Malware Detection: Static vs Dynamic

WARNING

- HUGE and EXTREMELY COMPLEX topic
- We will only scratch the surface of the surface
- Focus of this section: **EDR** on a **single** node (in **isolation**)

Malware detection (REMIND)

- Identification of **malicious software**
- Typically done on **endpoints**
- Detection **before** or **during** execution
- Focus on **prevention**

Static vs Dynamic

- Identification of **malicious software**
- Typically done on **endpoints**
- Detection **before** or **during** execution
- Focus on **prevention**

- **Static** analysis (AV)
  - Scan of **files/memory content** in search of **predefined signatures**
- **Dynamic** analysis (AV/EDR)
  - Analysis of **execution events** in search of **predefined behaviors**

Scanning

- **Signature**-based scanning
  - Hundreds of thousands of signatures (≈200K in Windows Defender)

- **Files**
  - **On-access**: Download, Open, Delete ("Real-time protection" in Windows Defender)
- **Memory**
  - When a process is created and a **file** is mapped in memory

Scanning Bypass

- **Signature**-based scanning
- Restructure the file content before using it so that:
  - **Functionality** preserved
  - Signature **not** matched
- Polymorphism ("each sample is different")

- Not so simple in practice, but done more or less routinely
- We need a **further** line of defense: **execution** (**behavior**)

Encrypted shellcode

```
const char str1[] = .../* encrypted shellcode */
#define XOR_KEY = 0xAA
for (DWORD i = 0; i < size; i++) {
      str1[i] ^= str1[i] ^ XOR_KEY;  // bitwise XOR
}
const size_t lenstr1 = sizeof(str1);
PVOID runIt = VirtualAlloc(0, lenstr1, ..., PAGE_RWX);
memcpy(runIt, str1, lenstr1);
CreateThread(..., runIt,);
```

- Most malware contains **encrypted** shellcode that is decrypted at runtime
- One of the **many** ways for defeating scanners

Obfuscation, not Encryption

- Target contains:
  - Encrypted data
  - **Decryption key**
- **Not** really an "encryption" aimed at providing **secrecy**

- Objective:
  - **Defeating scanners**
  - Making analysis and reverse engineering more difficult

- Many other ways for **obfuscating** a malicious content

Dynamic (Behavioral) Analysis

- **Dynamic** analysis (AV/EDR)
  - Analysis of **execution** events in search of **predefined behaviors**

- **What** can be analyzed?
  - Memory accesses
  - Machine instructions?

- What it means "**behavior**", exactly?

What can be analyzed: EDR Sensors (I)

1. **System call invocations**

2. **Predefined events created by O.S. or applications**
   - Activity related to:
     - Processes
     - Memory
     - Files
     - Network

What can be analyzed: EDR Sensors (II)

- EDR may receive sensor outputs ("**events**") as:
  1. Logging
  2. Callback-before // May **block** suspicious operation
  3. Callback-after

- Each event has **a lot** of information:
  - Process ID, parent process ID, process image, ...
  - File / Message content, ...
  - ...

- Analysis of events **may** detect suspicious **behavior**

Behavioral analysis in practice

Remark

- Obfuscation omitted from following examples

- Ease of discussion
- Problem unchanged

Example: Self-Injection (I)

- Attacker on his machine:
  - Write malicious program M
  - Compile M and obtain sequence of instructions **I(M)** (**shellcode**)
  - Write **another** malicious program **M1** that *(next slide)*
- Attacker executes **M1** on target

Example: Self-Injection (II)

- Write program M1 that, **during execution**:
  1. Allocate a memory page P with RWX access rights
  2. Declare a variable initialized with I(M)
  3. Copy I(M) to P
  4. Jump to I(M)

M1 **injects** code into itself

```
const char str1[] = .../* shellcode: I(m) */
const size_t lenstr1 = sizeof(str1);
PVOID runIt = VirtualAlloc(0, lenstr1, ..., PAGE_RWX);
memcpy(runIt, str1, lenstr1);
CreateThread(..., runIt,);
```

Self-Injection: Suspicious Behavior

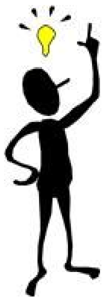
```
const char str1[] = .../* shellcode: I(m) */
const size_t lenstr1 = sizeof(str1);
PVOID runIt = VirtualAlloc(0, lenstr1, ..., PAGE_RWX);
memcpy(runIt, str1, lenstr1);
CreateThread(..., runIt,);
```

- No malicious code at process creation time
- Self-injection is a **suspicious behavior**:
  What you **inspected** at load time <> what you **execute**
- What you do might not be malicious...but this behavior is

Hhmmm…

- Write program M1 that, **during execution**:
  1. Allocate a memory page P with RWX access rights
  2. Declare a variable initialized with I(M)
  3. Copy I(M) to P
  4. Jump to I(M)
- Execute M1 on target

- I(M) could match a signature
- **Memory scanning on page P** could detect this malicious behavior



Memory Scanning

- **Memory**
  - When a process is created and a file is mapped in memory

- Memory is **not** scanned while a process is **running**
  - It might be scanned, but it is not: excessively costly

- It suffices that process memory looks **innocuous upon process creation**

Self-Injection: How to detect?

```
const char str1[] = .../* shellcode: I(m) */
const size_t lenstr1 = sizeof(str1);
PVOID runIt = VirtualAlloc(0, lenstr1, ..., PAGE_RWX);
memcpy(runIt, str1, lenstr1);
CreateThread(..., runIt,);
```

- How to **detect** this specific **behavior**?
- How to detect it with high precision (**no false positives**)?

