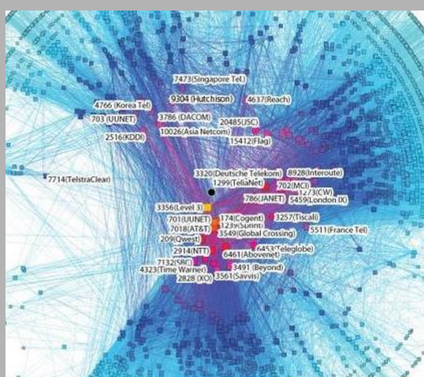
Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

Prof. Dr. Mathias Fischer
Winter term 2020/2021



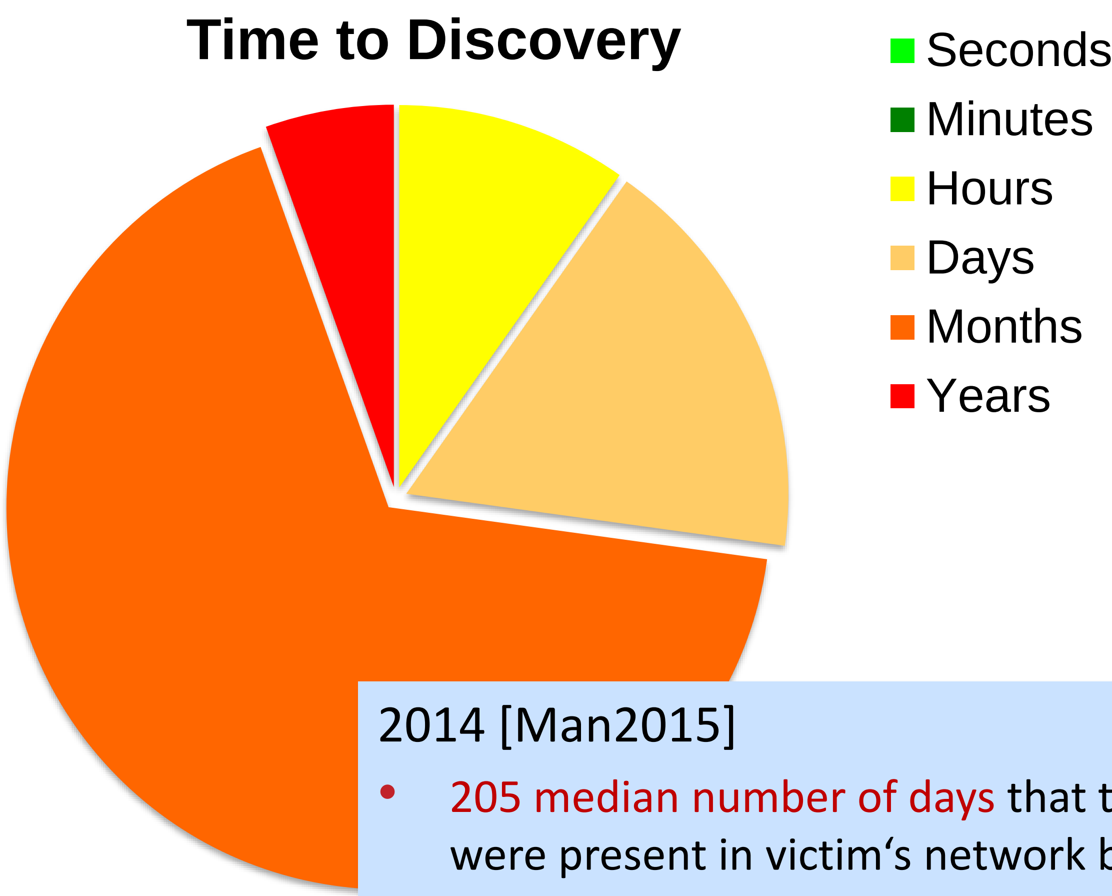
Resilient Networks

Network Monitoring and Intrusion Detection

Outline

- Goals of IDS
- Requirements to an IDS
- Classification of IDS
  - Signature-based Detection
  - Policy-based Detection
  - Anomaly Detection
- Problems of IDS
- Alert Correlation
- Cyber-Killchain
- IDS Evasion

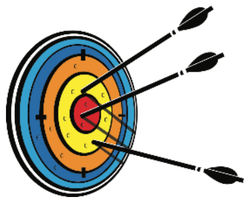
Time to Discovery of Attacks



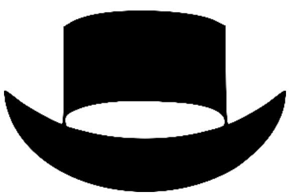
2014 [Man2015]

- 205 median number of days that threat groups were present in victim's network before detection
- Longest Presence: 2982 days
- 31% victims discovered breach internally
- 69% victims notified by external entity

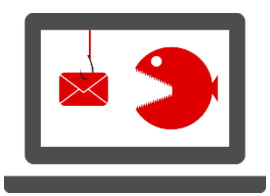
Goal of Intrusion Detection/Prevention Systems



- Overall goal:
  - Intrusion Detection Systems (IDS)
    Supervision of computer systems and communication infrastructures to detect intrusions and misuse
  - Intrusion Prevention Systems (IPS)
    Detect and stop intrusion/misuse



- Why detection of attackers?
  - Full protection not possible!
  - Security measures too expensive or too inflexible
  - Wrong postulates about attacker capabilities (NSA!?)
  - Unpatched systems for compliance reasons
  - …

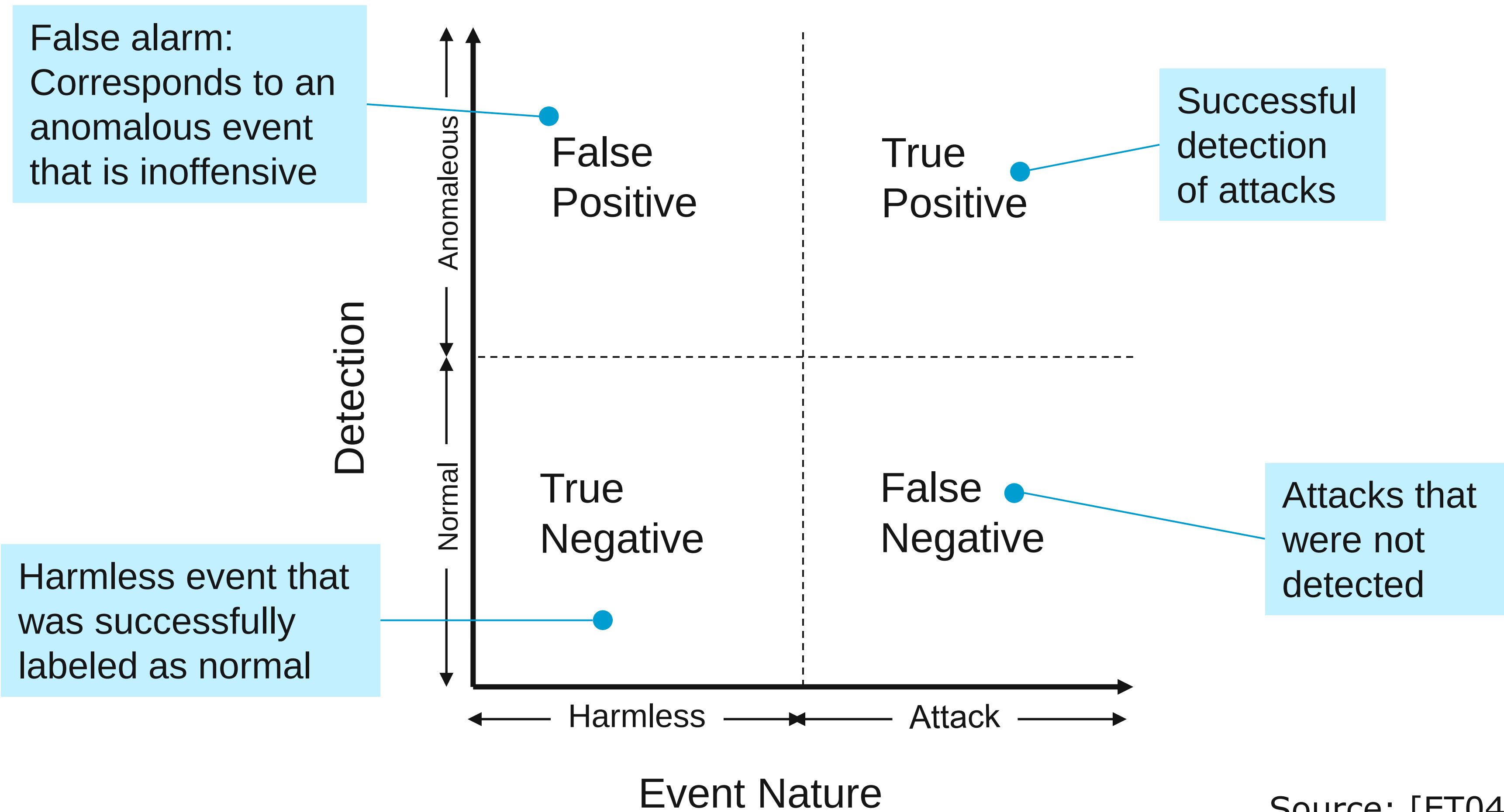


- What can be attained with intrusion detection?
  - Detection of attacks and attackers + detection of system misuse
  - Limitation of damage if (automated) response mechanisms exist
  - Gain of experience to recover from attack, improve preventive measures
  - Deterrence of other potential attackers (if police is able to arrest them!)

