

Detecting Environment-Sensitive Malware

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Motivation

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- Sandboxes widely used to observe malicious behavior
- Anubis: Dynamic malware analysis sandbox
 - Online since February 2007
 - Over 2,000 distinct users
 - Over 10,000,000 samples analyzed
- Malware tries to differentiate sandbox from real system
- No malicious activity in sandbox → analysis evasion
- Attackers can use samples to perform reconnaissance

Motivation

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The screenshot displays two overlapping windows. The background window is a web browser showing an "Anubis - Analysis Report" for "sample.exe". The report includes a summary stating "No threats could be detected by Anubis. This does not mean that the sample is safe.", a table of contents, and a "Program output" section with a "Stdout:" field containing the text "CB9YB-Q73J8-RKPM". A "Registry Value" section is also visible, showing a key "HKLM\SOFTWARE\MICROSOFT\Windows NT\CurrentV".

The foreground window is a QEMU virtual machine running a Windows desktop. A dialog box titled "Fuck You Anubis" is open in the center of the screen, with the text "Fuck You Anubis" and an "OK" button. The desktop background is blue, and the taskbar at the bottom shows the Start button, several application icons, and the system tray with the time "1:52 PM".

Evasion Techniques

- “Environment-sensitive” malware checks for
 - Characteristics of the analysis environment
 - Characteristics of the Windows environment
- Emulation/Virtualization detection
- Timing
- Unique identifiers
- Running processes
- Restricted network access
- Public IP addresses

Evasion Countermeasures

- Transparent Monitoring Platform (e.g. Ether)
 - “undetectable”
 - Vulnerable to timing attacks
 - Vulnerable to detection of the specific Windows environment
- Evasion Detection
 - Execute malware in multiple environments
 - Detect deviations in behavior and identify root cause
 - Modify analysis sandboxes to thwart evasion techniques

Our Approach

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- DISARM
“Detecting Sandbox-AwaRe Malware”
 - Agnostic to root cause of divergence in behavior
 - Agnostic to employed monitoring technologies
- Automatically screen samples for evasive behavior
- Collect execution traces in different environments
- Eliminate spurious differences in behavior caused by different environments
- Compare normalized behavior and detect deviations
- Use findings to make sandbox resistant against evasion

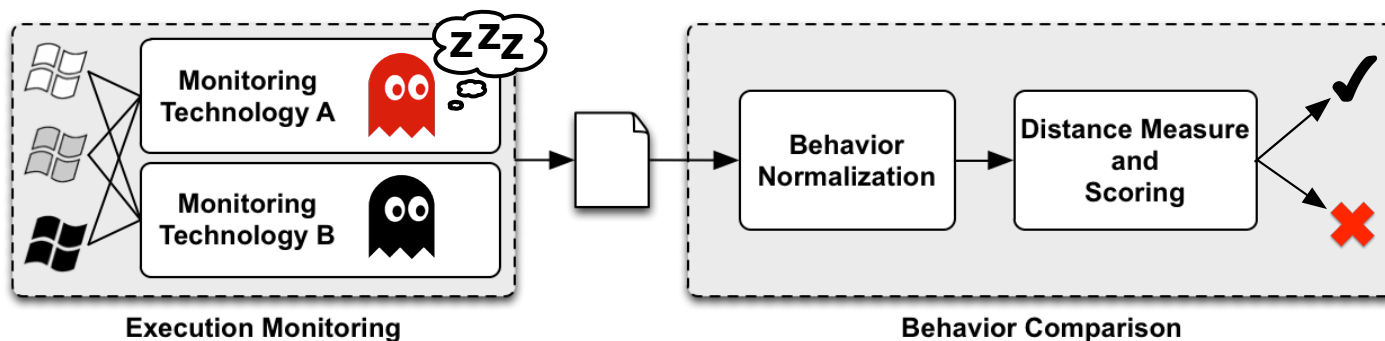
Outline

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- DISARM
- Evaluation
- Conclusion

DISARM

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- Execution monitoring
 - Execute malware in multiple sandboxes
 - Different monitoring technologies & Windows installations
- Behavior comparison
 - Normalize behavior from different environments
 - Measure distance of behavior and calculate evasion score

