Integrity Monitoring

Detecting changes in the filesystem

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What is Integrity Monitoring?

- “the process of validating the integrity of operating system files and directories”
- Integrity: file/directory content and metadata are unchanged with regards to a given “known good” state
- However: changes to files and directories are intented
  - Updates: OS, software etc.
  - Configuration changes: users, network (addresses), settings, etc.
- Detecting unauthorized or unintended changes
  - Those made by attacks or mistakes

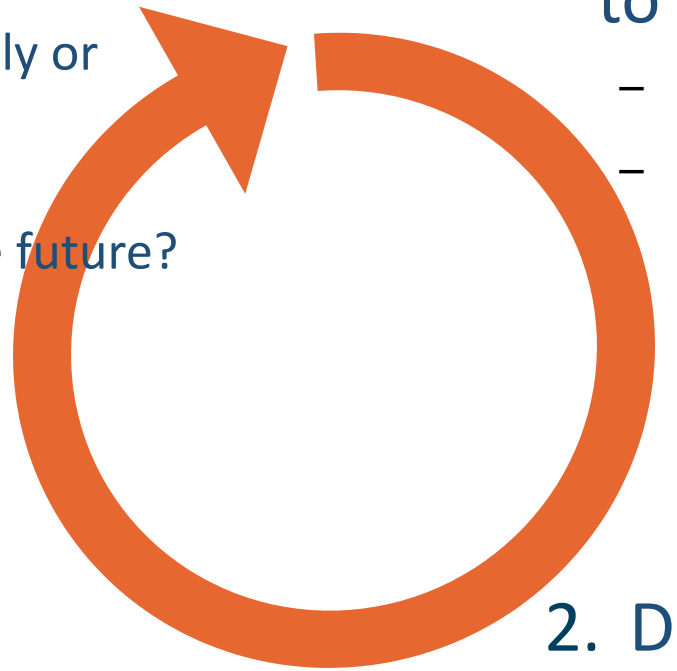
⟶ **File Integrity Monitoring (FIM)**

Why is (File) Integrity Monitoring useful?

- Assessing the impact of integrity violations
  - Which changes were made?
    - I.e. new firewall rules, new users, changed daemon/service configurations, unparseble configurations/libraries
    - Changed binaries/libraries/kernel (modules/drivers), ...
    - Additionally installed or removed files?
      - Crypto-miners, Spam-SW, phishing pages, AV, firewall, FIM, …
  - What happened? How did it happen?
- Detecting unintended changes
  - Critial: configuration mistakes that open weaknesses
    - Empty passwords, disabling authentication, …

Integrity monitoring workflow

1. Plan: what to monitor, how to monitor
   - Systems, files, directories
   - Attributes: content, permissions, etc.
2. Do: Take Baseline
   - Record valid state(s)
3. Check: at regular intervals
   - Examine attributes of monitored files & directories
   - Compare exam results with baseline → Report
4. Act
   - Valid state?
   - Change deliberately or unintentionally?
   - Consequences?
   - Preventable in the future?



Plan: what systems should be monitored?

- Rule of thumb: By order of impact/mission criticality
  - Look at your Business Impact Analysis (if present)
  - Identity management, authentication databases/servers
    - I.e. KDCs, Domain Controllers, LDAP servers with authentication information
    - Compromising these will compromise most other systems
  - Systems storing your mission critical data
    - Database servers, file servers, backup servers
  - Security critical systems
    - Firewalls, SIEM, loghost, …
  - Other mission critical systems
    - Webservers, application servers, load balancers, VM-hosts, central switches/routers, central DNS, central Email, HR, CRM, …

Plan: what files should be monitored?

- Trusted computing base
  - Kernel, kernel modules/drivers
    - `/boot, /lib/modules, C:\BOOTMGR, C:\Boot\BCD`
  - Binaries, libraries
    - `/bin, /usr/bin, /lib, /usr/lib`
    - `C:\Windows\System32`
    - Directories in $PATH (Linux) or %PATH% (Windows)
  - System configuration
    - Linux/Unix: `/etc`
    - Windows: Registry
  - Critical files in Home directories
    - `~/.ssh/authorized_keys, ~/.config`

Plan: Limited checks

- Sockets, named pipes, IPC objects
  - Reading (i.e. checksumming) will likely block
  - Inode number will change when socket gets re-created at boot
  - Permissions, ownership, major/minor device number can be monitored
- Symlinks
  - Not all FIMs will monitor where the symlink points to
- Confidential data
  - Key material, esp. private keys
  - No text diffs
  - May show up in text diffs or logs
- Temporary filesystems/directories
  - `/tmp, /usr/tmp, /var/tmp, /dev/shm, /run/user/, /etc/mntab`
  - Permissions (sticky bit) are OK

Plan: What to exclude from checking?