Detecting Self-Injection (I)

```
const char str1[] = .../* shellcode */
const size_t lenstr1 = sizeof(str1);
PVOID runIt = VirtualAlloc(0, lenstr1, ..., PAGE_RWX);
memcpy(runIt, str1, lenstr1);
CreateThread(..., runIt,);
```

- Creation of memory pages with RW access rights is very commonplace (dynamically allocated memory)
- But with **execution** access rights? Why?
- Detection rule: `process allocates memory page with WX access rights`

Detecting Self-Injection (II-a)

- **Legitimate** usages of self-injection: **Interpreted** languages
  - Javascript, Python, Java, ...
- We do not want to trigger the detection for them

- More precise Detection rule:

```
process allocates memory page with WX access
rights
AND
process.name is not
("Chrome.exe", "Edge.exe", "python.exe", ...)
```

Detecting Self-Injection (II-b)

- `process allocates memory page with WX access rights`
  `AND`
  `process.name is not` **`(...)`**

- Let us assume we have an **exhaustive** list
  - It must be based on **full** pathnames
  - Relative pathnames can be circumvented easily

Practical Scenario

- `process allocates memory page with WX access rights`
  `AND`
  `process.name is not (...)`

1. A **new** program that uses Javascript (e.g. Electron) is **legitimately** installed somewhere
2. Detection rule fires
3. ALERT

EXTREMELY Important (I)

1. Program that uses Javascript but is not listed is legitimately installed somewhere
2. Detection rule fires
3. ALERT

- Alerts must be **triaged** to **exclude false positives**
  - **Huge** practical problem

- Alert triage must be based on **contextual** information
  - You **cannot outsource** knowledge of your specific context

EXTREMELY Important (II)

1. Program that uses Javascript but is not listed is legitimately installed somewhere
2. Detection rule fires
3. ALERT

- Even if your detection rules were carefully tuned...
- The IT profile of organizations **changes routinely**
  - Programs are routinely installed / modified
  - New users are routinely onboarded
  - User behavior may change
  - ...

Hhmmm...

- **/* self-injection */**
  `process allocates memory page with WX access rights AND` **`process.name is not (...)`**

- Could an Attacker **modify the code of a process** listed in the rule?
- That would allow the Attacker to achieve self-injection without triggering the rule

Bypass: Process Hollowing

- FD = Any executable in the detection rule (easy to guess)
- Write malicious program M2 that, **during execution**:
  1. Create process P1 that executes FD in **suspended** state
  2. **Unmap** memory image of P1
  3. **Map** memory image of P1 to **M1** (the one seen before)
  4. Resume execution of P1

- P1.name = FD ⇒ Detection rule **not** triggered
- Malicious behavior **not** detected

Hypothesis: Process Hollowing detected

- **`/* self-injection */`**
  `process allocates memory page with WX access rights AND process.name is not (...)`
- **`/* process hollowing */`**
  `...`

Detection of this **suspicious** behavior is **solved**!

Bypass: Process Doppelgänging

1. Prepare a file F with content=GoodExec
2. **TransactionStart** with F
3. F.content := BadExec
4. Create MemorySection **M** with F
5. Create Process P associated with **M** (multistep legacy API)
6. **TransactionRollback**
7. Complete creation of P and start execution
   - Process memory contains BadExec
   - Fileysystem contains GoodExec

- Existing rules (at the time) did not detect this behavior
- Scanners do **not** see BadExec

To make a long story short

- A **huge** amount of possibly malicious behaviors

- **Endless game**
  - Defenders detect "almost everything"
  - Attackers discover a new trick and go undetected for some time
  - Defenders detect the new trick
  - Attackers discover yet another trick and go undetected for some time
  - ...

- Devising / Detecting malicious behaviors requires a **deep technical knowledge**

Curiosity...

Persistence

23 techniques

Privilege Escalation

14 techniques

Defense Evasion

45 techniques

Process Injection (12)

- Dynamic-link Library Injection
- Portable Executable Injection
- Thread Execution Hijacking
- Asynchronous Procedure Call
- Thread Local Storage
- Ptrace System Calls
- Proc Memory
- Extra Window Memory Injection
- Process Hollowing
- Process Doppelgänging
- VDSO Hijacking
- ListPlanting

Malware Detection: Forensics

Malware Detection: Forensics

- **Is this system / device clean or infected?**

- If infected:
  - Which malware?
  - How initial access / persistence?
  - How to restore it?

Rule of thumb for "sophisticated" malware

- IF you **don't** know whether it is infected
- THEN detection is **very hard / hardly possible**
  // just too many things to analyze

- IF you **do** know there is some malwared
- THEN detection is more likely

Attack Detection: SIEM

What can be analyzed: EDR Sensors (REMIND)

1. **System call invocations**

2. **Predefined events created by O.S. or applications**
   - Activity related to processes, memory, files, network

- Each sensor output ("event") has a lot of information:
  - Process ID, parent process ID, process image, ...
  - File / Message content, ...
  - ...

