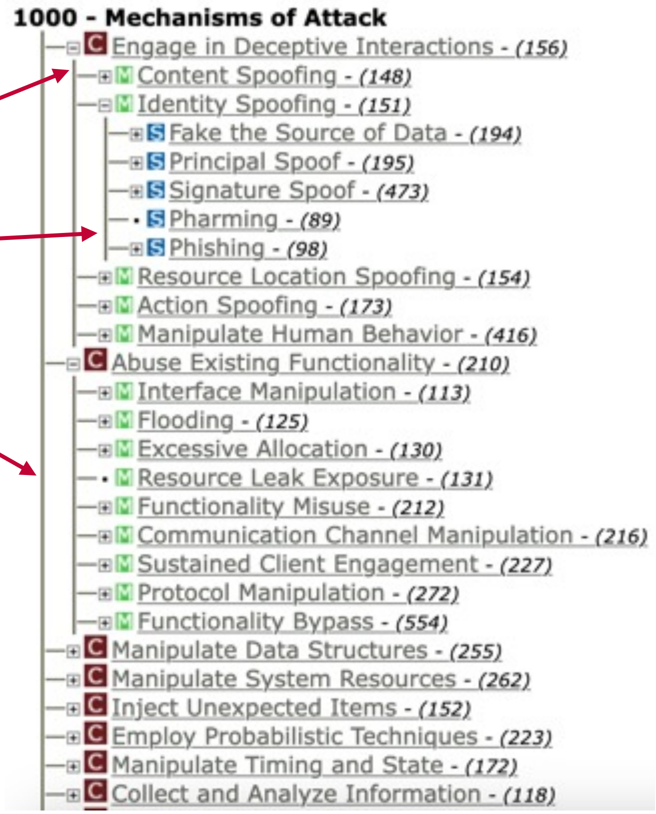
https://capec.mitre.org/

Mapping CVE to CWE to CAPEC

- We want to know what attack sequences can be taken taken given CVE descriptions
- CVE-CWE mapping ---- CWE-CAPEC mapping

"CVE-2004-0366: SQL injection vulnerability in the libpam-pgsql library before 0.5.2 allows attackers to execute arbitrary SQL statements."





https://cve.mitre.org

Adversarial Tactics, Techniques & Common Knowledge (ATT&CK)

ATT&CK™
Adversarial Tactics, Techniques & Common Knowledge

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- Describes operational phases in adversary's lifecycle (e.g., Persistence, Lateral Movement, Exfiltration)
- Details specific tactics, techniques, and procedures (**TTPs**) used in advanced persistent threats (APT)
- Attack patterns enumerated by CAPECs are used in specific ATT&CK techniques

Problem Setting: Summary

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CybOX MAEC STIX TAXII

CVSS

Known Exploited Vulnerabilities Catalog

Most Dangerous Top 25 CWE Software Weaknesses

CVE
- Specific
- >200k

CWE
- Abstract
- ~1k

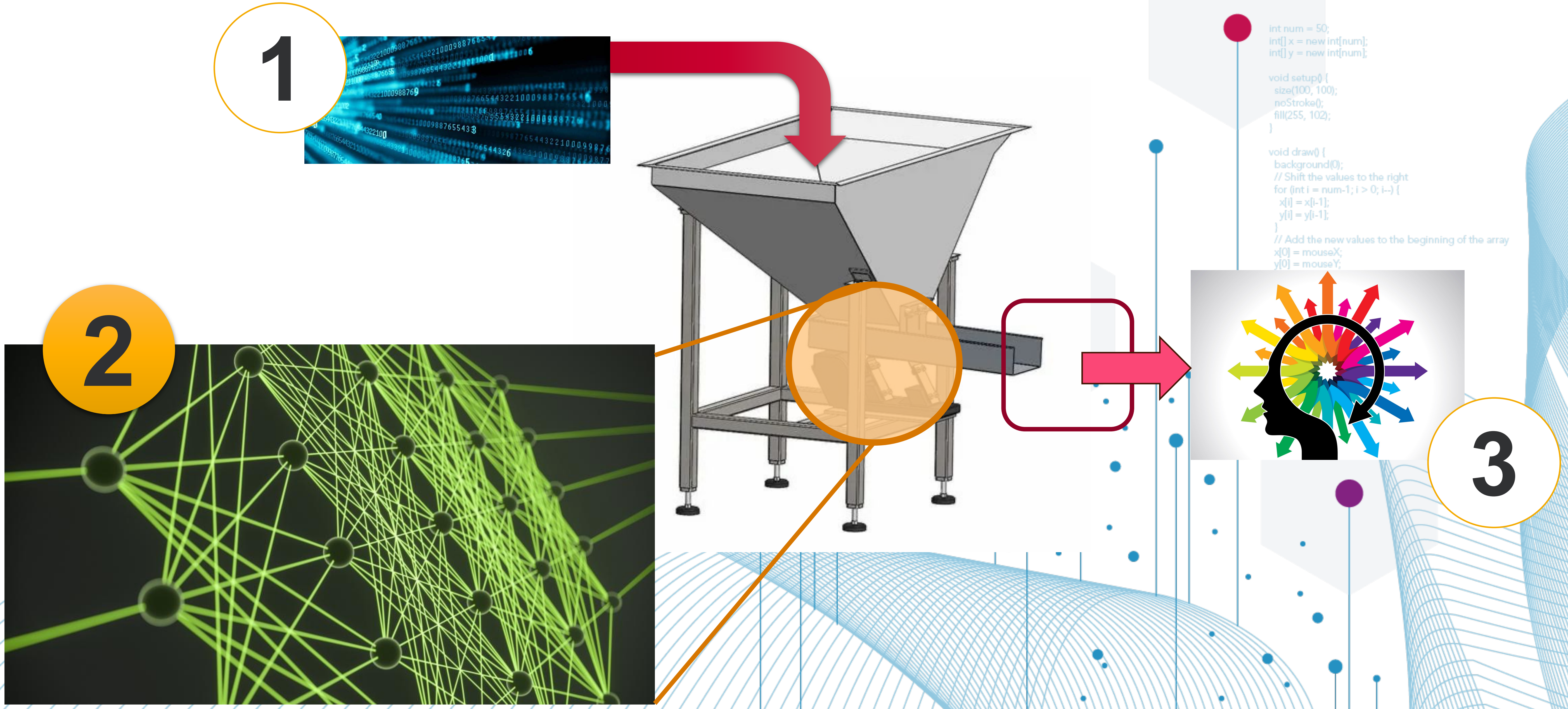
CAPEC
- Abstract
- ~600

ATT&CK
- Specific
- 196 tech.; 411 sub

CVE | CWE | CAPEC | ATT&CK Adversarial Tactics, Techniques & Common Knowledge

Specific | Abstract/Generalization | Specific

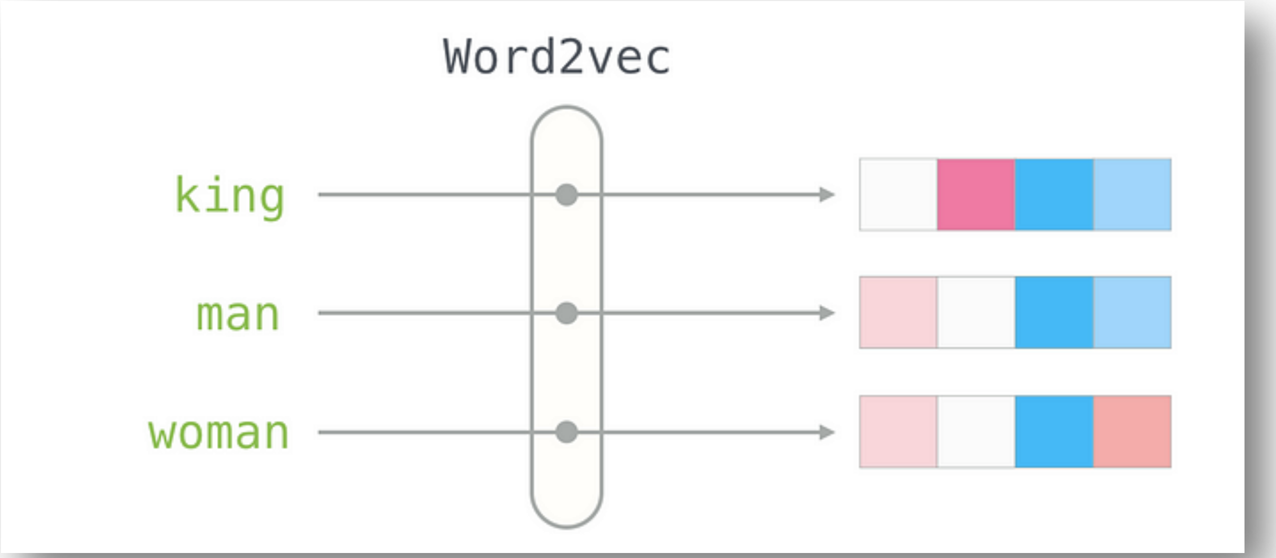
2. Approach: V2W-BERT & VWC-MAP



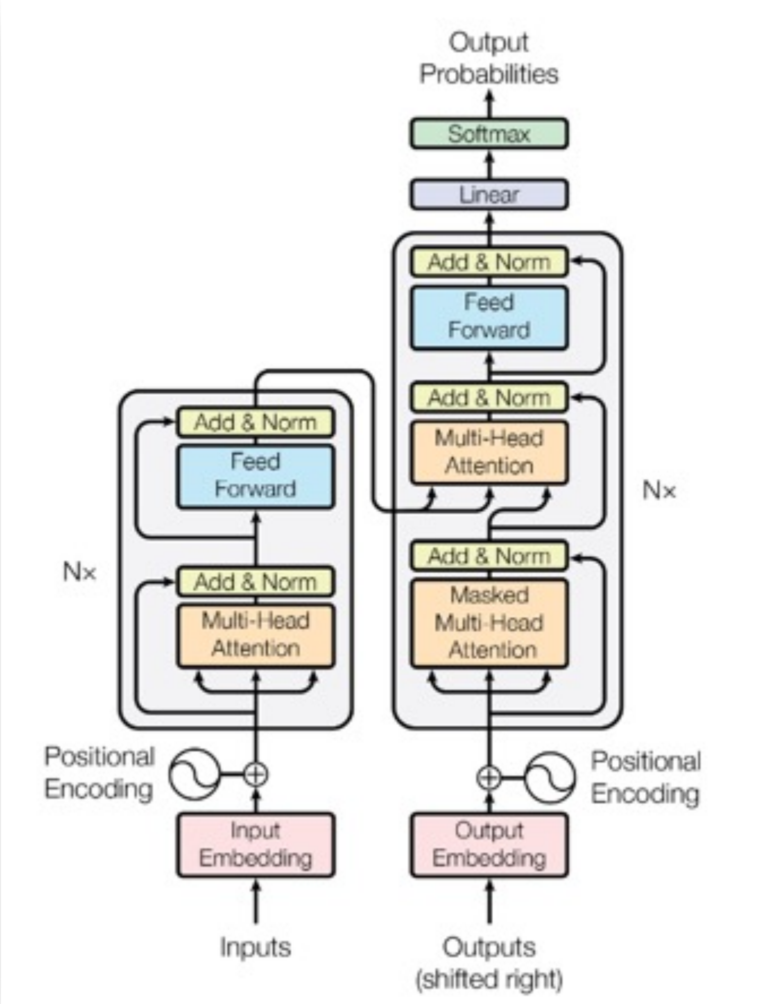
Key Ideas

"You shall know a word by the company it keeps"
– Firth (1957)

- Meaning ≈ Location in semantic space
  - Latent Semantic Analysis (LSA) – *state-of-the-art*
    - ✓ Vector Based on SVD of Word by Document Matrix



