Sharing Computer Network Logs for Security and Privacy: A Motivation for New Methodologies of Anonymization

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Abstract

Logs are one of the most fundamental resources to any security professional. It is widely recognized by the government and industry that it is both beneficial and desirable to share logs for the purpose of security research. However, the sharing is not happening or not to the degree or magnitude that is desired. Organizations are reluctant to share logs because of the risk of exposing sensitive information to potential attackers. We believe this reluctance remains high because current anonymization techniques are weak and one-size-fits-all—or better put, one size tries to fit all. We must develop standards and make anonymization available at varying levels, striking a balance between privacy and utility. Organizations have different needs and trust other organizations to different degrees. They must be able to map multiple anonymization levels with defined risks to the trust levels they share with (would-be) receivers. It is not until there are industry standards for multiple levels of anonymization that we will be able to move forward and achieve the goal of widespread sharing of logs for security researchers.

1 Introduction

Log data is essential to security operation teams at any organization large enough to have full-time security personnel. While IDSs operate on streaming data, matching signatures and producing alerts, it is still necessary for human beings to examine logs to understand these alerts. Logs also form the core source of evidence for computer forensic investigations following security incidents. The current state-of-the-art is for each autonomous organization to use log data to locally optimize network management and security protection. For instance, it may only be when they themselves are scanned by an individual that an organization will block a particular IP address. Administrators may miss the bigger picture and not see that they are just a piece of a larger target. Furthermore, administrators may only start to scan their own network for a particular vulnerability once an attacker has exploited it on their systems. There are very few cross-sectional views of the Internet, and until recently there have been no mechanisms to enable such wider views. Additionally, current examples of wide views, such as spam blacklists and worm signatures, are often focused on a specific characteristic even though signatures are gathered from events across the entire Internet.

Sharing data is in fact common among attackers. They trade zombies, publicly post information on vulnerable systems/networks and coordinate attacks. Recent events at several U.S. supercomputing centers [15] have demonstrated examples of coordinated attacks against organizations that do not have good mechanisms of data sharing and log correlation. Real, not simulated, data is necessary. While worms that are let go without further human interaction could possibly be modeled and simulated, human motives and specific interactions cannot. It is no longer satisfactory to focus solely on the local picture; there is a need to look globally across the Internet. While the data
needed exists, tapping into thousands of data sources effectively and sharing critical information
intelligently and to the data owners’ satisfaction is an open problem.

In fact, the Department of Homeland Security has recognized the importance of sharing in-
formation and has established Information Sharing and Analysis Centers (ISACs) to facilitate the
storage and sharing of information about security threats [9]. The importance of log sharing has
also gained industry recognition with investments in infrastructure dedicated solely for this purpose
across multiple industry sectors [12]. The National Strategy to Secure Cyberspace (NSSC) explicitly
lists sharing as one of its highest priorities—data sharing within the government, within industry
sectors and between the government and industry. In fact, of the eight action items reached in
the NSSC report, three of them are directly related to log data sharing: Item 2: “Provide for the
development of tactical and strategic analysis of cyber attacks and vulnerability assessments”; Item
3: “Encourage the development of a private sector capability to share a synoptic view of the health
of cyberspace”; and Item 8: “Improve and enhance public/private information sharing involving
cyber-attacks, threats, and vulnerabilities”.

While it is understood and well-accepted that log sharing is important, it happens on a very
limited scale if at all. We believe that the problem, while social on the surface, is technical at the
heart. Organizations realize the importance of sharing such data, but they are reluctant because
sharing log data allows their networks to be “mapped out”. This exposure creates an increased risk
for those who share. Anonymization of logs is still in its infancy and the technology to date does not
meet the needs of many organizations. Even the largest public source of network traces [10] contains
logs anonymized in inconsistent ways. Some data is anonymized, some is not. Anonymized data
may preserve prefixes or it may just truncate IP addresses. Even prefix-preserving anonymization
has different mappings between data collections from the same sources but recorded at different
times. Lastly, few data sets anonymize anything beyond IP addresses.

We believe there is a need for standards in anonymization. There should be defined levels
of anonymization and methods to express those different levels succinctly. There must also be
ways to map an organization’s needs and trust levels with other organizations to the appropriate
anonymization levels. In addition to defining these levels, methodologies and algorithms should be
developed to anonymize log data in new ways.

The rest of this paper is organized as follows. Section 2 discusses current efforts for sharing
log data and related work in anonymization. Section 3 covers the many types of logs and different
fields that could potentially be anonymized. Section 4 discusses attacks against currently immature
anonymization systems. Section 5 discusses our goals and vision for a new system of anonymization.
We conclude in section 6.