- Ephemeral/dynamic file systems
  - `/proc, /sys, /dev, /etc/mntab`
  - Too many changes in operation to be useful
- Network file systems
  - NFS, CIFS, AFS, etc.
  - Check these on the server – not over the network
- Removable media
  - USB/flash drives, CD/DVD/BD, Floppy(?)
  - Content will change with different media mounted

Plan: what attributes should be monitored?

- Content, of course
  - Complete file? – that's called a backup;)
  - Usually cryptographic checksums: SHA256, … (too often still MD5, SHA1)
  - For very large files (> 1 GByte), checksumming may take too long
  - Full content for small (vital) text files - allows diff to show changes
- Permissions/ACLs
  - S-UID/S-GID bits
  - Write permissions on configuration files for ordinary users?
  - Read permissions for world appearing on confidential data?
- Owner, Group
  - System binaries/libraries should be owned by root
- Size
  - Binaries, libraries should not change size – except through updates
  - Others (log files) should only grow – what about log rotation?

Plan: what attributes could be monitored?

- Device ID, Inode:
  - Somebody might have replaced stuff with mounts to another filesystem
- Number of links:
  - Each file in a directory has one link to it, plus itself and the parent directory
  - Hidden files/directories will show up as mismatch on link count
  - Works well on Ext2/3/4, vfat, and (old) standard Unix filesystems
  - Does not work with modern filesystems: XFS, Btrfs, ZFS
- MACtimes
  - Modification
  - Access
  - Creation (Windows), Change (of metadata/inode: Linux/Unix)
  - B(orn) or D(eleted) timestamps – if supported by filesystem
  - Timestamps can be changed by attackers
    - Even creation with root privileges & anti-forensic tools

