Malaware: the beginning of a behavioral malware detection

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Research topic proposed and supervised by
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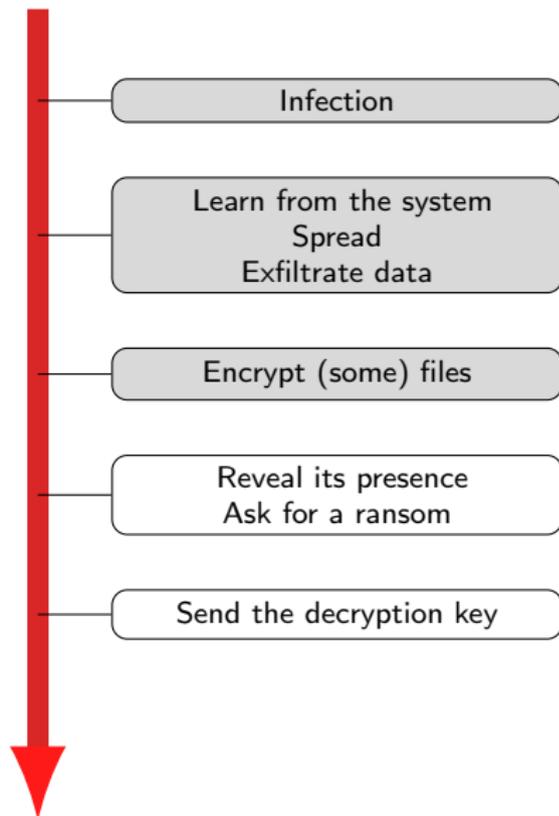June 28, 2023
Campus Cyber, Puteaux, France

What is a ransomware?

What is a ransomware?

How does a ransomware work?

A story of money

Ransomware : des pirates paralysent un hôpital français et exigent 10 millions d'euros

Cyberattaque : tous les serveurs de la ville de Caen sont hors-service

Global Ransomware Damage Costs [Bra21]
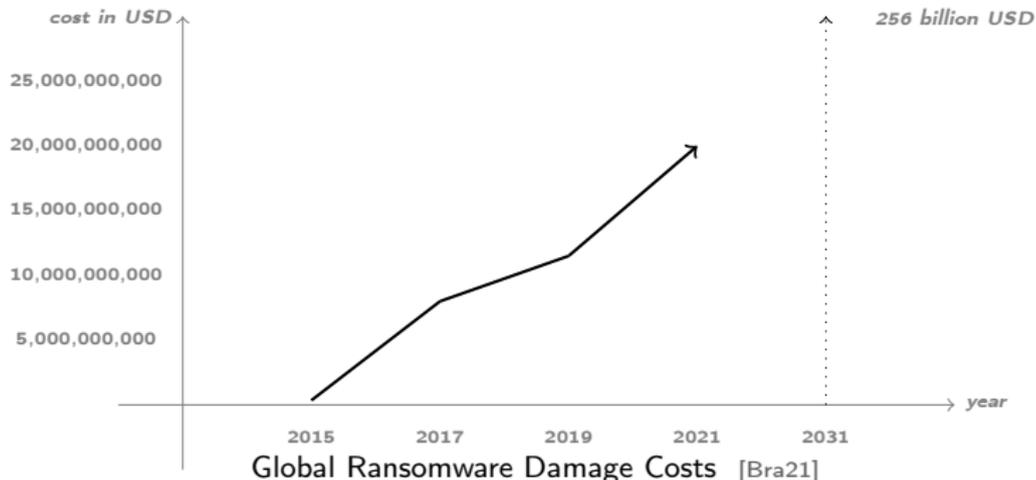
[Bra21] David Braue. Global Ransomware Damage Costs Predicted To Exceed 265 Billion USD By 2031. June 2021

A cat and mouse game

	Simple malware
No defense	√

[Bio+18] **Fabrizio Biondi et al**. "**Tutorial: an Overview of Malware Detection and Evasion Techniques**". In:
ISoLA 2018 - 8th International Symposium On Leveraging Applications of Formal Methods, Verification and Validation.
Oct. 2018, pp. 1–23
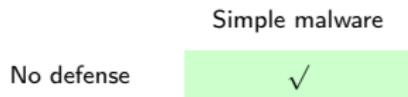
A cat and mouse game [Bio+18]