Fact

- System call invocations
- Predefined events created by O.S. or applications

- Sensors do **not** collect **all** potentially relevant information

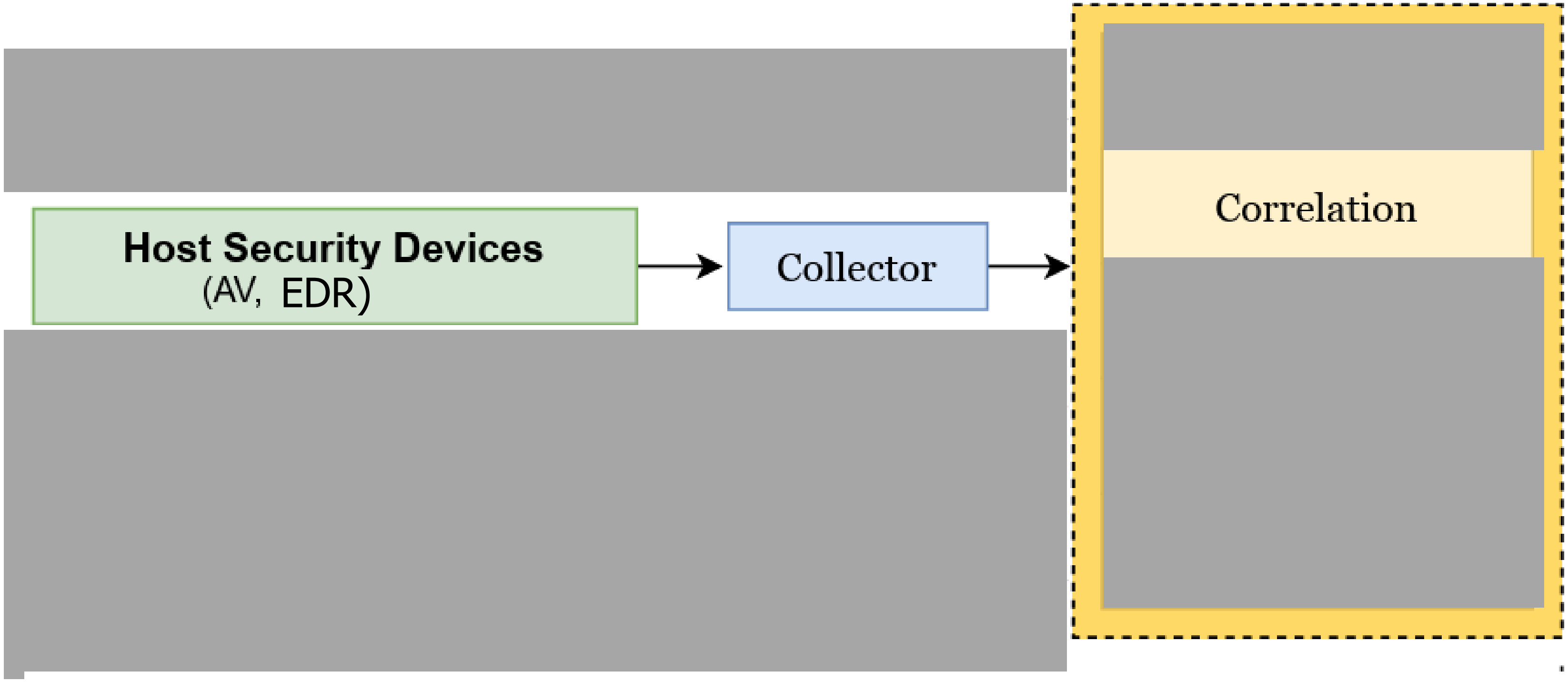
1. Intrinsic technological limitations
   - Most EDRs do not log `ReqQueryMultiple`
   - August 2025: Someone has realized it can be used for exfiltration
2. Excessive amount of information
   (limited by installation-specific **configuration**)

EDR at work

1. Collect a **configuration-specific subset** of the "events" that could be collected
2. Apply a set of **detection rules** locally
3. Stream sensor outputs to **central platform** (perhaps with some aggregation)

- Central platform will apply detection rules on sensor outputs from **multiple endpoints**

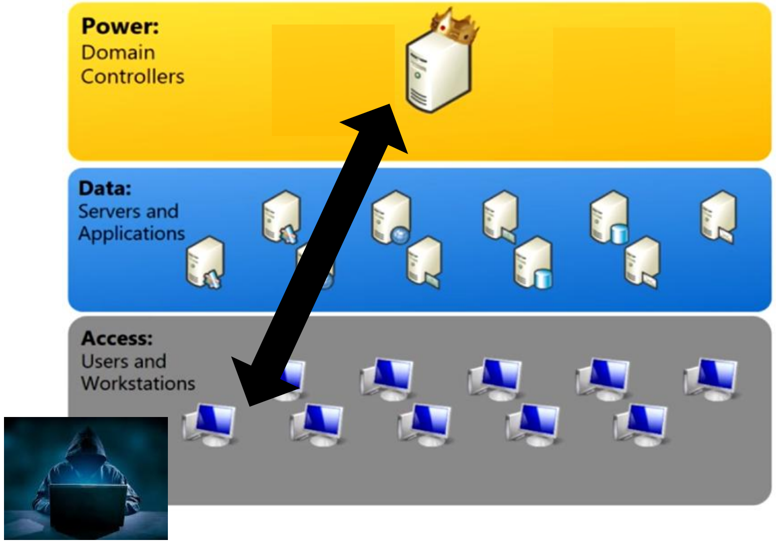
Attack detection: SIEM



- Central platform will apply detection rules on sensor outputs from **multiple endpoints**

Example: Kerberoasting Attack

1. Connect with Domain Controller on port 88
2. Kerberos protocol:
   a. Authenticate as user U (credentials needed)
   b. Ask **service ticket ST(U,S)** for some service S
3. Attempt to crack **ST(U,S)** for **finding password** of service account S



How to detect?

Example Detection: Tool

- Sensors collect:
  - ...
  - Process creation for executing a file
  - Command line arguments
  - ...
- Detection rule:
  - Execution of `Bifrost` software tool with certain invocation arguments
  - Consider only invocation arguments because changing filename is very easy

```
event.category:process and event.type:start and process.args:
("-action" and ("-kerberoast" or askhash or asktgs or asktgt or
s4u or ("-ticket" and ptt) or (dump and (tickets or keytab))))
```

Hhmmm…

- Detection rule:
  - Execution of Bifrost software tool with certain invocation arguments
  - Consider invocation arguments because changing filename is very easy

- Attacker may:
  1. Modify `Bifrost` software tool so that invocation arguments are **different**
  2. Recompile it

  or

  1. Use a different software tool (e.g., Rubeus)

  - **Detection rule not triggered!**

Example Detection: Anomalous Network Comm.