Source: http://jalammar.github.io/illustrated-word2vec/



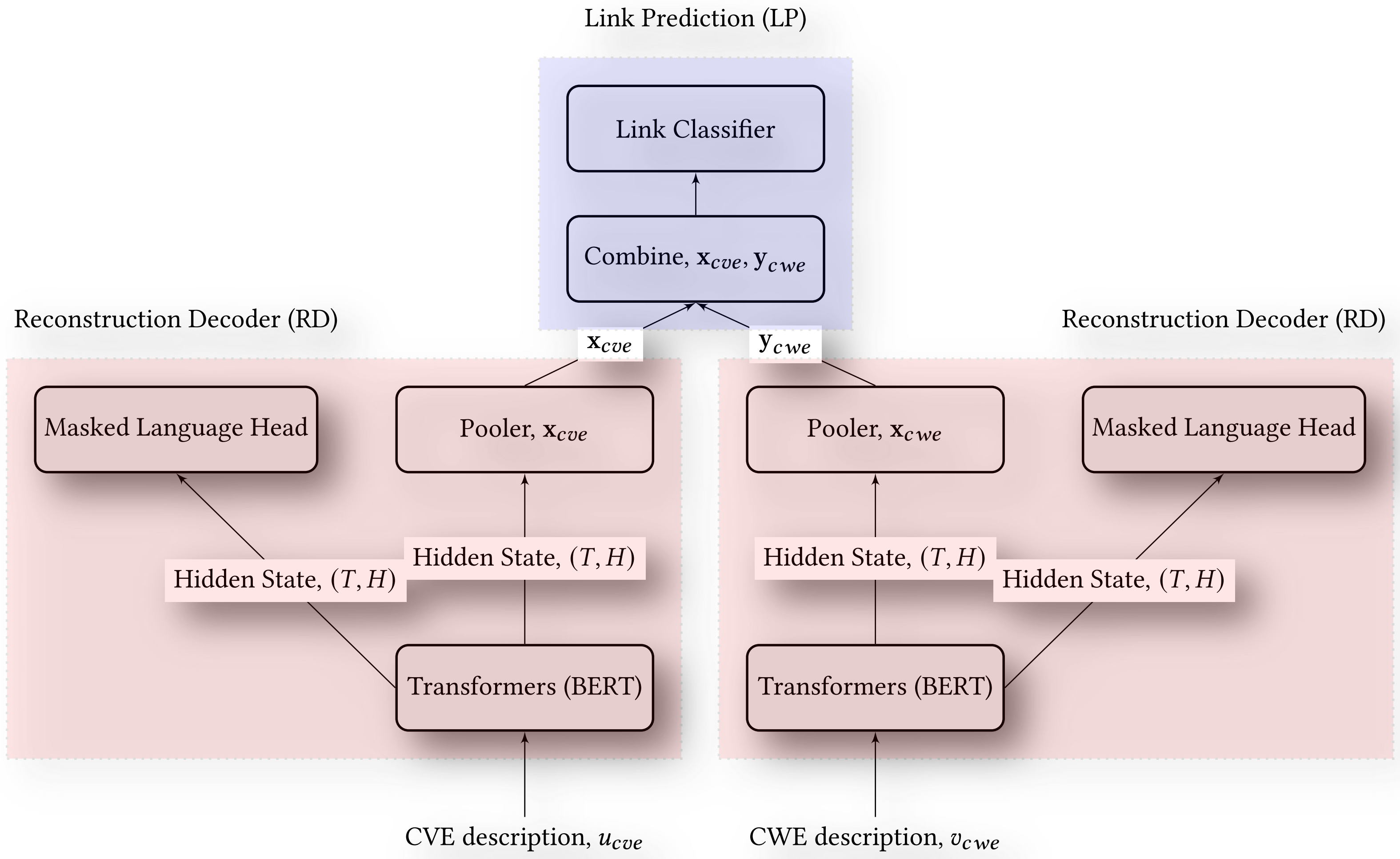
From "Attention is all you need" paper by Vaswani, et al., 2017

CVE-CWE: V2W-BERT Framework

- The Transformer component including the Reconstruction-Decoder (RD) is highlighted in pink, and the Link Prediction (LP) component is highlighted in blue
- Pre-training is done only on the Masked Language Model, and during link prediction the entire framework is considered
- Learnable function:

$$l = F_\theta(v, w)$$

S Das, E. Serra, M. Halappanavar, A. Pothen, and E. Al-Shaer. "V2W-BERT: A Framework for Effective Hierarchical Multiclass Classification of Software Vulnerabilities." In proceedings of the *8th IEEE International Conference on Data Science and Advanced Analytics (DSAA)*. Porto, Portugal. October 2021. [**Best Application Paper Award**]

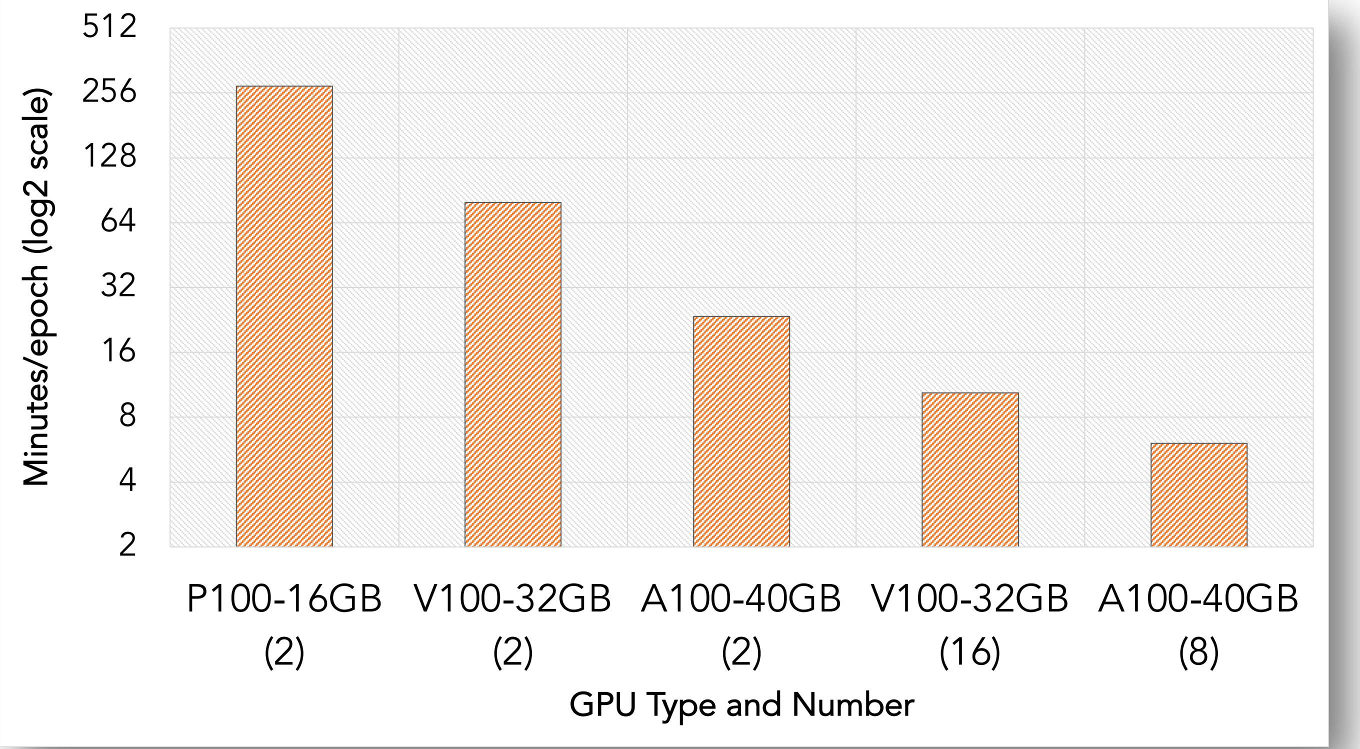


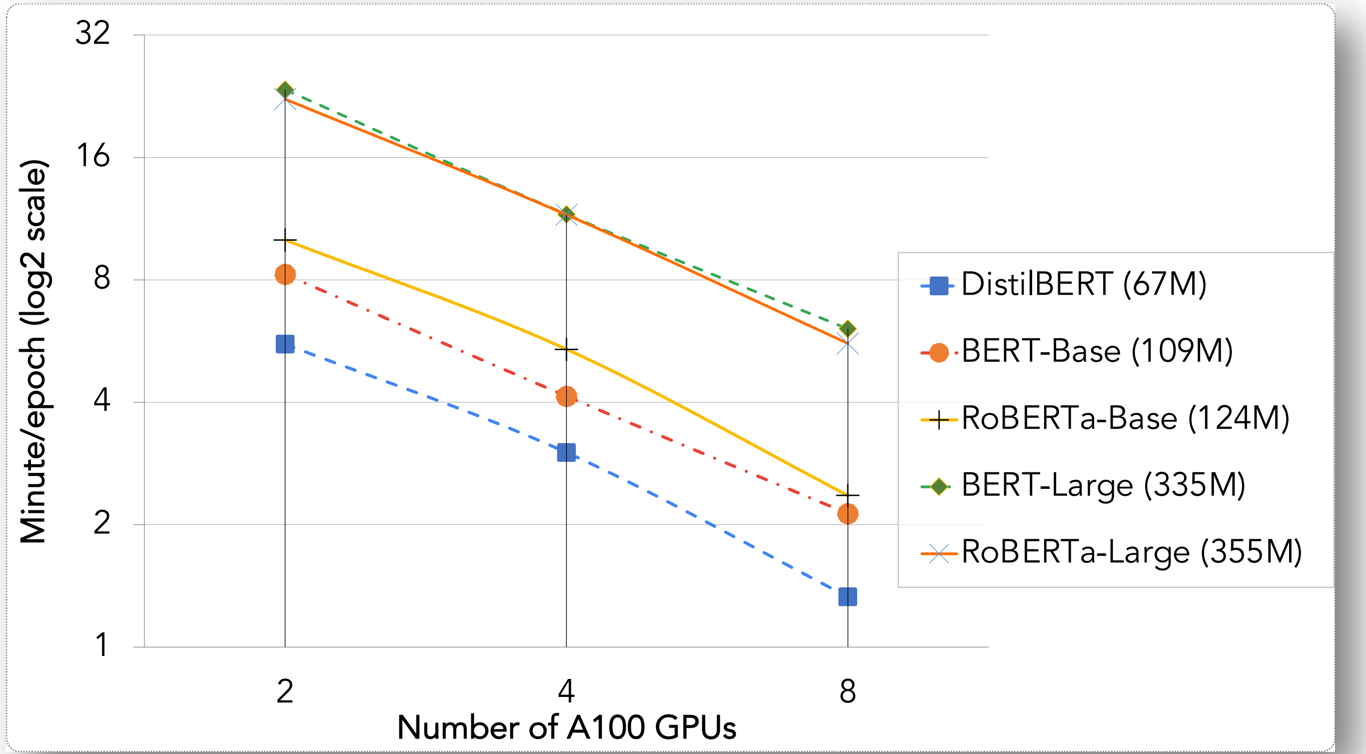
Architectural overview of V2W-BERT framework

Implementation details

- Huggingface and PyTorch Lightning :
  - Huggingface provides a wide range of transformer-based models
  - PyTorch Lightning helps organize and parallelize PyTorch implementations efficiently (DP, DDP)
- Step 1: V2W-BERT pretraining with CVE/CWE descriptions
  - Retraining BERT model with domain specific CVE descriptions
  - Take a batch of CVEs and update
- Step 2: V2W-BERT linking CVEs with CWEs
  - Take batch of CVEs, batch of CWEs, process them parallel
  - Create training links process them parallel
  - Process reconstruction loss of the batch of CVEs and CWEs parallel

Strong Scaling of V2W-BERT: GPUs vs. #parameters



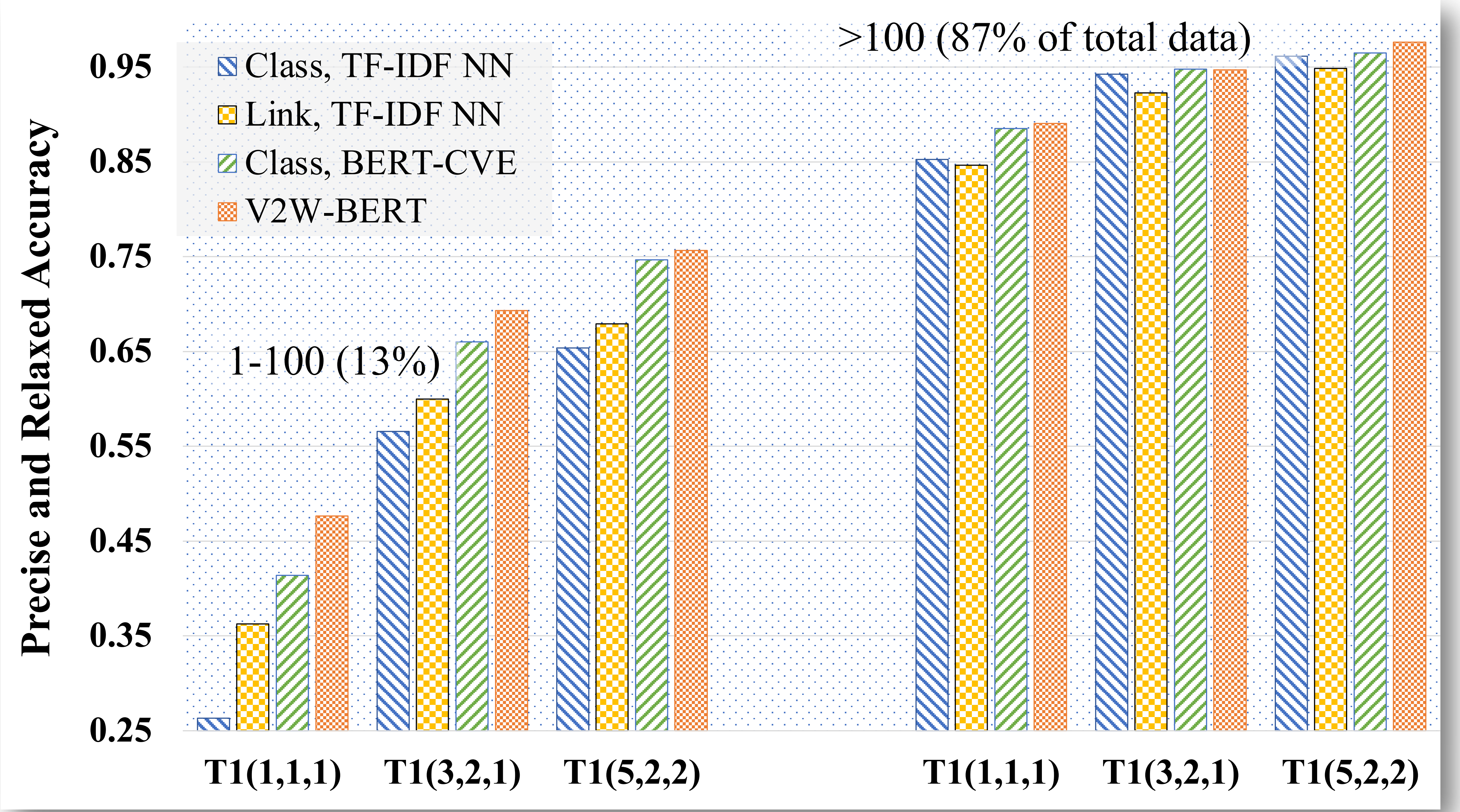


Pre-training time for BERT-Large across different generations of Nvidia accelerators with different number of GPUs

Scaling of different language models on A100 system with a batch size of 16

Das S., M. Halappanavar, A. Tumeo, E. Serra, A. Pothen, and E. Al-Shaer. "VWC-BERT: Scaling Vulnerability–Weakness–Exploit Mapping 59 60 3 on Modern AI Accelerators." In *IEEE International Conference on Big Data* (IEEE BigData 2022) December 17-20, 2022. Osaka, Japan.