2 Related Work

2.1 Current Internet Log and Data Collection Centers

While there are a growing number of data centers that collect and analyze logs, few are dedicated
to sharing logs with the research community. Those that do share do not anonymize sufficiently,
and they tend to focus on only one particular type of log. The goal is to share as many types of
logs from as many sources as possible. Furthermore, there needs to be adequate protection of these
logs to suit the different needs of those who share them. To accomplish this goal, there must be
multiple, standardized levels of anonymization.
2.1.1 CAIDA

CAIDA [5] has one of the largest Internet log data catalogs available for public analysis. They have an index to many data sets stored off site and are developing a cataloging system for these data sets. They also seek to develop tools to analyze the data sets. CAIDA focuses on macro-level data to support network measurement research. As such, they do not have the level of detail or the many heterogeneous types of logs necessary for security research. The usefulness of these logs to security research is limited to a very high level. The network traces that CAIDA provides could be used to get a big picture of worm activity, but they do not contain the level of detail to capture new exploit binaries or hacker behaviors post-compromise.

Even though these logs are not primarily intended for security research, they still suffer from the problems of undefined anonymization standards. While it is important to anonymize logs so that adversaries cannot map out contributor networks, CAIDA itself does not anonymize logs that it does not generate. Different organizations anonymize to different levels—some not anonymizing at all—and in different manners. There is no consistency in the way anonymization is done because all of the contributors do it their own way. Thus we see that development of anonymization standards applies to more than just security research.

2.1.2 DeepSight

Symantec’s DeepSight [16] does utilize a cross-sectional view of the Internet and analyzes detailed IDS, firewall and virus scanner logs. However, it is not a log sharing system for research, but rather it is a data collection system with a commercial purpose. Anonymization is not a real issue because data is not shared, but rather all data is collected and sent to a trusted third party. The purpose of this collection is to notice trends and provide early warnings of attacks and new threats to customers. They allow certain thresholds and other variables to be set by customers to somewhat customize their alerts and reports, but mostly it is a way to alert their customers of new worms, viruses or software exploits being used in the wild. It does not provide data sets to share with the research community.

2.1.3 Internet Storm Center

The Internet Storm Center (ISC) [10] is like a grass-roots version of DeepSight that is run by SANS. They collect IDS logs from volunteers and analyze them to detect trends. Their purpose is to provide an early warning system of new worm activity on the Internet. They provide reports on the top ports being scanned with respect to time, and they use the trend information they find to determine the INFOCon threat level, much like Symantec defines the ThreatCon level with DeepSight data.

ISC does not share actual logs, but they produce high level statistics. For this reason, their port activity and trends data do not need to be sanitized. They sanitize information about scanner source IPs by looking very broadly at the number of scans per class C network. This kind of anonymization is also used in some of the CAIDA logs where they simply truncate IP addresses. The danger is pretty low in sharing this kind of information, but its usefulness is also minimal. It does nothing more than allow inferences such as “The US does the most scanning” or “Universities contribute to most of the P2P traffic”. Many of these statistics can be predicted from the density of addresses assigned in the respective class C networks. ISC does share specific addresses in one place: it lists the top 10 scanners by IP address. Many organizations use this information to block misbehaving machines. The repercussion of doing this is again minimal. They do not provide specific details about those machines or the networks they are on. It simply serves to embarrass
the ISPs that host the compromised machines. Any sort of anonymization here would defeat the purpose.

Overall, the type of data they provide is a homogeneous set of aggregated statistics. More information can be gathered from CAIDA logs because raw access is provided. Thus, one is not restricted to only the statistics they provide. The main difference of course is that the ISC is real-time and uses a more distributed sample. In conclusion, ISC works very well for monitoring general worm behavior, detecting trends that indicate new worms and analyzing the life cycle of an exploit. However, they are not gathering many types of logs, and they are not sharing them with the general community for research.

2.1.4 DShield.org

DShield.org is a grass-roots log collection system, though it is now funded partially by SANS. They gather firewall logs and convert them to a standard format. Currently, they exclusively accept packet filter traces. These are used to create reports of types similar to the Internet Storm Center. They have reports on port activity trends, the top 10 most offensive scanners and the top 10 most probed ports. They produce the blacklist of offenders that the ISC uses and provide searches on activity by particular IP addresses.

Anonymity is not dealt with seriously here, and they say “You should not submit any information you consider business critical or proprietary”. They say that they “try” to hide destination IPs to mask who is being attacked, but raw data is searchable and may be made available raw to the public. Of course they do not indicate the submitter of the data. Decisions of what and how to release raw data is made on a per individual basis.

Several problems exist with the system as is. First, there is only one type of log. Second, there are no precautions to keep people from resubmitting logs and polluting the data set. If special clients are used instead of web submissions, accidental resubmissions are prevented. Third, anonymous submissions allow fake data to be submitted that could wrongly blacklist individuals. Fourth, even if their non-guaranteed anonymization of target hosts works, anyone can query information about specific hosts and networks. This allows attackers to find already compromised machines on a network rather easily. In conclusion, DShield.org provides data of limited types and minimal data protection mechanisms.

