Carnegie Mellon University
Software Engineering Institute

Network Traffic Analysis with SiLK

Analyst's Handbook for SiLK Version 3.15.0 and Later

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Handbook Goals

How to Use This Handbook

This handbook is an introduction to methods of analyzing network traffic, illustrated by commands from the SiLK tool suite. The focus is on learning to identify traffic features important to the security of information on the network. The handbook moves from a basic understanding of network flow and the SiLK tool suite through a series of examples that illustrate how to use SiLK to analyze network behavior.

The examples in this handbook are mainly command sequences that illustrate specific analysis concepts. Examples are commonly discussed on a line-by-line basis in the text and presented as command and output listings. In general, examples are also associated with a specific task (or tasks), indicated in the section and in the example caption. Case studies take a deeper dive into specific topics for analysis.

For readers already familiar with SiLK, the explanations of SiLK commands in the text of this handbook are kept short enough not to be redundant. More complete discussions of the commands and their parameters are provided in the appendices of this guide, the *SiLK Reference Guide*, and the `man` pages for the SiLK commands. Readers who are interested in analyzing network flow records with other tools than SiLK are encouraged to read the overall description of the analysis approaches, then use the description of commands to find parallels using the tool suite of their choice.

How This Handbook Is Organized

This handbook contains the following chapters:

1. **Introduction to SiLK** provides a short overview of some of the background necessary to begin using the SiLK tools for analysis. It includes a brief introduction to the SiLK suite and describes the basics of network flow capture by sensors and storage in the SiLK flow repository. It also discusses the analysis process used in this handbook.

2. **Basic Single-path Analysis with SiLK: Profiling and Reacting** describes the most straightforward analysis approach and applies it to several example analyses. It introduces some of the core SiLK commands and uses them to analyze network traffic.

3. **Case Studies: Basic Single-path Analysis** applies the single-path analysis approach to several extended examples, focusing on how those examples were developed from an initial problem statement through executable commands.

4. **Intermediate Multi-path Analysis with SiLK: Explaining and Investigating** explains a more complex, intermediate form of analysis which applies basic, single-path analysis in a multi-pronged

structure. The chapter describes how multi-path analysis can be applied and includes a fuller exploration of SiLK tools that may be useful for this type of analysis.

5. **Case Studies: Intermediate Multi-path Analysis** applies multi-path analysis to extended examples.
6. **Advanced Exploratory Analysis with SiLK: Exploring and Hunting** discusses the use of SiLK to deal with open-ended, often iterative analyses that incorporate both single-path and multi-path methods. It also describes more sophisticated uses of the SiLK tool suite that support complex analyses of network behavior.
7. **Case Studies: Advanced Exploratory Analysis** applies exploratory analysis to an extended example.
8. **Extending the Reach of SiLK with PySiLK** describes how to extend the functionality of the SiLK tool suite by using the Python scripting language.
9. **Tuning SiLK for Improved Performance** discusses techniques to improve the efficiency and performance of SiLK when working with very large datasets.

The appendices to this guide introduce fundamental networking concepts, describe useful Unix commands, summarize the SiLK commands referenced in this guide, and list sources for additional information about the SiLK tool suite and network analysis.

What This Handbook Doesn't Cover

This handbook does not contain an exhaustive description of all the tools in the SiLK tool suite or of all the options in the described commands. Rather, it offers concepts and examples to allow analysts to accomplish needed work while continuing to build their skills and familiarity with SiLK.

- Every SiLK tool includes a `--help` option that briefly describes the command and lists its parameters.
- Every tool also has a manual page (also called a `man` page) that provides detailed information about the use of the tool. These pages may be available on your system by typing `man` *command*. For example, type `man rwfilter` to see information about the `rwfilter` command.
- The SiLK Documentation page at https://tools.netsa.cert.org/silk/docs.html includes links to individual manual pages.
- The *SiLK Reference Guide* is a single document that bundles all of the SiLK manual pages. It is available in HTML and PDF formats on the SiLK Documentation page (https://tools.netsa.cert.org/silk/docs.html).

This handbook deals solely with the analysis of network flow record data using an existing installation of the SiLK tool suite. For information on installing and configuring a new SiLK tool setup and on the collection of network flow records for use in these analyses, see the "Installation Information" section of the SiLK Documentation page at https://tools.netsa.cert.org/silk/docs.html#installation.

Chapter 1

Introduction to SiLK

Network analysts need to build an ongoing perspective on the traffic passing over their networks. This perspective is often built on information about the traffic (such as volumes, timing, and communication paths), rather than on the traffic itself. This chapter introduces the tools and techniques used to store such information, particularly in the form known as *network flow*. It will help you to become familiar with the structure of network flow data, how the SiLK collection system gathers those data from sensors, and how to use those data.

Upon completion of this chapter you will be able to

- describe a network flow record and the conditions under which the collection of one begins and ends
- describe the types of SiLK flow records
- describe the structure of the SiLK flow repository
- understand the steps involved in analyzing network flow data
- describe the dataset for the examples in this guide

1.1 What is SiLK?

The System for internet-Level Knowledge[1] (SiLK) tool suite is a highly scalable flow-data capture and analysis system developed by the CERT Situational Awareness group at Carnegie Mellon University's Software Engineering Institute (SEI). The SiLK tools provide network security analysts with the means to understand, query, and summarize both recent and historical traffic data represented as network flow records (also referred to as "network flow" or "network flow data" and occasionally just "flow"). These tools provide network security analysts with a relatively complete high-level view of traffic across an enterprise network, subject to placement of sensors.

