

TOWARDS A TRUSTWORTHY AND RESILIENT Machine Learning Classifier A Case Study of Ransomware Detector Creation

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Outline

- Background
- Issues of Classifier
- Model Fidelity
- Adversarial Research
- Conclusion

Background (Al-rimy, B. et al. 2018)

- Ransomware is a category of malware which hijacks victim's data or machine and demands monetary returns
- Taxonomy:
 - Locker-ransomware: hijack resources without encryption
 - Crypto-ransomware: encrypt files
- The damage done by crypto-ransomware is irreversible in most cases due to the use of cryptography

Typical Steps of Ransomware (McAfee 2017)



Purpose of Detector:

Find crypto-ransomware early by its behavior when AV missed it



Ransomware Dataset

- From VirusTotal
 - Downloaded total ~22k ransomware by Microsoft and Kaspersky's labels
 - ~5min execution for each sample
 - In bare-metal sandbox system with anti-evasion mechanism
- Decoy files to identify crypto-ransomware
- Total ~4.4k active samples:



Behavior Data – File Input/Output Events

- Collected by POC Windows application
 - Based on C#.Net framework, FileSystemWatcher (FSW)
 - Entropy of target files calculated by normalized Shannon entropy
- Sample data:

- Time stamp, I/O event type, target filename, entropy etc.

"2018-04-06T12:21:28","27937	,"Changed",	c:\Windows\System32\wbem\Repository\MAPPING1.MA	",0.465655021998745,	CDAB00001AB000006F0200006E020000
"2018-04-06T12:21:29","28890	,"Created",	c:\temp\start_00b4d8bf603522c86b572819beac6d7c5	ded1800368071fe74ed3	.280e2ca45_kasperskyransom_typepeex
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"2018-04-06T12:21:30","29984	,"Changed",	c:\Windows\System32\ <u>wbem</u> \Repository\MAPPING1.MA	",0.466994188018237,	DAB00007AB800007202000071020000

Machine Learning Analysis

- ~3.7k ransomware and similar amount of benign data (~100 applications). 80/20 split for training/testing dataset
- Featuring by event type with bucketed entropy (-,0.2,0.4,0.6,0.8,0.9)
 - Categorize into distinct features
- ML Algorithms for supervised learning:
 - Long-Short Term Memory (LSTM), Recurrent Neural Networks
 - Linear Support Vector Machine (SVM) with bag of N-gram, N=1 & 2

ML Pipeline & Outcome of Supervised Learning



Model	N-gram	Accuracy	FPR	Dist. Features
Linear SVM	1 & 2	98.31%	2.89%	90
LSTM	n/a	98.67%	1.38%	9

Online Detector

- A POC program utilized the ML classifier
 - Sample the I/O event stream by a sliding window
 - Real-time inference: small footprint and run fast
- Issues found after deployment:
 - 1. False alarms from some applications
 - 2. Size of sliding window affects the detection rate
 - 3. Cannot find ransomware early

1. Early Detection Issue

- Early detection is important
 - No practical value if can't detect encryption early
- When will the ransomware start doing encryption?
 - Identify the starting time by the decoy file

: malicious observation

Starting Time of Malicious Activities

 Ransomware may not show malicious activities at the beginning of execution



Early Detection and Sliding Window Testing

- Prepare samples to measure the performance
 - From ~700 unseen out-of-sample ransomware logs
- Extract early-stage data from each logs by
 - different time periods
 - different sliding windows



Detection Rate of Early-stage and Sliding-window



Data Augmentation

- Synthesize samples from existing dataset for a re-train
 - Early-stage samples
 - Sliding-window samples
 - Exclude samples without malicious events
- "Augmented" dataset count: 17.2k ransomware (80/20 split)

Model	N-gram	Accuracy	FPR	Dist. Feature
Linear SVM	1 & 2	99.13%	1.21%	90
LSTM	n/a	99.47 %	0.60%	9

Detection Rate by Augmented Classifier

SVM-A 319

LSTM-A 320



3. False Positive Issue

- Some benign-ware has similar ransomware behaviors
 - Delete or rename many files, change files with high entropy
- Solution: Add a new dimension to feature
 - Path: system vs. non-system folders
 - System path list: c:\Windows, c:\ProgramData, c:\Program Files, c:\Progra~, c:\AppData, \Downloads\, \Downlo~, c:\Config.msi

Results with Path Flag

Lower FPR with flag added

Model	N–gram	Accuracy	FPR	Dist. Features
Linear SVM	1 & 2	99.00%	1.34%	90
Linear SVM (+ <mark>path</mark>)	1 & 2	99.53%	0.54%	339
LSTM	-	98.26%	3.82%	9
LSTM (+ path)	-	98.35%	1.80%	18

- 22k out-of-sample clean execution log:
 - FPR down from 0.18% to 0.00% for SVM (40->0/22,174)
 - FPR down from 0.09% to 0.04% for LSTM (21->9/22,174)

Model Fidelity by Integrated Gradients Sundararajan M et al '17

Attribution: which feature/time step contribute the most?

Original image



Top label and score

Integrated gradients

Gradients at image

Top label: reflex camera

how many townships have a population above 50 ? [prediction: NUMERIC] what is the difference in population between fora and masilo [prediction: NUMERIC] how many athletes are not ranked ? [prediction: NUMERIC] what is the total number of points scored ? [prediction: NUMERIC] which film was before the audacity of democracy ? [prediction: STRING] which year did she work on the most films ? [prediction: DATETIME] what year was the last school established ? [prediction: DATETIME] when did ed sheeran get his first number one of the year ? [prediction: DATETIME] did charles oakley play more minutes than robert parish ? [prediction: YESNO]





Explanation of LSTM Models

C

Feature attribution plot of ransomware:



Adversarial Research

- A *simulated* ransomware, the *Red* team, was developed in C#
 - Rename, encrypt and delete files etc.
 - Evasive tricks to probe the detector (grey box attack):
 - Behavior temporal changes: e.g. slowdown the malicious activities
 - Encryption changes: e.g. insert dummy data to lower the file entropy
 - It's not difficult to evade our ML detector
- Improve model's resiliency by:
 - Discover weakness by the Red team with various conditions
 - Re-train model by the false negatives samples

Probing LSTM Models – by Event Insertion

Insert 7 benign events, -, 0.01

Createds 0			
Changed_0.2+_s 0		Changed_0.2+_s 0	
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Conclusion: ML Pipeline +++



+Adversarial ML/DL Iteration

Our Team Members and Projects

- Erdem Aktas; Li Chen; Anindya Paul
- MLsploit: a platform for ML model comparison and sample sharing for adversarial research
 - github.com/mlsploit
 - github.com/intel/Resilient-ML-Research-Platform



THANK YOU !

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