- Sensors collect:
  - ...
  - TCP connections
  - Executable file of the client process that creates the connection
  - ...
- Detection rule:
  - Connection to port 88 by **unusual clients**

```
network where event.type == "start" and network.direction ==
"outgoing" and destination.port == 88 and source.port >= 49152
and process.name not in ("swi_fc.exe", "fsIPcam.exe",
"IPCamera.exe", "MicrosoftEdgeCP.exe", "MicrosoftEdge.exe",
"iexplore.exe", "chrome.exe", "msedge.exe", "“opera.exe",
"firefox.exe")
```

Detection Rules: Fragile vs Robust

- Detection rules may be:
  - Fragile:
    - **Easy** to write and test (and to circumvent)
    - **Cheap** to Defenders (and to Attackers)
  - Robust
    - **Difficult** to write and test (and to circumvent)
    - **Costly** to Defenders (and to Attackers)

- In practice you have a mix of both

Scores

- Alerts are hardly the result of a **single** detection rule

- Common heuristics:
  - Each detection rule has a predefined **score**
  - When an Account exceeds a predefined **aggregate score** in a predefined **time interval**
    → Alert

False Positives

- Detection rule:
  - Connection to port 88 by unusual clients

```
...and process.name not in ("swi_fc.exe", "fsIPcam.exe",
"IPCamera.exe", "MicrosoftEdgeCP.exe", "MicrosoftEdge.exe",
"iexplore.exe", "chrome.exe", "msedge.exe", "“opera.exe",
"firefox.exe")
```

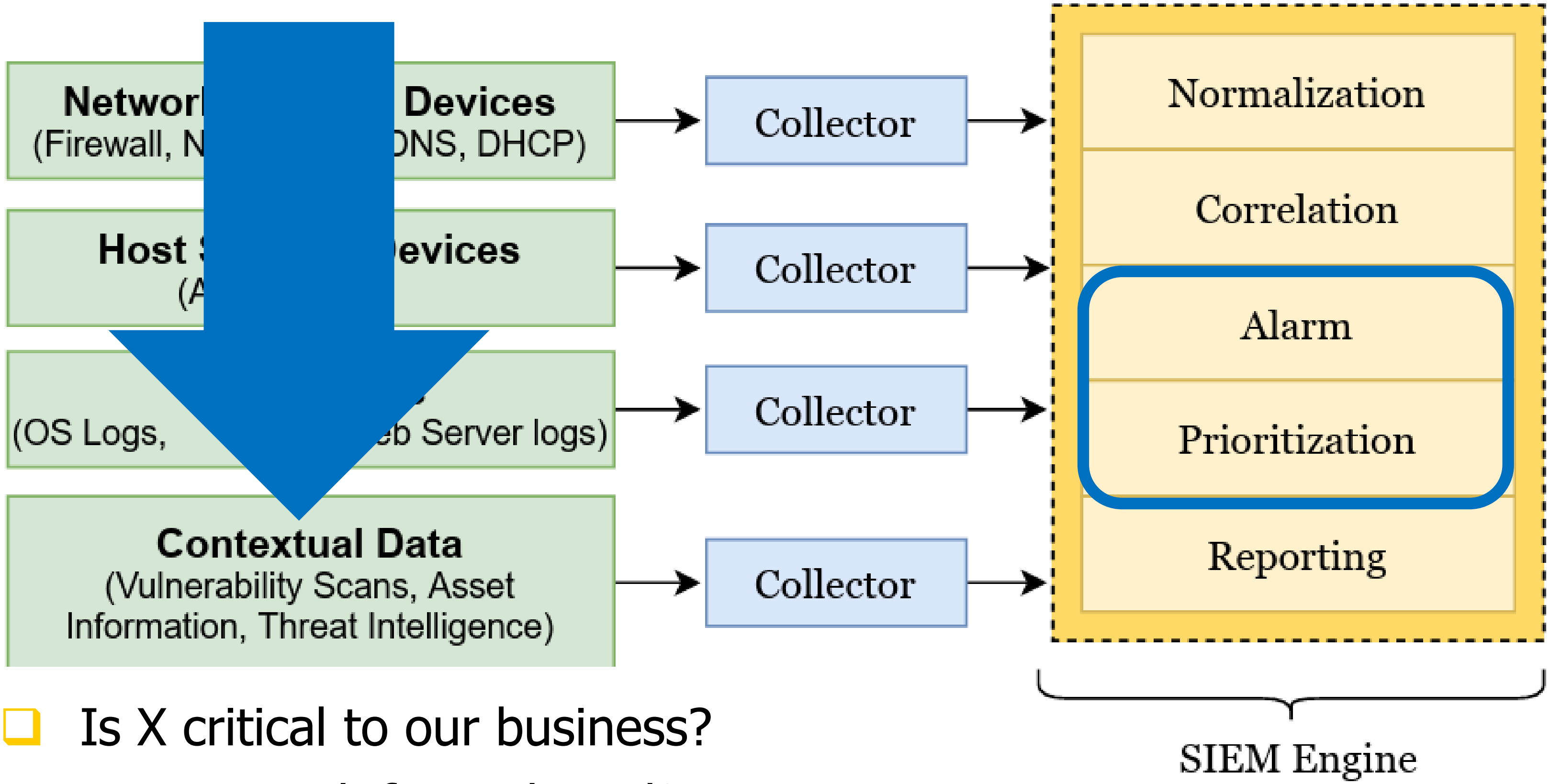
- What if some new software that **legitimately** asks for service tickets is installed?

Extremely Important (REMIND)

1. Program that uses … legitimately installed somewhere
2. Detection rule fires
3. ALERT

- Alerts must be triaged to **exclude false positives**
  - **Huge** practical problem
- Alert triage must be based on **contextual** information
  - You **cannot outsource** knowledge of your specific context
- Even if your detection rules were carefully tuned
  …The IT profile of organizations **changes routinely**

Contextual Information



- Is X critical to our business?
- Does Y work from abroad?
- ...

Kerberoasting: Other Detection Logic (I)

- Attempt to crack ST(U,S) for **finding password** of service account S
- Attacker does not know in advance whether cracking will succeed: usually **several** service tickets are requested: ST(U,S1), ST(U,S2), ST(U,S3), ...
- Detection rule:
  - Is there any user that asked too many ST in a predefined amount of time?