Analyses using the SiLK tools provide insight into various aspects of network behavior. Some example applications of this tool suite include:

[1] The suite name, and in particular the capitalization, were chosen in memory of Dr. Suresh L. Konda, who was the inspirational leader for the creation of the initial suite prior to his sudden passing.

- supporting network forensics: identifying artifacts of intrusions, vulnerability exploits, worm behavior, etc.
- providing service inventories for large and dynamic networks (on the order of a /8 Classless Inter-Domain Routing (CIDR) block)
- generating profiles of network usage (bandwidth consumption) based on protocols and common communication patterns
- enabling non-signature-based scan detection and worm detection, for detection of limited-release malicious software and for identification of precursors

These examples, and others, are explained further in this handbook. By providing a common basis for these analyses, the SiLK tools provide a framework for developing network situational awareness.

Common questions addressed via flow analyses include (but aren't limited to)

- What is on my network?
- What constitutes typical network behavior?
- What happened before, during, and after an event?
- Where are policy violations occurring?
- Which are the most popular web servers?
- How much volume would be reduced by applying a blacklist?
- Do my users browse to known infected web servers?
- Is a spammer on my network?
- When did my web server stop responding to queries?
- Is my organization routing undesired traffic?
- Who uses my public Domain Name System (DNS) server?

1.2 The SiLK Flow Repository

1.2.1 What is Network Flow Data?

NetFlow is a traffic-summarizing format that was first implemented by Cisco Systems® primarily for accounting purposes. Network flow data (or network flow) is a generalization of NetFlow. Network flow collection differs from direct packet capture (such as with `tcpdump`) in that it builds a summary of communications between sources and destinations on a network. For NetFlow, this summary covers all traffic matching seven relevant keys: the source and destination IP addresses, the source and destination ports, the transport layer protocol, the type of service, and the router interface.

SiLK uses five of these attributes to constitute the *flow label*:

1. source IP address

2. destination IP address
3. source port
4. destination port
5. transport layer protocol

These attributes (also known as the *five-tuple*), together with the start time of each network flow, distinguish network flows from each other. The SiLK *repository* stores the accumulated flows from a network.

1.2.2 Structure of a Flow Record

A network flow often covers multiple packets that all match the fields of their common labels. A *flow record* thus provides the label and statistics on the packets covered by the network flow, including the number of packets covered by the flow, the total number of bytes, and the duration and timing of those packets (among other fields). A *flow file* is a series of flow records.

The fields in the flow record are listed in Table 1.2.2. Every field is identified by a name and number that can be used interchangeably. For example, the source IP address field of a flow record can be identified by either its field name (`sIP`) or its field number (`1`). Capitalization does not matter: `sIP` is equivalent to `sip` or `SIP`.

Because network flow is a summary of traffic, it does not contain packet payload data, which are expensive to retain on a large, busy network. Each network flow record created by SiLK is very small: it can be as little as 22 bytes (the exact size is determined by several configuration parameters). However, even at that tiny size, a sensor may collect many gigabytes of flow records daily on a busy network.

Some of the fields are actually stored in the record, such as start time and duration. Some fields are not actually stored; rather, they are derived either wholly from information in the stored fields or from a combination of fields stored in the record and external data. For example, end time is derived by adding the start time and the duration. Source country code is derived from the source IP address and a table that maps IP addresses to country codes.

1.2.3 Flow Generation and Collection

To understand how to use SiLK for analysis, it helps to have some knowledge of how network flow data are collected, stored, and managed. Understanding how the data are partitioned can produce faster queries by reducing the amount of data searched. In addition, by understanding how the sensors complement each other, it is possible to gather traffic data even when a specific sensor has failed.

Every day, SiLK may collect many gigabytes of network flow records from across the enterprise network. This section reviews the collection process and shows how data are stored as network flow records.

A network flow record is generated by sensors throughout the enterprise network. Usually, the majority of these sensors are routers. Specialized sensors such as `yaf`[2] can be employed when a data feed from a router is not available, such as on a home network or on an individual host. `yaf` can also be used to avoid artifacts in a router's implementation of network flow or to use non-device-specific network flow data formats such