2.1.5 Packet Vault

The University of Michigan has worked on a secure, long-term archive of network packet data they call the Packet Vault. It is basically a special purpose network device and encrypted database system specifically designed for packet sniffers. It is designed so that selected traffic can be made available without exposing other traffic.

They use the “black marker” approach to anonymize logs by completely encrypting packet information. As such, it cannot really be called anonymization because all fields are either encrypted or decrypted, essentially having the same effect as printing a log and using a black marker on most of the lines. They group items under the same encryption key if the packets are part of the same “conversation”.

Now, if instead they used different keys for different fields, that would allow them to release different views of the same records to different organizations. That would be a crude sort of black marker (all-or-nothing) anonymization of selected fields. But their goals are different. They are not trying to share logs while preserving privacy. They are making logs available to participants of
the conversation, but not to anyone else. They give the appropriate keys to decrypt logs records that describe a participant’s actions but not those in which they were not a participant.

In conclusion, we see that while there are some centers dedicated to collecting log files, they all suffer from one or more of the following problems: (1) They do not have a wide view of the Internet but are quite localized, (2) the repositories are very specific, addressing one or only a few types of logs, (3) anonymization is weak or nonexistent and usually inconsistent or (4) they collect many logs but do not share them with the research community.

2.2 Anonymizers

There has been some research in log anonymization. However, most work addresses only a small subset of all the available log sources (particularly network traces) and focuses exclusively on anonymizing IP addresses within a log. While IP addresses could simply be removed or randomized in logs, such a solution is undesirable since it destroys a basic structure used in analyzing logs. Significant work has been accomplished on prefix-preserving anonymization of IP addresses. In prefix-preserving anonymization, IP addresses are mapped to pseudo-random anonymized IP addresses by a function we will call \( \tau \). Let \( P_n() \) be the function that truncates an IP address to \( n \) bits. Then \( \tau \) is a prefix preserving permutation of IP addresses if \( \forall 1 \leq n \leq 32, P_n(x) = P_n(y) \) if and only if \( \tau(P_n(x)) = \tau(P_n(y)) \). TCPdpriv \[17\] is a free program that performs prefix-preserving TCP-dump trace anonymization using tables. Because of the use of tables, it is difficult to process logs in parallel with this tool. In \[19, 20\], Xu et al. have created a prefix-preserving IP pseudonymizer that overcomes this limitation by eliminating the need for centralized tables to be shared and edited by multiple entities. Instead, with their tool CryptoPAn, one only needs to distribute a short key between entities that wish to pseudonymize consistently with each other. Furthermore, they have shown that all prefix-preserving pseudonymizers must take a particular form and that their solution is optimal with respect to security. But while theoretically optimal solutions have been created for this reduced problem, the larger problem of anonymizing whole log files remains unsolved.

One of the earliest uses of pseudonyms can be found in \[6\] where public keys are used as pseudonyms. We now recognize what Chaum described in \[6\] as a “digital pseudonym” to be a specific type of pseudonym called an authorization certificate. As noted in \[11\], pseudonyms help define middle ground in the zero-sum tradeoff between security and privacy of audit logs. In \[14\], Sobirey et al. first suggested privacy-enhanced intrusion detection using pseudonyms and provided the motivation for the work of Biskup et al. in \[3, 4\].

While the work in \[11, 3, 4\] does deal with log data and anonymization, their goals are significantly different than ours. All three works deal specifically with pseudonymization in Intrusion Detection Systems (IDSs). The adversary in their model is the system administrator, and the one requiring protection is the user of the system. In our case, we instead assume that the system/network administrators have access to raw logs, and we are trying to protect the systems from those who would see the shared logs. To contrast how this makes a difference, consider that in their scenario the server addresses and services running are not even sensitive—just information that could identify clients of the system. Furthermore, we do not care about reversal of pseudonyms. We have no need for that capability, but since the system/network administrators do not have raw data in their case, the privacy officer must help the system security officer reverse pseudonyms if alerts indicate suspicious behavior. In \[3, 4\], they take this further and try to support automatic re-identification if a certain threshold of events is met. In that way their pseudonymizer must be intelligent, like an IDS, predicting when re-identification may be necessary and thus altering how it pseudonymizes data. They also differ from us in that they create transactional pseudonyms, so a pseudonym this week might map to a different entity the next week. We, however, require
consistency with respect to time for logs to be useful. Lastly, all of the anonymizing solutions in these papers filter log entries and remove them if they are not relevant to the IDS; we dispose of no entries because completeness is very important for logs released to the general research populace.

In [8], Flegel takes his previous work in privacy preserving intrusion detection [3, 4] and changes the motivation slightly. Here he imagines a scenario of web servers volunteering to protect the privacy of visitors from themselves, and he believes IP addresses of visitors need pseudonymization. However, to a web server IP addresses already act as a pseudonym protecting the client’s identity since ISPs rarely volunteer IP address to person mappings. The case where this is not true is if the web server is that of the ISP. Then in that particular instance IP addresses are not pseudonyms. Though the motivation differs slightly, the system described is the same underlying threshold based pseudonymization system, and the focus of this paper is really about the implementation and performance of the system. As such, the results of [8] can be applied to [3, 4].