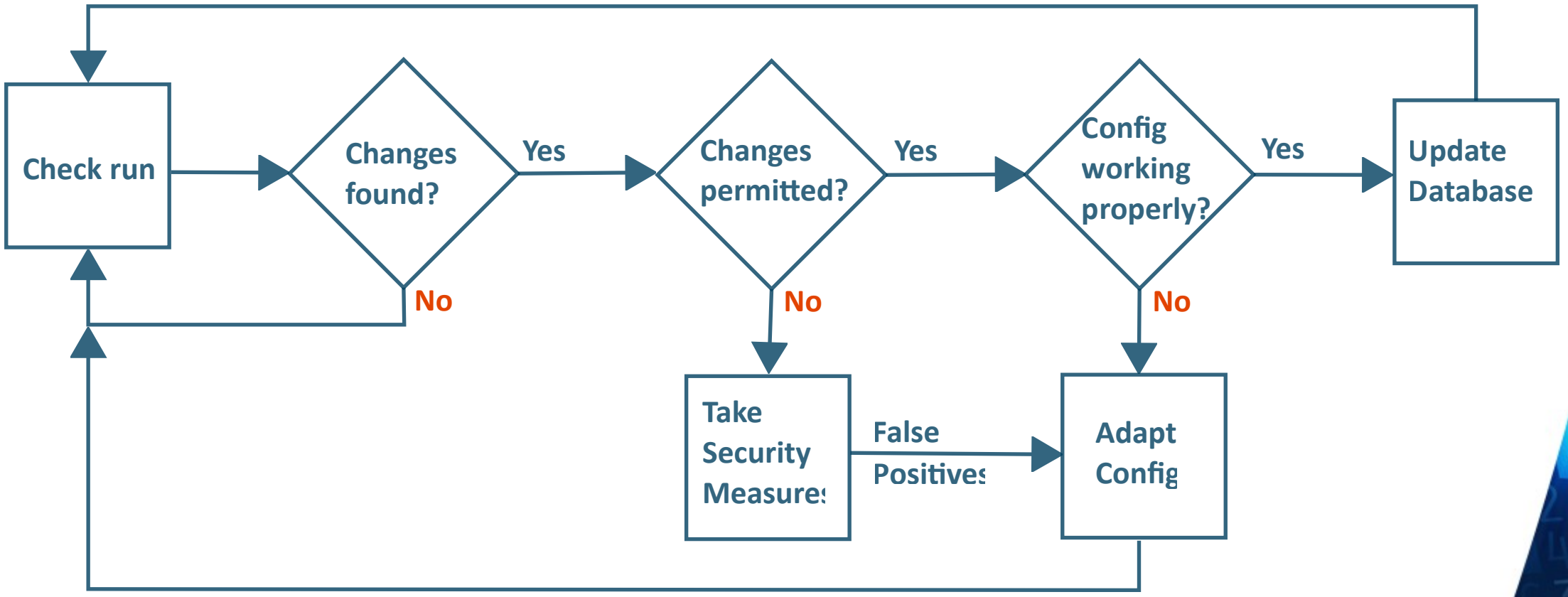
Do: Baselining

- Naive: `find / -print0 | xargs -0 sha256sum > /tmp/my.db`
- Baseline must be secured against tampering/loss
  - Best done by keeping on a central server
  - Same goes for configuration of the FIM
  - If kept locally, sign digitally, check before use
  - Availability issues: deleted locally, no network, how to act then...
- Baseline must be taken form a “known good”/valid/legal state
  - After a fresh/complete install?
  - After initial setup?
  - Patches, updates, later installs?

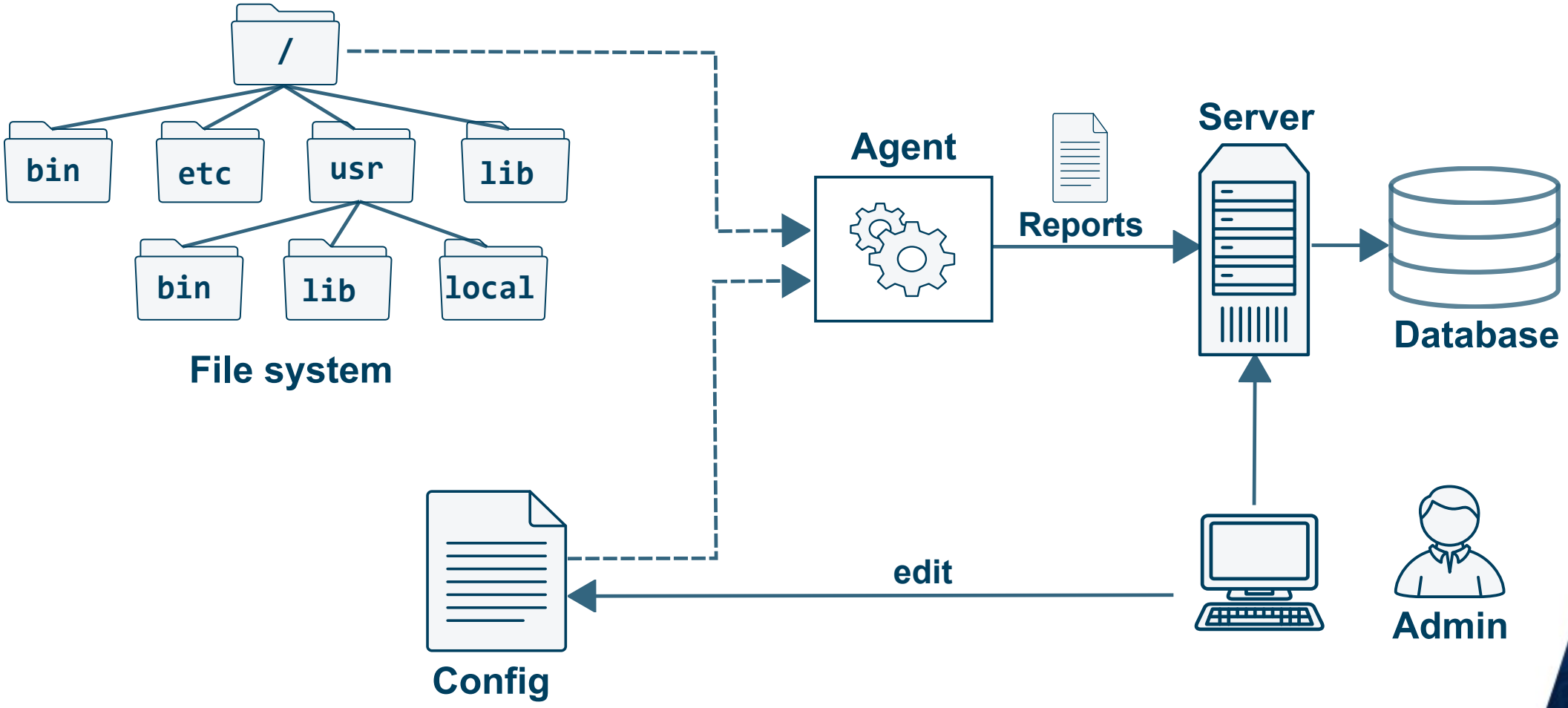
Check

- How often to check?
  - Depends, anywhere between once/hour and once/day
  - More checks – more work, more load on the systems
  - OTOH: checking more often may spot attacks earlier
  - Ideal: real-time monitoring for changes (Linux: inotify system call)
- What to report?
  - Need **actionable** data: Report + Background = enough information to draft a plan to act upon
- How to report changes?
  - Log messages (syslog, eventlog) – best to SIEM/central loghost
  - Email (standalone systems)
  - Console log?