[2] https://tools.netsa.cert.org/yaf/

Field Number	Field Name	Description
1	sIP	Source IP address for flow
2	dIP	Destination IP address for flow
3	sPort	Source port for flow (or 0)
4	dPort	Destination port for flow (or 0)
5	protocol	Transport layer protocol number for flow
6	packets, pkts	Number of packets in flow
7	bytes	Number of bytes in flow (starting with IP header)
8	flags	Cumulative TCP flag fields of flow (or blank)
9	sTime	Start date and time of flow
10	duration	Duration of flow
11	eTime	End date and time of flow
12	sensor	Sensor that collected the flow
13	in	Ingress interface or VLAN on sensor (usually zero)
14	out	Egress interface or VLAN on sensor (usually zero)
15	nhIP	Next-hop IP address (usually zero)
16	sType	Type of source IP address (pmap required)
17	dType	Type of destination IP address (pmap required)
18	scc	Source country code (pmap required)
19	dcc	Destination country code (pmap required)
20	class	Class of sensor that collected flow
21	type	Type of flow for this sensor class
—	iType	ICMP type for ICMP and ICMPv6 flows (SiLK V3.8.1+)
—	iCode	ICMP code for ICMP and ICMPv6 flows (SiLK V3.8.1+)
25	icmpTypeCode	Both ICMP type and code values (before SiLK V3.8.1)
26	initialFlags	TCP flags in initial packet
27	sessionFlags	TCP flags in remaining packets
28	attributes	Termination conditions
29	application	Standard port for application that produced the flow

Table 1.1: Fields in a SiLK Network Flow record

as IPFIX[3]. It provides more control over network flow record generation and can convert packet data to network flow records via a script that automates this process.

A sensor generates network flow records by grouping together packets that are closely related in time and have a common flow label. "Closely related" is defined by the sensor and typically set to around 30 seconds. Figure 1.2.3 shows the generation of flows from packets. Case 1 in that figure diagrams flow record generation when all the packets for a flow are contiguous and uninterrupted. Case 2 diagrams flow record generation when several flows are collected in parallel. Case 3 diagrams flow record generation when timeout occurs, as discussed below.

Network flow is an approximation of traffic. Routers and other sensors make a guess when they decide which packets belong to a flow. These guesses are not perfect; there are several well-known phenomena in which a long-lived session will be split into multiple flow records:

[3]See https://tools.ietf.org/html/rfc7011 for definitions of the IPFIX information elements; see the IPFIX protocol description and https://www.iana.org/assignments/ipfix for their descriptions.

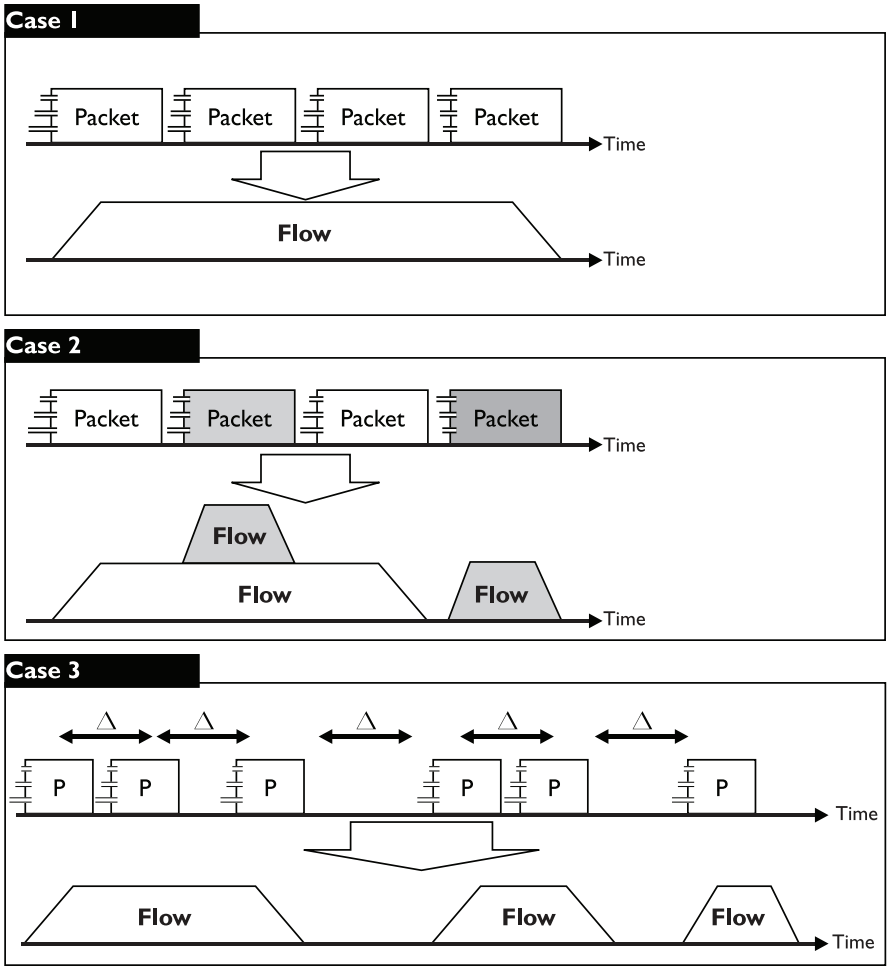

Figure 1.1: From Packets to Flows

1. *Active timeout* is the most common cause of a split network flow. Network flow records are purged from the sensor's memory and restarted after a configurable period of activity. As a result, all network flow records have an upper limit on their duration that depends on the local configuration. A typical value would be around 30 minutes.

2. *Cache flush* is a common cause of split network flows for router-collected network flow records. Network flows take up memory resources in the router, and the router regularly purges this cache of network flows for housekeeping purposes. The cache flush takes place approximately every 30 minutes as well. A plot of network flows over a long period of time shows many network flows terminate at regular 30-minute intervals, which is a result of the cache flush.