Requirements to Intrusion Detection Systems

- Easy to integrate into a system / network
- Easy to configure & maintain
- Autonomous and fault tolerant operation
- Low resource requirements
- Self-protection, so that IDS cannot be deactivated by deliberate attack (to conceal subsequent attacks)
- High accuracy
  (= low rate of false positives and false negatives)

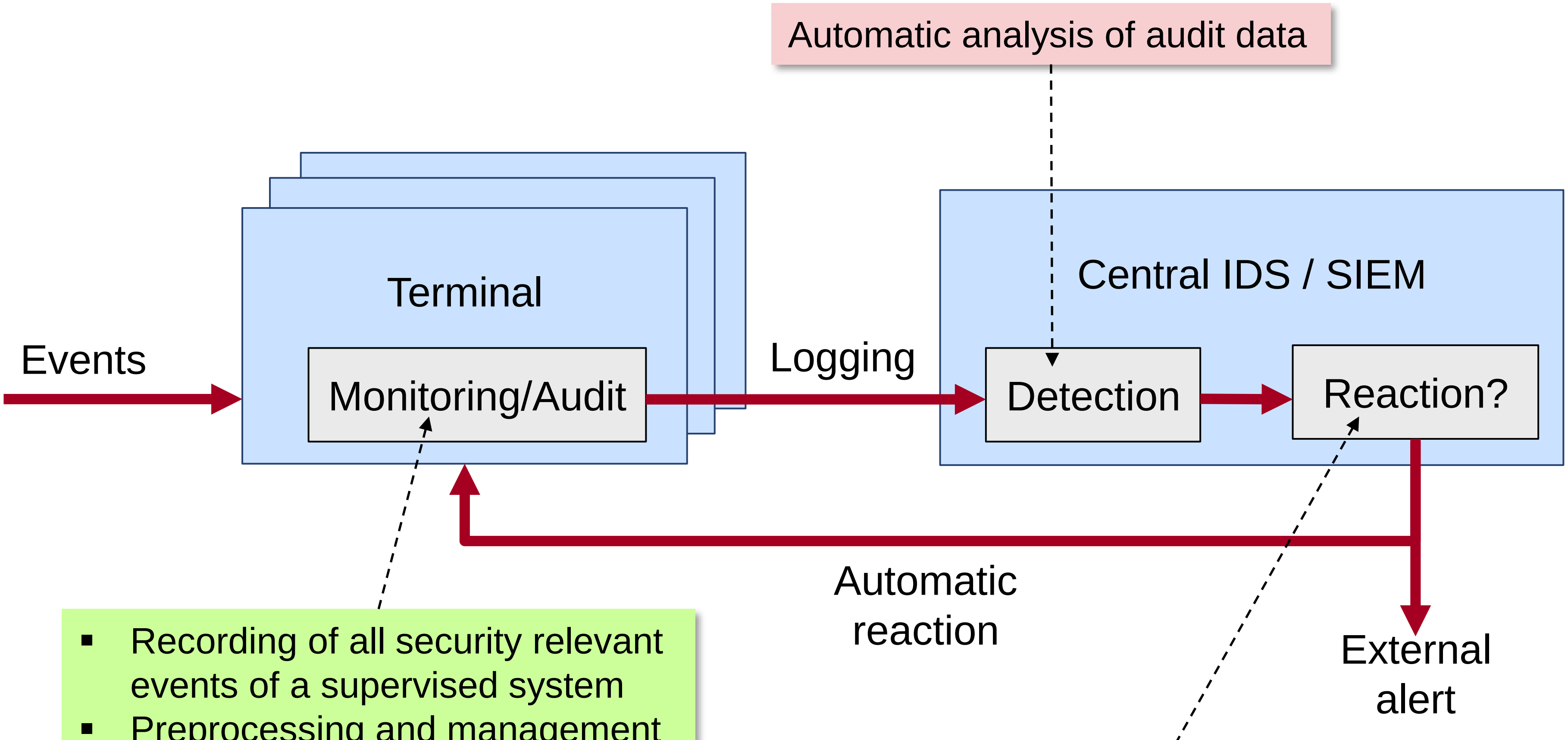
Detection Quality



Source: [ET04]

Operation of Intrusion Detection/Prevention Systems

SIEM = Security Information and Event Management



- Recording of all security relevant events of a supervised system
- Preprocessing and management of recorded audit data

Reporting of detected attacks (alarms or alerts)
Potentially initiating countermeasures (reaction)

Types of Audit Data

- Events recorded in a computer system:
  - Opening of files
  - Execution of programs
  - Detected access violation
  - Failed password verification
  - etc.

- Events recorded in a network:
  - Connection establishment and release
  - Packets transferred from / to specific systems / ports
  - Specific signaling events, e.g. ICMP network unreachable message, etc.

- Application specific events:
  - Have to be programmed for a specific application
  - Events are application specific and indicate security relevant activities

Classification of IDS

- Scope
  - Host-based: analysis of system events
  - Network-based: analysis of exchanged information (IP packets)
  - Hybrid: combined analysis of system events and network traffic

- Time of analysis
  - Post mortem analysis
  - Online analysis

- Detection mechanism
  - Signature-based
  - Policy-based / Misuse-based / Anomaly-based

Types of IDS (1) – Host IDS

Host Intrusion Detection Systems (HIDS)

- Works on information available on a system, e.g., OS-Logs, application-logs, timestamps
- Can easily detect attacks by insiders, as modification of files, illegal access to files, installation of Trojans or rootkits
- Problems:
  - has to be installed on every system
  - produces lots of information
  - often no real-time-analysis but predefined time intervals
  - hard to manage a large number of systems

```
osquery> SELECT uid, name FROM listening_ports l, processes p WHERE l.pid=p.pid;
```

Example of a Host-Monitor – Osquery (1)

- Allows to use OS as high-performance relational database
  - SQL tables representing abstract concepts
- Power of complete SQL language on top of dozens of useful tables

processes

All running processes on the host system.

Column	Type	Description
pid	BIGINT_TYPE	Process (or thread) ID
name	TEXT_TYPE	The process path or shorthand argv[0]
path	TEXT_TYPE	Path to executed binary
cmdline	TEXT_TYPE	Complete argv
state	TEXT_TYPE	Process state
cwd	TEXT_TYPE	Process current working directory
root	TEXT_TYPE	Process virtual root directory
uid	BIGINT_TYPE	Unsigned user ID
gid	BIGINT_TYPE	Unsigned group ID
euid	BIGINT_TYPE	Unsigned effective user ID
egid	BIGINT_TYPE	Unsigned effective group ID
suid	BIGINT_TYPE	Unsigned saved user ID
sgid	BIGINT_TYPE	Unsigned saved group ID
on_disk	INTEGER_TYPE	The process path exists yes=1, no=0, unknown=-1
wired_size	BIGINT_TYPE	Bytes of unpagable memory used by process
resident_size	BIGINT_TYPE	Bytes of private memory used by process
total_size	BIGINT_TYPE	Total virtual memory size
user_time	BIGINT_TYPE	CPU time spent in user space
system_time	BIGINT_TYPE	CPU time spent in kernel space
start_time	BIGINT_TYPE	Process start in seconds since boot (non-sleeping)
parent	BIGINT_TYPE	Process parent's PID
pgroup	BIGINT_TYPE	Process group
threads	INTEGER_TYPE	Number of threads used by process
nice	INTEGER_TYPE	Process nice level (-20 to 20, default 0)

```
select * from processes where pid = 1
```

Tables

All Platforms

- carbon_black_info
- chrome_extensions
- cpuid
- etc_hosts
- etc_protocols
- etc_services
- interface_addresses
- interface_details
- kernel_info
- listening_ports
- os_version
- platform_info
- process_open_sockets
- processes
- system_info
- uptime
- users

- running processes
- logged in users
- password changes
- USB devices
- firewall exceptions
- listening ports
- ....

usb_devices

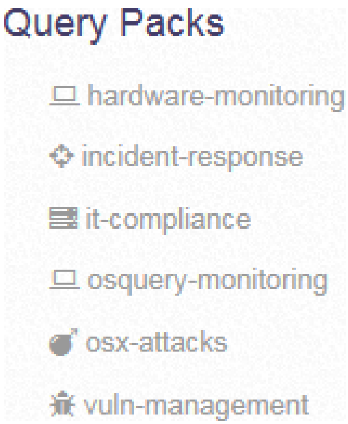
USB devices that are actively plugged into the host system.