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No defense	√
Signature analysis	×

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A duck and dodge game [Bio+18]

	Simple malware	Small variations
No defense	√	√
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A duck and dodge game [Bio+18]

	Simple malware	Small variations
No defense	√	√
Signature analysis	×	√
Dynamic analysis	×	×

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A duck and duck game [Bio+18]

	Simple malware	Small variations	Anti-sandboxing
No defense	√	√	√
Signature analysis	×	√	√
Dynamic analysis	×	×	√

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A duck and duck game [Bio+18]

	Simple malware	Small variations	Anti-sandboxing
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Signature analysis	×	√	√
Dynamic analysis	×	×	√
Concolic analysis	×	×	×

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Quaaaaack

	Simple malware	Small variations	Anti-sandboxing	Symbolic explosion
No defense	√	√	√	√
Signature analysis	×	√	√	√
Dynamic analysis	×	×	√	√
Concolic analysis	×	×	×	√

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Dynamic analysis	×	×	√	√
Concolic analysis	×	×	×	√

Most of the widespread anti-malwares only uses signature analysis

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Dynamic analysis	×	×	√	√
Concolic analysis	×	×	×	√

Most of the widespread anti-malwares only uses signature analysis

But, you can imagine more advanced statistical analysis

e.g. checking the imported libraries

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An overview of malware detection techniques

Signature-based analysis

Classify binaries by looking at particular patterns in their code

"Have I already seen this binary?"

Quack
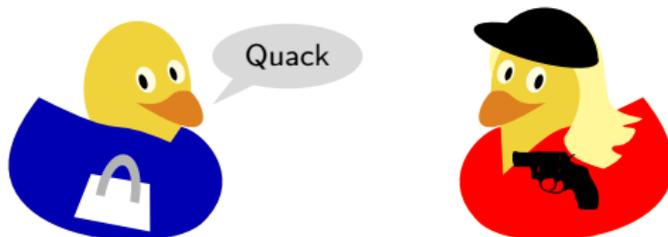
Behavioral-based analysis

Detect malware based on their behavior

"What does it want to do?"

Outline

Outline

Outline

Entropy related functions

Shannon Entropy

$$H(X) = -\sum_{i=1}^{n} P(x_i) \log_2 P(x_i)$$

Where H is the entropy (in bits)
n is the number of bytes
$P(x_i)$ probability of byte i

Monte Carlo

$$E(X) \approx \frac{1}{N} \sum_{n=1}^{N} x_n$$

Where E is the result of the approximation
x_n is a randomly choosen value

Chi-quare

$$\chi^2 = \sum_{i=0}^{255} \frac{(O_i - E_i)^2}{E_i}$$

Where O_i is the observed value
E_i is the expected value

Arithmetic mean

$$M = \frac{S}{T}$$

Where M is the arithmetic mean
S is the sum of the osbervations
T is the number of values

Serial Byte Correlation Coefficient

$$C = \frac{n(U_0 U_1 + U_1 U_2 + \cdots + U_{n-2} U_{n-1} + U_{n-1} U_0) - (U_0 + U_1 + \cdots + U_{n-1})^2}{n(U_0^2 + U_1^2 + \cdots + U_{n-1}^2) - (U_0 + U_1 + \cdots + U_{n-1})^2}$$

How the entropy-related analysis is conducted?

Dataset → Malware → Post malware Analysis

- ▶ Created from NapierOne
- ▶ 41 types of extensions
- ▶ 5 files by extension

List of Malware:
- ▶ Karma,
- ▶ Sugar,
- ▶ Black Matter,
- ▶ Revil,
- ▶ HiKitty

Computation of the evolution of our metrics

Which files are modified ?