3. *Router exhaustion* also causes split network flows for router-collected flows. A router has limited processing and memory resources devoted to network flow. During periods of stress, the flow cache will fill and empty more frequently due to the number of network flows collected by the router.

Use of specialized flow sensors can avoid or minimize cache-flush and router-exhaustion issues. All of these

cases involve network flows that are long enough to be split. As we show later, the majority of network flows collected at the enterprise network border are small and short-lived.

1.2.4 Introduction to Flow Collection

An enterprise network comprises a variety of organizations and systems. The flow data to be handled by SiLK are first processed by the collection system, which receives flow records from the sensors and organizes them for later analysis. The collection system may collect data through a set of sensors that includes both routers and specialized sensors that are positioned throughout the enterprise network. After records are added to the flow repository by the collection system, analysis is performed using a custom set of software called the SiLK analysis tool suite.

The SiLK project is active, meaning that the system is continually improved. These improvements include new tools and revisions to existing collection and analysis software. See Appendix E for information on how to obtain the most up-to-date version of SiLK.

1.2.5 Where Network Flow Data Are Collected

While complex networks may segregate flow records based on where the records were collected (e.g., the network border, major points within the border, at other points), the generic implementation of the SiLK collection system defaults to collection only at the network border, as shown in Figure 1.2.5. The default implementation has only one class of sensors: *all*. Further segregation of the data is done by type of traffic.

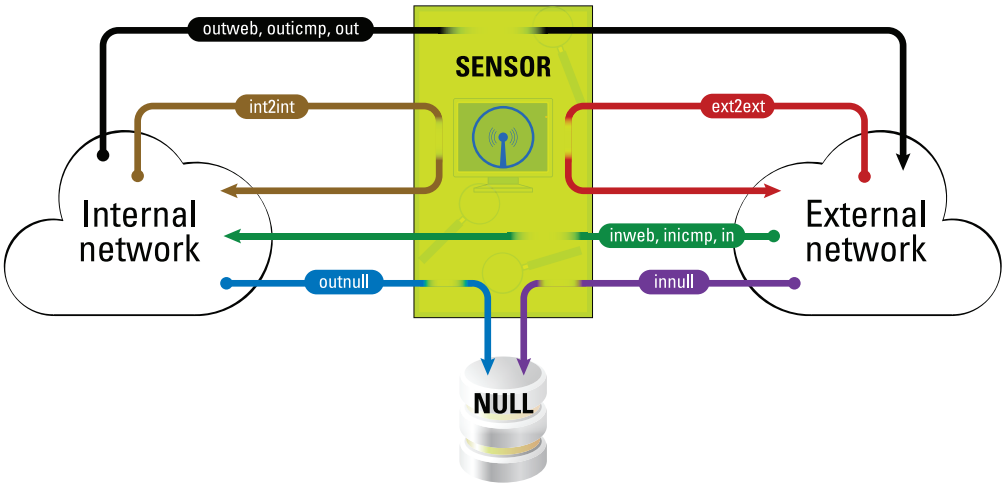

Figure 1.2: Default Traffic Types for Sensors

The SiLK tool `rwsiteinfo` can produce a list of sensors in use for a specific installation, reflecting its configuration. For more information on how to use this tool, see Section 2.2.1.

1.2.6 Types of Enterprise Network Traffic

In SiLK, the term *type* mostly refers to the direction of traffic, rather than a content-based characteristic. In the generic implementation (as shown in Figure 1.2.5), there are six basic types and five additional types. The basic types are

- `in` and `inweb`, which is traffic coming from the Internet service provider (ISP) to the enterprise network through the border router. Web traffic is separated from other traffic due to its volume, making many searches faster.
- `out` and `outweb`, which is traffic coming from the enterprise network to the ISP through the border router.
- `int2int`, which is traffic going both from and to the enterprise network, but which passes by the sensor.
- `ext2ext`, which is traffic going both from and to the ISP, but which passes by the sensor. (The presence of this type of traffic usually indicates a configuration problem either in the sensor or at the ISP.)

The additional SiLK types are

- `inicmp` and `outicmp`, which represent ICMP traffic entering or leaving the enterprise network. These types are operational only if SiLK was compiled with the option to support them.
- `innull` and `outnull`, which only can be found when the sensor is a router and not a dedicated sensor. They represent traffic from the upstream ISP or the enterprise network, respectively, that terminates at the router's IP address or is dropped by the router due to an access control list.
- `other`, which is assigned to traffic where one of the addresses (source or destination) is in neither the internal nor the external networks.
- The constructed type `all` selects all types of flows associated with a class of sensors.

These types are configurable. Configurations vary as to which types are in actual use (see the discussion below under Sensors: Class and Type).

1.2.7 The Collection System and Data Management

Data collection starts when a flow record is generated by one of the sensors: either a router or a dedicated sensor. Flow records are generated when a packet relevant to the flow is seen, but a flow is not *reported* until it is complete or flushed from the cache. Consequently, a flow can be seen some time after the start time of the first packet in the flow, depending on timeout configuration and on sensor caching, among other factors.