A Summary of Key Results



Relative Performance (temporal partition)

Table 5: Performance comparison of V2W-BERT

	Model	Test 1 (k_1, k_2, k_3)			Test 2 (k_1, k_2, k_3)		
		(1,1,1)	**(3,2,1)**	**(5,2,2)**	**(1,1,1)**	**(3,2,1)**	**(5,2,2)**
1-100	Class, TF-IDF NN	0.2631	0.5656	0.6537	0.2519	0.4838	0.5739
	Link, TF-IDF NN	0.3626	0.5998	0.6791	0.3395	0.564	0.659
	Class, $BERT_{CVE}$	0.4138	0.6602	0.7466	0.2914	0.6105	0.6902
	Link, V2W-BERT	**0.4765**	**0.6933**	**0.7564**	**0.4072**	**0.6293**	**0.7179**
>100	Class, TF-IDF NN	0.8524	0.9425	0.9616	0.7815	0.8953	0.9404
	Link, TF-IDF NN	0.8463	0.9227	0.9485	0.7604	0.8738	0.9153
	Class, $BERT_{CVE}$	0.8852	0.9479	0.9649	0.8067	0.9064	0.9414
	Link, V2W-BERT	**0.8905**	**0.947**	**0.9763**	**0.8113**	**0.9123**	**0.9492**
All	Class, TF-IDF NN	0.775	0.893	0.9298	0.6886	0.8231	0.8761
	Link, TF-IDF NN	0.7828	0.8803	0.9132	0.6863	0.8196	0.8706
	Class, $BERT_{CVE}$	0.8232	0.9101	0.9363	0.7163	0.8578	0.9038
	Link, V2W-BERT	**0.8362**	**0.914**	**0.9442**	**0.7345**	**0.8594**	**0.9151**

Randomly Partitioned (across years)

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Table 4: Performance with randomly partitioned dataset

Model	**Test Set** (k_1, k_2, k_3)		
	(1,1,1)	**(3,2,1)**	**(5,2,2)**
Class, TF-IDF NN	0.8606	0.9464	0.9668
Link, TF-IDF NN	0.8642	0.9502	0.9693
Class, $BERT_{CVE}$	0.8812	0.9503	0.9689
Link, V2W-BERT	**0.8916**	**0.9523**	**0.9723**

Quality Across Models

- Best performance from RoBERTa
- Hierarchical Mapping

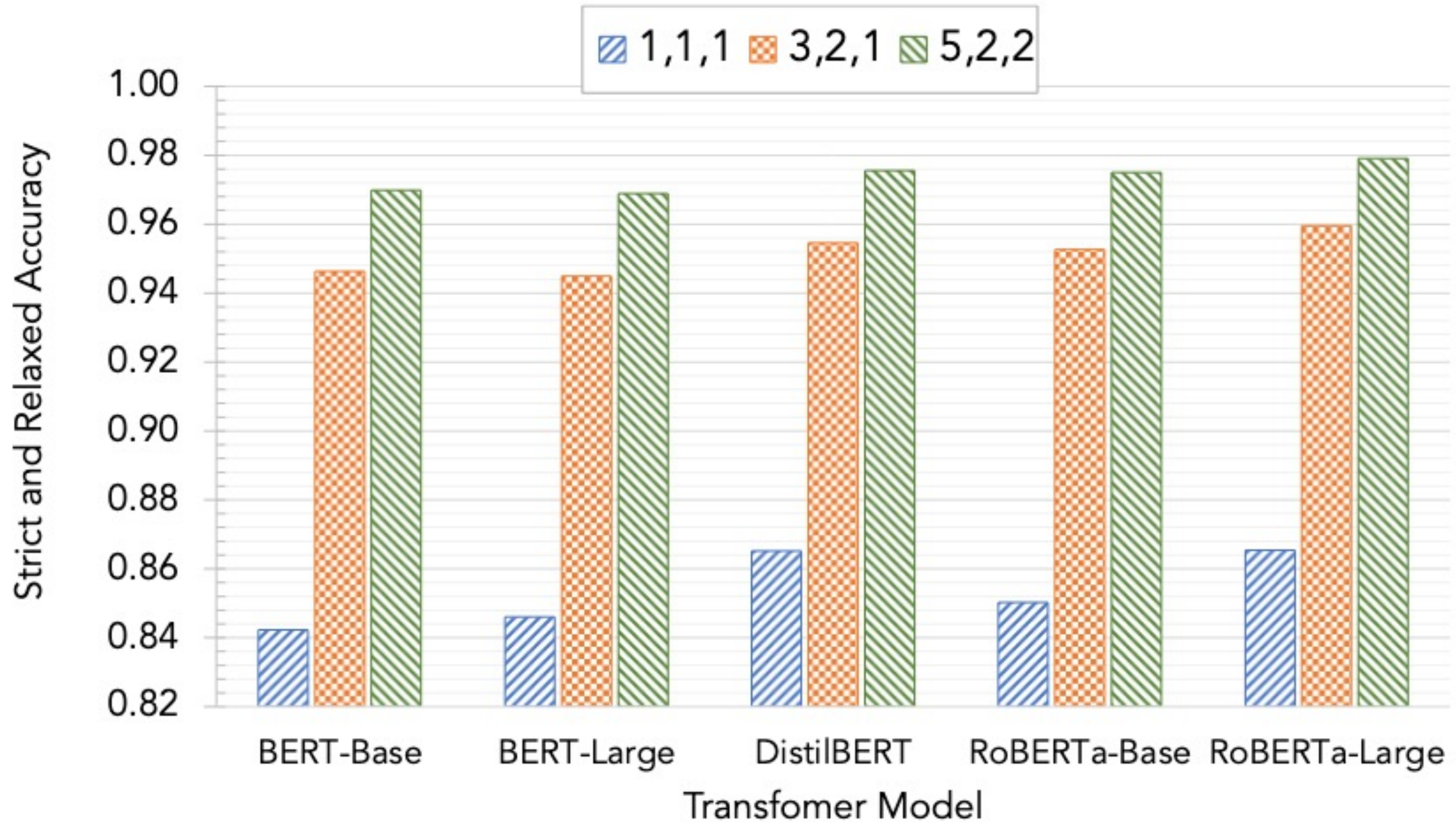
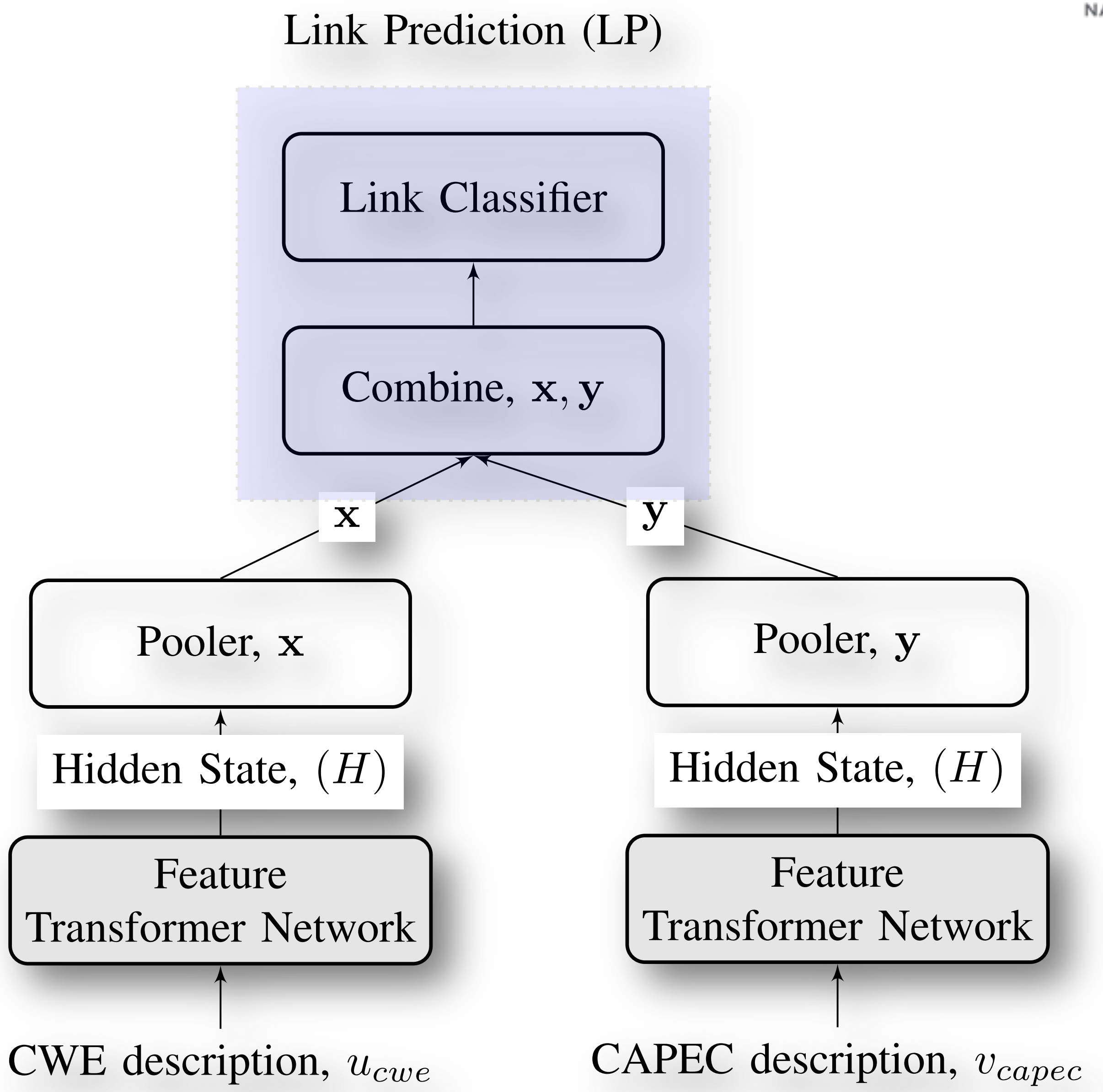


Fig. 3: Prediction accuracy of CVEs to CWEs using different language models. The (3,2,1) Refers to taking top 3 predictions from root, 2 from their children and 1 from leaf nodes of the CWE hierarchy.