Not Modified by Karma

Exe, DLL

Not Modified by REvil

Exe, DLL, ICS

Not Modified by Black Matter

Exe, DLL, ICS

Results by type of measure
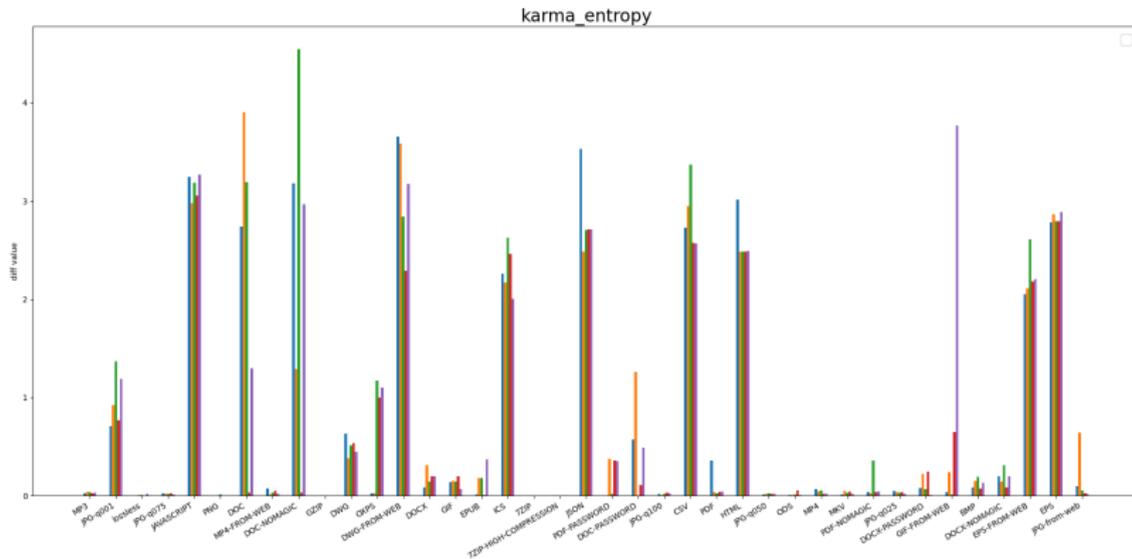
Figure: Entropy Measure for Karma
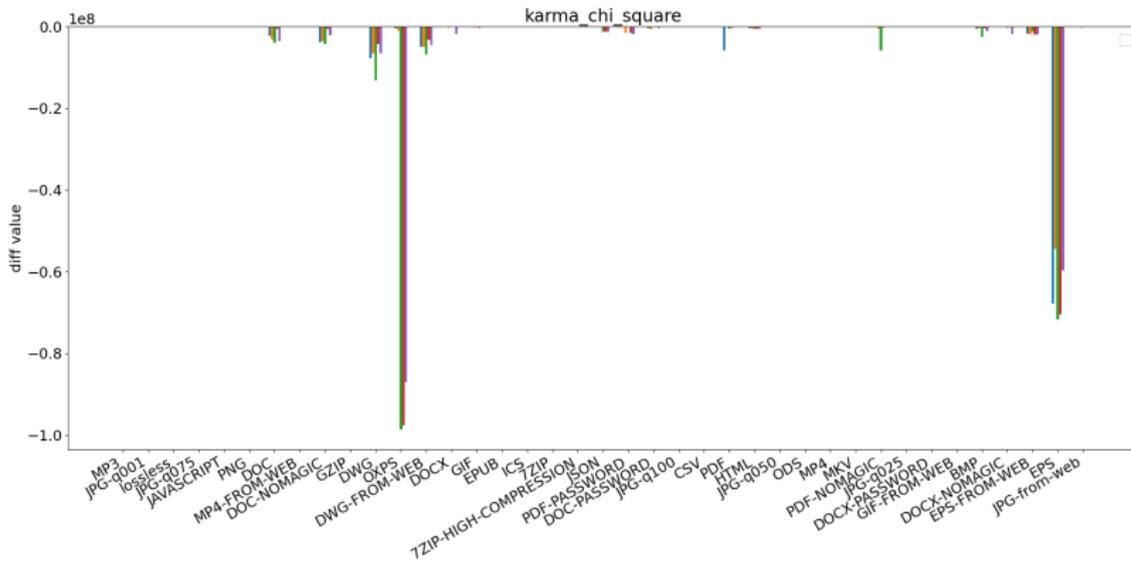