Execution Monitoring

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- Out-of-the-box monitoring
 - Anubis
 - modified version of Qemu emulator
 - Heavy-weight monitoring
- In-the-box monitoring
 - Light-weight monitoring → portable to any host
 - Windows kernel driver
 - Intercept system calls by SSDT hooking
- Multiple executions in each sandbox to compensate for randomness in behavior

Behavior Normalization

- Eliminate differences not caused by malware behavior
 - Differences in hardware, software, username, language, ...
1. Remove noise
 2. Generalize user-specific artifacts
 3. Generalize environment
 4. Randomization detection
 5. Repetition detection
 6. File system & registry generalization

Example Repetition Detection

File system Sandbox A

```
...  
C:\WINDOWS\system32\w32tm.exe  
C:\WINDOWS\system32\wdfmgr.exe  
C:\WINDOWS\system32\wextract.exe  
C:\WINDOWS\system32\wiaacmgr.exe  
C:\WINDOWS\system32\winchat.exe  
C:\WINDOWS\system32\WinFXDocObj.exe  
C:\WINDOWS\system32\winhlp32.exe  
C:\WINDOWS\system32\winlogon.exe  
C:\WINDOWS\system32\winmine.exe  
C:\WINDOWS\system32\winmsd.exe  
C:\WINDOWS\system32\winpool.exe  
C:\WINDOWS\system32\winver.exe  
C:\WINDOWS\system32\wowdeb.exe  
C:\WINDOWS\system32\wowexec.exe  
C:\WINDOWS\system32\wpabaln.exe  
C:\WINDOWS\system32\wpdshextautoplay.exe  
C:\WINDOWS\system32\wppninst.exe  
C:\WINDOWS\system32\write.exe  
...
```

File system Sandbox B

```
...  
C:\WINDOWS\system32\w32tm.exe  
C:\WINDOWS\system32\wextract.exe  
C:\WINDOWS\system32\wiaacmgr.exe  
C:\WINDOWS\system32\winchat.exe  
C:\WINDOWS\system32\winhlp32.exe  
C:\WINDOWS\system32\winlogon.exe  
C:\WINDOWS\system32\winmine.exe  
C:\WINDOWS\system32\winmsd.exe  
C:\WINDOWS\system32\winpool.exe  
C:\WINDOWS\system32\winver.exe  
C:\WINDOWS\system32\wmpstub.exe  
C:\WINDOWS\system32\wowdeb.exe  
C:\WINDOWS\system32\wowexec.exe  
C:\WINDOWS\system32\wpabaln.exe  
C:\WINDOWS\system32\wppninst.exe  
C:\WINDOWS\system32\write.exe  
...
```

C:\WINDOWS\system32*.exe

Behavior Comparison

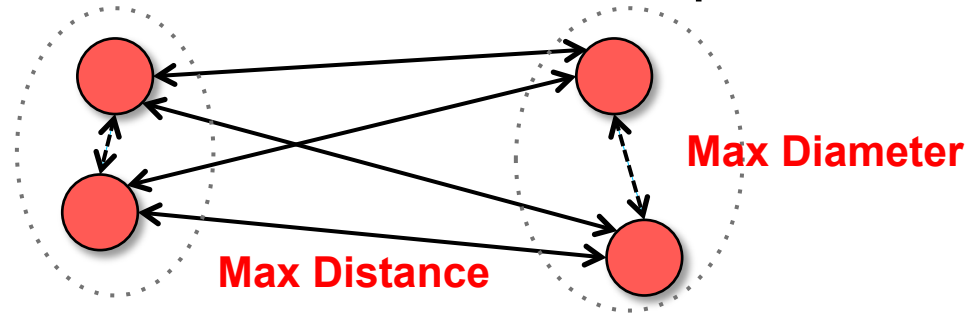
- Behavioral Profiles

```
file|C:\foo.exe|write:1  
process|C:\Windows\foo.exe|create:0  
network|tcp_conn_attempt_to_host|www.foobar.com
```