Column	Type	Description
usb_address	INTEGER_TYPE	USB Device used address
usb_port	INTEGER_TYPE	USB Device used port
vendor	TEXT_TYPE	USB Device vendor string
vendor_id	TEXT_TYPE	Hex encoded USB Device vendor identifier
model	TEXT_TYPE	USB Device model string
model_id	TEXT_TYPE	Hex encoded USB Device model identifier
serial	TEXT_TYPE	USB Device serial connection
removable	INTEGER_TYPE	1 If USB device is removable else 0

https://osquery.io

Example of an Host-Sensor - Osquery (2)

- High-performance and low-footprint distributed host monitoring
  - To query the system in an abstract way
  - Independent of OS, software or hardware configuration
- Host monitoring daemon
  - allows to schedule queries to be executed across entire infrastructure
  - takes care of aggregating query results over time and generates logs which indicate state changes in the infrastructure
- Cross platform operating system instrumentation framework for
  - intrusion detection,
  - infrastructure reliability
  - or compliance monitoring



https://osquery.io

- Only monitoring, no intrusion detection capabilities on its own

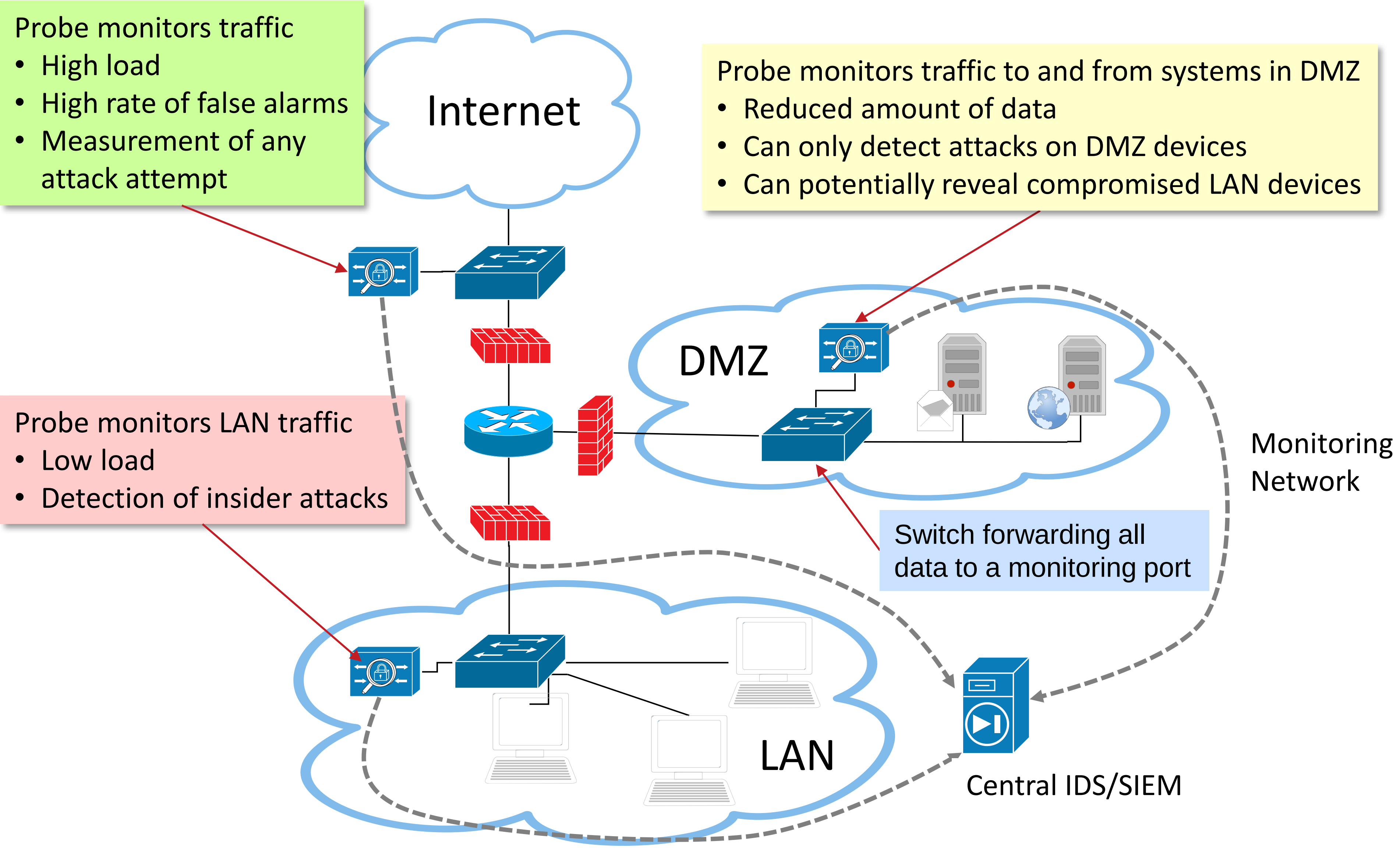
Types of IDS (2) – Network IDS

Network Intrusion Detection System (NIDS)

- Works on information provided by network, mainly packets sniffed from network layer.
- Existing systems use combination of
  - signature detection,
  - protocol decoding,
  - statistical anomaly analysis

- Can detect DoS with buffer overflow attacks, invalid packets, attacks on application layer, DDoS, spoofing attacks, port scans
- Often used on network hubs to monitor a segment of the network

Network IDSs



SIEM = Security Information and Event Management

Signature Detection

- Basic idea
  - Some attack patterns can be described with sufficient detail
    $\rightarrow$ specification of "attack signatures"
  - The event audit analyzed if it contains known attack signatures

- Identifying attack signatures
  - Analyzing vulnerabilities
  - Analyzing past attacks that have been recorded in the audit

- Specifying attack signatures
  - Based on identified knowledge so-called rules describing attacks are specified
  - Most IDS offer specification techniques for describing rules

- Drawbacks of signature-based detection
  - Requires prior knowledge of potential attacks
  - Signature database requires continuous updating
  - High rate of false negatives if signature database is not up to date

Signature Detection – Example: Snort (1)

Network IDS and intrusion prevention system

- Analysis of IP packets in real time
- Mainly signature based, each intrusion needs a predefined rule

```
alert tcp $HOME_NET any -> any 9996 \
 (msg:"Sasser ftp script to transfer up.exe"; \
content:"|5F75702E657865|"; depth:250; flags:A+; classtype: misc-activity; \
sid:1000000; rev:3)
```

- Three step processing of captured information (capturing is done by libpcap):
  - Preprocessing (normalizing and reassembling packets)
  - Detection Engine works on data and decides what action should be taken
  - Action (log, alert, pass)

Policy-based Detection

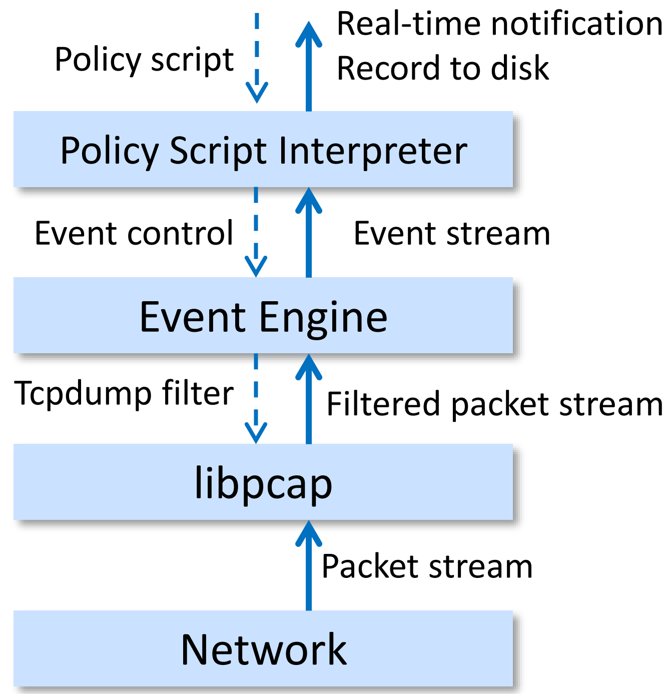
- Also called misuse-based detection

- Basic Idea
  - Specify what is allowed in a network and/or what is forbidden
  - Violations create alerts
  - In that sense, similar to a Firewall

- Drawbacks
  - You can only detect what you configured / what deviates from what you have configured
  - Needs expert knowledge of the system to be protected

Policy-based Detection – Example: Zeek (1)

- Real-time network analysis framework
  - Primary a network monitoring tool
  - Can be used for pure traffic analysis
  - Powerful IDS
- Focus on
  - Application-level semantic analysis
  - Policy-based detection in protocols
  - Tracking information over time
- Zeek comes with >10,000 lines of script code
  - Prewritten functionality that's just loaded
  - Extensive customization and extension possible
  - Growing community writing 3rd party scripts
- Intrusion prevention
  - Zeek can act as dynamic and intelligent firewall



[Pa99]

Zeek Logs (1)

```
> zeek -i eth0
[ … wait … ]
> ls *.log
app_stats.log          irc.log                socks.log
communication.log      known_certs.log        software.log
conn.log               known_hosts.log        ssh.log
dhcp.log               known_services.log     ssl.log
dns.log                modbus.log             syslog.log
dpd.log                notice.log             traceroute.log
files.log              reporter.log           tunnel.log
ftp.log                signatures.log         weird.log
http.log               smtp.log
```

Zeek Logs (2)

```
> zeek -i eth0
[ … wait … ]
> cat conn.log
#separator \x09
#set_separator  ,
#empty_field    (empty)
#unset_field    -
#path   conn
#open   2013-04-28-23-47-26
#fields ts                uid          id.orig_h      id.orig_p  id.resp_h      […]
#types  time              string       addr           port       addr           […]
1258531221.486539  arKYeMETxOg  192.168.1.102  68         192.168.1.1    […]
1258531680.237254  nQcgTWjvg4c  192.168.1.103  37         192.168.1.255  […]
1258531693.816224  j4u32Pc5bif  192.168.1.102  37         192.168.1.255  […]
1258531635.800933  k6kgXLOoSKl  192.168.1.103  138        192.168.1.255  […]
1258531693.825212  TEfuqmmG4bh  192.168.1.102  138        192.168.1.255  […]
1258531803.872834  5OKnoww6xl4  192.168.1.104  137        192.168.1.255  […]
1258531747.077012  FrJExwHcSal  192.168.1.104  138        192.168.1.255  […]
1258531924.321413  3PKsZ2Uye21  192.168.1.103  68         192.168.1.1    […]
[…]
```