Figure: Chi Square Measure for Karma
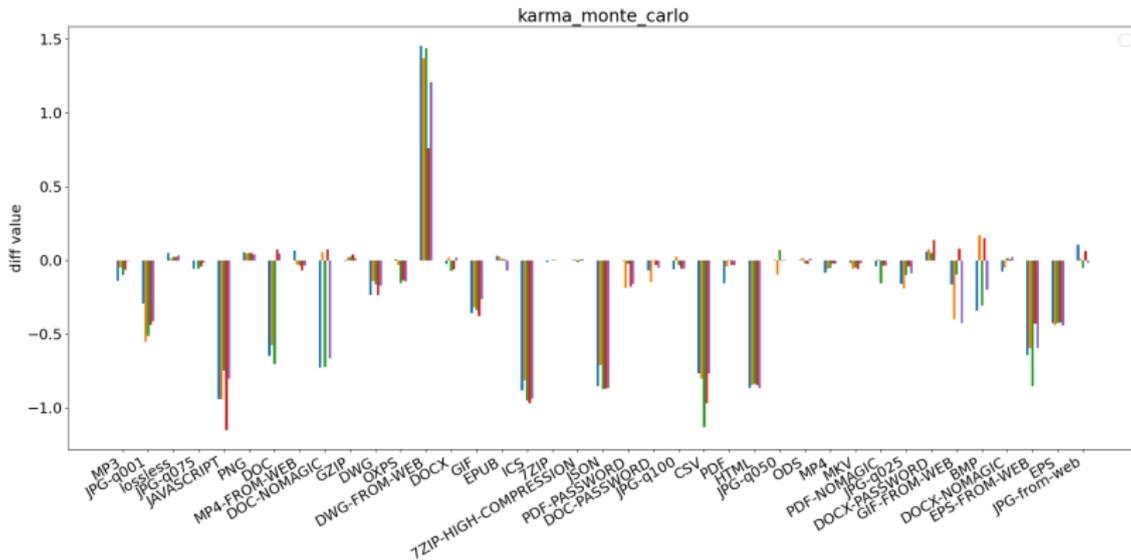
Figure: Monte Carlo Measure for Karma
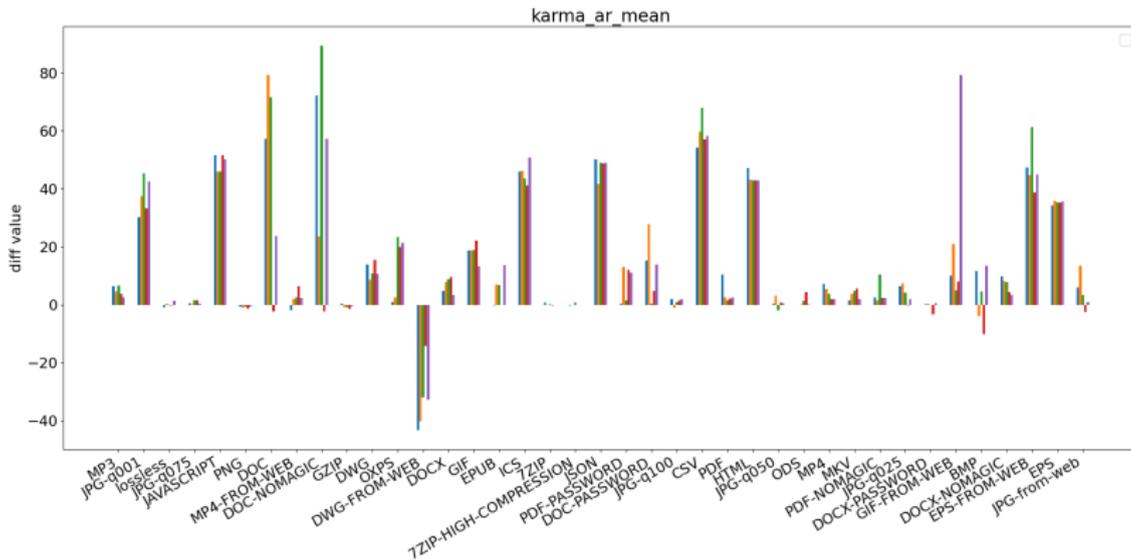
Figure: Arithmetic Mean Measure for Karma
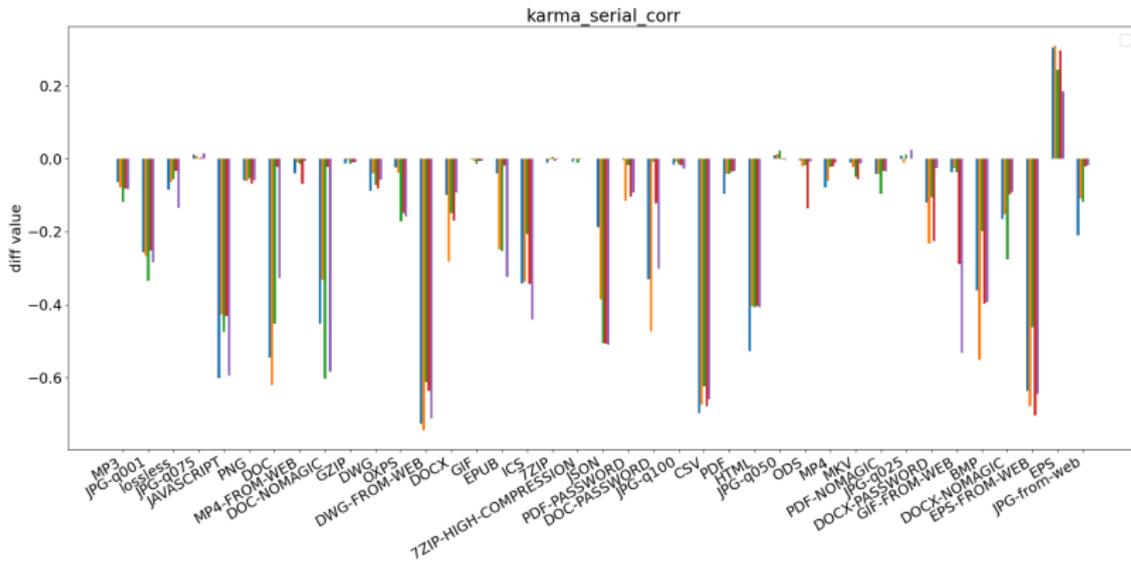
Figure: Serial Correlation Measure for Karma