Packed flows are stored into files indicated by class, type, sensor, and the hour in which the flow started. So for traffic coming from the ISP through or past the sensor named SEN1 on March 1, 2018 for flows starting between 3:00 and 3:59:59.999 p.m. Coordinated Universal Time (UTC), a sample path to the file could be `/data/SEN1/in/2018/03/01/in-SEN1_20180301.15`.

1.2.8 How Network Flow Data Are Organized

The data repository is accessed via the SiLK tools, particularly the `rwfilter` command. An analyst uses `rwfilter` to choose the type of data to be viewed by specifying a set of selection parameters. This handbook discusses selection parameters in more detail in Section 2.2.2 and Appendix C.3; this section briefly outlines how data are stored in the repository.

Dates

The SiLK repository stores data in hourly divisions, which are referred to in the form *yyyy/mm/dd*T*hh* in UTC. Thus, the hour beginning 11 a.m. on February 23, 2018 in Pittsburgh would be referred to as `2018/2/23T16` when compensating for the difference between UTC and Eastern Standard Time (EST)—five hours.

In general, data for a particular hour starts being recorded at that hour and will continue recording until some time after the end of the hour. Under ideal conditions, the last long-lived flows will be written to the file soon after they time out (e.g., if the active timeout period is 30 minutes, the last flows will be written out 30 minutes plus propagation time after the end of the hour). Under adverse network conditions, however, flows could accumulate on the sensor until they can be delivered. Under normal conditions, the file for 2018/3/7 20:00 UTC would have data starting at 3 p.m. in Pittsburgh and finish being updated after 4:30 p.m. in Pittsburgh.

Sensors: Class and Type

Data are divided by time and sensor. The class of a sensor is often associated with the sensor's role as a router: access layer, distribution layer, core (backbone) layer, or border (edge) router. The classes of sensors that are available are determined by the installation. By default, there is only one class—`all`—but based on analytical interest, other classes may be configured as needed. As shown in Figure 1.2.5, each class of sensor has several types of traffic associated with it: typically `in`, `inweb`, `out`, and `outweb`.

Data types are used for two reasons:

1. They group data together into common directions.
2. They split off major query classes.

As shown in Figure 1.2.5, most data types have a companion web type (i.e., `in` and `inweb`, `out` and `outweb`). Web traffic generally constitutes about 50% of the flows in any direction; by splitting the web traffic into a separate type, we reduce query time.

Most queries to repository data access one *class* of data at a time but access multiple *types* simultaneously.

1.3 The SiLK Tool Suite

The SiLK analysis suite consists of over 60 command-line UNIX tools (including flow collection tools) that rapidly process flow records or manipulate ancillary data. The tools can communicate with each other and with scripting tools via pipes (both unnamed and named) or via intermediate files; see Section B.2 for more information.

Flow analysis is generally input/output bound (I/O bound)—the amount of time required to perform an analysis is proportional to the amount of data read from disk. A major goal of the SiLK tool suite is to minimize that access time. Some SiLK tools perform functions analogous to common UNIX command-line tools and to higher level scripting languages such as Perl®. However, the SiLK tools process this data in non-text (binary) form and use data structures specifically optimized for analysis.

Consequently, most SiLK analysis consists of a sequence of operations using the SiLK tools. These operations typically start with an initial `rwfilter` call to retrieve data of interest and culminate in a final call to a text output tool like `rwstats` or `rwuniq` to summarize the data for presentation.

Keeping data in binary for as many steps as possible greatly improves efficiency of processing. This is because the structured binary records created by the SiLK tools are readily decomposed without parsing, their fields are compact, and the fields are already in a format that is ready for calculations, such as computing netmasks.

In some ways, it is appropriate to think of SiLK as an awareness toolkit. The flow-record repository provides large volumes of data, and the tool suite provides the capabilities needed to process these data. However, the actual insights come from analysts.

1.4 How to Use SiLK for Analysis

The SiLK tool suite provides a robust collection of tools to facilitate network traffic analysis tasks. It is designed to be very flexible in its support of analysis methods. Over time, different analysts have used a variety of approaches in their use of SiLK. This section discusses three approaches that have been useful in analyzing network flow records.

The chapters following this one expand on these approaches in more detail, focusing on the support that network flow analysis can provide to such analyses. Being aware of and practicing multiple approaches to analysis enables an analyst to gain insight into a wide variety of network traffic behaviors.

1.4.1 Single-path Analysis

The *single-path* approach is the most basic and most commonly-used approach to analyzing network behavior. It makes use of a single sequence of commands to produce the analytic results. In this approach, the analyst formulates an initial hypothesis, constructs a query to retrieve traffic of interest, produces a table, summary, or series to profile this traffic, and then interprets this profile either numerically or through a graph. Iteration can be used if needed (e.g., to refine the initial query), but may not be necessary for many simpler, more straightforward analyses.

This approach could be used for service identification, network device inventories, incident response, or usage studies. Chapter 2 provides an overview of single-path analysis, including the SiLK commands that are most commonly used with it. Chapter 3 describes example case studies of single-path analyses.