Act: Workflow



FIM: Schema

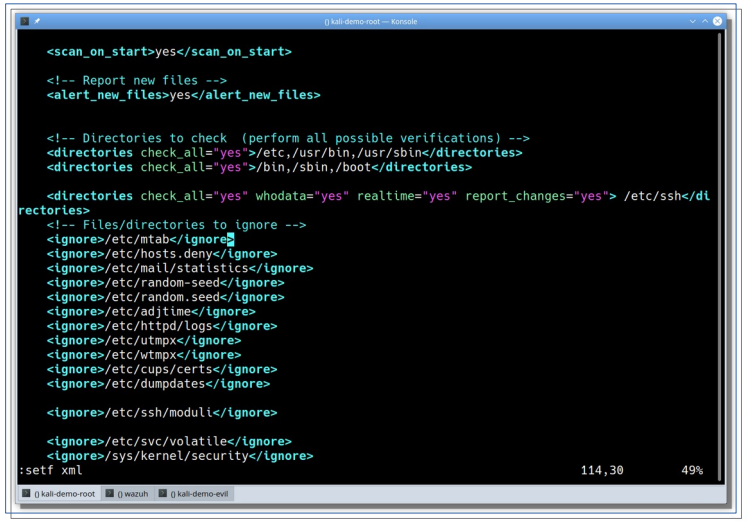

/
bin
etc
usr
lib
bin
lib
local
File system
Agent
Reports
Server
Database
Config
edit
Admin

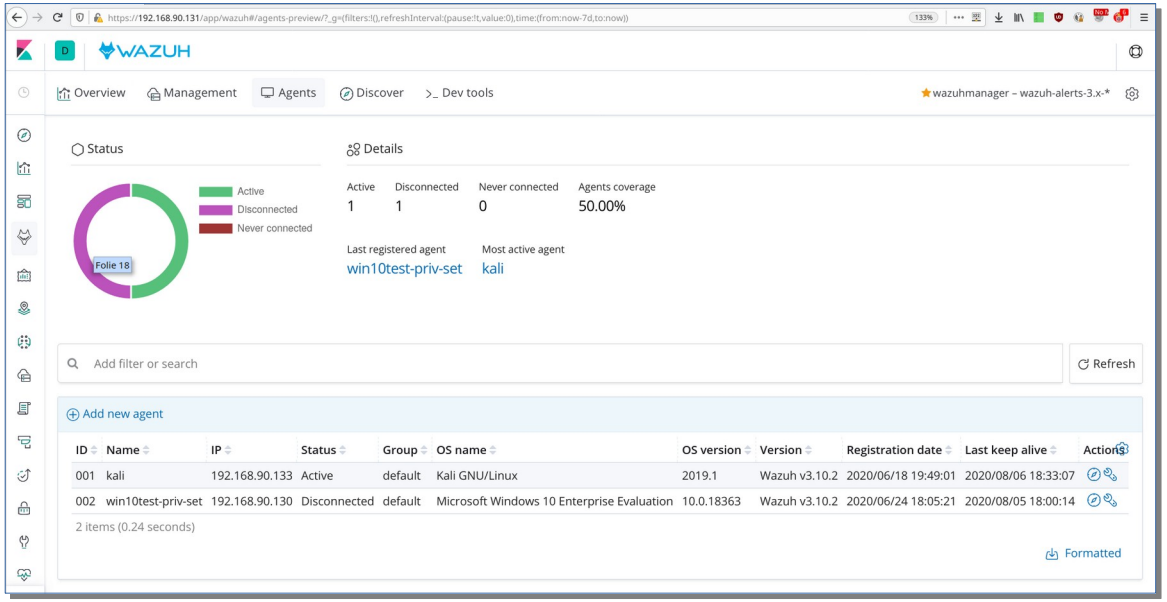
How to start?