Result for low entropy file
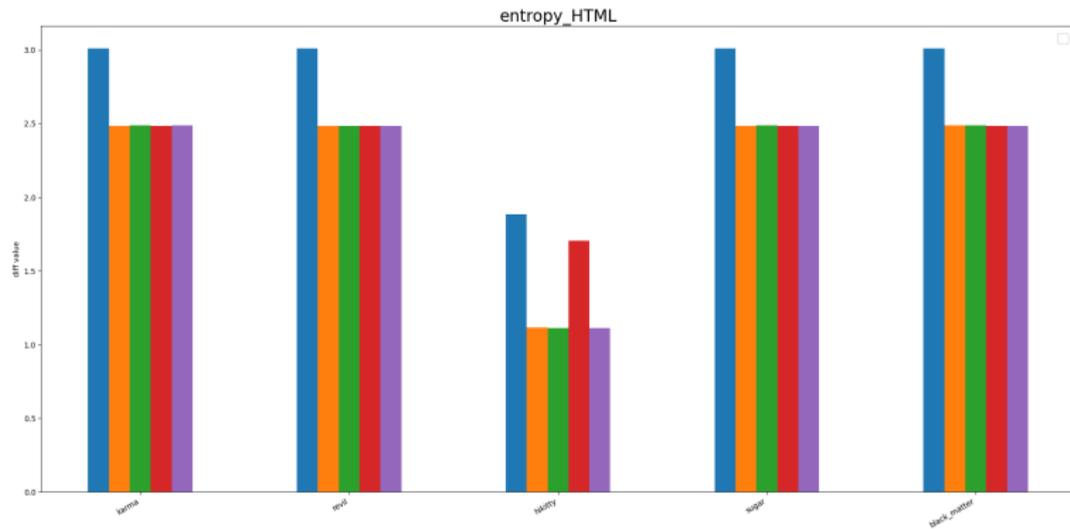
Result for low entropy file
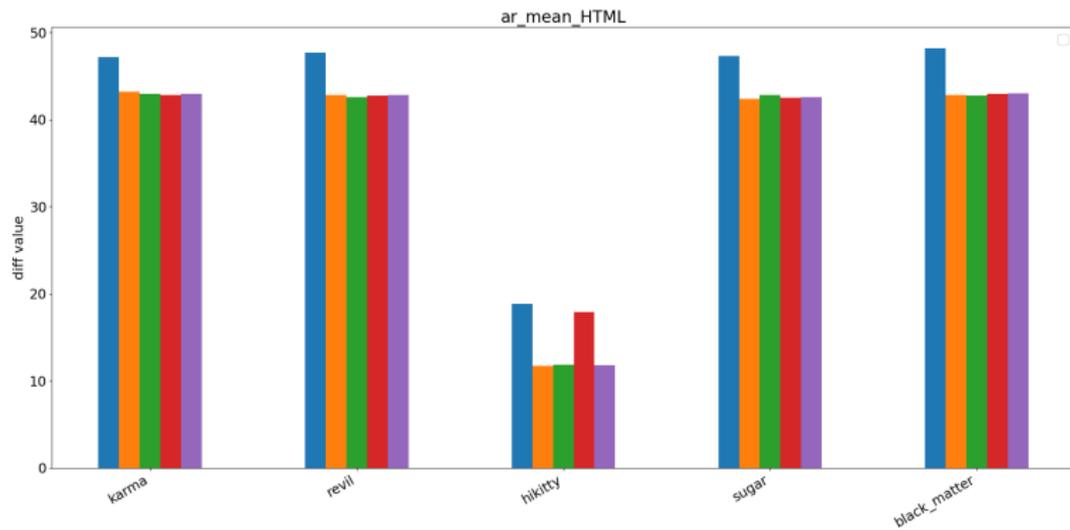