1.4.2 Multi-path Analysis

The *multi-path* approach uses a sequence of tools that frequently involve several alternatives, and often includes iterating over some steps. Although a multi-path approach can be done manually, it more often involves scripting to select alternatives based on categories of data and then iterate until the desired traffic is isolated or the desired summaries are produced. The alternatives are used as required for processing groups of records in differing ways to reach results that profile behavior of interest.

This approach could be used for examining traffic using several protocols, each following its own alternative set of characteristics, to accomplish the same goal. For example, there are multiple ways that malware can beacon to its command-and-control network. Each of those ways could be examined separately via a chain of SiLK commands, generating sets of results that contribute to overall awareness of beaconing.

Chapter 4 provides an overview of multi-path analysis, including the SiLK commands that are most commonly used with it. Chapter 5 describes an example case study of multi-path analysis.

1.4.3 Exploratory Analysis

We do not always know ahead of time what the scope of our analysis will be—or even what questions we should be asking! *Exploratory* analysis is an open-ended approach to formulating, scoping, and conducting a network analysis. It uses single-path and multi-path analyses as building blocks for investigating anomalous network traffic. These simpler types of analysis help us to formulate different scenarios, investigate alternative hypotheses, and explore multiple aspects of the data. Exploratory analysis is initially manual in nature, but can transition to scripted analysis for ease of repetition and for regularity of results.

This approach is used for complex or emerging phenomena, where multiple indicators need to be combined to gain understanding. An example of this approach to analysis would be a study of data exfiltration, which can be performed in a wide variety of ways. Each of those exfiltration methods could be profiled using a set of indicators, and the results of all such analyses combined to produce a composite understanding of traffic being passed to various groups of suspicious addresses.

Chapter 6 provides an overview of exploratory analysis, including advanced SiLK commands and concepts. Chapter 7 describes an example case study of exploratory analysis.

1.5 Workflow for SiLK Analysis

SiLK analyses share a common workflow, shown in Figure 1.5. While single-path, multi-path, and exploratory analysis may incorporate different steps in this workflow, all follow its general sequence.

1.5.1 Formulate

The *Formulate* step investigates the context of the event. Essentially, it involves collecting information to identify the unique attributes of the network, its operation, and the event. How large is the network? How is it structured? Where are network sensors located? When did the event occur? Is it associated with specific sensors, IP addresses, hosts, network spaces, ports, protocols, and so forth? Do any earlier analyses of the network offer insight? The information may be incomplete at this point, but it serves as a starting point for launching the analysis and establishing its scope. We can use it to formulate a hypothesis for the network's behavior. This hypothesis serves as the basis of our analysis. In more sophisticated exploratory analyses, we can formulate multiple scenarios and hypotheses for investigation and analysis.

Information gleaned from exploring the event's context helps us to establish which network behaviors should be included in (or excluded from) our analysis. We can use this information to construct a *query* to select and partition network flow records from the SiLK repository or a stored file. Queries typically incorporate information such as where the flow was collected, the date of data collection, and the flow direction. Within the SiLK community, query selection is commonly called a *data pull*.

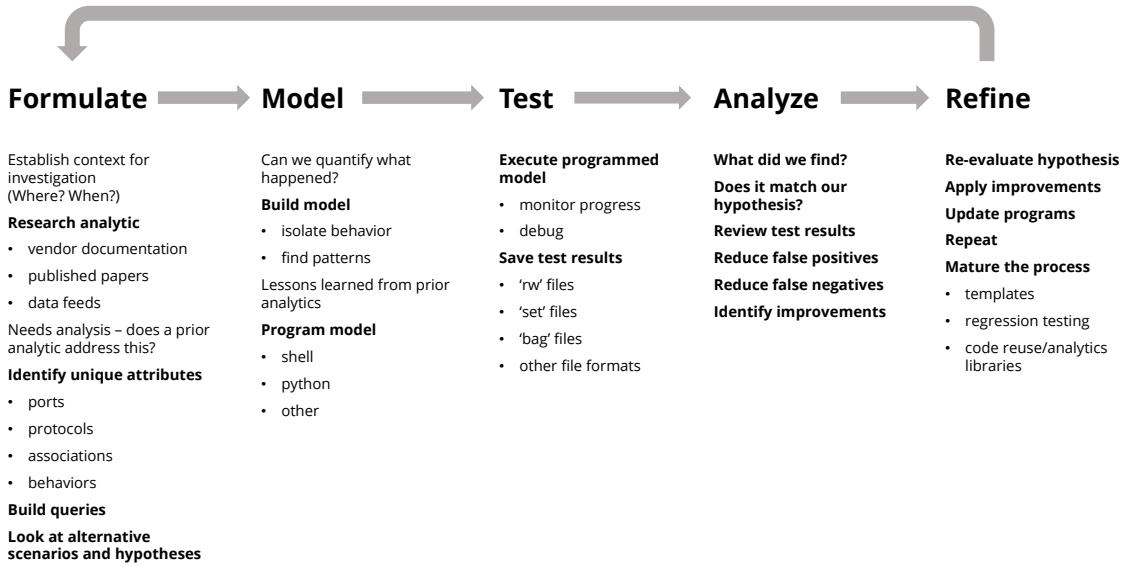

Figure 1.3: SiLK Analysis Workflow

Partitioning applies tests to selected flow records to separate (or partition) them into categories for further inspection and investigation. A default set of tests is provided with SiLK. It includes IP addresses, ports, protocols, time, and volumes. (If additional tests are needed for analyses, the SiLK tools can be extended via *plugins* to provide them.)