- Set of actions on operating system resources
- Only persistent state changes
 - file/registry writes, network actions, process creations
- Distance between two profiles: Jaccard Distance

Evasion Score

- Evasion Score calculated in two steps:



1. Intra-sandbox distance (*diameter*) between executions in the same sandbox
2. Inter-sandbox distance (*distance*) between executions in different sandboxes

- If $E \geq \text{threshold} \rightarrow$ classify as different behavior

Evaluation

Setup

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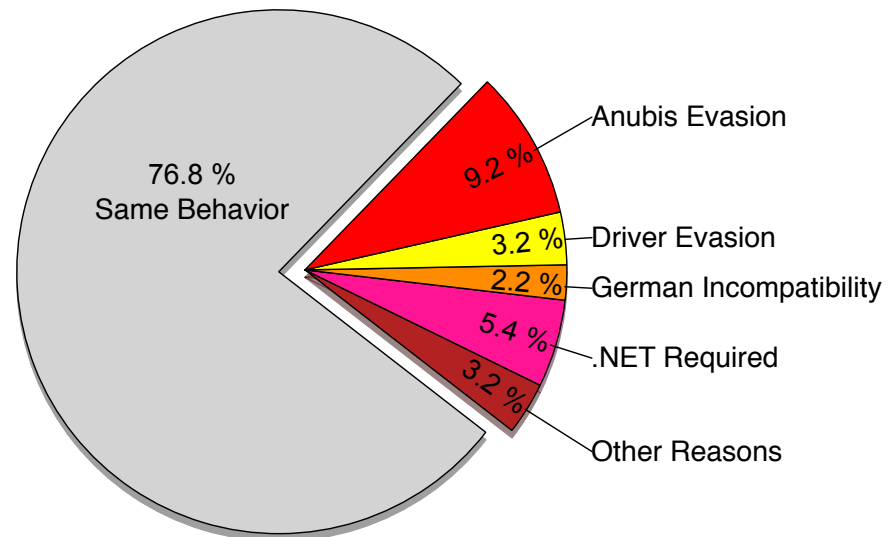
- 2 different monitoring technologies
- 3 different Windows images
- Driver inside Qemu to facilitate deployment

Sandbox	Monitoring Technology	Image Characteristics		
		Software	Username	Language
1	Anubis	Windows XP SP3, IE6	Administrator	English
2	Driver	Same as Anubis		
3	Driver	Windows XP SP3, IE7, JRE, .NET, Office	User	English
4	Driver	Windows XP SP2, IE6, JRE	Administrator	German