Result for high entropy file
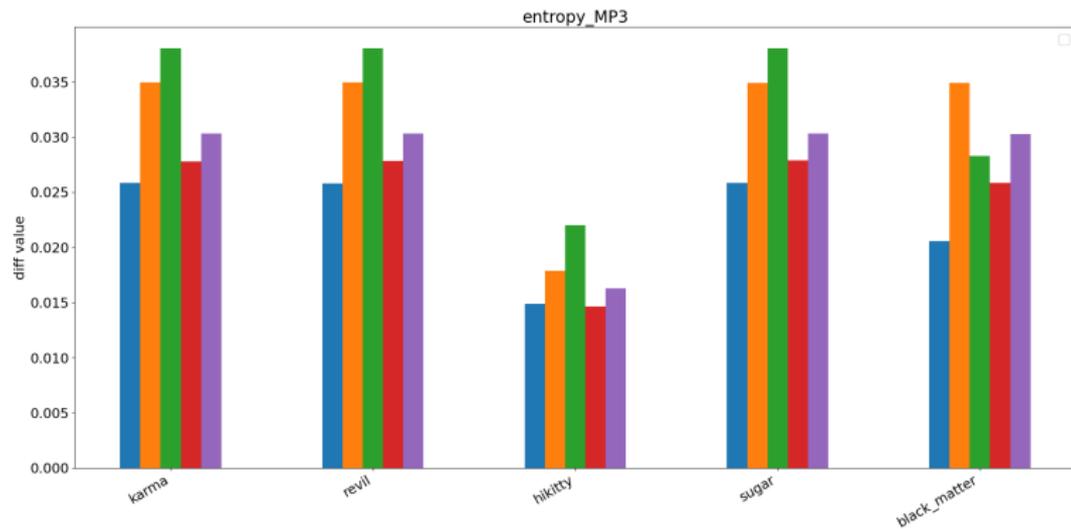
Result for high entropy file
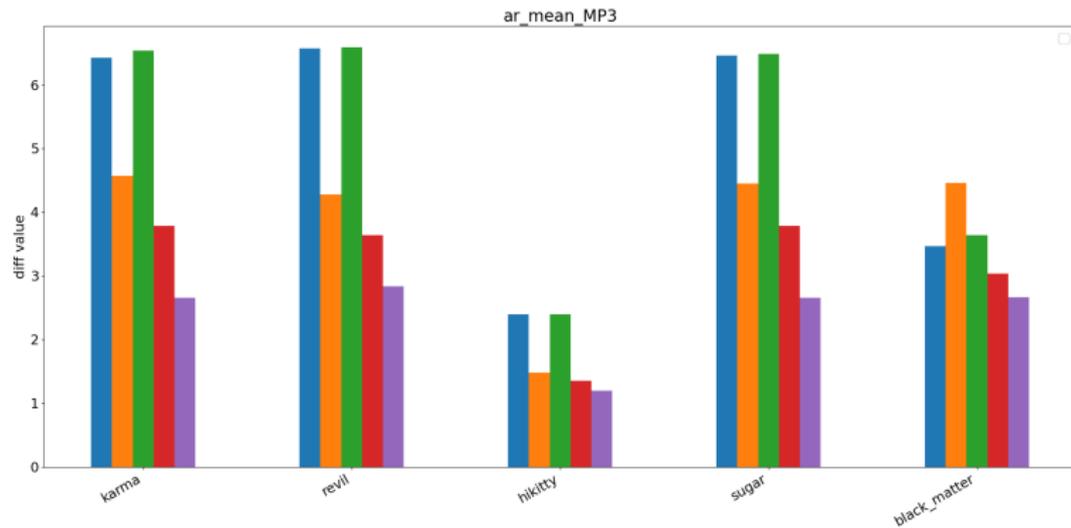
Outline