The combination of selection and partitioning (commonly referred to as *filtering*) is performed with the `rwfilter` command. Records that meet the filtering criteria are sent to *pass* destinations. Records that do not are sent to *fail* destinations. Both can be combined into *all* destinations. This provides flexibile options to either store query results in files or use pipes to send them to other commands for processing.

1.5.2 Model

The *Model* step summarizes data and investigates behaviors of interest. What is the network's behavior during normal operation? What happened during an event? What patterns and behaviors can we identify? Are they similar to those observed during other events? By examining the information gathered during the Formulate step, you can come up with a model of the event that perhaps explains what is going on.

SiLK provides a variety of tools for examining network flow data associated with an event. Each tool offers different views into the data that can be considered independently or in combination for analysis. For example, SiLK includes tools for generating time-series summaries of traffic (the `rwcount` command), computing summary statistics (the `rwstats` command), and summing up the values of flow attributes for user-defined time periods (the `rwuniq` command).

This step can be done manually. For analyses that are larger in scope, it can be automated by using shell or Python scripts.

1.5.3 Test

The *Test* step runs the model that you created—either manually or by executing shell or Python scripts. This gives you a chance to check the progress of the analysis.

SiLK includes commands for sorting flow records according to user-defined keys (the `rwsort` command), creating sets of unique IP addresses from flow records (`rwset` and its related commands), and creating groups of records by other criteria (`rwbag` and its related commands). These commands help you to organize output from the various SiLK commands and save it for further use.

1.5.4 Analyze

The *Analyze* step reviews the results of the previous steps. What do these results tell us about the event? What behaviors have been identified? What types of events are they associated with? What relationships can we identify between flows? Do our initial hypotheses still hold up? Can we find and eliminate false positives and false negatives?

This step involves examining and interpreting output from the analysis tools mentioned earlier. SiLK can also translate binary flow records into text for analysis with graphics packages, spreadsheets, and mathematical tools (the `rwcut` command).

1.5.5 Refine

The *Refine* step improves the analysis. Did we successfully explain the event? If not, what problems did we encounter? Did we properly understand the event's context? Did our query into the SiLK repository pull too much data? Do we need to dig deeper into the data during the modeling and testing steps? Should we take another look at the results to see if we missed or misinterpreted important patterns and behaviors?

The preceding steps in the workflow can be combined in an iterative pattern. For example, you may want to isolate flow records of interest from unrelated network traffic by making additional queries with the `rwfilter` command and repeating subsequent steps in the analysis. This narrows the data to focus on the time periods and behaviors of interest and eliminate unneeded flow records.

The workflow described in this section gives us the flexiblity to begin our data exploration with a general question, apply one or more analyses to the question, and complete the workflow with a repeatable analytic. This flexiblity does come with trade-offs, however. Queries typically increase proportionally with the time window and flow record attributes of an analysis. Therefore, a precise model of an analysis should be produced to minimize the query results.

1.6 Applying the SiLK Workflow

The SiLK workflow can be applied in different ways to meet the requirements of analysis groups. Groups that are primarily concerned with network operations will often focus on network monitoring or service and device validation. Incident response groups commonly focus on changes in network behavior that may be associated with an incident. Security improvement groups often focus on understanding problematic network behavior and changes that identify the impact of improvements.

While the SiLK suite offers features that support all groups, the work required to use them will vary. Many of these applications are addressed in the remaining chapters of this handbook.

1.7 Dataset for Single-path, Multi-path, and Exploratory Analysis Examples

The dataset used for the command examples and case studies of single-path, multi-path, and exploratory analysis in this document is the FCCX-15 dataset[4]. It originates from a June, 2015 Cyber Exercise conducted by the Software Engineering Institute at Carnegie Mellon University in a virtual environment.

The exercise network topology is documented in the data download and comprises a distributed enterprise for the period from June 2-16, 2015. Internet and transport layer protocols such as IPv4, TCP, UDP, and ICMP are well represented in the data. Link layer protocols such as IGMP and OSPF are also included; however, they are not as prevalent as the Internet and transport layer protocols.

The analyses in this guide investigate events that occurred during this exercise.

[4] https://tools.netsa.cert.org/silk/referencedata.html

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Chapter 2

Basic Single-path Analysis with SiLK: Profiling and Reacting

This chapter introduces basic single-path analysis through application of the analytic development process with the SiLK tool suite. It discusses basic analysis of network flow data with SiLK, in addition to specific tools and how they can be combined to form a workflow.

Upon completion of this chapter you will be able to

- describe basic single-path analysis and how it maps to the analytic development process
- understand SiLK tools commonly used with basic single-path analysis
- describe SiLK IPsets and their application
- describe the single-path analysis workflow using network flow data

2.1 Single-path Analysis: Concepts

Single-path analysis is the approach of combining data with methods that do not require conditional steps, integration, or a great deal of refinement. In layman's terms, single-path analysis can be described as the 'start-to-finish' approach of combining one or more analytical steps to characterize network behavior. Its output may contain multiple attributes and characteristics; however, it results in information that normally does not need continued iteration. Figure 2.1 provides an overview of single-path analysis.