Zeek Logs (3) – conn.log

ts	1393099191.817686	Timestamp
uid	Cy3S2U2sbarorQgmw6a	Unique ID
id.orig_h	177.22.211.144	Originator IP
id.orig_p	43618	Originator Port
id.resp_h	115.25.19.26	Responder IP
id.resp_p	25	Responder Port
proto	tcp	IP Protocol
service	smtp	App-layer Protocol
duration	1.414936	Duration
orig_bytes	9068	Bytes by Originator
resp_bytes	4450	Bytes by Responder
conn_state	SF	TCP state
local_orig	T	Local Originator?
missed_bytes	0	Gaps
history	ShAdDaFf	State History
tunnel_parents	(empty)	Outer Tunnels

Zeek Logs (4) - http.log

ts	1393099291.589208
uid	CKFUW73bIADw0r9pl
id.orig_h	17.22.7.4
id.orig_p	54352
id.resp_h	24.26.13.36
id.resp_p	80
method	POST
host	com-services.pandonetworks.com
uri	/soapservices/services/SessionStart
referrer	-
user_agent	Mozilla/4.0 (Windows; U) Pando/2.6.0.8
status_code	200
username	anonymous
password	-
orig_mime_types	application/xml
resp_mime_types	application/xml

Zeek Logs (5) – ssl.log

ts	1392805957.927087
uid	CEA0512D7k0BD9Dda2
id.orig_h	2a07:f2c0:90:402:41e:c13:6cb:99c
id.orig_p	40475
id.resp_h	2406:fe60:f47::aaeb:98c
id.resp_p	443
version	TLSv10
cipher	TLS_DHE_RSA_WITH_AES_256_CBC_SHA
server_name	www.netflix.com
subject	CN=www.netflix.com,OU=Operations, O=Netflix, Inc.,L=Los Gatos, ST=CALIFORNIA,C=US
issuer_subject	CN=VeriSign Class 3 Secure Server CA, OU=VeriSign Trust Network,O=VeriSign, C=US
not_valid_before	1389859200.000000
not_valid_after	1452931199.000000
client_subject	-
client_issuer_subject	-
cert_hash	197cab7c6c92a0b9ac5f37cfb0699268
validation_status	ok

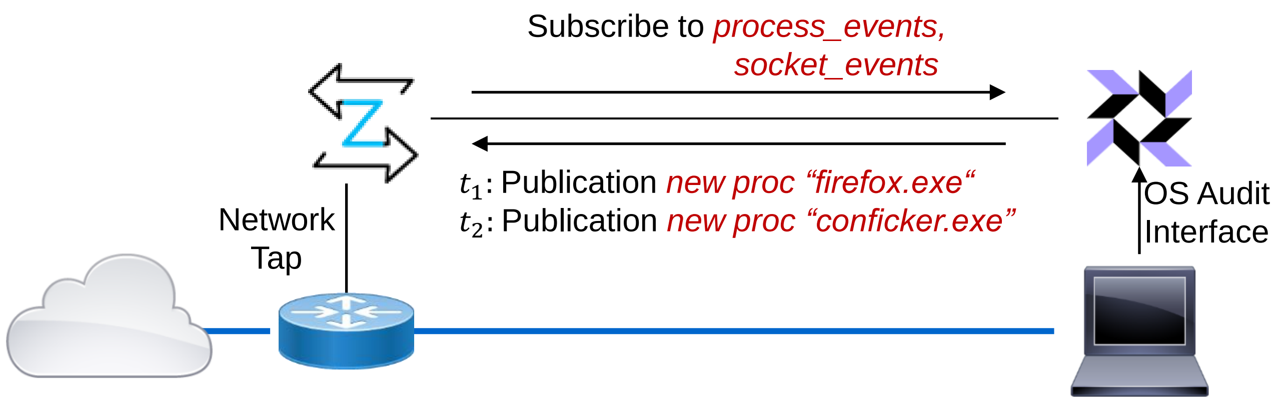
Our Work: zeek-osquery (1)

Zeek

- Flexible network monitoring and IDS
- Integrated scripting language

osquery

- Host monitor
- Information from OS audit interface



Osquery Example Tables	
acpi_tables	firefox_addons
apt_sources	iptables
arp_cache	kernel_modules
certificates	known_hosts
cpu_info	memory_map
cpu_time	process_events
device_partitions	processes
disk_events	socket_events
docker_container_labels	usb_devices
docker_container_mounts	user_ssh_keys
…	

zeek-osquery framework

- Zeek framework that connects to Zeek-enhanced osquery instances
- Attributes network to host activity
- Joint processing of host-events and network data in Zeek scripts

How effective is zeek-osquery in the attribution of connections to processes?

Is zeek-osquery scalable with an increasing amount of osquery hosts?

Our Work: zeek-osquery (2) - Evaluation

Test run on 11 office machines during three days:

- Attribution of network flows to processes

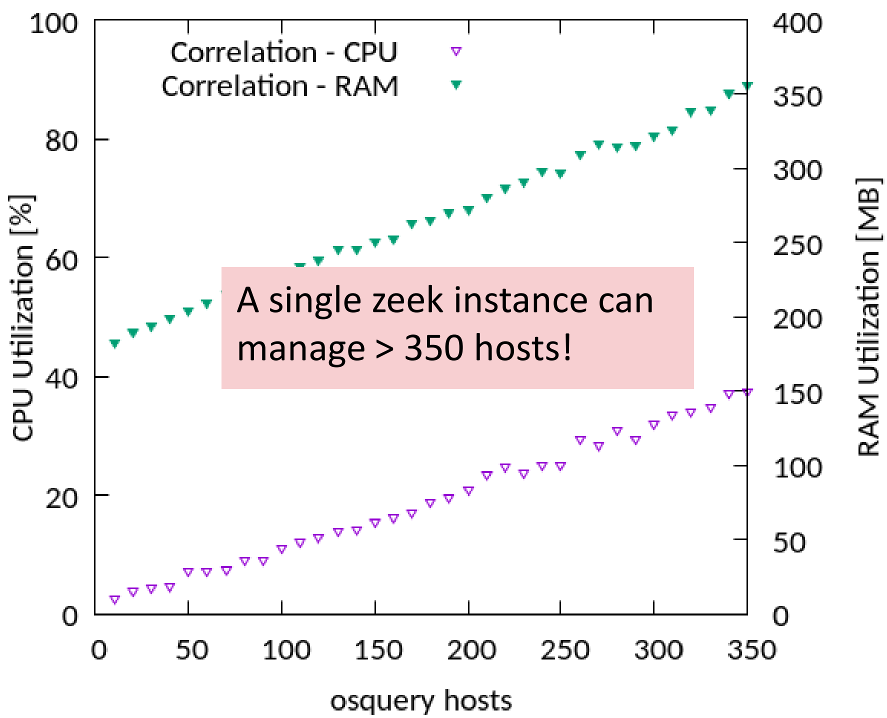
Prot.	# Flows	Zeek	zeek-osquery
All	334.366	0,06%	86,61%
TCP	273.241	0,07%	96,05%
UDP	70.929	0%	50,43%

zeek-osquery		
1	Firefox	23,17%
2	Thunderbird	12,30%
3	Spotify	6,11%
4	Opera	5,41%
5	Syncthing	5,39%
6	Chromium	4,55%
7	Skype	3,86%
8	Seafile	3,80%
9	Chrome	3,56%

zeek-osquery enhances the visibility of Zeek and can attribute connections to processes and users!

Scalability: CPU and RAM utilization at Zeek host

- One Zeek instance, varying number hosts
- 2 events per second per host



A single zeek instance can manage > 350 hosts!