System Call

How to act on a system ?

Everything is OS, OS is everything :

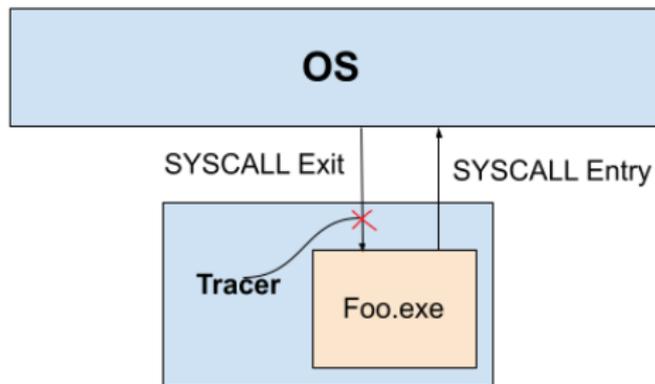- ▶ Act on file, process, device, network. . .
- ▶ Open, read, write, delete. . .

How to manage with OS ?

Just ask and pray
Asking with signal called **System Call**

If we can see the System Call send by a ransomware, we know its behaviour !

A useful tool : The Tracer

Tracer adapted to our project : Pin-tool

- ▶ NtOpenFile **(1)**
- ▶ NtCreateFile **(2)**
- ▶ NtWriteFile **(2)**
- ▶ NtDeleteFile **(3)**
- ▶ NtOpenProcess **(3)**
- ▶ NtTerminateProcess **(3)**

A little illustration


```
NtOpenProcess syscall exit detected
Name for process opened is wZNt
CreateFile systcall exist detected
```

Disclaimer

Be careful with the results !

Non neutral impact on the ransomware's execution !
- ▶ Impact on the performance
- ▶ Impact on the behaviour of the ransomware

Crafty ransomware : tricks for hiding from the tracer
→ Not seeing a system call doesn't mean it doesn't exist !

Dataset

Study of 15 ransomwares : tracer + empirical observation on the state of the environment
---

SYSCALL observed by the tracer

	Karma (Normal behaviour)	Hentai Oniichan (Tracer killed !)	Sugar (Altered behaviour)
OpenFile	X	X	X
CreateFile	X		X
WriteFile	X		X
DeleteFile			
OpenProcess		X	
TerminateProcess	X		X

No SYSCALL observed, but interessant observations

Observations	Ransomware
Normal run	Wannacry
	gandcrab
	Zeoticus
	Blackmatter
	Hi_Kitty 2
	Mallox
Run but no effect	CNH
	Hello
	LockBit
	Chaos
Altered behaviour	Ranzy
	Revil

Empirical observations without tracer

Observations	Ransomware
Add a new extension	Majority
No encryption for app	Blackmatter Karma Mallox REvil ...
Kind of replacing of file by evil README	gandcrab REvil
Open terminal for killing process	Hi_Kitty 2 (with deletion of file) Mallox
If no extension, no encryption	Chaos
New local disk, but no user access	Zeoticus Lockbit

Outline

Outline

Contexts

Simulated

Simulated The analysis is performed in a virtual machine
→ We can break anything

Not simulated The analysis is <u>not</u> performed in a virtual machine
→ We can <u>not</u> break anything
→ If there <u>is</u> a ransomware, it has to be detected/killed as soon as possible

Contexts

Controlled

Controlled All the updates of the file system comes from the observed programm
→ If a change is done, it is done by the observed programm

Not controlled Other programms or the user can use the machine during the analysis