- Begin small
  - One or two servers, only a handful of files
  - Can be implemented on spare hardware
- Observe, adapt, expand
  - Learn how and when changes happen and why
  - Adapt your configuration
  - Write down in knowledge base
- Expand bit-by-bit
  - Have a plan (what to monitor)
  - It’s better to observe too few things than too much

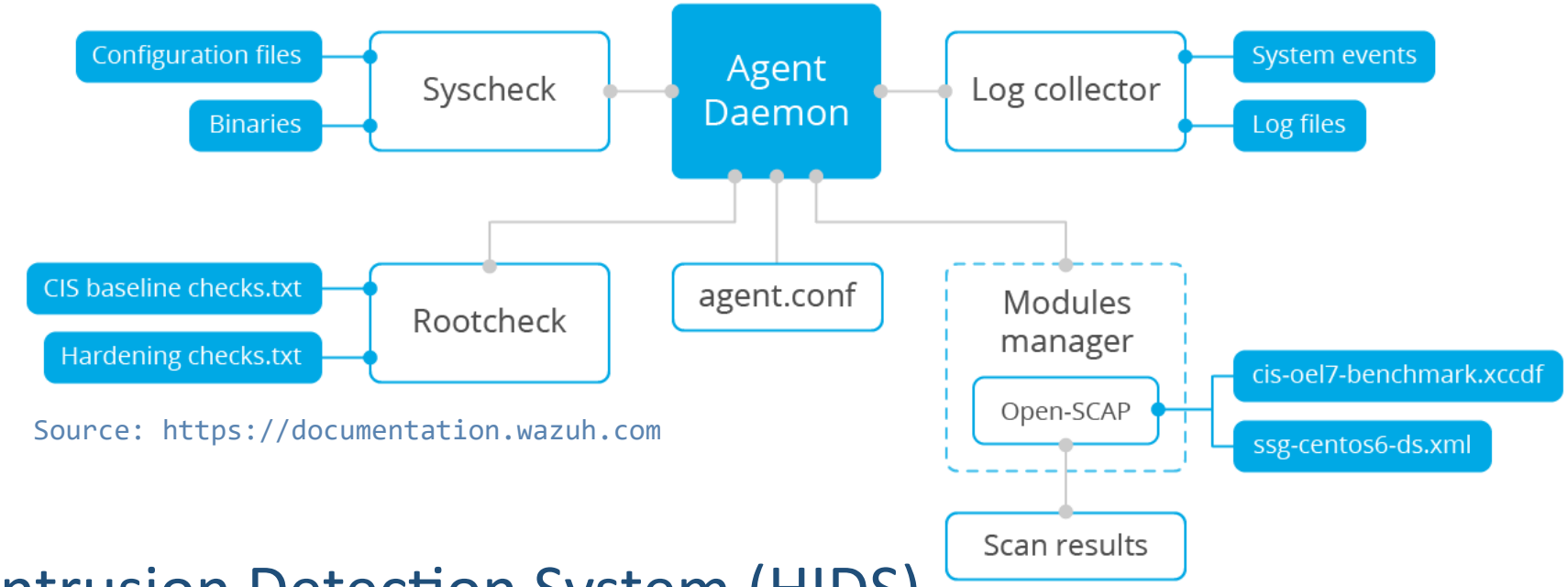
Wazuh Live Demonstration

- Configuring syscheck
- Adding/deleting a file
- Changing the content of a file
- Looking into events/reports