Scales via distributed Zeek deployment

Our Work: zeek-osquery (3)

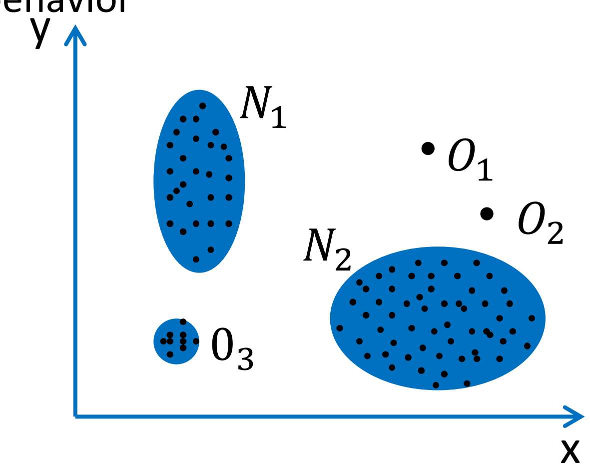
https://github.com/zeek/zeek-osquery
https://github.com/zeek/zeek-agent

- Further application scenarios of zeek-osquery/zeek-agent
  - Transparent decryption of TLS connections
  - Detection of malicious file attachements in Emails + information if user opened the attachement
  - Detection of SSH chain logins
  - …

Anomaly Detection (1)

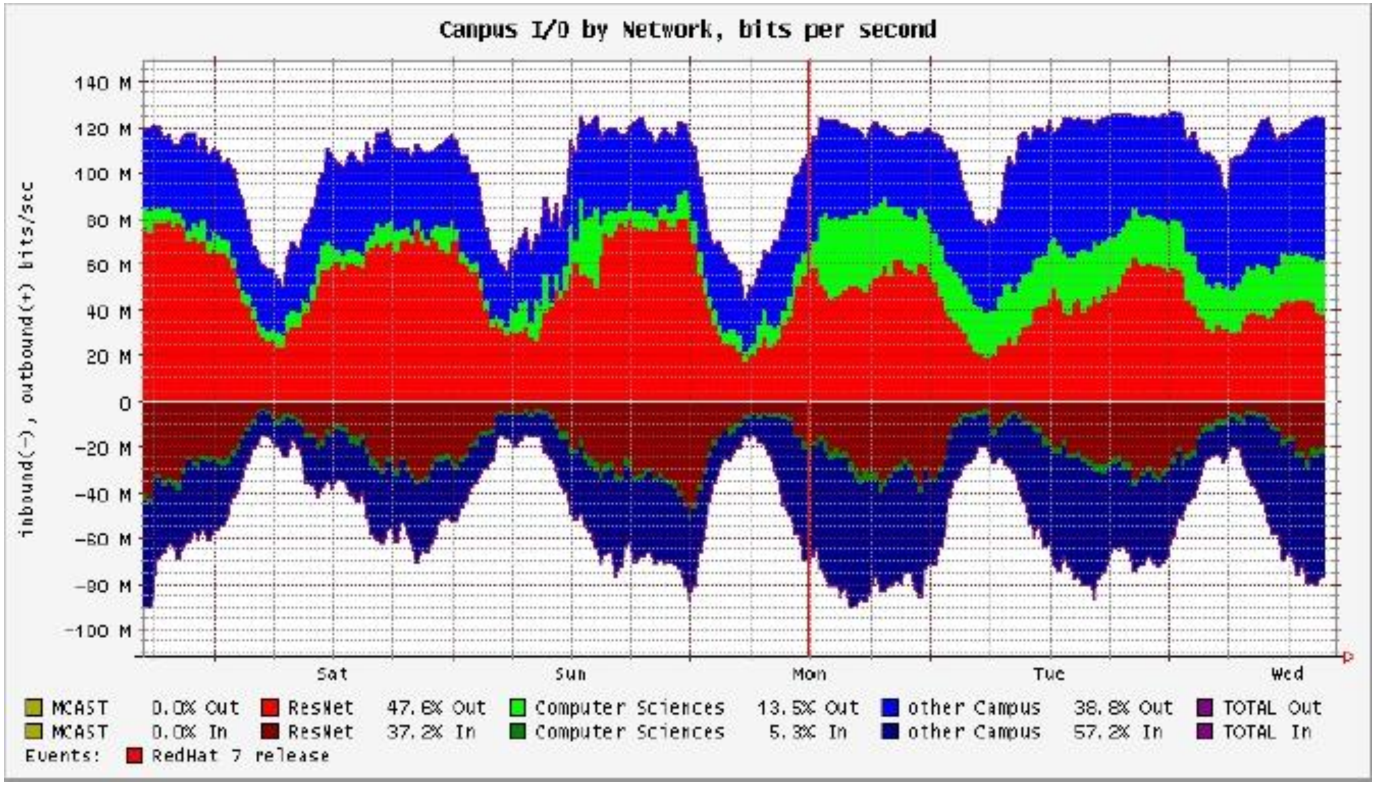
Basic idea – detect behavior that differs significantly from normal use:

- Users have certain habits in their system usage:
  - Duration of usage
  - Login times
  - Amount of file system usage
  - Executed programs, accessed files, …
- Assumption: "normal user behavior" can be described statistically
  - Requires a learning phase / specification of normal behavior
  - Most approaches require labeled data
- Analysis:
  - compares recorded events with reference profile of normal behavior
- Advantage:
  - An attack scenario needs not to be defined a priori
  - This approach can, in principle, detect unknown attacks



Anomaly Detection (2)

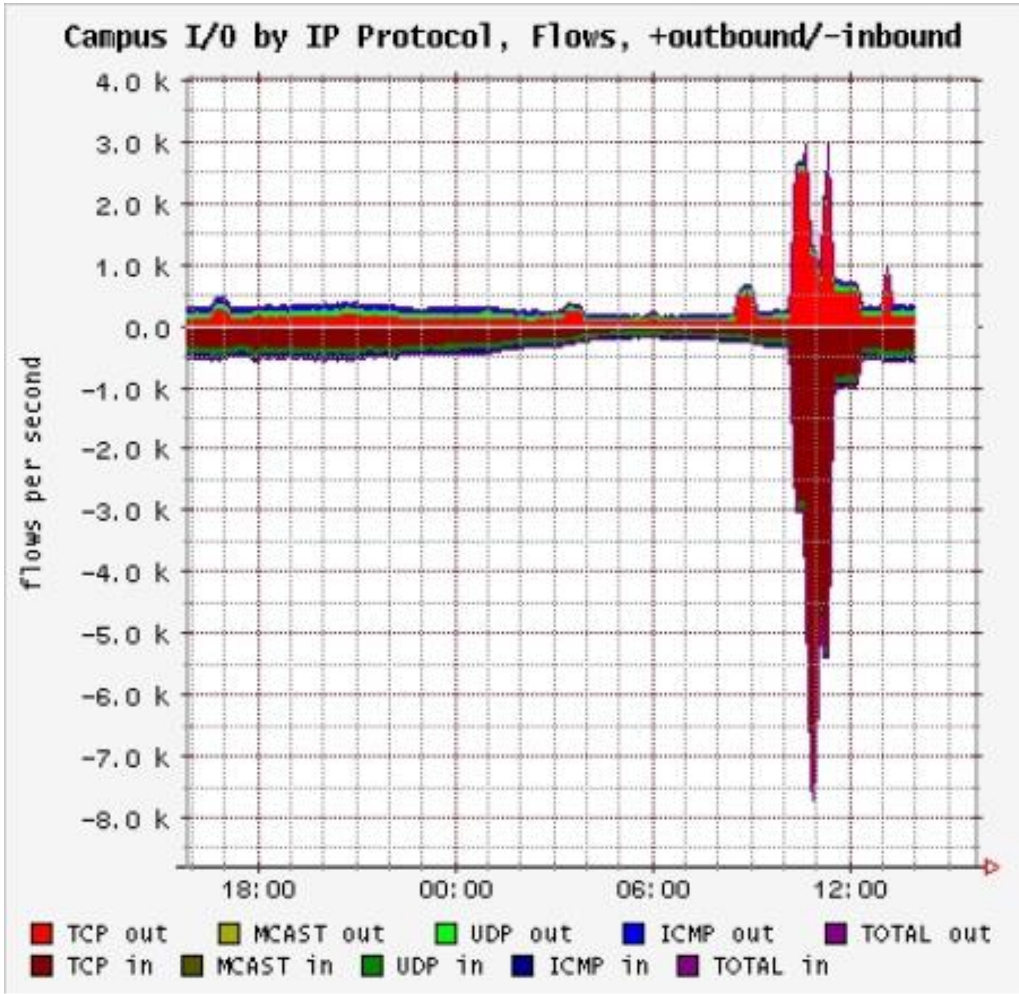
- "Flash crowd anomalies"
  - Caused by software releases or special interest in a web site



[Bar01]

Anomaly Detection (3)

- Network abuse anomalies
  - DoS flood attacks
  - Port scans

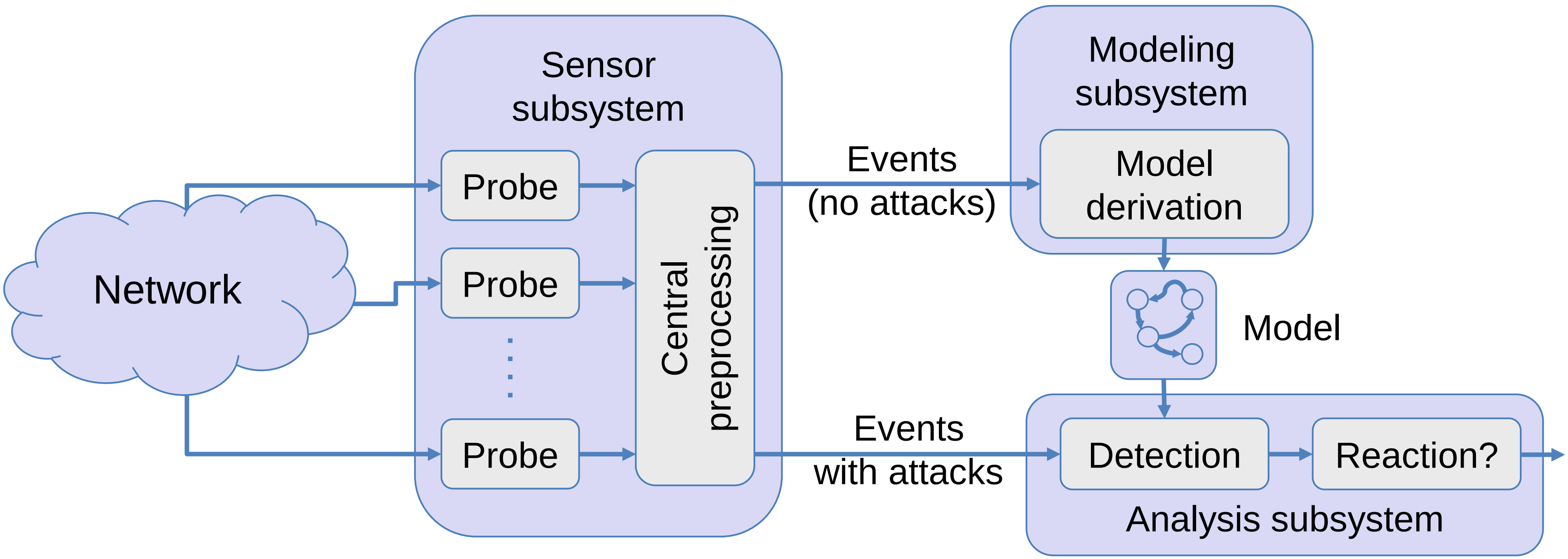


[Bar01]