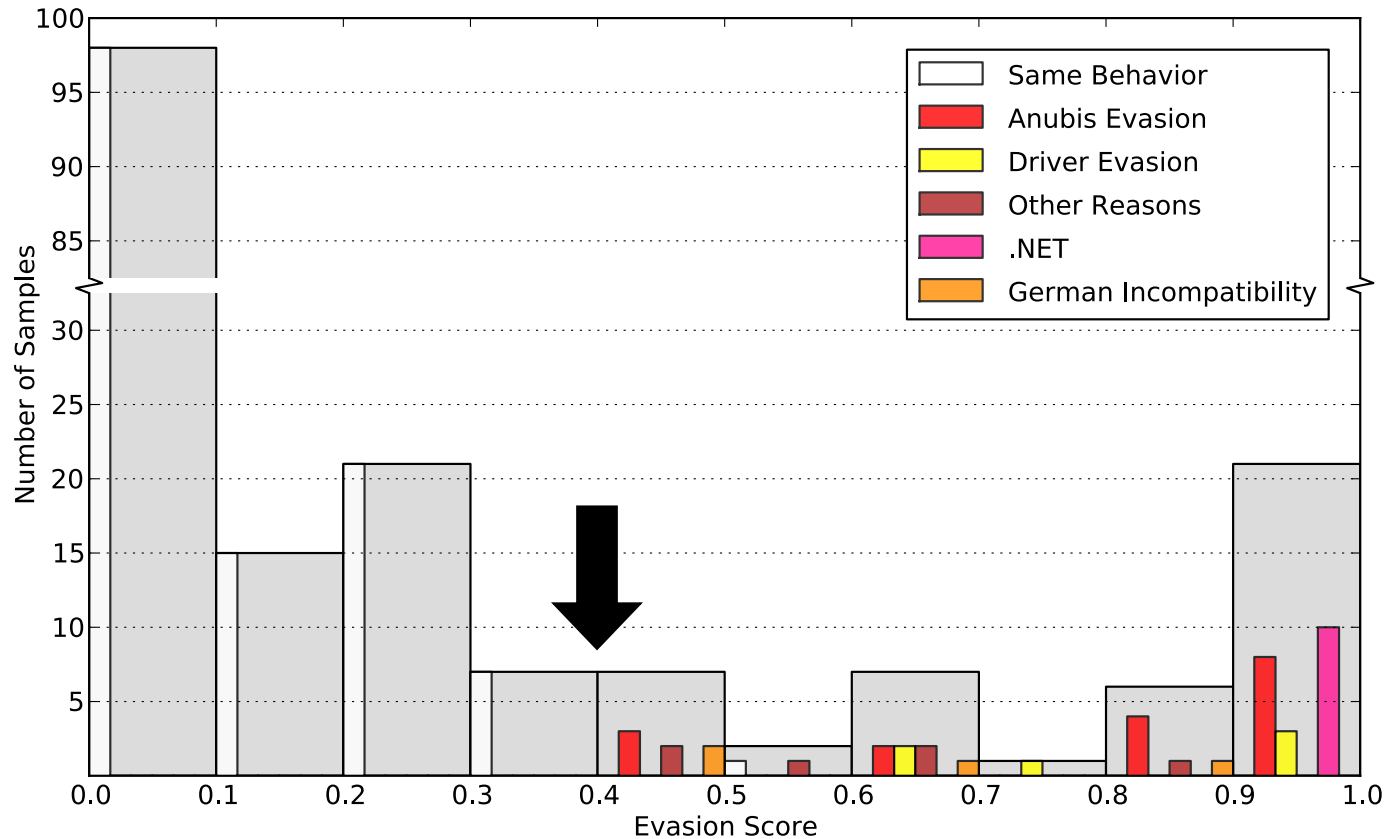
Training Dataset

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- 185 malware samples
 - Randomly selected from submissions to Anubis
 - Only one sample per malware family
- Optimize normalization and scoring
- Manual classification