Kerberoasting: Other Detection Logic (II)

- One does not know in advance whether cracking will succeed
- Attackers often ask for **several** service tickets: ST(U,S1), ST(U,S2), ST(U,S3), ...
- Attackers often ask for **certain service names**: those that were likely installed many years ago (have weak configuration)

- Detection rule(s):
  - Is there any user that asked ST for service names that **do not exist**?
  - ...and that asked for several ST in a short time?

Detection Rules: Execution Cost

- Certain detection rules require **searching for / counting multiple events** in a specified **time interval**
- There are usually **millions** of events to consider

- Detection rules qualities:
  - Fragile / Robust
  - Precision
  - **Execution cost**

Detection Rules: Practical Remark

- **Many detection rules can be bypassed**
  - Just think a little about the previous examples
- It is mostly a matter of **Attacker effort**
- Knowledge of the detection rule helps a lot

Evasion

Lack of detection

- Attacker activity may go undetected because:
  1. **Sensor** do not collect relevant information
  2. **Detection rules** do not trigger
  3. **Alerts** are **not investigated** or they are deemed **false positives**

- **Evasion** (bypass) refers to activity that aims at 1 / 2

Evasion (Bypass) (I)

- **Perceptual**
  - Relevant information **cannot be collected** due to technological limitation
- **Configuration**
  - Relevant information **is not collected** due to configuration
- Related to **sensors**

Evasion (Bypass) (II)

- **Logical**
  - Relevant information has been collected but detection rules have a logical gap
  - No detection rule for the specific activity

- **Classification**
  - Detection rules are volumetric or score-based
  - Relevant information in the considered time interval is not enough to trigger the rule

- Related to **detection rules**

Practical Remark

- Attacker activity may go undetected because:
  1. **Sensor** do not collect relevant information
  2. **Detection rules** do not trigger
  3. **Alerts** are **not investigated** or they are deemed **false positives**

- **In most cases, THIS is THE problem**

Ahem...

Advisory on New Endpoint Detection and Response (EDR) Killer Tool Used by Multiple Ransomware Groups

16 August 2025

There have been reports of a new malicious tool, known as Endpoint Detection and Response (EDR) killer, being actively used by at least eight ransomware groups to disable EDR solutions.

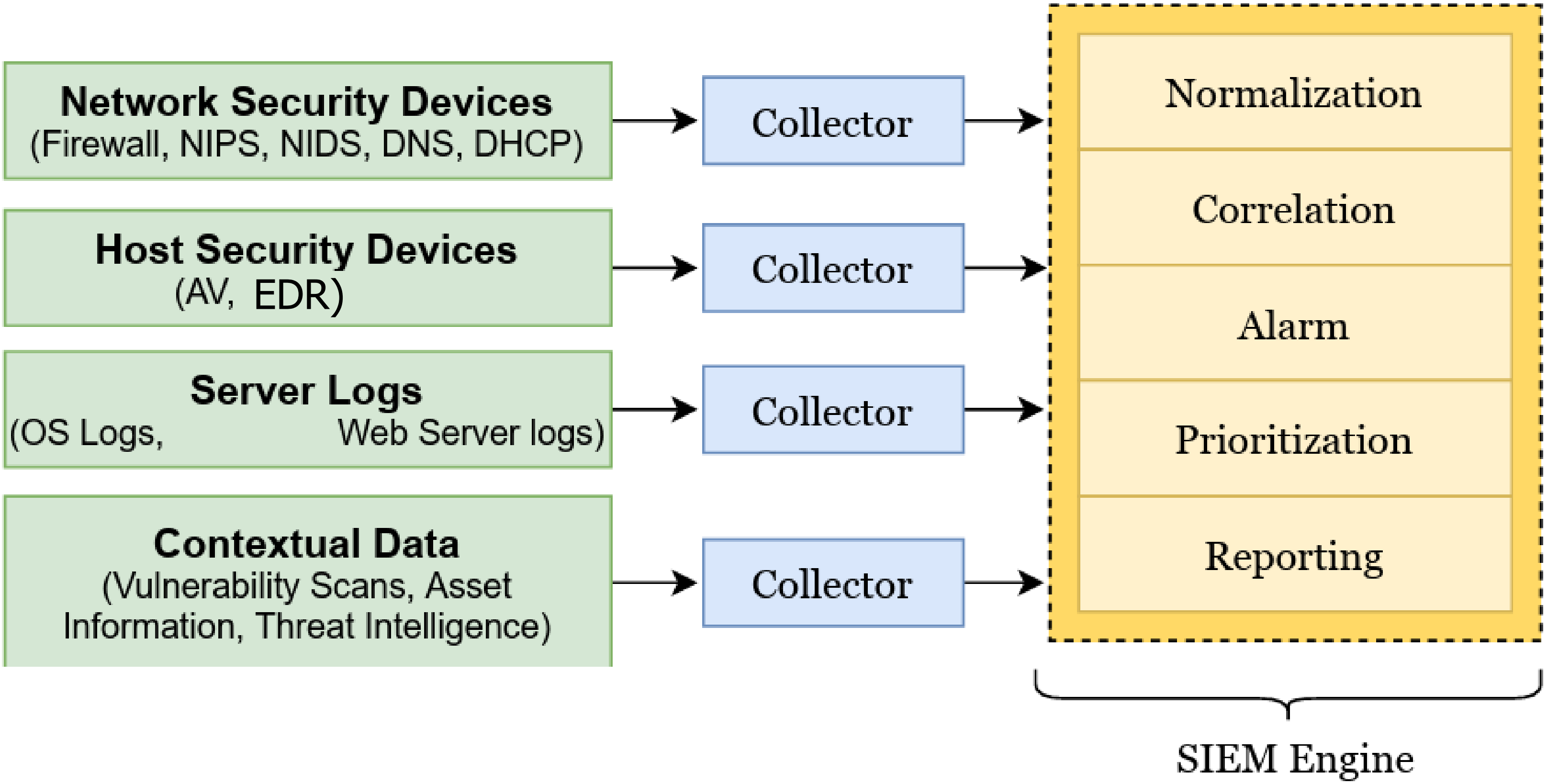
Cyber Security Agency of Singapore

Ahem…Cough…

Fortinet is no stranger to the watchTowr Labs research team. Today we're looking at CVE-2025-25256 - a pre-authentication command injection in FortiSIEM that lets an attacker compromise an organization's SIEM (!!!).