Automatic Anomaly Detection – System model

[ET04]

Generic anomaly detection system



Problems of IDS – Audit Data

- Amount of log data
  - Auditing often generates a rather high data volume
  - Significant storage capacities are required
  - Processing of audit data should be automated as much as possible
- Location of audit data storage
  - Alternatives: on specific “log server” or the system to be supervised
  - If stored on log server, data must be transferred to this server
  - If stored on system to be supervised, the log uses significant amounts of resources of the system
- Protection of audit data
  - If a system gets compromised, audit data stored on it might get compromised either
- Expressiveness of audit data
  - Which information is relevant?
  - Audits often contain a rather low percentage of useful information

Problems of IDS – Privacy *(data protection)*

- User identifying data elements are logged, e.g.,
  - Directly identifying elements*:* user IDs
  - Indirectly / partly identifying elements*:* names of directories and subdirectories (home directory), file names, program names
  - Minimally identifying elements*:* host type + time + action, access rights + time + action

- IDS audits may violate the privacy of users
  - Violation of the user's right to determine himself which data is collected regarding his person
  - Collected information might be abused if not secured properly
  - Recording of events puts a psychological burden on users (→ "big brother is watching you")

- Potential solution
  - Pseudonymous audit*:* log activities with user pseudonyms and ensure, that they can only be mapped to user IDs upon incident detection

Problems of IDS - Analysis

- Limited efficiency of analysis
  - Most IDS follow a centralist approach for analysis: so-called agents collect audit data and one central evaluation unit analyzes this data

  $\Rightarrow$ No (partial) evaluation in agents

  $\Rightarrow$ Performance bottleneck
  - Insufficient efficiency, especially concerning attack variants and attacks with parallel actions

- High number of false positives
  - In practice, many IDS report too many false alarms (some publications report up to 10.000 per month)
  - Potential countermeasure: alert correlation ($\rightarrow$ hierarchical approach)

The bigger Picture of an Attack - Alert Correlation

- Distributed attacks and multi-step attacks result in large number of alerts
- Temporal and spatial distribution of attacks possible

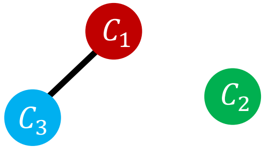
- Alert aggregation and correlation required
- Operates in three phases
  1. Filtering of alerts
  2. Clustering/Grouping of alerts, e.g., according to alert attribute similarities
  3. Cluster/group interconnection to assemble multi-step attacks

- Most correlation algorithms only cover the first two phases
- Most can only correlate bulk attacks, e.g., DDoS, port scans, worm spreadings

Alert Level – Alert Correlation Process

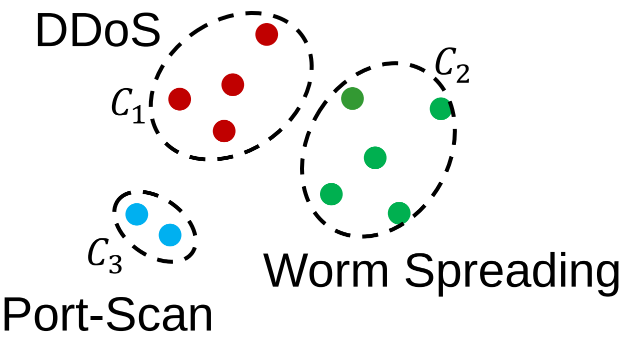
Attack Interconnection

Multi-step Attacks
e.g., Port-Scan -> Targeted attack



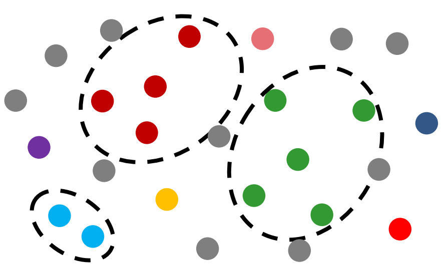
Context Supplementation

Distributed Attacks
DDoS,
Distributed Port-Scans,
Worm spreadings …



Alert Clustering

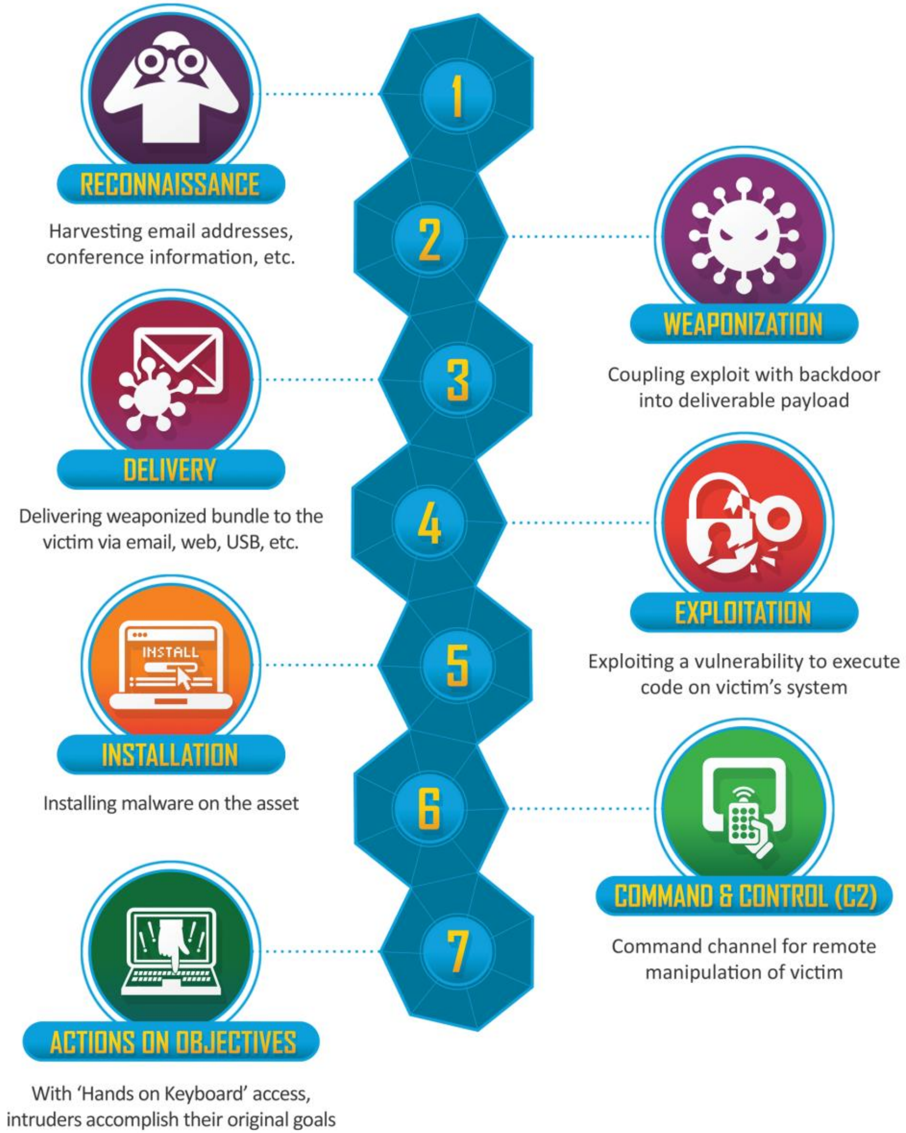
Alert attributes
Src IP, Dst IP
Src Port, Dst Port
…



Alerts from Network- or Host IDS .