In [13], Pang et al. developed a new packet anonymizer that anonymizes packet payloads as well as transactional information, though their methodology only works with application level protocols that their anonymizer understands (HTTP, FTP, Finger, Ident and SMTP). The process can also alter logs significantly, losing fragmentation information, the size and number of packets and information about retransmissions, skewing time stamps, sequence numbers and checksums. While their anonymizer is limited in its capabilities, it is fail-safe because it only leaves information in the packets that it can parse and understand. Further, they create a classification of anonymization techniques and a classification of attacks against anonymization that we found useful. We use a similar classification which is based off of their work.

Most recently Waters et al. [18] address the tension between data access control and searchability of audit logs through a new method they developed to search asymmetrically encrypted logs. In this way the encrypted log can be made public for search, and the owner distributes private keys corresponding to keywords. Thus, instead of the data owner decrypting the log and running the search, he can simply give the query maker the ability to perform the query with a set of keywords he deems acceptable.

3 Log Varieties

A computer network contains a variety of different infrastructure devices, each of which may be instrumented to produce multiple audit logs. Although the topic of computer and network audit logs is broad, a topic of its own, we feel a brief survey of some of the different types of logs is an important starting point in understanding the issues of sharing heterogeneous logs for network measurement and security research.

Note that we are making it a point to emphasize heterogeneous audit logs. The fact that the audit logs are different is significant because it promotes multiple views for discovery, robustness against attack, interoperability, extensibility and flexibility. However, heterogeneity also provides new avenues of attack against the anonymization system. While one type of log may not be enough to break the anonymization system, information may be inferred from multiple logs that can be used in a successful attack against anonymized data. Thus we seek to create anonymization schemes for many types of logs.

What follows is a description of commonly implemented network and system logs summarized from [22]. These logs provide situational awareness of what is happening where and when on networks/systems by auditing system activities, transactions performed and network signaling. These logs are useful for detecting network problems, malicious activity and recovery from accidental or intentional failures.
3.1 TCPdump

One of the most common ways of collecting network data into logs is through use of the TCPdump utility. This utility captures headers from packets on a network interface set in promiscuous mode and displays the binary data in a human-readable formats.

While TCPdump is a valuable tool, it focuses only on the TCP/IP suite of protocols. There are a variety of other utilities for sniffing raw packets of any protocol from any point on a network. Referred to as sniffers, the most common examples are the open source tool Ethereal and Sniffer from Network General Corporation—until recently Sniffer was owned by McAfee. As networks increasingly employ switch technology, sniffers that rely on a shared medium network (e.g. traditional Ethernet) are being moved from end systems to servers and routers (and now wireless networks). Alternatively, commercial switches often employ special ports created particularly for sniffers to tap into. Sniffer logs are valuable in discerning low-level attacks such as abnormal traffic attacks (e.g. 802.11 ARP poisoning); however, their scope is limited by their monitoring position within a network, and the log size makes them cumbersome to analyze.

3.2 NetFlows

NetFlow logs contain records of unidirectional flows between computer/port pairs across an instrumentation point (e.g. router) on a network. Ideally, there is an entry per socket. These records can be exported from routers or software such as ARGUS or NTOP. NetFlows are a rich source of information for traffic analysis consisting of some or all of the following fields depending on version and configuration: IP address pairs (source/destination), port pairs (source/destination), protocol (TCP/UDP), packets per second, time-stamps (start/end and/or duration) and byte counts.

3.3 Syslog

Syslogs are a UNIX standard for capturing information about networked devices, daemon processes and even kernel messages. Messages are encoded by level (e.g. warning, error, emergencies) and by facility (e.g. service areas such as printing, e-mail and network). Syslog can also serve as a distributed error manager by forwarding log entries to centralized syslog servers for processing. Syslogs can be pattern-matched for known attack signatures. They can also be searched for potentially suspicious activities such as critical events (e.g. modules being loaded and core dumps), unsuccessful login attempts, new account creation (especially accounts with special privileges), suspicious connections to unused ports, or simply the cessation of logging messages from a host (which may indicate the logging process has suspended or logs wiped).

3.4 Workstation Logs

Workstation logs are standard utilities that keep login/logout entries on a workstation’s local hard disk (e.g. Window’s event viewer). Some application software also maintain access logs. For example, virus scanners maintain logs of previous scans. Virus scanners and mail agents themselves may log all outgoing mail messages as well. Workstation logs are enabled by default on most operating systems, but it is almost always possible for an adversary with escalated privileges to disable them.

3.5 ARP Cache

Routers and switches contain cached tables of recent resolutions of MAC addresses to IP addresses called ARP (Address Resolution Protocol) caches. The entries are of two types: dynamic entries
that are added/removed automatically over time and static entries which remain in the cache until the computer is restarted. Each dynamic ARP cache entry has a potential lifetime of between 2 and 10 minutes (depending on operating system settings, traffic levels and cache size), and a log of all entries can be created over a specified time period.