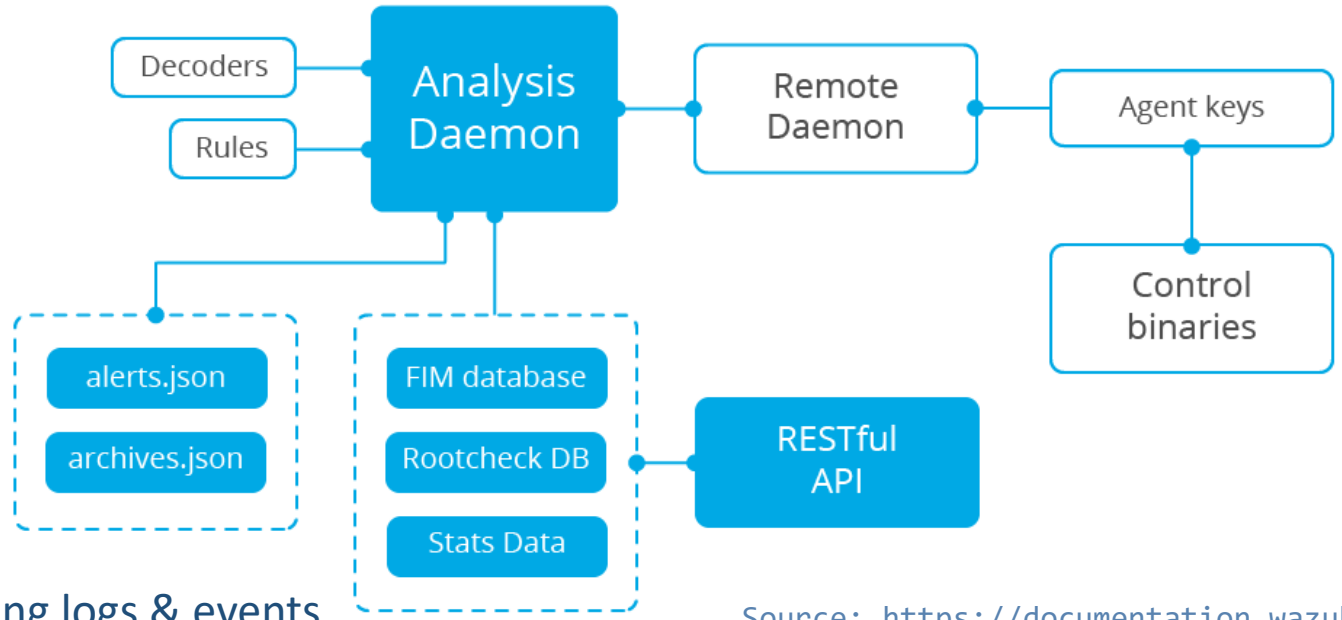
Wazuh: Agent



Source: https://documentation.wazuh.com

- Full Host Intrusion Detection System (HIDS)
  - Syscheck: Integrated FIM
  - Rootcheck: configuration check & rootkit detection
  - Log collector: Event & log file monitoring/forwarding (Filebeat)
  - Modules Manager: Place to plug-in user defined (scan) modules

Wazuh: Server



Source: https://documentation.wazuh.com

- Analysis Daemon
  - Decodes and analyses incoming logs & events
- Remote Daemon: Agent management
- Elasticstack: Kibana, Filebeat
  - Analysis (ElasticSearch)
  - Log/Event forwarding reception (Filebeat)
  - Dashboard (Kibana)

Limits of FIM: Malware

- Some malware doesn't write anything to the filesystem
  - What's not there, can't be found
  - But most malware needs a means of persistence: Autostart keys, kernel modules, boot loader/parameters, etc.
  - This will leave traces
- Rootkits hide files/directories from **every** user
  - What is not visible can't be checked or seen
  - But hiding a file/subdir also alters the parent directory: Timestamps, Link counts, etc.
- A thorough check will detect ***something***
- But it's up to the admin to pick up on strange reports

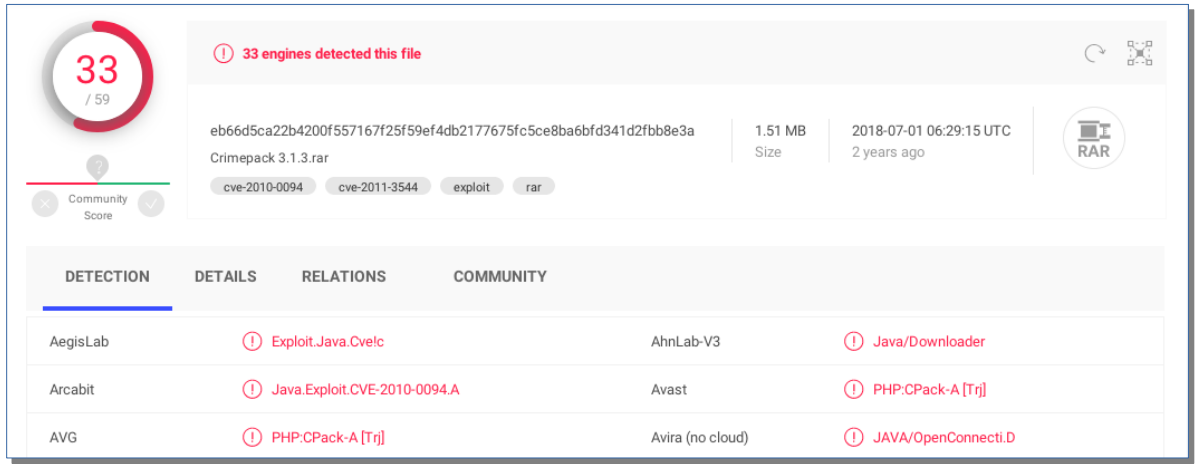
Limits of FIM: File signature evasion

- Find a collision,
  - I.e. a file that has the same cryptographic hash sum as the original
  - Can be done with weak/broken hash algorithms, like MD5 or SHA1
  - Very rare in practice
    - Do not confuse with cases where valid Authenticode signatures were used
    - These were made with leaked/stolen certificates
- Mitigation
  - Multiple checksums – attacker has to find collisions for all employed hash algorithms
  - Stronger hash algorithms: SHA256, SHA-512, SHA-3, etc.
  - Full content comparision, i.e. diff