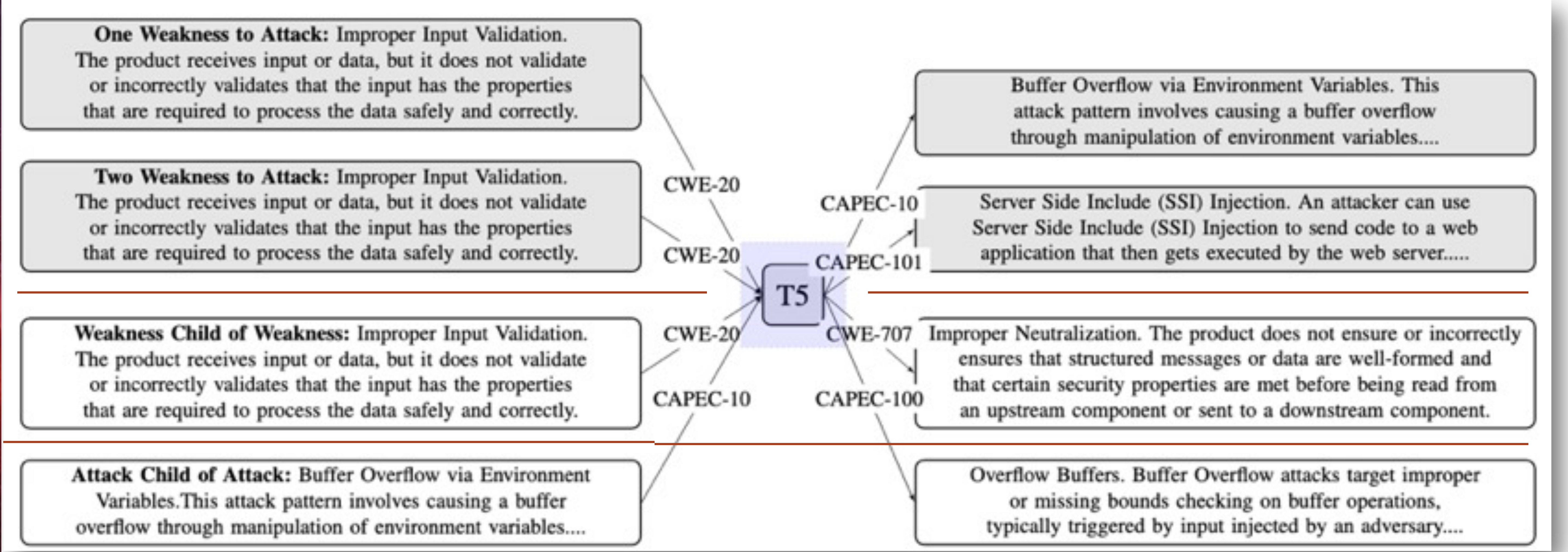
CWE-CAPEC: VWC-MAP Framework:
Approach1: Link prediction

Architectural overview of the Link Prediction network. The Feature Transformer components have shared weights. The model takes CWE-CAPEC feature information and transforms and combines them for prediction



S. Das, A. Dutta, S. Purohit, E. Serra, M. Halappanavar and A. Pothen, "Towards Automatic Mapping of Vulnerabilities to Attack Patterns using Large Language Models," 2022 *IEEE International Symposium on Technologies for Homeland Security* (HST), Boston, MA, USA, 2022, pp. 1-7, doi: 10.1109/HST56032.2022.10025459. [**Best Paper Award in Cyber Security Track**]

CWE-CAPEC: VWC-MAP Framework
Approach2: Using LLMs (Google T5)



Text-2-Text Mapping: Training process for VWC-MAP framework

CWE-CAPEC Mapping Result: CWE-131

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CWE	Link Prediction		T5-model	
	CAPEC	Rating	CAPEC	Rating
CWE-131: Incorrect Calculation of Buffer Size	CAPEC-100: Overflow Buffers*	10	CAPEC-100: Overflow Buffers*	10
	CAPEC-47: Buffer Overflow via Parameter Expansion*	10	CAPEC-47: Buffer Overflow via Parameter Expansion*	10
	CAPEC-14: Client-side Injection-induced Buffer Overflow	8	CAPEC-14: Client-side Injection-induced Buffer Overflow	8
	CAPEC-24: Filter Failure through Buffer Overflow	10	CAPEC-24: Filter Failure through Buffer Overflow	10
	CAPEC-256: SOAP Array Overflow	10	CAPEC-67: String Format Overflow in syslog()	3
	CAPEC-45: Buffer Overflow via Symbolic Links	5	CAPEC-45: Buffer Overflow via Symbolic Links	5
	CAPEC-46: Overflow Variables and Tags	10	CAPEC-46: Overflow Variables and Tags	10
	CAPEC-8: Buffer Overflow in an API Call	3	CAPEC-8: Buffer Overflow in an API Call	3
* - Ground truth				

Predictions from our Link Prediction model for CWE-131. Both models predict the ground truth of two CAPECs perfectly. The additional predictions were evaluated manually and we have found them to be highly relatable. It’s also interesting to see both of these give almost same predictions with one difference.

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CWE-CAPEC Mapping Result: CWE-22

CWE	Link Prediction		T5-model	
	CAPEC	Rating	CAPEC	Rating
CWE-22: Improper Limitation of a Pathname to a Restricted Directory ('Path Traversal')	CAPEC-126: Path Traversal*	10	CAPEC-126: Path Traversal*†	×
	CAPEC-64: Using Slashes and URL Encoding Combined to Bypass Validation Logic*†	×	CAPEC-64: Using Slashes and URL Encoding Combined to Bypass Validation Logic	10
	CAPEC-76 Manipulating Web Input to File System Calls*	10	CAPEC-76: Manipulating Web Input to File System Calls*	10
	CAPEC-78: Using Escaped Slashes in Alternate Encoding*†	×	CAPEC-78: Using Escaped Slashes in Alternate Encoding	10
	CAPEC-79: Using Slashes in Alternate Encoding*†	×	CAPEC-79: Using Slashes in Alternate Encoding*†	×
	CAPEC-597: Absolute Path Traversal	10	CAPEC-80: Using UTF-8 Encoding to Bypass Validation Logic	10
	CAPEC-139: Relative Path Traversal	10	CAPEC-139: Relative Path Traversal	10
			CAPEC-3:Using Leading 'Ghost' Character Sequences to Bypass Input Filters	5

* - Ground truth   † - not predicted

Predictions from our Link Prediction model for CWE-22. We kept the original CWE-CAPEC mapping hidden during training time. We can see Link prediction model predicted two out of five CAPECs successfully, and the suggested two CAPECs match the context. The T5-model predicted three CAPECs successfully, and among the suggestions, two of the three CAPECs match contexts.

3. Insights and Next Steps

Vulnerability Exploration (http://enigma.pnl.gov:8501/)

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CVE Home

SOM Cluster

CAPEC Cluster

CVSS Metric

○ cvss_v2 ● cvss_v3

Time range

2010 2023

2010 2023

CVE Lookup

CVE-2017-11882

CVE-2017-11882

2017-11-15 03:29:00 UTC

Score: 7.8

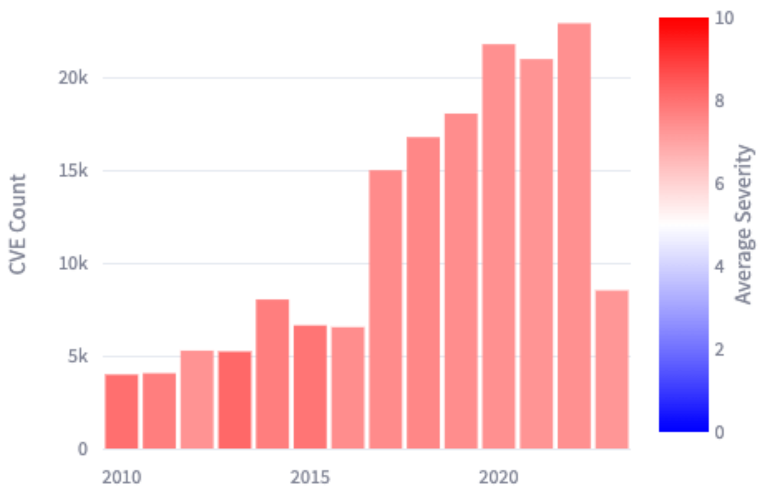
Microsoft Office 2007 Service Pack 3, Microsoft Office 2010 Service Pack 2, Microsoft Office 2013 Service Pack 1, and Microsoft Office 2016 allow an attacker to run arbitrary code in the context of the current user by failing to properly handle objects in memory, aka "Microsoft Office Memory Corruption Vulnerability". This CVE ID is unique from CVE-2017-11884.

Vector: 'CVSS:3.1/AV:L/AC:L/PR:N/UI:R/S:U/C:H/I:H

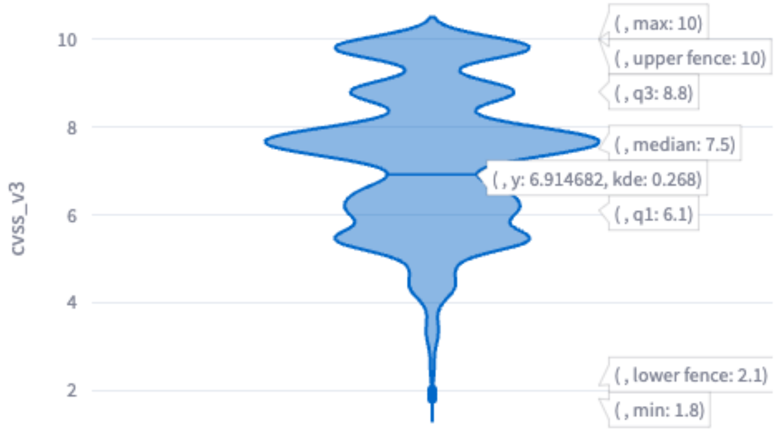
Annual Monthly

2023 2022 2021 2020 2019 2018 2017 2016 2015 2014 2013

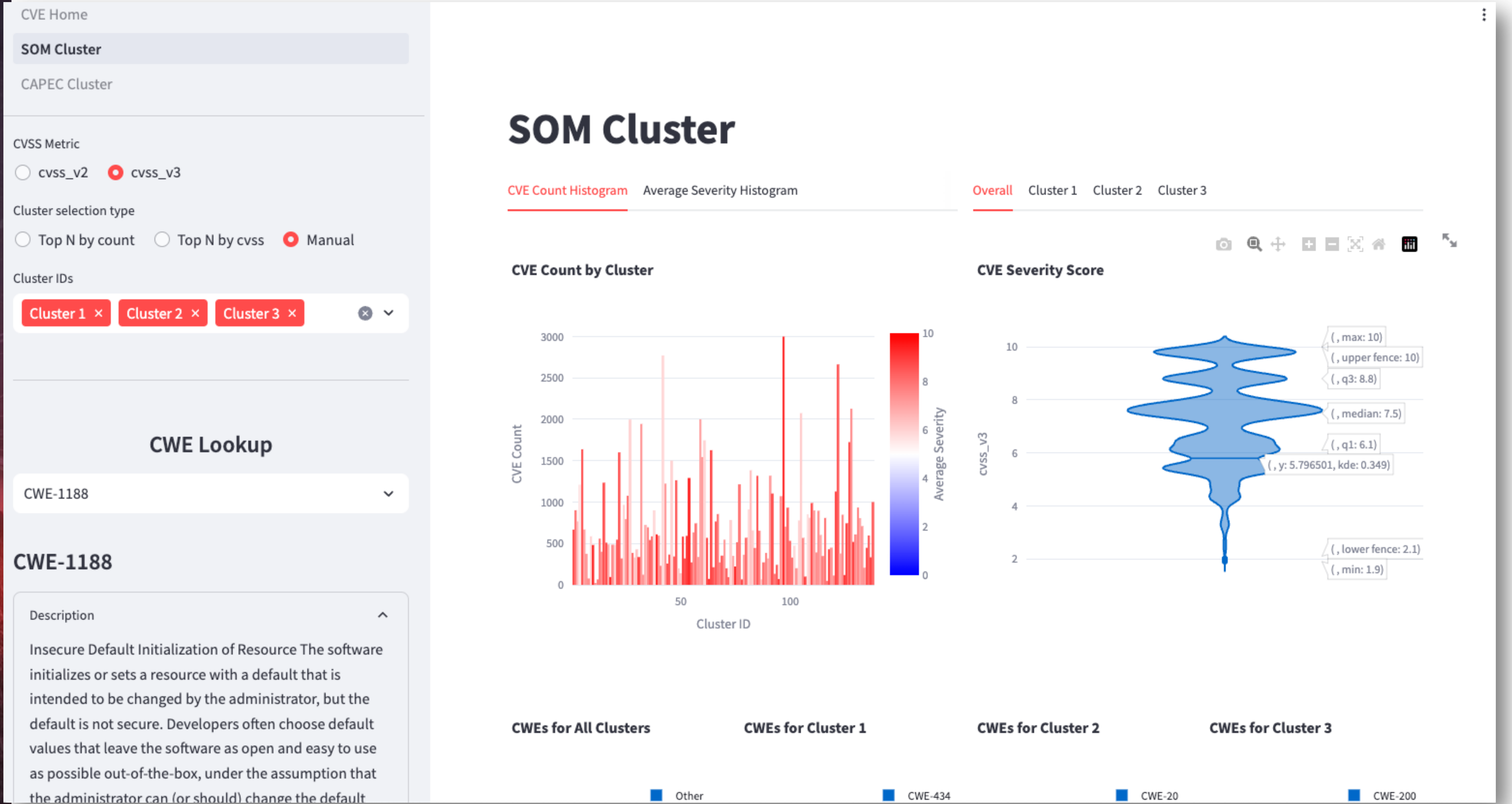
CVE Histogram



CVE Severity Score



	publishedDate	CVE ID	CVE Description	impact.baseM
1	2017-02-13 21:59:00+00:00	CVE-2017-5145	An issue was discovered in Carlo Gavazzi VMU-C EM prior to firmware Version A11_U0	CVSS:3.0/AV:N,
2	2018-08-20 19:31:00+00:00	CVE-2018-1000652	JabRef version <=4.3.1 contains a XML External Entity (XXE) vulnerability in MsBibImp	CVSS:3.0/AV:N,
3	2018-08-20 19:31:00+00:00	CVE-2018-1000651	Stroom version <5.4.5 contains a XML External Entity (XXE) vulnerability in XML Parser	CVSS:3.0/AV:N,
4	2018-08-20 19:31:00+00:00	CVE-2018-1000644	Eclipse RDF4j version < 2.4.0 Milestone 2 contains a XML External Entity (XXE) vulneral	CVSS:3.0/AV:N,
5	2018-11-07 05:29:00+00:00	CVE-2018-19047	** DISPUTED ** mPDF through 7.1.6, if deployed as a web application that accepts arl	CVSS:3.0/AV:N,
6	2019-07-02 17:15:00+00:00	CVE-2019-7268	Linear eMerge 50P/5000P devices allow Unauthenticated File Upload.	CVSS:3.1/AV:N,



K. Panchal, S. S. Das, L. De La Torre, J. Miller, R. Rallo and M. Halappanavar, "Efficient Clustering of Software Vulnerabilities using Self Organizing Map (SOM)," 2022 *IEEE International Symposium on Technologies for Homeland Security* (HST), Boston, MA, USA, 2022, pp. 1-7, doi: 10.1109/HST56032.2022.10025443.