The ARP cache is useful for determining static IP addresses, identifying unregistered/unknown (including maliciously spoofed) and misconfigured devices attached to a network, detecting certain layer 2 attacks (e.g. ARP poisoning), identifying what IP address(es) a particular hardware address is using, to debugging connectivity problems a device may be experiencing and tracking unsuccessful connection attempts to devices that either are not currently on the network or do not exist (e.g. port scans to non-existent hosts). These logs are becoming more important with the recent growth of wireless networks and ease at which it is possible to perpetrate ARP poisoning and man-in-the-middle attacks against them.

3.6 DNS Cache

DNS (Domain Name Server) caches contain mappings between fully-qualified hostnames and their corresponding IP addresses based on recent requests to other name servers. The amount of time a name server retains cached data is controlled by the time-to-live (TTL) field for the data. These logs can be created via periodic (period is shorter than minimum TTL) snap shots of the cache timed to capture data at least once before it expires. Host tables (.rhosts and hosts.equiv), which also map hostnames to IP addresses, provide static mapping information. DNS cache records provide useful evidence of attacks purported against DNS services and sometimes of DDoS worms that create high volumes of DNS queries for a target.

3.7 Dial-up Servers

Dial-up server logs maintain system accounting records of who makes incoming network connections. They are a very reliable source of information to investigators because the log is difficult to poison with false information. Even if an attacker steals another’s credential to login, the telephone records are very difficult to fake, thus giving away the attackers location if nothing else. However, as VoIP becomes more prevalent, the reliability of telephone records may diminish somewhat. Also, dial-up connections are much slower than many attackers can tolerate, and with the prevalence of broadband, attacks through dial-up servers have become less common. We expect VPN logs to replace the role of dial-up server logs in the near future.

3.8 Kerberos

Kerberos logs contain records of all ticket requests and uses. This information can be used to generate login graphs and determine who was logged into a particular workstation at a particular time. This may help in detecting tickets that have been compromised, perhaps by a brute force password attack, and used by automated tools and scripts.

3.9 SNMP

SNMP (Simple Network Management Protocol) logs, referred to as Management Information Bases (MIBs), are databases of managed objects that store information about a wide variety of network devices. The SNMP operator application monitors network devices via polls to network device agents for specified MIB information or traps from network device agents notifying the operator of an event.
3.10 Routing Tables
Routing table logs (e.g., inter-domain BGP, intra-domain OSPF or RIP) provide information about routing-based attacks and errors ranging from individual misbehaving routers that drop/misroute packets or inject disruptively large routing tables to the systemic network-wide advertisement of false routing information or instability caused by the propagation of worms. Global, local or peer routing tables all provide different vantage points for analysis.

3.11 Firewalls
A firewall is a computer or network device that interfaces between an internal network/computer and external networks that are trusted to a lesser extent (e.g., the Internet) to enforce an organizational access control policy by processing packets/connections based on the rule set. Note this definition is being expanded as there are now personal firewalls that are being installed on workstations. These differ in that they are positioned at the endpoints and hence can be more application aware. Firewall logs are important in a recursive way, to maintain the effectiveness of the firewall’s internal rule set. A rule set exactly specifies what traffic to permit/block and typically grows in the number of rules beyond human comprehension in a commercial setup.

Firewalls can be used to monitor both normal activity (types of services requested and used, common external IP addresses accessing internal services, common access time patterns) and suspicious activity (probes to ports with no authorized services, external-to-internal flows with spoofed internal IP addresses, out-bound connections from uncharacteristic internal machines and modification/disabling of the firewall rule set).

3.12 Intrusion Detection Systems
Logs from Intrusion Detection Systems (IDS) contain alerts indicating specific attacks that have occurred. Generally, while a firewall has a proactive, preventative focus, an IDS has a passive, reactive focus. The assumption is that eventually someone will break through the perimeter firewalls, and then one needs to be able to detect intruders. IDSs can be categorized by sensor placement (network versus host) and by technique (signature versus anomaly), with all types producing both alerts and detailed logs. Real-time IDSs have been plagued by large log sizes and high false positive rates—especially in anomaly based systems, but incremental improvements are increasing their effectiveness for post-mortem forensics.

3.13 Mail Servers
Mail logs maintain a log of completed transactions (as well as a queue of pending transactions) including the sender and recipient addresses, subject titles, time-stamps and file sizes. Common log reports generated include: total length of time spent receiving and sending e-mail, the number of e-mails by an entity (organization, group, or individual) over a specific period of time (day/week/month), stratification of e-mail by time (work hours/off-hours) and common addresses, stratification by size and type of file attachments and identification of dormant accounts.

3.14 Web Servers
Web server logs have traditionally been used to provide feedback on performance and misconfigurations (e.g., link errors). Web logs provide detailed records of requests to the web-server and statistical information about network traffic. Web log record attributes can include: the source IP
address from which a request was generated, whether the request was satisfied, a userid determined by the HTTP authentication, a status code and the size of the object returned with each satisfied request.