Other uses for file hashes: Virustotal

- Unknown file, good or malicious?
  - Scan with your own Anti-Virus
    - What if it says nothing?
  - Use more AV-Scanner
  - **`https://virustotal.com`**
- Can’t/won’t send file
  - Malware upload blocked
  - May contain sensitive information
  - Search by cryptographic hash
  - md5, sha1, sha256

```
> sha256sum Crimepack\ 3.1.3.rar
eb66d5ca22b4200f557167f25f59ef4db2177675fc5ce8ba6bfd341d2fbb8e3a  Crimepack 3.1.3.rar
>
```



What have you learned?

- What integrity monitoring (at the OS level) is
- How to do integrity monitoring
- How to configure the integrity monitoring software

What has been left out?

- Boot process integrity
  - TPM, secure boot (MS), EVM/LMA (Linux)
- Binary signing under (elfsign - Linux, Authenticode - Windows)
- Cryptographic signing of files (PGP, S/MIME)

Thank you

Any questions?

Next module: ***Network 1st Hop Security***, 11th of August 2020

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The research leading to these results has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 731122 (GN4-2).

References

- Kim, Gene H.; Spafford, Eugene H. (1994). "The Design and Implementation of Tripwire: A File System Integrity Checker"
  - https://dl.acm.org/doi/10.1145/191177.191183
- Lawrence Grim: “IDS: File Integrity Checking”
  - https://www.sans.org/reading-room/whitepapers/detection/ids-file-integrity-checking-35327
- OSSEC Host-Based Intrusion Detection Guide
  - Rory Bray, Daniel Cid, Andrew Hay, Syngress, 2008, ISBN: 978-1597492409
- Host integrity monitoring using OSIRIS and Samhain
  - Brian Wotring, Syngress, 2005, ISBN-13: 978-1597490184

Some Open Source FIM software

- Tripwire: the grandparent of many FIM software (1992)
  - https://github.com/Tripwire/tripwire-open-source
- Aide: Advanced Intrusion Detection Environment
  - https://aide.github.io/
- Afick: Another File Integrity CheckKer
  - http://afick.sourceforge.net/
- Samhain: Linux FIM with additional monitoring of kernel data structures
  - https://www.la-samhna.de/samhain/
- OSSEC, Wazuh: Full open source HIDS with FIM (syscheck)
  - https://www.ossec.net/
  - https://wazuh.com/

Wazuh Live Demonstration

- Wazuh Server Appliance
  - https://documentation.wazuh.com/3.10/installation-guide/virtual-machine.html
  - https://packages.wazuh.com/vm/wazuh3.10.2_7.3.2.ova
- Kali Linux
  - https://www.kali.org/downloads/
- Windows 10 from Microsoft Evaluation Center
  - https://www.microsoft.com/en-us/microsoft-365/windows

Backup material

Stuff that didn’t make it due to time constraints

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Decoding Wazuh file modes

```
/* File types.  */
#define __S_IFDIR       0040000 /* Directory.  */
#define __S_IFCHR       0020000 /* Character device.  */
#define __S_IFBLK       0060000 /* Block device.  */
#define __S_IFREG       0100000 /* Regular file.  */
#define __S_IFIFO       0010000 /* FIFO.  */
#define __S_IFLNK       0120000 /* Symbolic link.  */
#define __S_IFSOCK      0140000 /* Socket.  */

/* Protection bits.  */
#define __S_ISUID       04000   /* Set user ID on execution.  */
#define __S_ISGID       02000   /* Set group ID on execution.  */
#define __S_ISVTX       01000   /* Save swapped text after use (sticky).  */

#define __S_IREAD       0400    /* Read by owner.  */
#define __S_IWRITE      0200    /* Write by owner.  */
#define __S_IEXEC       0100    /* Execute by owner.  */
```

In-House Tools

- What if no FIM software on the system?
  - By default, there is none, or it's not active
- Some tools come with the operating system
  - Linux: Package database (rpm, dpkg)
    - Already has checksums, permissions, sizes, and more
  - Windows: sfc, sigverif, sigcheck
    - Checks the Authenticode signatures on executables and DLLs
- None of them will replace an FIM
  - Meant for system administration, not security
  - But better than nothing in emergencies (see shortcomings)