Case Studies

- Microsoft Office Memory Corruption (**CVE 2017-11882**):
  - This Microsoft Office software bug allows attackers to execute arbitrary code on the user's system by convincing the user to open a malicious file. It was patched in a later version of Office.
  - **CWE-119** (from V2W-BERT): Improper Restriction of Operations within the Bounds of a Memory Buffer --- The software performs operations on a memory buffer, but it can read from or write to a memory location that is outside of the intended boundary of the buffer.
- Citrix Netscaler Directory Traversal (CVE-2019-19781):
  - An issue was discovered in Citrix Application Delivery Controller (ADC) and Gateway 10.5, 11.1, 12.0, 12.1, and 13.0. They allow Directory Traversal.
  - CWE-22: Improper Limitation of a Pathname to a Restricted Directory ('Path Traversal') The software uses external input to construct a pathname that is intended to identify a file or directory that is located underneath a restricted parent directory, but the software does not properly neutralize special elements within the pathname that can cause the pathname to resolve to a location that is outside of the restricted directory

CISA CYBERSECURITY ADVISORY: Top Routinely Exploited Vulnerabilities
August 20, 2021 -- Alert CodeAA21-209A

CVE-2017-11882

CVE-2017-11882

2017-11-15 03:29:00 UTC

`Score: 7.8`

Microsoft Office 2007 Service Pack 3, Microsoft Office 2010 Service Pack 2, Microsoft Office 2013 Service Pack 1, and Microsoft Office 2016 allow an attacker to run arbitrary code in the context of the current user by failing to properly handle objects in memory, aka "Microsoft Office Memory Corruption Vulnerability". This CVE ID is unique from CVE-2017-11884.

`Vector: 'CVSS:3.1/AV:L/AC:L/PR:N/UI:R/S:U/C:H/I:H`

More information: https://www.cvedetails.com/cve/CVE-2017-11882

CWEs

['CWE-119']

The CVE to CWE mappings are provided by employing the V2W-BERT tool using the DistilBERT model. These mappings have not been validated by subject matter experts and should be used only as a suggestion.

CWE Lookup

CWE-119

CWE-119

Description

Improper Restriction of Operations within the Bounds of a Memory Buffer The software performs operations on a memory buffer, but it can read from or write to a memory location that is outside of the intended boundary of the buffer. Certain languages allow direct addressing of memory locations and do not automatically ensure that these locations are valid for the memory buffer that is being referenced. This can cause read or write operations to be performed on memory locations that may be associated with other variables, data structures, or internal program data. As a result, an attacker may be able to execute arbitrary code, alter the intended control flow, read sensitive information, or cause the system to crash.
::SCOPE:Integrity:SCOPE:Confidentiality:SCOPE:Availability:IMPACT
Unauthorized Code or Commands:IMPACT
Memory:NOTE
the memory accessible by the attacker can be effectively controlled, it may be possible to execute arbitrary code, as with a standard buffer overflow. If the attacker can overwrite a pointer's worth of memory (usually 32 or 64 bits), they can redirect a function pointer to their own malicious code. Even when the attacker can only modify

CWE Lookup

CWE-119

CWE-119

Description

CVEs

Linked Clusters: 2, 4, 5, 8, 10, 13, 14, 15, 17, 21, 22, 23, 25, 26, 28, 31, 32, 34, 35, 36, 37, 43, 44, 45, 46, 48, 56, 57, 58, 62, 63, 64, 66, 70, 71, 72, 77, 80, 81, 89, 92, 94, 95, 96, 98, 99, 100, 101, 105, 106, 107, 109, 110, 111, 112, 113, 114, 115, 116, 120, 122, 125, 127, 128, 129, 131, 132, 133, 134, 135, 136

View linked clusters

Cluster 122 × Cluster 125 ×
Cluster 127 × Cluster 128 ×
Cluster 129 × Cluster 131 ×
Cluster 132 × Cluster 133 ×
Cluster 134 × Cluster 135 ×

CWE Lookup

CWE-119

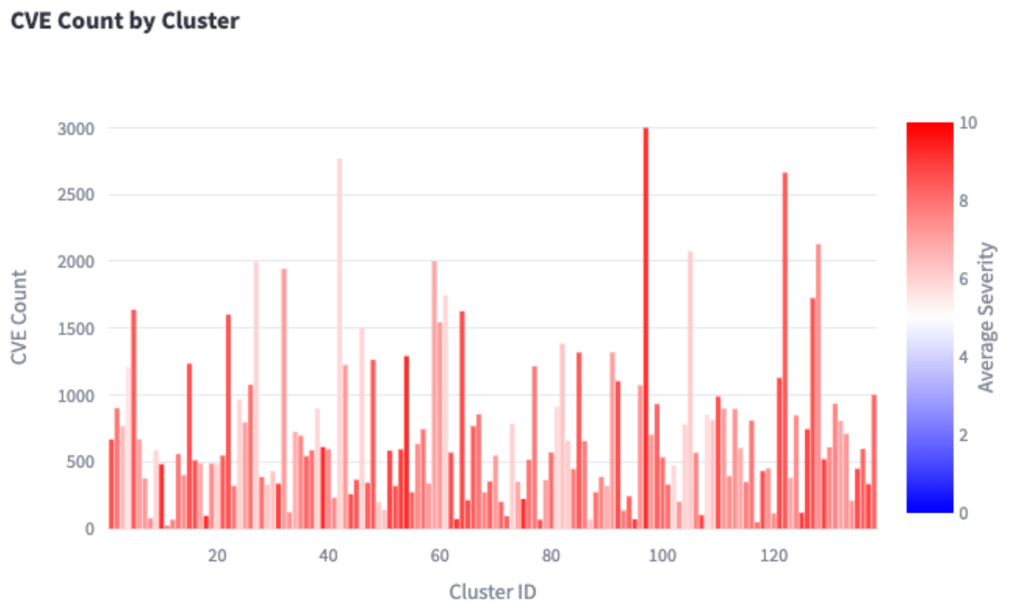
CWE-119

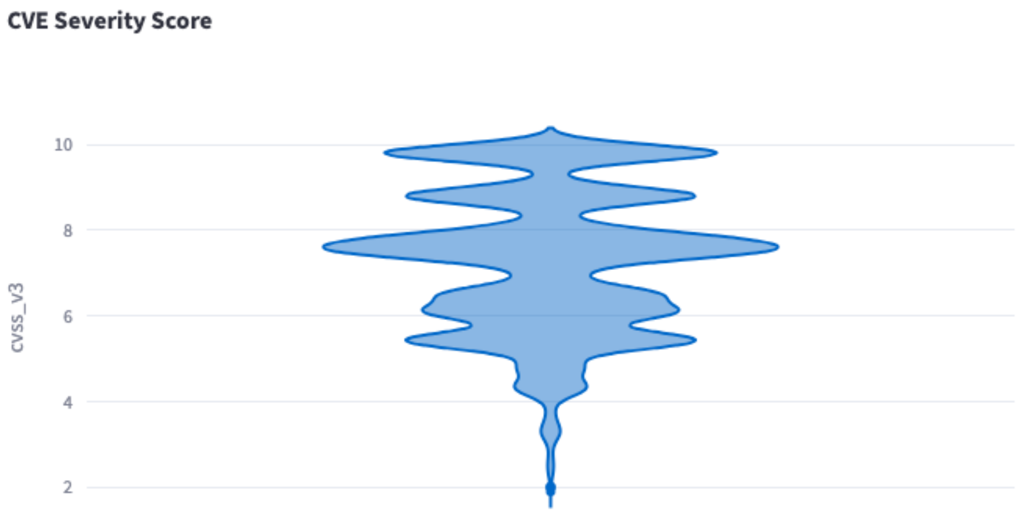
Description

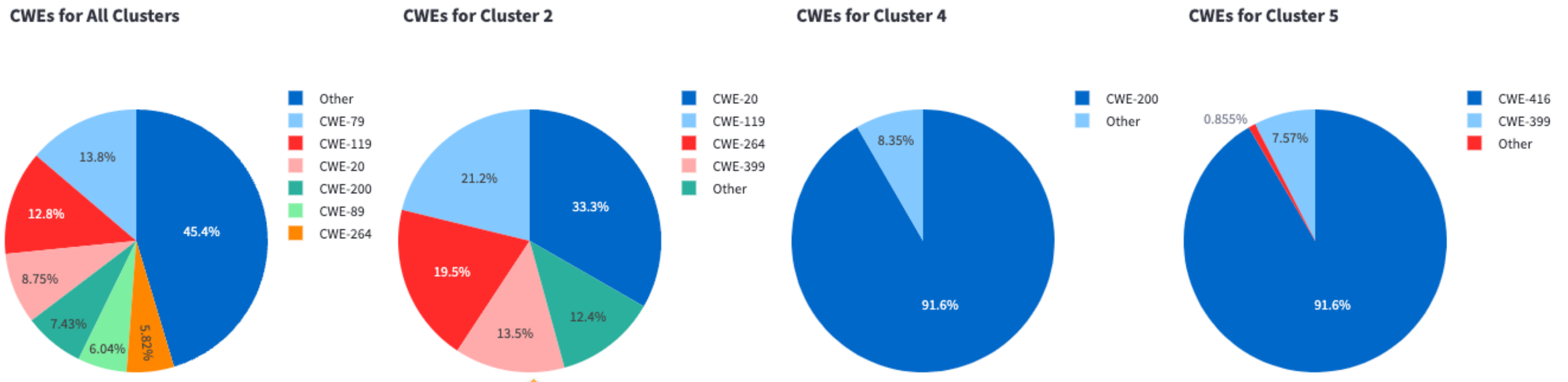
CVEs

Linked Clusters: 2, 4, 5, 8, 10, 13, 14, 15, 17, 21, 22, 23, 25, 26, 28, 31, 32, 34, 35, 36, 37, 43, 44, 45, 46, 48, 56, 57, 58, 62, 63, 64, 66, 70, 71, 72, 77, 80, 81, 89, 92, 94, 95, 96, 98, 99, 100, 101, 105, 106, 107, 109, 110, 111, 112, 113, 114, 115, 116, 120, 122, 125, 127, 128, 129, 131, 132, 133, 134, 135, 136

View linked clusters





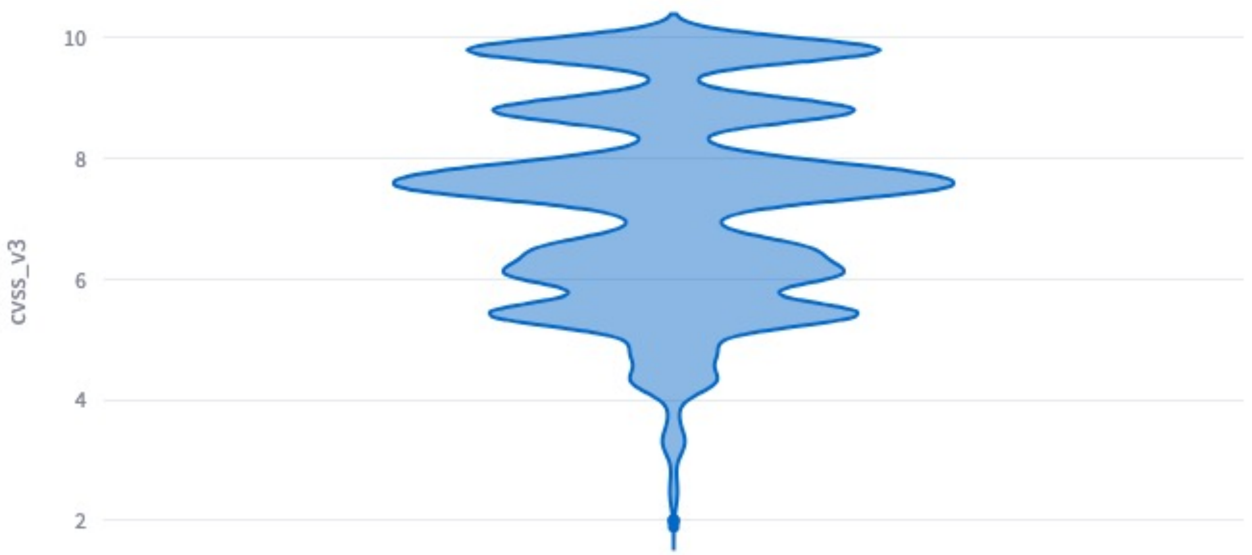


CVE Count Histogram
Average Severity Histogram
Overall
Cluster 2
Cluster 4
Cluster 5
Cluster 8
Cluster 10
Cluster 13
Cluster 14
Cluster 15
Average Severity by Cluster
Average Severity
0
2
4
6
8
20
40
60
80
100
120
Cluster ID
CVE Count
0
500
1000
1500
2000
2500
CVE Severity Score
cvss_v3
4
5
6
7
8
9
10