While traditionally used for performance information, web logs are being used more frequently for security analysis. They can be used to detect illegitimate requests (e.g. asking to run a script in a directory that should not be accessible) that exploit misconfigurations, buffer overflow attacks on the web server used to run arbitrary processes with the privileges of the web server daemon and attacks targeting specific web applications and scripts that are not secure.

3.15 DHCP

Dynamic Host Configuration Protocol (DHCP) server logs can be used to track IP address assignments to devices as they join/leave a network. DHCP servers manage two databases: (1) an Address Pool database for holding IP addresses and other network configurations and (2) a Binding database for mappings between hardware MAC addresses and an entry in the Address Pool. Though most frequently used to assign dynamic IP addresses, DHCP can also assign a dedicated static address for a device that re-joins. On a network that uses DHCP with dynamic addresses, maintaining a log is absolutely necessary to be able to forensically associate dynamically changing IP addresses to specific devices.

3.16 Scanners

Scanners for defensive purposes are used to perform risk management by detecting vulnerabilities and notifying system administrators of the vulnerabilities and patches that need to be installed. They typically generate reports rather than logs, though. Scanners range from simple port scanners such as NMAP that report open ports and operating systems detected, to very advanced scanners such as NESSUS that runs NMAP to detect open ports and determines exact versions of services running, and whether these systems are vulnerable to known exploits. Along with the rise in managed security, there are companies such as Qualys that provide proprietary scanners through a web interface and scan for you. Qualys, for example, will scan from the outside—or inside if you purchase a special network device—and produce a complete, customizable report in multiple formats that indicates what vulnerabilities your systems have. With these managed services you typically get easier to read reports and the most up-to-date vulnerability databases.

While this list of sixteen log types may seem exhaustive, it is not. The list of potential log sources are more numerous than the number of services and daemon processes in deployment. There are many proprietary logs we did not mention, including reference monitor alerts, router traps and a myriad of application software logs—though many of the latter log through syslog on UNIX based platforms. The challenge to those working on the problem of log anonymization for security is that they must consider as many log sources as possible and try to generate a basis of logs that contain as much information as possible with minimal overlap between logs.

4 Attacks Against Current Anonymization Schemes

Anonymization—and particularly pseudonymization—schemes are difficult to secure. An anonymization scheme is said to be secure if one cannot link records or information to specific entities (e.g. hosts or users). Anonymization schemes try to achieve balance between security and utility—utility being a measure of how much useful information remains after anonymization. Schemes that can be proven secure tend not to be useful because of severe information loss. Pseudonymization tends
to have more utility, but there are often more attacks against such schemes. In what follows we 
examine five classes of attacks on anonymization and pseudonymization schemes. These are similar 
to what Pang et al. define in [13]. These attack types are the basic building blocks of more advanced 
attacks and are often combined together and used against multiple heterogeneous logs.

4.1 Fingerprinting

We closely match Pang et al. by defining fingerprinting as *the process of matching attributes of an 
anonymized object against attributes of a known object to discover a mapping between anonymized 
and unanonymized objects*. For example, consider an anonymized NetFlow log of an organization 
with only one web server with an IP address of 192.168.77.29. Suppose that we see an anonymized 
IP address of 10.19.21.3 that is responding to port 80 connections. Further, 95 per cent of all port 
80 connections are going to this address. Then we can infer that 192.168.77.29 maps to 10.19.21.3. 
This is most likely correct unless someone is running an illegal web server with a tremendous amount 
of traffic. Fingerprinting is most useful in identifying servers because of the unique attributes they 
have.

4.2 Structure Recognition

Structure recognition is *the act of recognizing structure between objects to use one mapping to 
discover multiple mappings between anonymized and unanonymized objects*. By themselves these 
attacks reveal no mappings, but used with a known mapping they can reveal new mappings. One 
example would be a common attack against all prefix-preserving IP address pseudonymization 
schemes. Knowing one IP address mapping in this case reveals bits of any addresses matching 
prefixes with the address of the known mapping. Here we are exploiting the structure of CIDR 
addressing and the structure-preserving properties of the anonymization technique. Another exam-
ple could be the recognition of a port scan in an anonymized trace. This could reveal a sequential 
ordering of anonymized addresses. Knowing just one mapping of anonymized to unanonymized 
addresses would reveal all mappings for the scanned machines.

Notice that our definition is more refined than Pang et al.’s. Their definition is ambiguous 

eough to allow overlap between fingerprinting and structure recognition. For example, one could 
recognize the structure of traffic patterns to determine a gateway server. By their definition that 
could be fingerprinting or structure recognition. We, however, do not count that as structure recog-
nition. Structure recognition itself does not reveal mappings. Rather, it discoveries relationships 
that allow the discovery of one mapping to aid in the discovery of more mappings.