Outline

Case 1: Studying the entropy of the files

Outline

A watcher: Mal-Aware
Monitoring

We can monitor each update in the file system

- ▶ Creation and deletion of files
- ▶ Modifications in a file
- ▶ Moves of files

We generate

- ▶ all the updates (in chronological order) of the filesystem
- ▶ the history of each file

A watcher: Mal-Aware
Analysis

We can raise alerts

- ▶ when the timestamps are manipulated
- ▶ when a lot of files are modified too quick
- ▶ when a lot of files are encrypted

Case 2: With the history of the file system

Context

Simulated   Controlled

Idea

- ▶ Monitoring the file system
- ▶ Running a suspicious programm
- ▶ Analysing the history of the file system

Case 2: With the history of the file system

Context

Simulated	Controlled

Idea

- ▶ Monitoring the file system
- ▶ Running a suspicious programm
- ▶ Analysing the history of the file system

- ▶ Are some files encrypted during the execution?
- ▶ Are suspicious actions performed? (eg. manipulation of timestamps)

Case 2: With the history of the file system

Idea for case 3: Detection on-the-fly, as soon as possible

Context

| Simulated - Controlled | or | Not simulated - not controlled |

Idea

- ▶ Monitoring the file system
- ▶ Running a suspicious programm
- ▶ Analysing <u>on-the-fly</u> the history of the file system

Idea for case 3: Detection on-the-fly, as soon as possible

Context

Simulated - Controlled   or   Not simulated - not controlled

Idea

- ▶ Monitoring the file system
- ▶ Running a suspicious programm
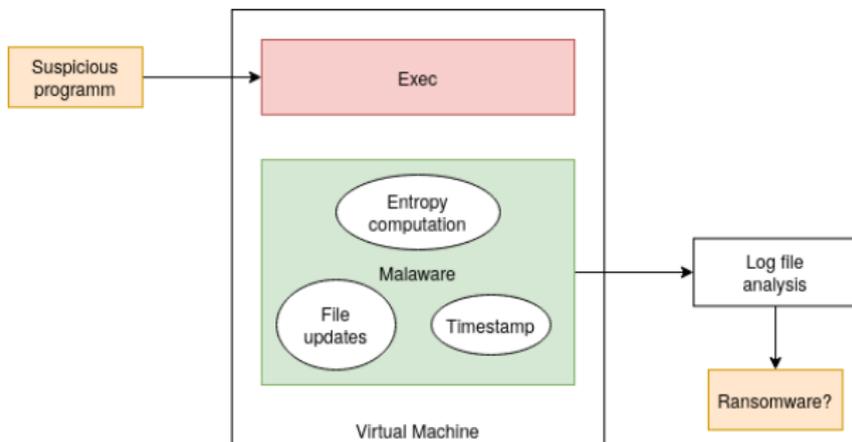- ▶ Analysing <u>on-the-fly</u> the history of the file system

- ▶ Are some files encrypted during the execution?
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Idea for case 3: Detection on-the-fly, as soon as possible

Context

Simulated - Controlled　　　　　or　　　　　Not simulated - not controlled

Idea

- ▶ Monitoring the file system
- ▶ Running a suspicious programm
- ▶ Analysing <u>on-the-fly</u> the history of the file system

- ▶ Are some files encrypted during the execution?
- ▶ Are suspicious actions performed? (eg. manipulation of timestamps)

We want to detect, as soon as possible, if the programm is a ransomware

Outline

Results

Entropy computation

- ▶ Study of different functions to compute files' entropy
- ▶ How malware execution affect files' entropy (or not) depending on file type

Empirical and tracer observations

- ▶ Monitoring of malwares' system calls with the tracer
- ▶ Empirical observations of malwares' execution
- ▶ Some pertinent events to monitor in order to detect a malware

Watcher

- ▶ Monitoring of creation, deletion, modifications and moves of files
- ▶ Focus on some directories
- ▶ Track files' history

Future works

Entropy computation

- ▶ Determining the best function to compute file entropy depending on file type
- ▶ Study a combination of entropy measurements

Tracer

- ▶ Enhance information received from events
- ▶ Intercept terminate process when tracer terminal is involved
- ▶ Print tracer information in a log file

Watcher

- ▶ Determine a pertinent set of directories to monitor
- ▶ Additional functions in the watcher