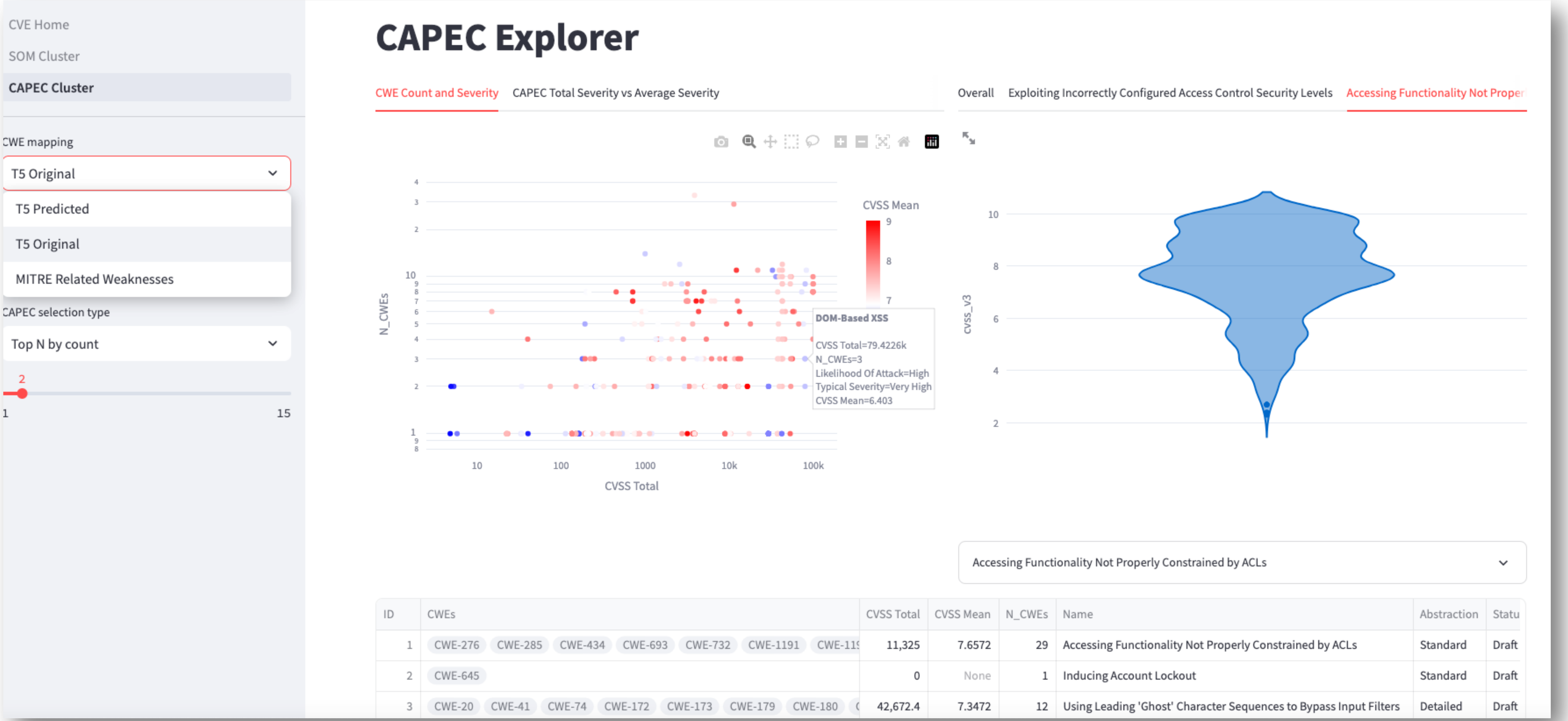
CAPEC Explorer

CWE Count and Severity | CAPEC Total Severity vs Average Severity

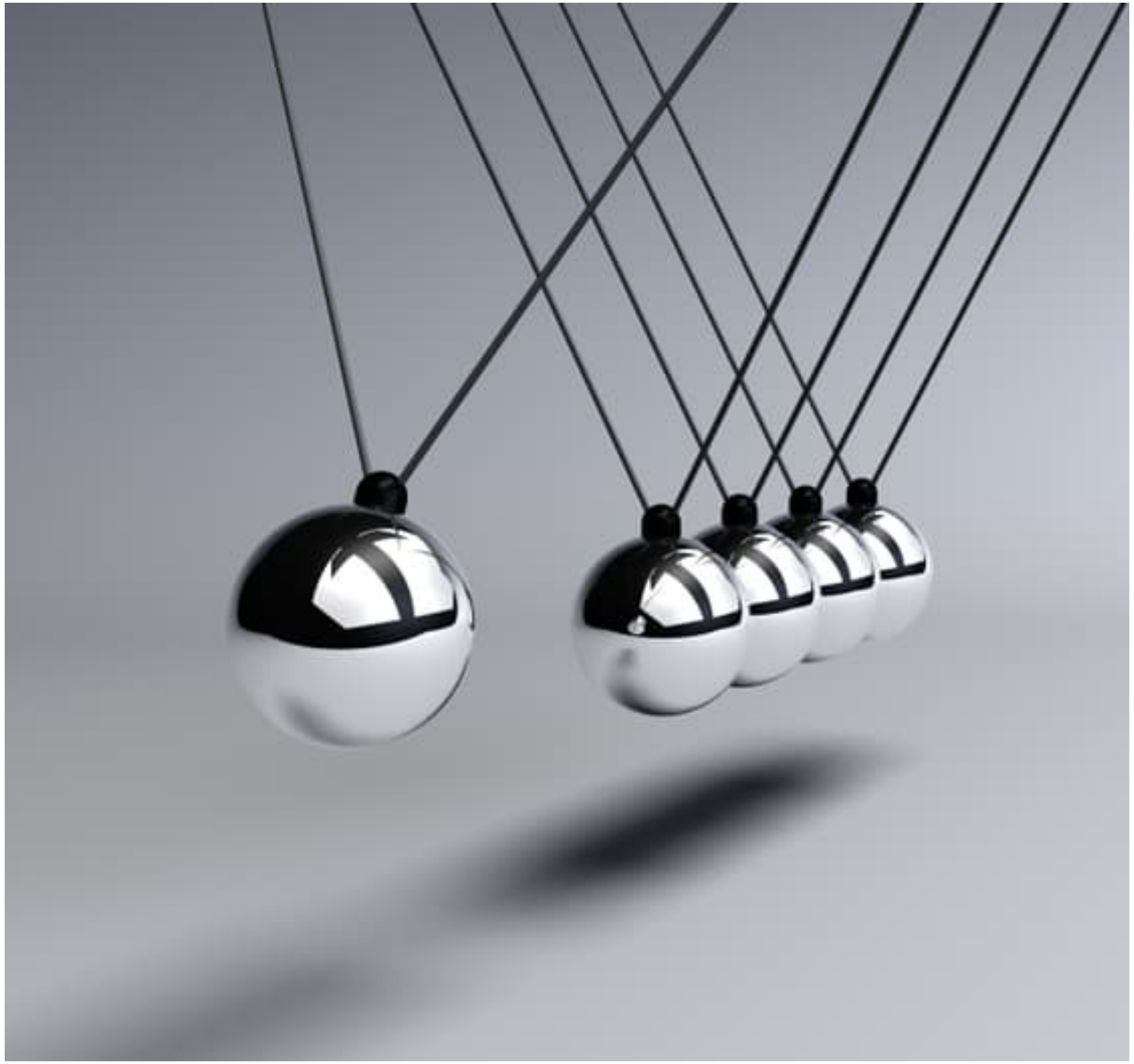
Overall | Buffer Overflow via Environment Variables | MIME Conversion | Buffer Overflow via Parameter Expa



ID	CWEs	CVSS Total	CVSS Mean	N_CWEs	Name	Abstraction	Statu
1	CWE-8 CWE-110 CWE-166 CWE-276 CWE-277 CWE-278 CWE-280	11,708.6	7.6327	55	Accessing Functionality Not Properly Constrained by ACLs	Standard	Draft
2	CWE-447 CWE-645	0	None	2	Inducing Account Lockout	Standard	Draft
3	CWE-8 CWE-24 CWE-26 CWE-28 CWE-29 CWE-30 CWE-32 CWE-3	10,270.4	8.1317	131	Using Leading 'Ghost' Character Sequences to Bypass Input Filters	Detailed	Draft
4	CWE-173 CWE-291 CWE-925	0	None	3	Using Alternative IP Address Encodings	Detailed	Draft
5	CWE-111 CWE-178 CWE-221 CWE-241 CWE-248 CWE-253 CWE-273	5,897.6	6.914	36	Blue Boxing	Detailed	Draft
6	CWE-78 CWE-141 CWE-142 CWE-143 CWE-145 CWE-146 CWE-153	8,028.7	8.5777	23	Argument Injection	Standard	Draft


CVE Home
SOM Cluster
CAPEC Cluster
CWE mapping
T5 Original
T5 Predicted
T5 Original
MITRE Related Weaknesses
CAPEC selection type
Top N by count
2
1
15
CAPEC Explorer
CWE Count and Severity
CAPEC Total Severity vs Average Severity
Overall
Exploiting Incorrectly Configured Access Control Security Levels
Accessing Functionality Not Prope
CVSS Mean
N_CWEs
CVSS Total
DOM-Based XSS
CVSS Total=79.4226k
N_CWEs=3
Likelihood Of Attack=High
Typical Severity=Very High
CVSS Mean=6.403
cvss_v3
Accessing Functionality Not Properly Constrained by ACLs
ID | CWEs | CVSS Total | CVSS Mean | N_CWEs | Name | Abstraction | Statu
1 | CWE-276 CWE-285 CWE-434 CWE-693 CWE-732 CWE-1191 CWE-11 | 11,325 | 7.6572 | 29 | Accessing Functionality Not Properly Constrained by ACLs | Standard | Draft
2 | CWE-645 | 0 | None | 1 | Inducing Account Lockout | Standard | Draft
3 | CWE-20 CWE-41 CWE-74 CWE-172 CWE-173 CWE-179 CWE-180 | 42,672.4 | 7.3472 | 12 | Using Leading 'Ghost' Character Sequences to Bypass Input Filters | Detailed | Draft

Summary & Conclusions



Summary of Contributions

- First work to provide complete mapping of CVEs to CWEs to CAPECs
- Showed how Siamese link predictions and large language models can be used for high quality mappings
- Scaled V2W-BERT on several generations of Nvidia systems and a GraphCore system
- Classified both frequent and rarely occurring CVEs better than all existing approaches
- Classified CVEs while maintaining the hierarchical relationships

Future Work

- Work with subject matter experts to perform validation and verification of mappings and clusters
- Enhance transfer learning techniques to classify CVEs/CWEs/CAPECs with few/zero training examples
- Build ability to predict if/when new CWE definitions are necessary
- Enhance mechanism to incorporate novel definitions over time
- Enhance the demonstration website

Pacific Northwest NATIONAL LABORATORY

The coming tsunami from AI disruptions

Sponsors:

- PNNL Lab Directed Research & Development
    - The Mathematics for Artificial Reasoning in Science (MARS) initiative
    - The Data Model Convergence (DMC) initiative
- Department of Energy's Office of Advanced Scientific Computing Research
- Department of Defense