Linux In-House Tools: rpm & dpkg

- **rpm:** package manager for Redhat-based systems
  - CentOS, Fedora, openSUSE, …
- **dpkg:** package manager for Debian-based systems
  - Ubuntu, Kali, …
- Verify option: -V
  - Checks against information in the local database of installed package
  - Example: size and modification time have changed

```
> rpm -V openssh
S.?....T.  c /etc/ssh/sshd_config
>
```

rpm & dpkg -V: Output Format

- Output format for differences from package database information

```
.........   ← Test passed
S           ← file Size differs
 M          ← Mode differs (includes permissions and file type)
  5         ← digest (formerly MD5 sum) differs
   D        ← Device major/minor number mismatch
    L       ← readLink(2) path mismatch
     U      ← User ownership differs
      G     ← Group ownership differs
       T    ← mTime differs
        P   ← caPabilities differ
?           ← Information not in the database
```

Linux In-House Tools: Shortcomings

- Does not cover
  - Other package formats (for example self-extracting software)
  - Manually installed files (.tar.gz)
  - Files copied to different locations (chroot jails)
  - Files added by the attacker
- Local system only
- No automation/reporting
- Dpkg implements only the checksum part
- On a live system, lots of deviations from install
  - No way to flag changes as good and include them in the database
- Database is not secured against attackers with root privileges

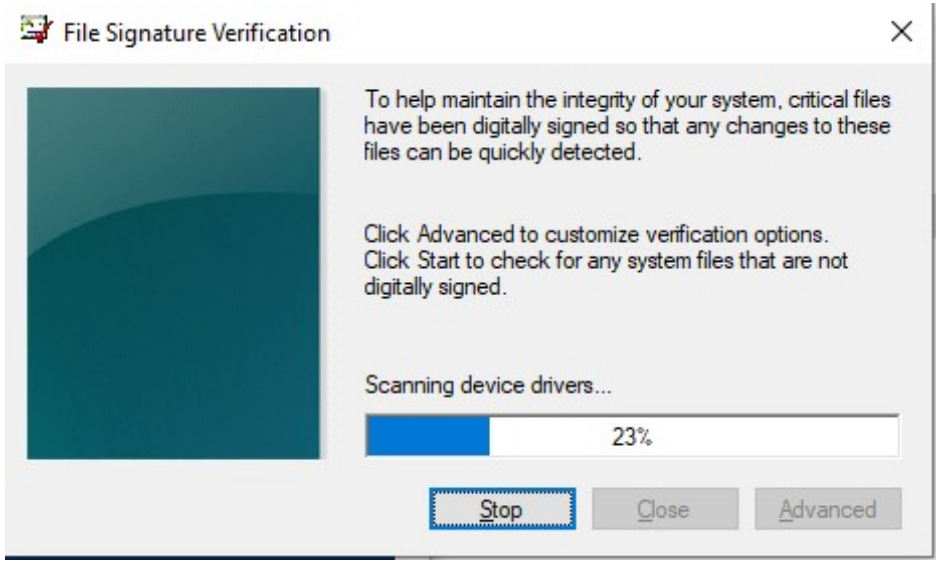
Windows In-House Tools: System File Checker

- Check if protected system files have been altered
  - Just verify: `sfc.exe /verifyonly`
  - Verify and restore: `sfc.exe /scannow`
  - Backups in `%windir%\system32\dllcache`
  - Or installation source
  - Not enabled by default
  - Log: `%windir%\Logs\CBS.log`
- Often bypassed by attackers
- Shortcomings
  - What is protected is not configurable by users/admins
  - Local system only

```
PS C:\Windows\system32> sfc /verifyonly

Beginning system scan.  This process will take
some time.

Beginning verification phase of system scan.
Verification 100% complete.

Windows Resource Protection did not find any
integrity violations.
PS C:\Windows\system32>
```

Windows In-House Tools: Sigverif

- Tool to verify signatures of device drivers in Windows
  - Device drivers (i.e. kernel modules) must be cryptographically signed to be loaded by the kernel
  - Reports to local log (default: `C:\Users\Public\Public Documents\Sigverif.txt`)
- Shortcomings
  - Checks only fixed list of drivers
  - List not configurable
  - No config file checks
  - No registry key checks



Windows In-House Tools: Sysinternals Sigcheck

- Verifies signatures like sigverif
- More fine-grained controls
  - CLI tool (scripting)
  - CSV output
  - Can show unsigned files only: `sigcheck -u`
  - Can check with virustotal
- Shortcomings
  - Still nothing for configuration/registry checks