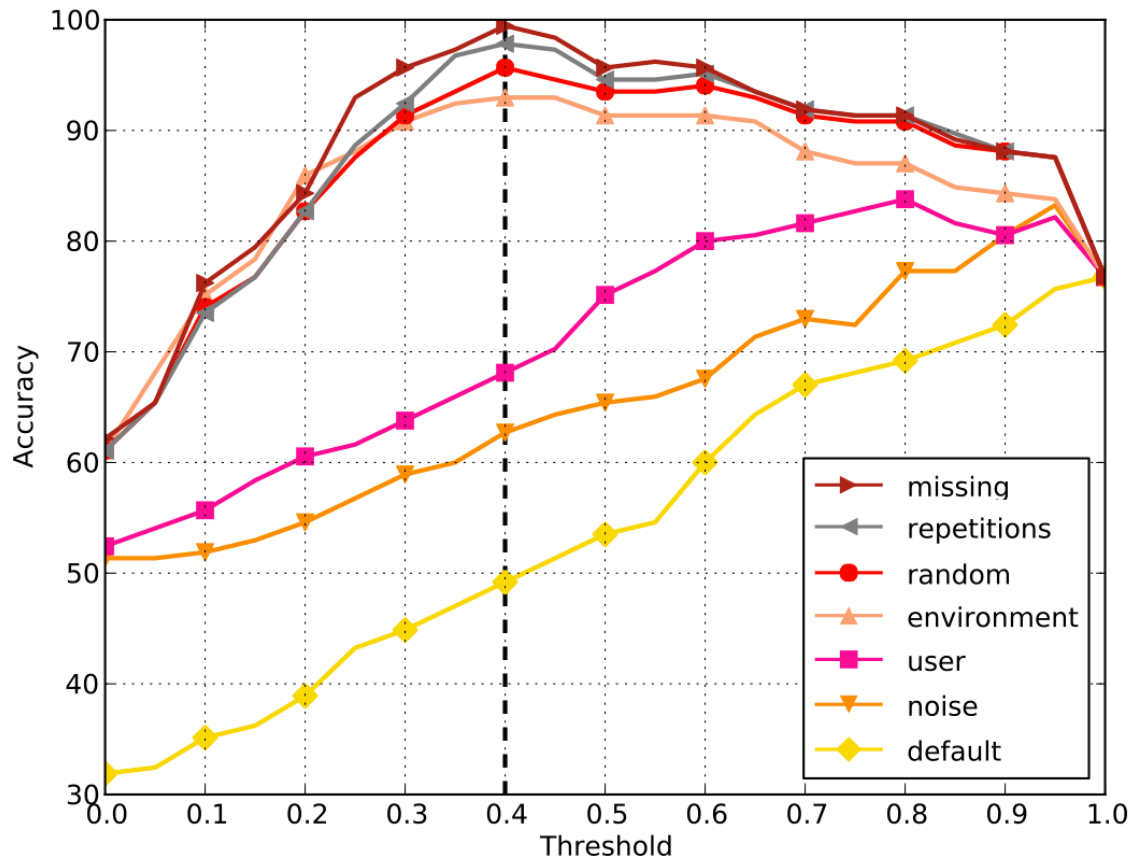


Threshold Selection



Result Accuracy

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- Proportion of correctly classified samples
- Each normalization improves results
- Accuracy > 90% for thresholds 0.3 – 0.6
- Max. accuracy 99.5 % for threshold 0.4

Test Dataset

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- 1,686 malware samples
 - Selected from submissions to Anubis Dec 2010 – March 2011
 - Max. 5 samples per malware family
- Used threshold of 0.4 selected from training dataset
- 25.65 % of samples above threshold
- Manual examination of randomly selected samples
 - Discovered evasion techniques against Anubis
 - Discovered ways to improve the software configuration

Qualitative Results

Anubis Evasion

- Timing (Anubis 10x slower than driver in Qemu)
- Check for parent process
- Incomplete randomization of Anubis characteristics
 - Computer name
 - Machine GUID
 - Hard disk information

Driver Evasion

- Some samples restored SSDT addresses
 - Restrict access to kernel memory

Qualitative Results

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Environment Sensitivity

- Configuration flaws in Anubis image
 - .NET environment
 - Microsoft Office
 - Java Runtime Environment (samples infect Java Update Scheduler)

False Positives

- *Sality* family creates registry keys and values dependent on username

Limitations

- Samples can evade DISARM by evading ALL sandboxes
→ eliminate shared sandbox characteristics
 - All sandboxes inside Qemu for our evaluation
 - Network configuration (restricted network access, public IPs)
- No automatic detection of root cause for evasion
→ use in combination with other tools:
 - Balzarotti et al.: Efficient Detection of Split Personalities in Malware (NDSS 2010)
 - Johnson et al.: Differential Slicing: Identifying Causal Execution Differences for Security Applications (Oakland 2011)

Conclusion

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- Automatic screening of malware for evasive behavior
- Applicable to any analysis environment that captures persistent state changes
- Comparison of behavior across sandboxes
 - Different monitoring technologies & different Windows installations
 - Behavior normalization
- Light-weight in-the-box monitoring
 - Portable to any Windows XP environment (virtual or physical)
- Evaluation against large-scale test dataset
- Discovery of several new evasion techniques

Questions?

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Related Work

- Chen et al.: Towards an Understanding of Anti-Virtualization and Anti-Debugging Behavior in Modern Malware (DSN 2009)
 - Comparison of single executions on plain machine, virtual machine and with debugger
 - Consider any difference in persistent behavior
- Lau et al.: Measuring virtual machine detection in malware using DSD tracer (Journal in Computer Virology 2010)
 - Focus on VM detection techniques in packers