Thank you

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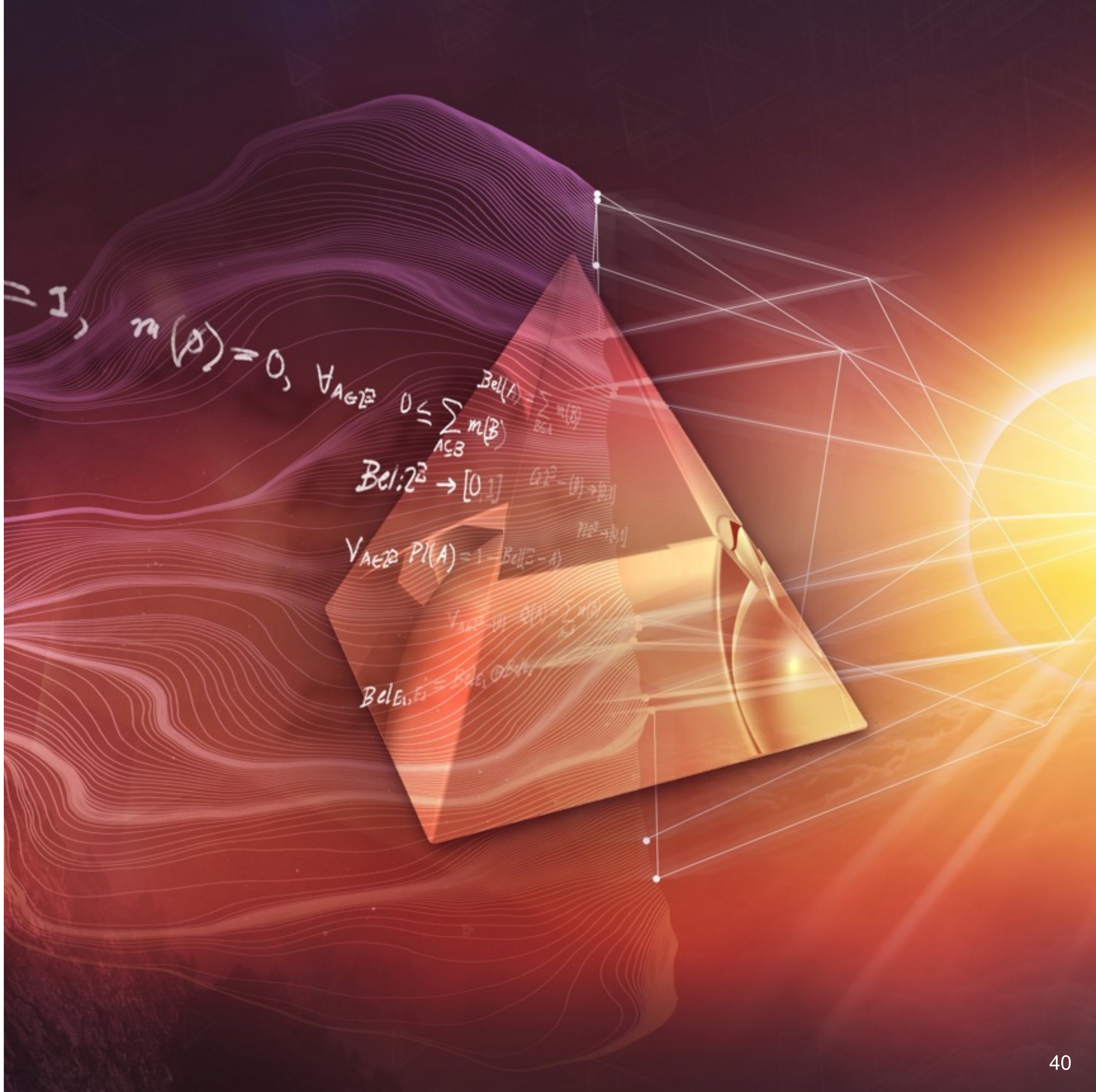


References

- S Das, E. Serra, M. Halappanavar, A. Pothen, and E. Al-Shaer. "V2W-BERT: A Framework for Effective Hierarchical Multiclass Classification of Software Vulnerabilities." In proceedings of the *8th IEEE International Conference on Data Science and Advanced Analytics* (*DSAA*). Porto, Portugal. October 2021. [**Best Application Paper Award**]
- S. Das, A. Dutta, S. Purohit, E. Serra, M. Halappanavar and A. Pothen, "Towards Automatic Mapping of Vulnerabilities to Attack Patterns using Large Language Models," 2022 *IEEE International Symposium on Technologies for Homeland Security* (HST), Boston, MA, USA, 2022, pp. 1-7, doi: 10.1109/HST56032.2022.10025459. [**Best Paper Award in Cyber Security Track**]
- K. Panchal, S. S. Das, L. De La Torre, J. Miller, R. Rallo and M. Halappanavar, "Efficient Clustering of Software Vulnerabilities using Self Organizing Map (SOM)," 2022 *IEEE International Symposium on Technologies for Homeland Security* (HST), Boston, MA, USA, 2022, pp. 1-7, doi: 10.1109/HST56032.2022.10025443.
- Das S., M. Halappanavar, A. Tumeo, E. Serra, A. Pothen, and E. Al-Shaer. "VWC-BERT: Scaling Vulnerability–Weakness–Exploit Mapping 59 60 3 on Modern AI Accelerators." In *IEEE International Conference on Big Data* (IEEE BigData 2022) December 17-20, 2022. Osaka, Japan.

Self Organizing Maps (Kohonen Maps)

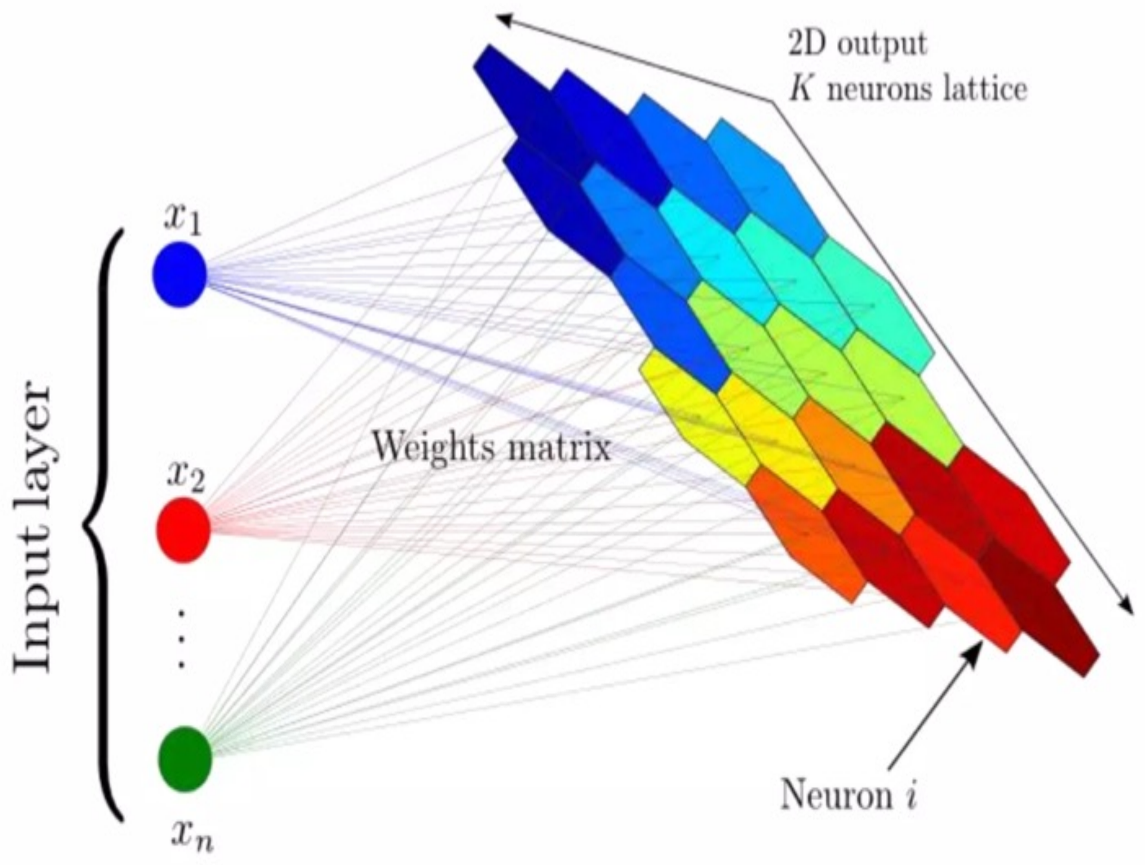
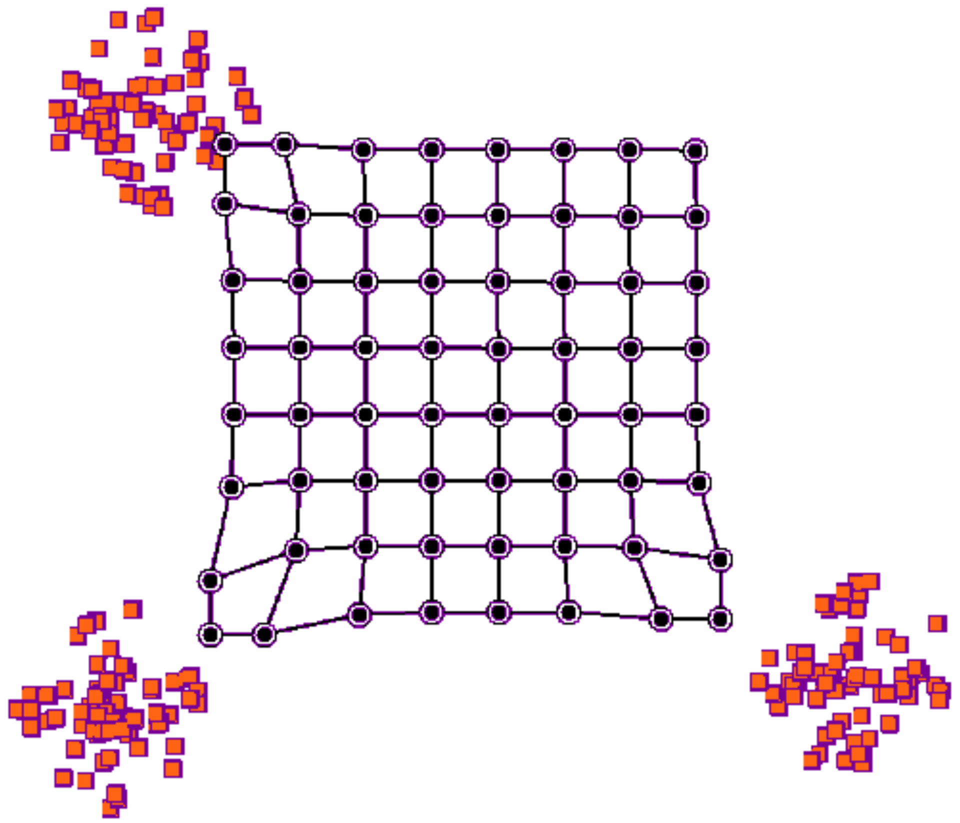


Image Adapted From: arxiv.org/pdf/1312.5753.pdf



Source: https://en.wikipedia.org/wiki/Self-organizing_map

SOM Training: Output from V2W-BERT (~100k CVEs)

- `sD = som_read_data('V2W-LINK-distilbert-base-uncased-dp_rep.txt’);`
- `sD is a struct with 99950×768 elements.`
- `sM=som_make(sD,'shape','toroid','mapsize','big','training','long','tracking',0);`
- `To Create, initialize and train Self-Organizing Map`
- sM struct with fields:

    type: 'som_map'

    codebook: [6417×768 double]

    topol: [1×1 struct]

    labels: {6417×1 cell}

    neigh: 'gaussian'

    mask: [768×1 double]

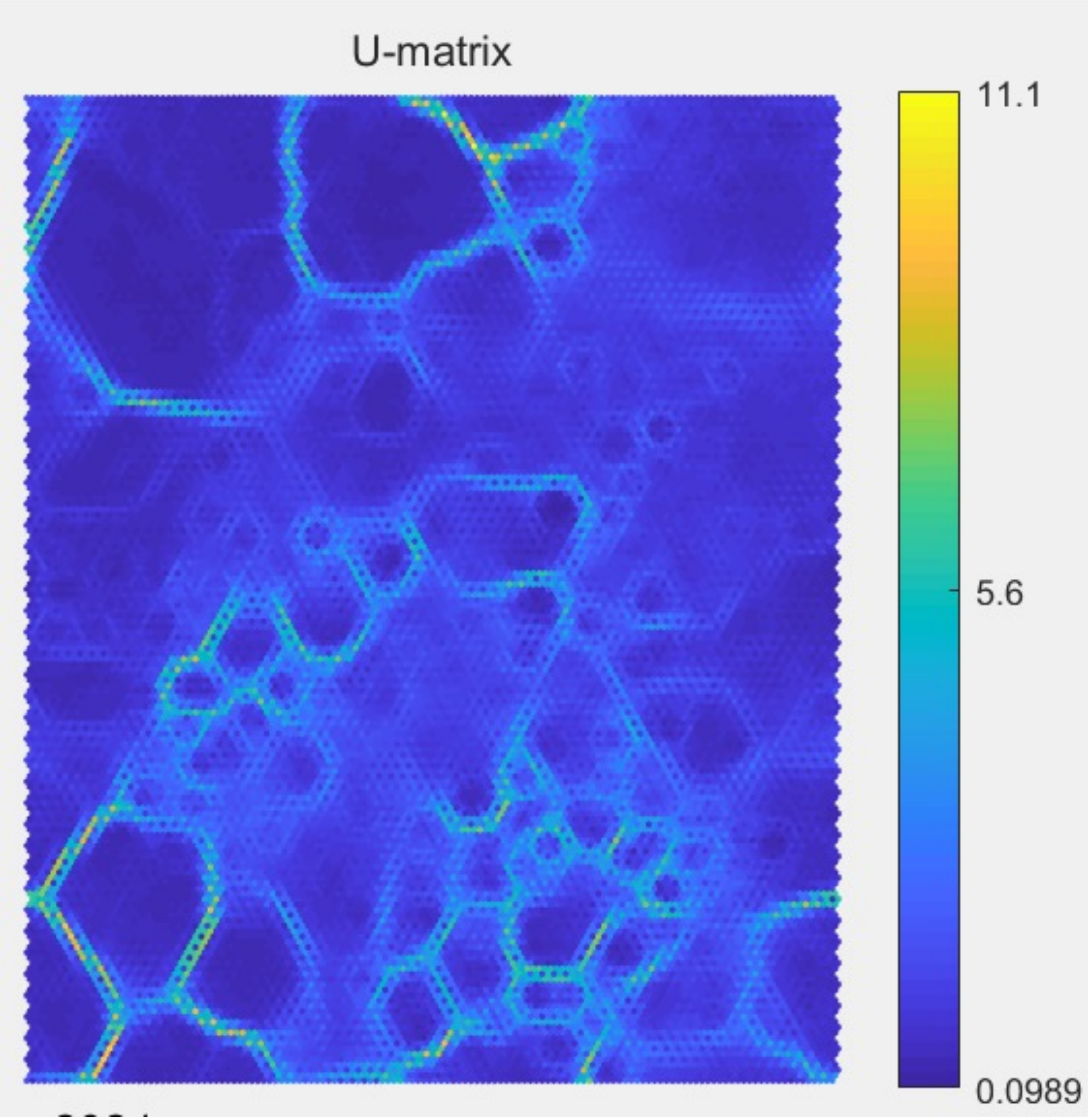
    trainhist: [1×3 struct]