4.3 Known Mapping Attacks

Known mapping attacks *exploit the discovery of a mapping between unanonymized and anonymized 
data in one reference, to undo anonymization of that same data in multiple places*. This kind of 
attack can occur in two manners. For example, a username and password field may be anonymized 
in exactly the same manner. In that case the word “Emily” could be used as a username in one 
record and a password in another. Revealing the mapping in one field would reveal it in another. 
A similar attack could be carried out if IP mappings are consistent across multiple logs. In that 

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4.4 Data Injection

Data injection attacks involve an adversary injecting information to be logged with the purpose of later recognizing that data in an anonymized form. To illustrate this type of attack, imagine the following scenario. Your organization has wanted to help the research community and has just heard about prefix-preserving anonymization. They now feel safe to share logs and decide to publicly post anonymized logs on a regular basis. An adversary, Anton, knows that anonymized logs are regularly posted from your organization and like everyone else has access to them. Anton, knows that if he had an internal view of your network, he could see a lot more about how machines interact and are setup. He can send limited probes to certain machines, but a lot of them are filtered and his IP address is often quickly blocked. He knows the logs from the firewalls, routers and IDS would help a lot, but they are protected by prefix-preserving anonymization. However, Anton quickly realizes that if he could recognize his own scans in the anonymized logs, he could figure out the mappings of several IP addresses through a structure recognition attack. Because of the prefix-preserving property, every mapping he discovers yields many bits in the IP addresses of machines he did not even scan. So with just a few scans, he can glean information about almost all of the pseudonyms. The only problem left is how does he make scans that he can later recognize. Well, this is easier than setting up a covert channel. His scans need only make use of special sequences that are not random, but could look random without tenacious investigation.

A quick solution might be to use something as simple as the Fibonacci sequence. A smarter solution would be to use a sequence determined by PRNG seeded with a password. For instance, what if Anton scanned a particular machine with the target or source ports being Fibonacci numbers? That should be very recognizable in a log if you know to look for it. He could do the same thing with timings between probes. Of course, the timing intervals must be large enough that jitter in the network does not cause mismatches on a pattern. In fact, such an attack could be made with a number of fields, even in obscure TCP options.

4.5 Cryptographic Attacks

Many anonymization techniques depend on cryptographic functions. Such systems can be vulnerable to attacks on the cryptographic algorithms, such as known or chosen plaintext attacks. These attacks could reveal secret keys or other information. Such attacks don’t affect just single objects, but all entries of a particular field in a log. However, cryptography is less likely the weak link in a scheme. It is usually easier to purport the other types of attacks. Also, this kind of attack typically requires mappings to first be discovered through other attacks. Of particular interest is a data injection attack which could then be used to attempt a chosen plaintext attack against the cryptographic algorithms.

5 Goals and Approach

Our grandest goal is to standardize anonymization techniques across most log types through IETF drafts and RFCs. We would also like to develop prototype anonymization tools and document scenarios of mapping trust levels between organizations to the newly standardized anonymization levels. However, many steps must be taken to reach these goals.

5.1 Requirements Gathering

In defining different anonymization levels, we begin by defining what we mean by anonymization. Anonymity is the state of not being identifiable within a set of potential subjects. In communi-
cation scenarios, both senders and receivers can be anonymous. Pseudonymity is a special type of anonymity and is often what we mean when speaking of anonymity. Specifically, providing pseudonymity is the ability to prove a consistent identity without revealing one's actual identity by use of an alias or pseudonym. Simply encrypting the identity would be an example of pseudonymity because we would still have unique identifiers. However, masking or removing identity fields is not providing pseudonymity since a particular subject’s set of activities cannot be identified. Ideal pseudonymity only has benefits as it means to be anonymous and able to separate the behavior of unidentified individuals. As such, less data is lost, and the same protection is provided. However, ideal pseudonymity is not always obtainable, and it is difficult to prove a system has that property. Often one finds certain attacks may be more effective against pseudonyms than systems that simply erase all identifiers. As such we will be using both anonymity and pseudonymity with the latter being preferred.

5.1.1 Log Identification and Correlation

We have already begun a very important first step in requirements gathering: we have been surveying the many types of logs available. But by no means have we exhaustively listed all log types in Section 3. Other useful, proprietary logs include reference monitor logs, router traps and a myriad of application software logs—though many UNIX applications log through syslog. We must eventually narrow this list of logs to those most useful to security researchers.

It is also important to be able to classify the logs by fields and type of information. We will most likely find that similar logs have similar anonymization solutions, but it is a real challenge to combine information from all these logs in a useful way. While often the attributes initially appear redundant—since they are contained in multiple logs—one finds that this overlap is vital to enable event correlation between logs.