Cyber Kill Chain (1)

[HuCl10]



- Proposed by Lockheed Martin in 2011
- Targets Advanced Persistent Threats (APTs)
- 7 consecutive stages that describe the attack campaign
- Inflexible and oversimplified when compared to known attacks

Cyber Kill Chain (2) - Variations

- Several adaptions of the original kill chain
  - By domain (industrial systems, insider attacks..)
  - For increased flexibility (new and optional stages)

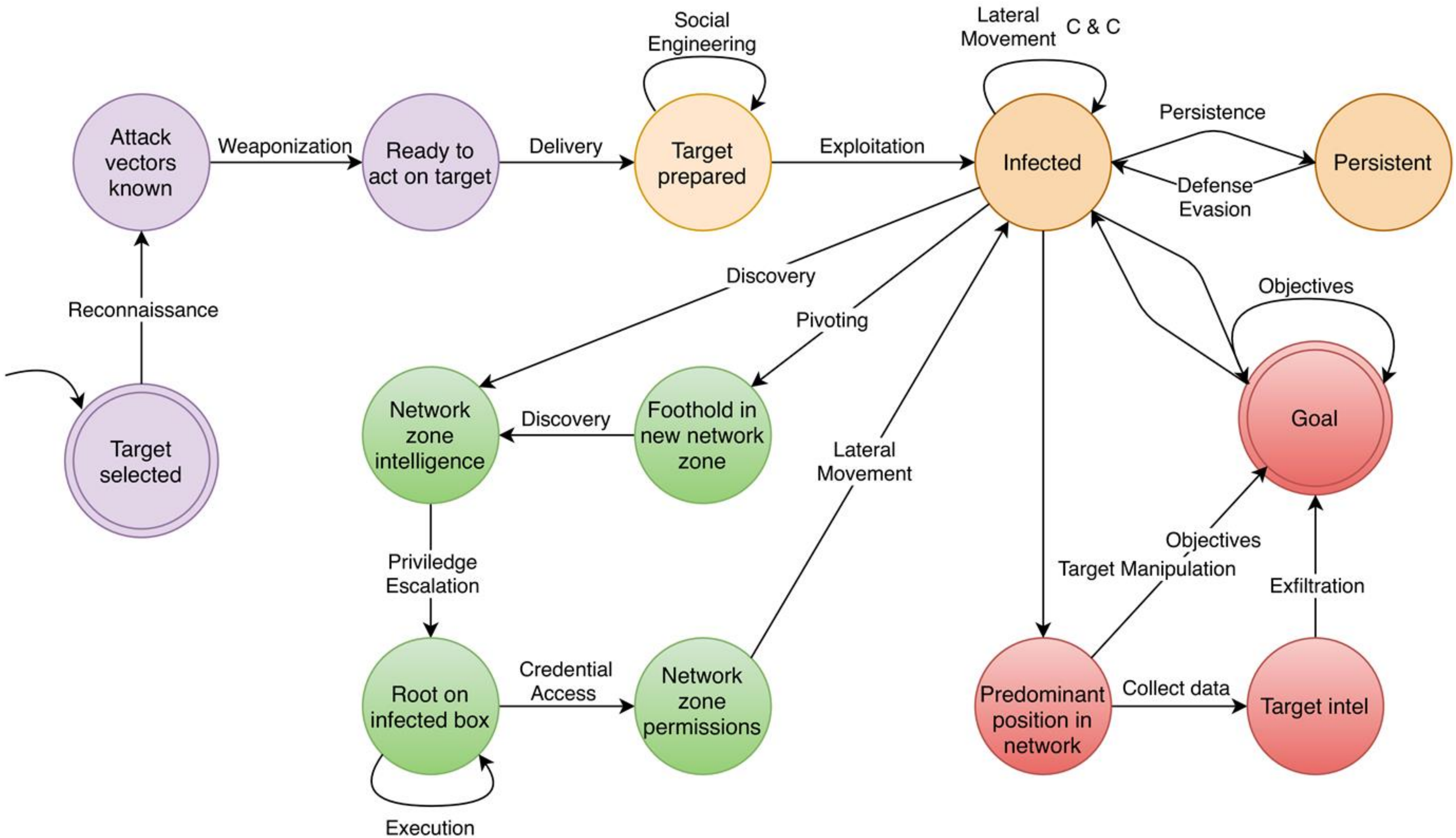
- More focus on zone breaching and lateral movement and host activity

- Unified Kill Chain (UKC) as most comprehensive model
  - 18 (partially optional) stages
  - Based on literature review and case studies

#	*Unified Kill Chain*
1	*Reconnaissance*
2	*Weaponization*
3	*Delivery*
4	*Social Engineering*
5	*Exploitation*
6	*Persistence*
7	*Defense Evasion*
8	*Command & Control*
9	*Pivoting*
10	*Discovery*
11	*Privilege Escalation*
12	*Execution*
13	*Credential Access*
14	*Lateral Movement*
15	*Collection*
16	*Exfiltration*
17	*Target Manipulation*
18	*Objectives*

Our Work: Kill Chain State Machine (1)

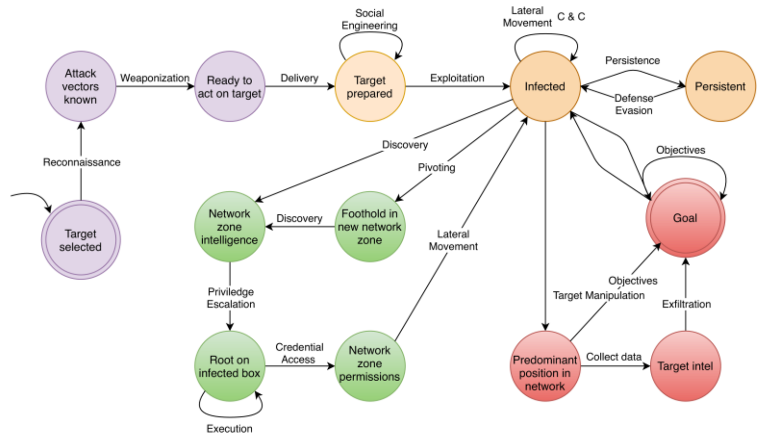
[WiOr+21]



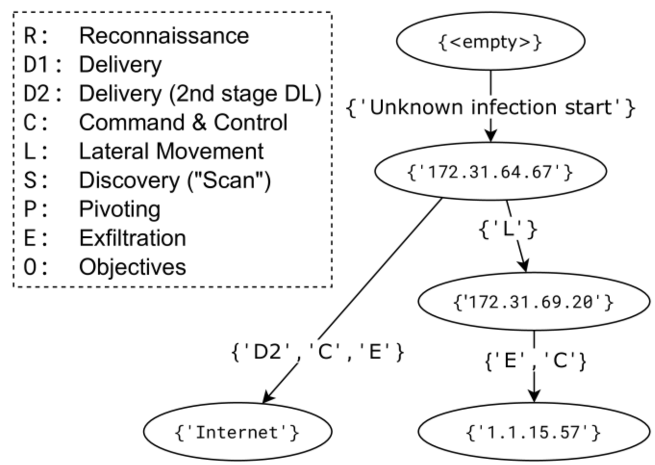
Our Work: Kill Chain State Machine (2)

[WiOr+21]

- State machine derived from UKC
  - Alerts → Transitions
  - Stages: Campaign progress



- Detection algorithm
  1. Maps alerts to transitions
  2. Connect transitions based on SM
  3. Deduplicate and optimize chains
  4. Prioritize scenarios based on length/complexity



- Currently network only, but extensible to other alert types

Our Work: Kill Chain State Machine (3) - Evaluation

- CSE-CIC-IDS2018 Dataset
- Realistically embedded (artificial) APT campaign

Table III. CSE-CIC-IDS2018: Overview

Property	Value
# Subnets/Zones	6 + *Internet*
# Target Hosts	450
# Attacker Hosts	50
# Connections	63 973 325
# (unrelated) attacks	7
Duration	10 days
Size in GB	559

Table IV. IDS2018-APT: Campaign overview

Day	Attack	Source	Target
1	*EternalRomance* RCE	1.1.13.37	172.31.64.67
1	2nd stage trojan download	172.31.64.67	12.34.12.34
4	Cosmic Duke C&C	172.31.64.67	1.1.14.47
8	PS-EXEC via SMB	172.31.64.67	172.31.69.20
10	Data exfiltration via HTTPS	172.31.69.20	1.1.15.57

Our Work: Kill Chain State Machine (4) - Evaluation

		IDS2018-APT-MIN			IDS2018-APT-FULL		
Source	Alert Type	# Alerts	APT related	Ratio	# Alerts	APT related	Ratio
Zeek Default	Conn::Retransmission_Inconsistency	1 171	0	0	1 171	0	0
	Scan::Address_Scan	1 555	0	0	1 555	0	0
	Scan::Port_Scan	38	0	0	38	0	0
	SSH::Password_Guessing	5	0	0	5	0	0
	SSL::Weak_Key	120	0	0	120	0	0
Custom Scenario Scripts	Custom::Stalled_HTTP_Connection	4 976	0	0	4 976	0	0
	Custom::HTTP_Windows_Executable_Download	13	0	0	13	0	0
	Custom::NON_HTTP_Windows_Executable_Download	8	2	0.25	8	2	0.25
	Custom::SMB_Executable_File_Transfer	1	1	1.00	1	1	1.00
	Custom::Javascript_Web_Injection_URI	5 934	0	0	5 934	0	0
	Custom::SQL_Web_Injection_URI	79	0	0	79	0	0
	Custom::Web_Login_Guessing	14	0	0	14	0	0
	Custom::Large_Outgoing_Tx	5 772	0	0	5 772	0	0
	Custom::Multiple_Large_Outgoing_Tx	187	0	0	187	0	0
	Custom::Very_Large_Outgoing_Tx	10	1	0.10	10	1	0.10
Mitre BZAR	ATTACK::Execution	—	—	—	2	2	1.00
	ATTACK::Lateral_Movement	—	—	—	4	4	1.00
	ATTACK::Lateral_Movement_and_Execution	—	—	—	1	0	0
	ATTACK::Lateral_Movement_Extracted_File	—	—	—	1	1	1.00
	ATTACK::Lateral_Movement_Multiple_Attempts	—	—	—	245	0	0
EternalSynergy	EternalSafety::DoublePulsar	—	—	—	1	1	1.00
	EternalSafety::EternalBlue	—	—	—	53	0	0
	EternalSafety::EternalSynergy	—	—	—	1	1	1.00
	EternalSafety::ViolationCmd	—	—	—	1 389	0	0
	EternalSafety::ViolationNtRename	—	—	—	8 731	0	0
	EternalSafety::ViolationPidMid	—	—	—	6 133	0	0
	EternalSafety::ViolationTx2Cmd	—	—	—	408 686	1	0.000002
	Total	19 883	3	0.000151	445 130	13	0.000029