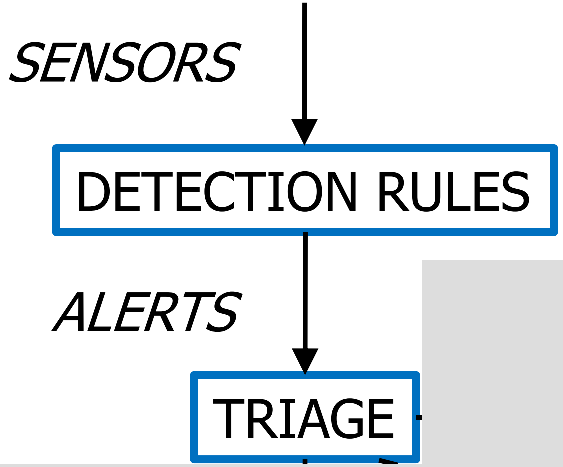
SIEM in practice

SIEM: MANY sensors

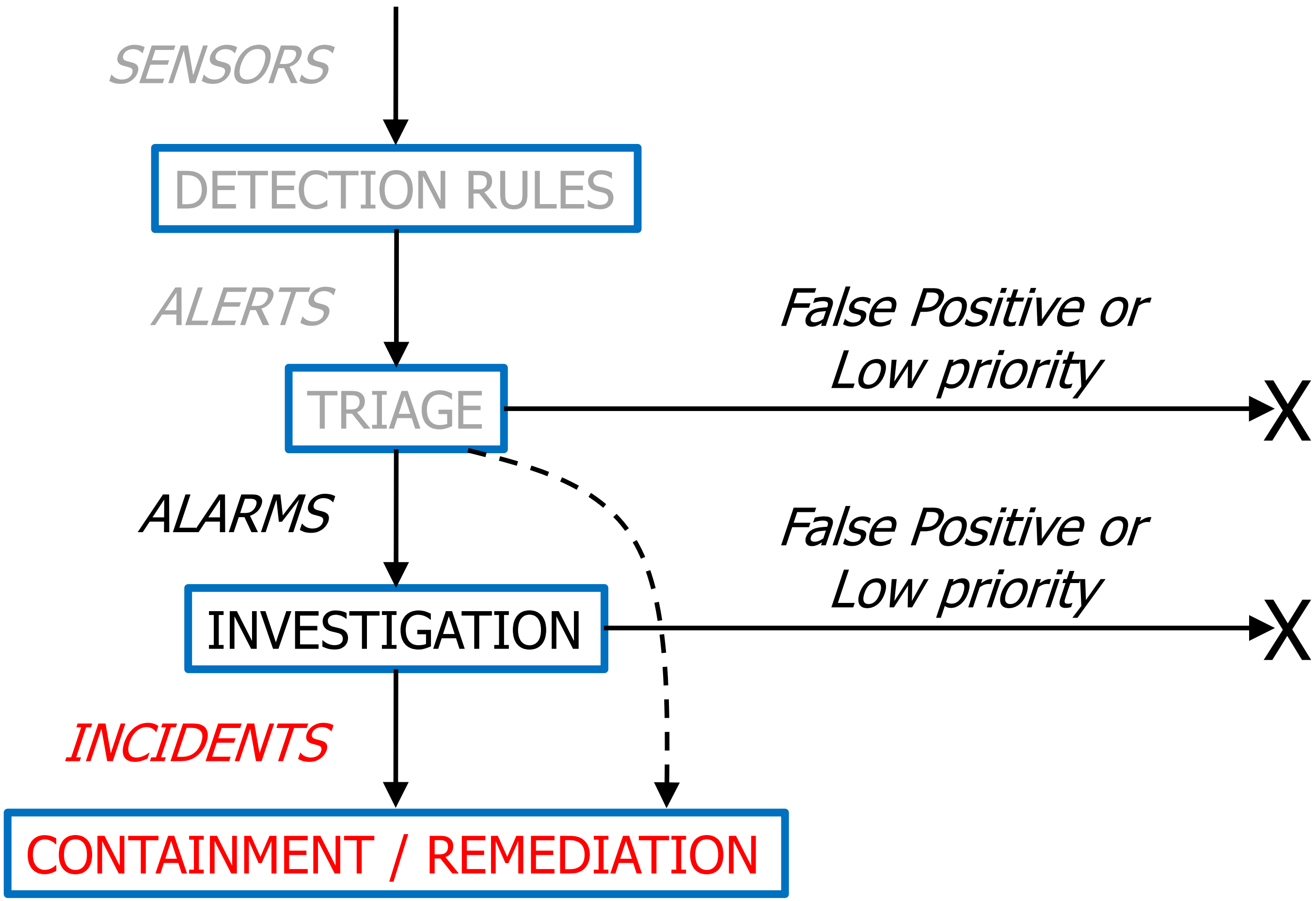


99% False Positives: A Qualitative Study of SOC Analysts' Perspectives on Security Alarms
31st USENIX Symposium