Given this set of potential log files, the more logs that can be processed for attribute correlation the better. However, the dominant constraint, computational power, limits the number of log files which can be quickly analyzed in real-time. In fact, storage can even become a limiting factor when analyzing large network traces from busy routers. Most Juniper routers cannot even make complete traces, but instead sample the data. In [21], Yin et al. discuss how to find a subset of logs that are orthogonal—with each log providing some information that is not present in the other logs—as well as complete. It is ideal to find such a reduced set that provides maximal information about network/system status. In mathematics such a set would be called a basis. Given this goal, [21] initially divides the entire set of potential logs into two categories: those logs that provide information about systems and those logs that provide information about the network. It is likely that other equally valid ways to divide the entire set of potential logs can be used, but we have found it useful to first make this separation in categorizing logs since there is usually minimal overlap between network and system logs. On the other hand, we often find that when comparing two network logs, one may almost be just a subset of the other log.

5.1.2 Putting on the Black Hat

We and others have thought of a few types of attacks against anonymized logs, as discussed in the previous chapter. However, we have just begun. Once the types of logs that are crucial to share are identified, we must put on our black hats and think about how an attacker can glean privileged information from them. This includes identifying what is privileged and sensitive information in the beginning, and it means putting back on our black hats when evaluating the mechanisms we have developed to protect logs. As mentioned, attacks against current anonymization systems are
simple, effective and fairly well known. That is in fact one of the main reasons parties are still reluctant to share logs. There are no good, holistic solutions as of yet. So, we must not only create solutions resilient to the current attack methodologies, but we must also look for potentially new attacks.

5.2 Defining Standards and Beyond

Obviously different organizations trust each other for different tasks and to different levels. Anonymization is a balance between security, meaning it is difficult to break the anonymization scheme or exploit the protected information, and utility, meaning the usefulness of the information to other parties. For example, in the previous chapter we saw that prefix-preserved IP addresses do not protect NetFlows from an active adversary. Anyone who can inject traffic to be logged can begin to determine actual IP addresses. A solution may be simple truncation or deletion of the IP address fields, but now pseudonymity is lost. One attacker cannot necessarily be distinguished from another. Still, port numbers can give away information, particularly if used with time-stamps. One could add noise to the time-stamps and delete port numbers, but now what useful information is left in the logs?

Organizations must determine how much they trust organizations that may see their logs and think of them as an adversary to some extent—by this we mean they must determine what kind of attacks are likely from parties who will see their logs. This, combined with the need-to-know level of the receiving party, will determine how to anonymize the logs. One may say this is easy because you simply never give more information out than is necessary, but our response to this is that you often do not realize how much information you are giving out.

Ideally, we would like to develop anonymization levels that are completely independent of the specific log type. Instead, they would depend upon the fields in the logs—of which there are many fewer types than of logs themselves. Even if we achieve such a goal, logs are still in many different, incompatible formats. We would thus like to create prototype tools to anonymize the most common types of logs. We also intend to develop a standard XML format to which we can output anonymized logs. Of course, it is always important to have the ability to anonymize logs while retaining the original format as well. This enables the same tools to operate on anonymized and unanonymized logs.

While our main goal is to define standards and our secondary goal is to develop tools, there is one more important component. People must understand how to apply the standards. Having different levels of anonymization is not enough. People must be able to map their specific situations and needs to the appropriate anonymization level. This is in effect a need to map trust levels to anonymization standards. For example, as a university we may trust graduate student researchers more than some lab in a foreign country for the simple fact that we can take action against students who exploit the privileged information. Plus, those with campus IP addresses already have a better view of our internal network. Thus, a lower level of anonymization may be needed for sharing logs with students. We intend to create examples and scenarios to help implementors use the new anonymization technology.

5.3 Architecture

Figure 1 presents the high-level architecture of the new anonymization system. Note that this system accepts heterogeneous network logs as input along with requirements profiling the level of anonymization. It is anticipated that different encryption algorithms will be needed for different types of data fields, so the encryption algorithm is a component plug-in to the anonymization
engine. The output will be log files at varied levels of anonymization corresponding to the input requirements profile.

6 Conclusion

Logs are vital to both security operations and researchers. Security professionals analyze them on a daily basis. Both government institutes and industry have recognized the importance of logs and furthermore the value of sharing logs with the security research community. Even though the importance of sharing logs is widely recognized, it is not happening on a large scale. While there are centers dedicated to collecting logs, they suffer from one or more of the following problems: (1) They do not have a wide view of the Internet but are quite localized, (2) the repositories are very specific, addressing one or only a few types of logs, (3) anonymization is weak or non-existent and usually inconsistent or (4) they collect many logs but do not share them with the research community.

We believe the problem, while social on the surface, is technical at the heart. Organizations realize the sensitivity of their information and that current anonymization techniques are inadequate and immature. Hence they are reluctant to share them because of the risk. We contend that the solution is standards and new methods of anonymization. There must be multiple levels of anonymization for the many and differing needs of organizations. Organizations need to have choices that can be clearly described and associated with specific risks so that they can choose the appropriate anonymization level corresponding with the trust level they have with those to whom they would share logs. It is only then that this reluctance to share logs will be overcome.

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