Evasion Techniques to Bypass IDS

- Signature Evasion
  - Attack Obfuscation
  - Packet Splitting
  - Duplicate Insertion
  - Packet Overlapping
- Anomaly Evasion
  - Training Data Injection
  - Mimicry Attacks
  - Covert Channel Attacks

Signature Evasion - Attack Obfuscation

- Transformation of malicious code into semantically equivalent one
- As the signature will defer from the original it will not be detected

Depending on the level of mutation

- Payload mutation
  - Change the signature of the payload of the packet

- Shellcode mutation
  - Obfuscate the shellcode with polymorphic techniques
  - Easily done via popular penetration testing tools like Metasploit Framework

Covert Channel Attacks

[Zander07]

- Aim to hide very existence of communication
- Using means of communication not normally intended to be used for it

- Covert channels similar to techniques hiding information in audio, visual, or textual content (steganography)
  - Steganography requires some form of content as cover
  - Covert channels require some network protocol as carrier

- Covert channels as method to evade IDS

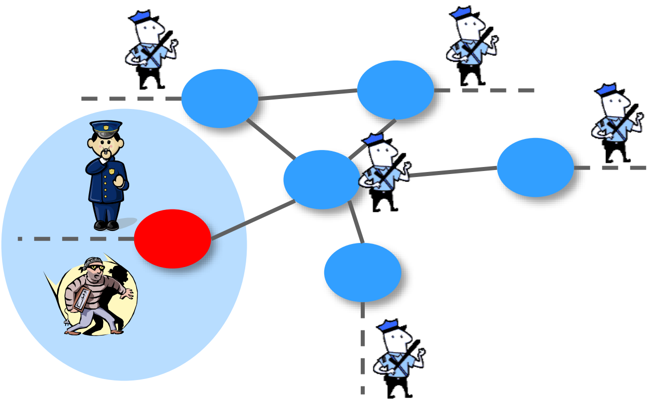
Covert Channel Attacks – Techniques (1)

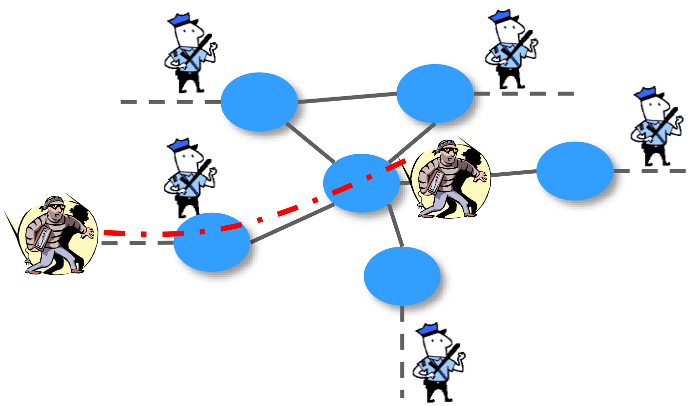
- Unused header bits, header extensions and padding
- IP identification and fragment offset
- TCP initial sequence number field
- Checksum field
- Modulating the IP TTL field
- Modulating address fields and packet lengths
- Modulating timestamp fields
- Packet rate and timing
- Message sequence timing
- Packet loss and packet sorting
- Application protocols, .e.g., HTTP or DNS
- …

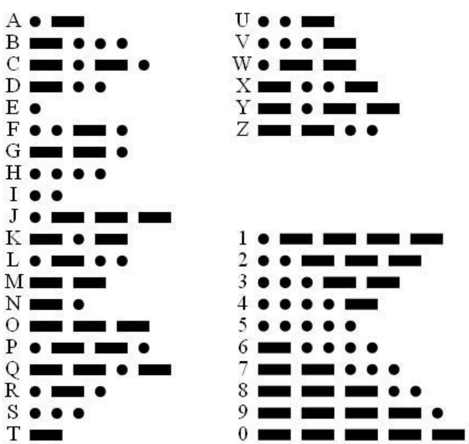
Covert Channel Attacks – Techniques (2)

Packet rate and packet timing

- Encode covert information by varying packet rates
  - equivalent to modulate packet timing
- Covert sender varies packet rate between two (binary channel) or multiple packet rates each time interval
- Binary channel can transport one bit and multi-rate channel can transmit $\log_2 r$ bits per time interval (r is number of different packet rates)







Summary

- IDS
  - Signature-based vs. policy-based vs. anomaly-based IDS
  - In combination with Firewalls: IPS
  - Classification according to kind of sensors deployed, level of distribution
- IDS problems
  - Huge amounts of data to process
  - Limited accuracy and large number of false positives
  - Privacy
  - IDS evasion techniques
- Alert correlation to obtain the bigger picture of attacks
  - Alert correlation process
  - Cyber Kill Chain and Alert Correlation

Additional References

[Zwi00a] E. Zwicky, S. Cooper, B. Chapman. *Building Internet Firewalls.* Second Edition, O'Reilly, 2000.

[Sem96a] C. Semeria. *Internet Firewalls and Security.* 3Com Technical Paper, 1996.

[Wack95a] J. P. Wack, L.J. Carnahan. *Keeping Your Site Comfortably Secure: An Introduction to Internet Firewalls.* NIST Special Publication 800-10, 1995.

[StaBro08] William Stallings and Lawrie Brown. Computer Security: Principles and Practice. Prentice Hall Press, Upper Saddle River, NJ, USA, 2nd edition, 2008.

[Bar01] P. Barford, D. Plonka, Characteristics of Network Traffic Flow Anomalies. Proceedings of ACM SIGCOMM Internet Measurement Workshop, October 2001.

[Chan09] Chandola, Varun, Arindam Banerjee, and Vipin Kumar. 2009. "Anomaly Detection: A Survey." ACM Computing Surveys 41 (3) (July 1): 1–58. doi:10.1145/1541880.1541882.

[Man2015] Mandiant, M-Trends® 2015: A View from the Front Lines https://www2.fireeye.com/WEB-2015-MNDT-RPT-M-Trends-2015_LP.html

[Sym2016] Symantec, Internet Security Threat Report, 2016, https://www.symantec.com/security-center/threat-report

[Yo2012] Yves Younan, 25 Years of Vulnerabilities: 1988-2012, RESEARCH REPORT, Sourcefire Vulnerability Research Team (VRT)

[Pa99] V. Paxson, "Bro: a system for detecting network intruders in real-time," in USENIX Security Symposium, 1999, vol. 7, pp. 1–22.

[VaKa+15] E. Vasilomanolakis, S. Karuppayah, M. Muehlhaeuser, and M. Fischer, "Taxonomy and Survey of Collaborative Intrusion Detection," ACM Computing Surveys, pp. 1–35, 2015.

Additional References

[Ju03] Julisch, K. (2003). Clustering intrusion detection alarms to support root cause analysis. ACM Transactions on Information and System Security (TISSEC), 6(4), 443–471. https://doi.org/10.1145/950191.950192

[Han92] HAN, J., CAI,Y., AND CERCONE, N. 1992. Knowledge discovery in databases: An attribute-oriented approach. In 18th International Conference on Very Large Databases, 547–559

[ZhoLe+10] C. V. Zhou, C. Leckie, and S. Karunasekera, "A survey of coordinated attacks and collaborative intrusion detection," Comput. Secur., vol. 29, no. 1, pp. 124–140, 2010.

[HuCl10] E.M. Hutchins, M.J. Cloppert and R.M Amin PH.D., "Intelligence-Driven Computer Network Defense Informed by Analysis of Adversary Campaigns and Intrusion Kill Chains," Proc. 6th Int'l Conf. Information Warfare and Security(ICIW 11), Academic Conferences Ltd., 2010, pp. 113–125; http://www.lockheedmartin.com/content/dam/lockheed/data/corporate/documents/LM-White-Paper-Intel-Driven-Defense.pdf

[WiOr+21] F. Wilkens, F. Ortmann, S. Haas, M. Vallentin, and M. Fischer, "Multi-Stage Attack Detection via Kill Chain State Machines," Submitted to: ACM Conference on Computer and Communications Security (CCS), 2021.

[HaFi18] S. Haas and M. Fischer, "GAC: Graph-Based Alert Correlation for the Detection of Distributed Multi-Step Attacks", ACM Symposium on Applied Computing (SAC), 2018.

[HaFi+19] S. Haas and M. Fischer, "On the alert correlation process for the detection of multi-step attacks and a graph-based realization", ACM SIGAPP Applied Computing Review 19, 1 (April 2019), 5-19