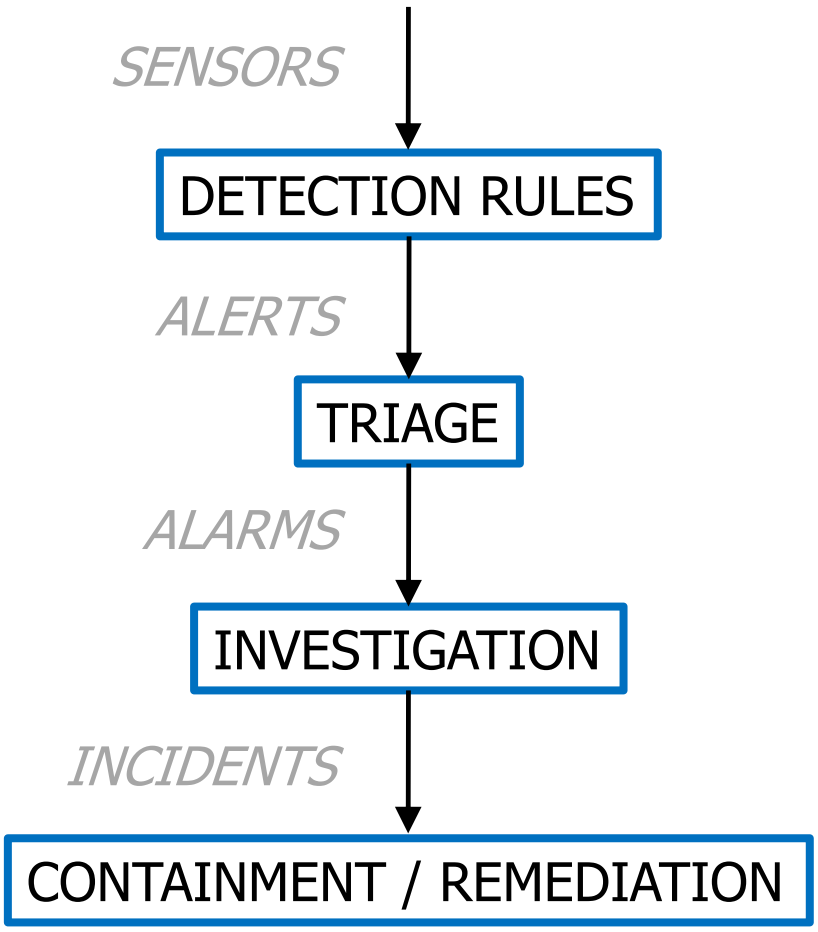
SIEM: Logical workflow (I-a)



SIEM: Logical workflow (I-b)



SIEM: Logical workflow (II)