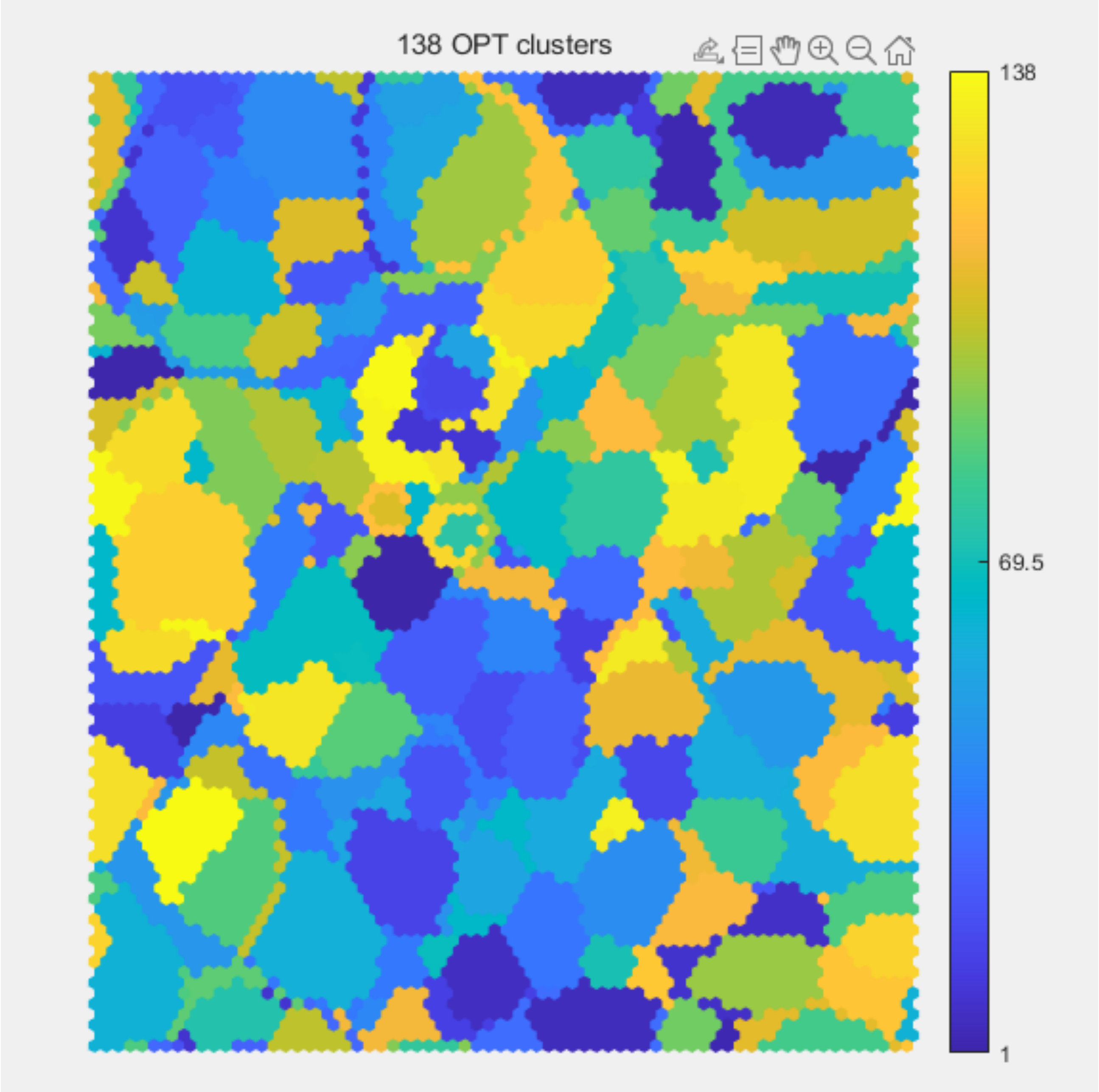
    name: 'SOM 01-Dec-2021'

    comp_names: {768×1 cell}

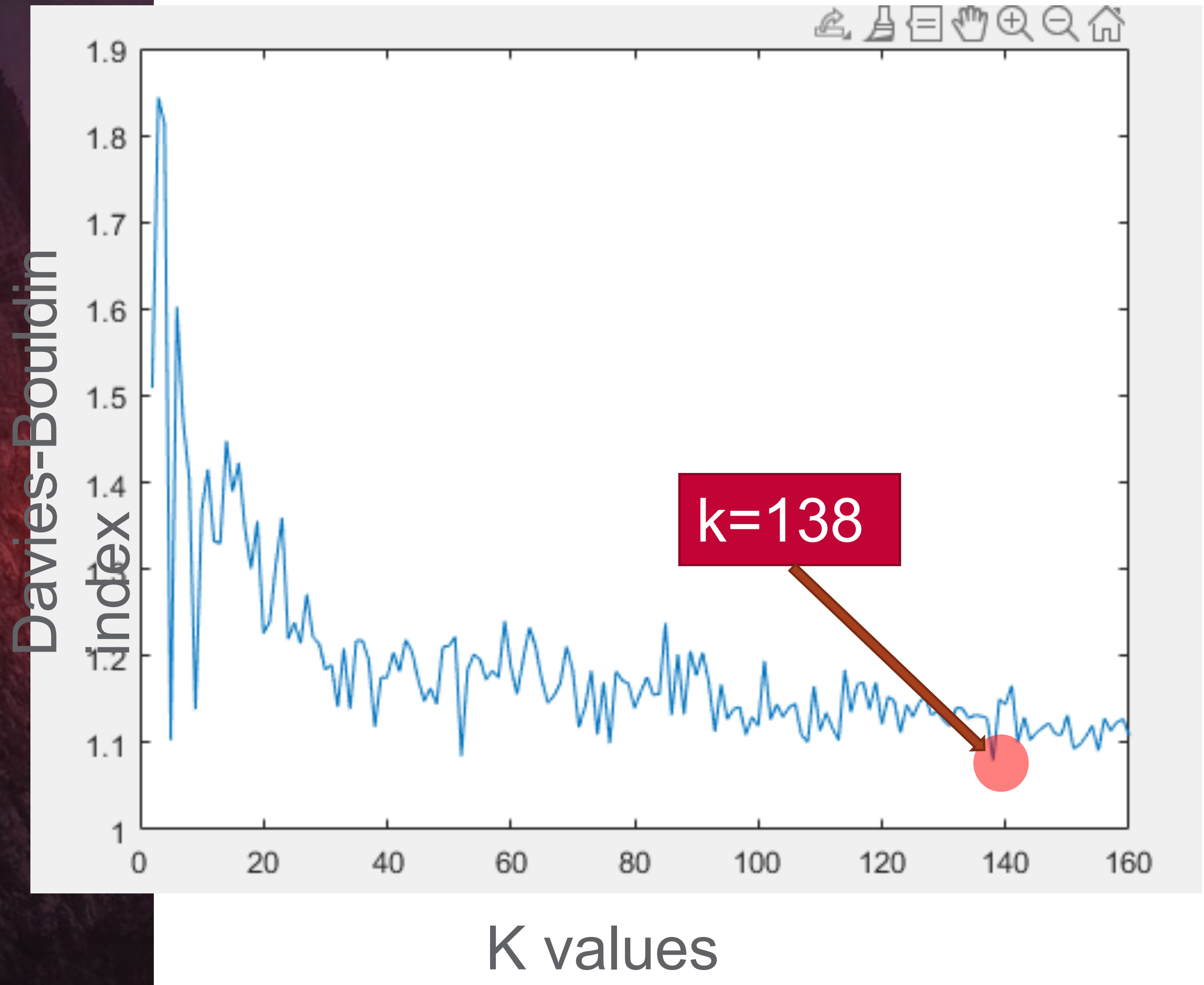
    comp_norm: {768×1 cell}

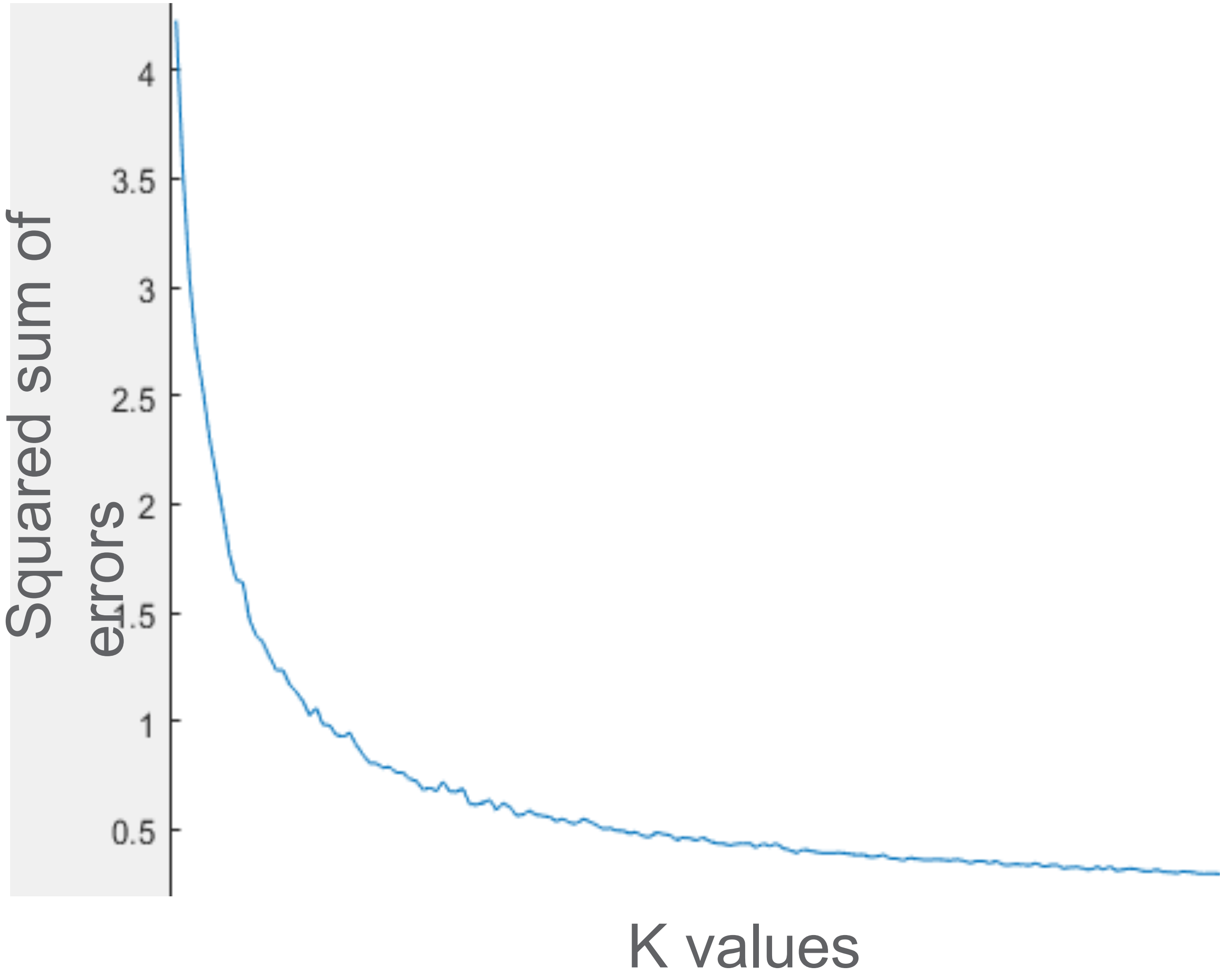
K-means clustering with K=138





K-means clustering with Davies-Bouldin optimization for selecting best k





Clusters: CWE label Representation Bar chart representation (first 10 clusters)

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