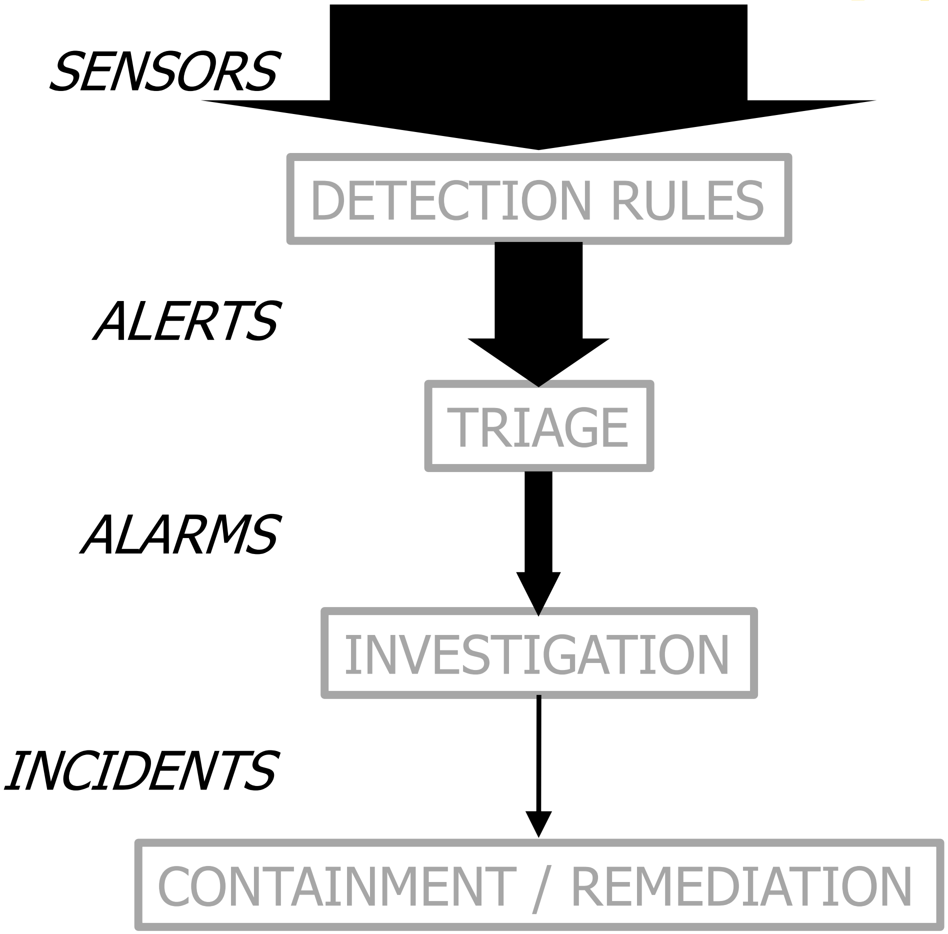
- **Automatic**
- Detection Engineers

- **Partly manual**
- SOC Analyst

- **Manual**
- SOC Analyst

- **Manual**
- Incident Responder

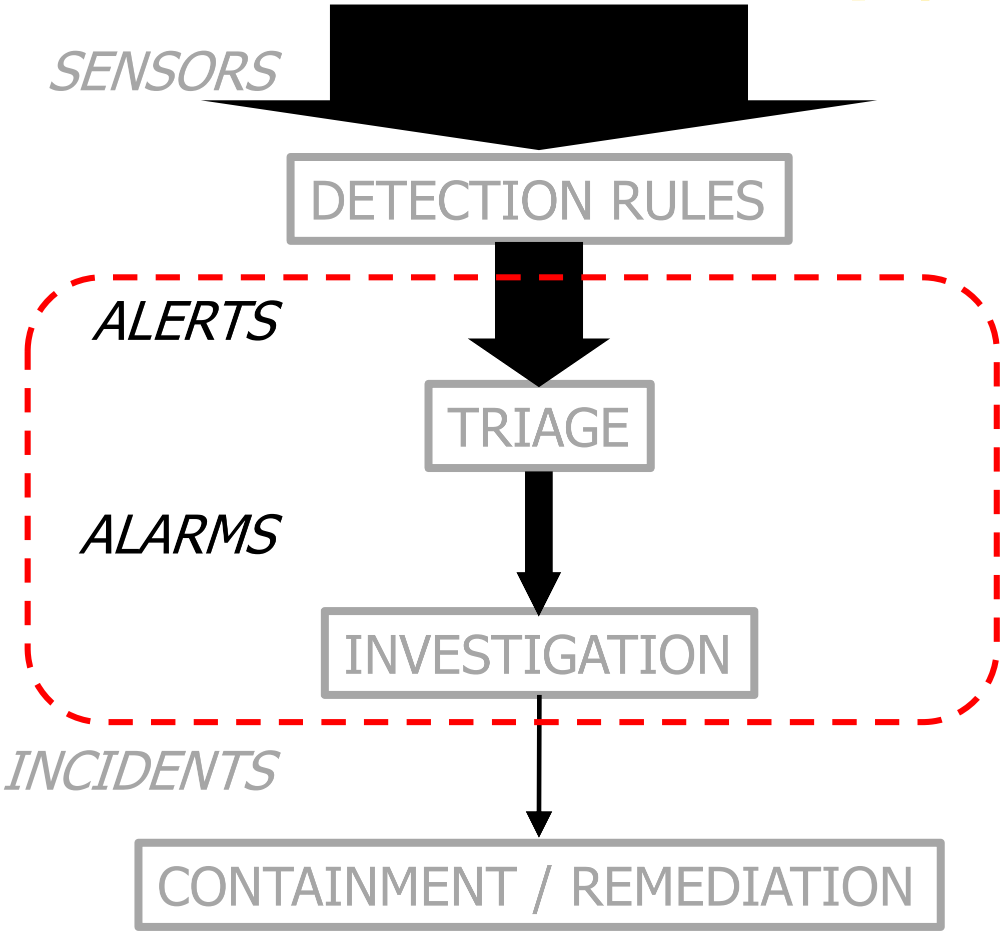
Daily Volumes (Typical)



Millions / Billions

Hundreds / Thousands

"THE" Practical Problem



Hundreds / Thousands

- **Partly manual**
- SOC Analyst

- **Manual**
- SOC Analyst

Just one of the many studies (I)

- 1000 SOC members, 100 orgs, 10 countries
- Orgs with >1000 employees

- Certainly high budget and awareness

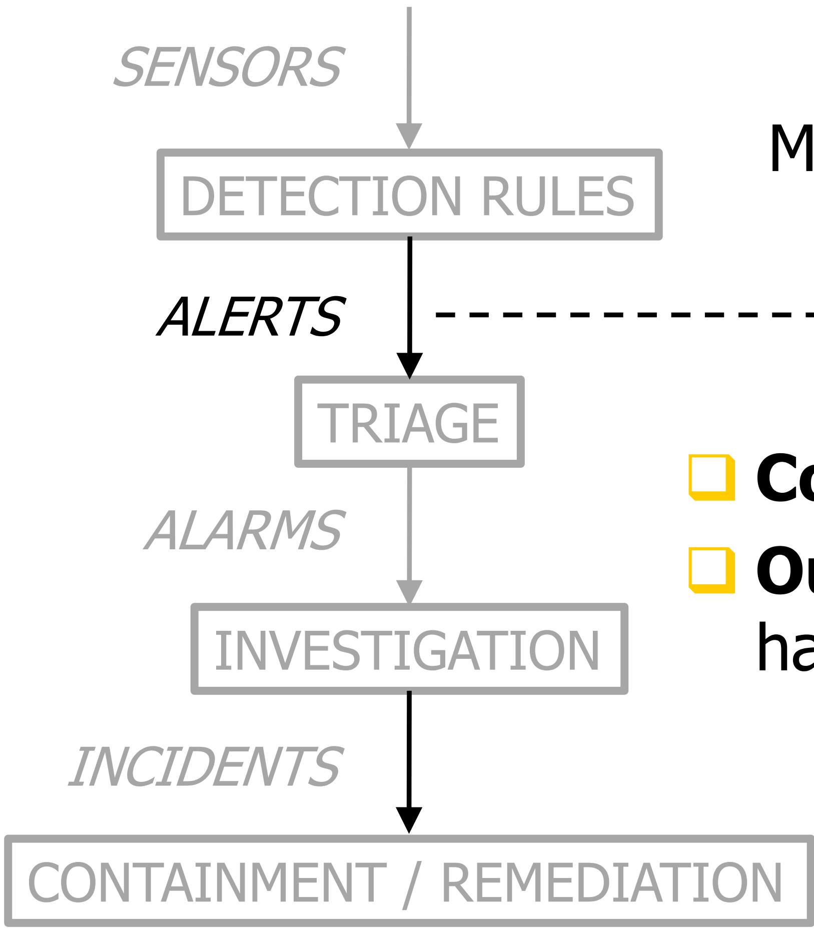
Just one of the many studies (II)

- *We can investigate* ***less than half*** *of all alerts*

- ***Most*** *are either* ***false positives*** *or* ***low priority***

- *Over the last two years, the time it takes to investigate an alert has* ***increased***

Outsourcing?



Managed Security Service Provider
(**MSSP**)

- **Contextual information is crucial**
- **Outsourcing these steps** is hard / unlikely / not effective

To make a long story short

- The problem is **not** "detecting attacks"
- The problem is "detecting **only** attacks" (i.e., with low false positives)

- AI? Good luck
  - **Contextual** information?
  - **Explanation** of alerts?