Single-path analysis typically incorporates the Formulate, Model, Test, and Analyze steps of the analysis workflow described in Section 1.5. The Refine step can also be included—for instance, to change the scope of a data pull from the SiLK repository—but is not always needed. The analysis begins by identifying the context of an analysis and formulating a hypothesis to explain the behavior under investigation. Event attributes such as hosts, networks, and time periods are used to identify, retrieve, and partition data for analysis. Attributes such as frequency, volume, and supporting network services provide additional behavioral context.

Single-path analysis then summarizes this data to produce sequences of event behavior. Data can be separated into logical groups such as successful and unsuccessful contacts, scanning, and misconfiguration. This

enables analysts to produce known and unknown activity, trends, and differences for comprehensive analysis of a network's behavior.

Analysts also use single-path analyses as building blocks for broader, more complex analyses. See Chapter 4 and Chapter 6 for descriptions of analysis workflows that include single-path analyses as building blocks for more comprehensive investigations of network activity.

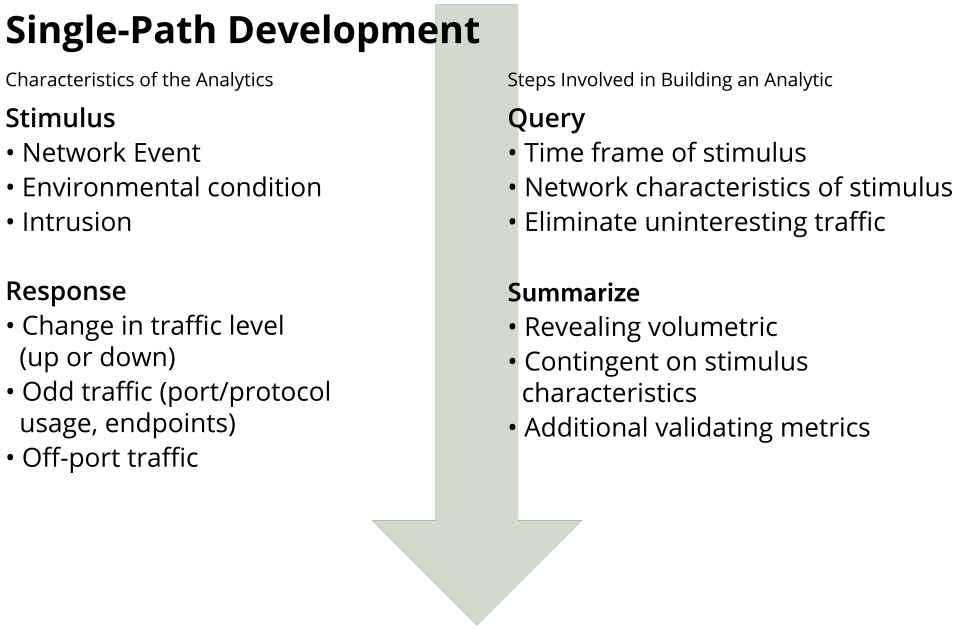

Figure 2.1: Single-Path Analysis

2.1.1 Scoping Queries of Network Flow Data

Be careful when defining the scope of an initial query into the SiLK repository or a file. The natural tendency is to make the partitioning criteria very inclusive, which has two drawbacks. It pulls over-large amounts of data, consuming storage and other computer resources. Overly-broad queries may match behaviors other than those of interest, which will complicate later steps in the analysis.

The preferred method for scoping queries is the opposite:

1. Make the partitioning criteria initially narrow, specific to the desired behaviors.

2. Once the traffic related to the behavior is retrieved, broaden the initial criteria to identify related network traffic.

Starting narrow and broadening the scope of the data query as the analysis proceeds will use computing resources more efficiently and facilitate clearer analysis by minimizing unwanted data.

2.1.2 Excluding Unwanted Network Traffic

Despite narrowing the initial query, unrelated traffic is commonly included in the intially-retrieved records. Analysis will often require isolating the desired activity from among the retrieved traffic. This may involve studying the traffic to identify unrelated behaviors and constructing further criteria to exclude them. It may also include eliminating traffic involving specific addresses (often by using the `rwset` tools to build IPsets), traffic that does not occur in the proper timeframe (often by using a further `rwfilter` call), or traffic that lacks specific protocol information associated with behavior of interest (again by using a further `rwfilter` call).

2.1.3 Example Single-Path Analysis

This chapter documents an example single-path analysis using the SiLK tool suite. It serves as an independent analysis, but could also depict the beginning of a multi-path (intermediate) or exploratory (advanced) analysis workflow. The example begins with identifying the context of an event by using `rwsiteinfo` to select relevant sensors and time periods for analysis. The time window is expanded beyond the event under analysis to select data to compare against the event period. `rwfilter` is then used to retrieve network flow records that apply to the defined sensor and period.

Traffic characteristics such as bytes, packets, and TCP flags options are then used with `rwfilter` on the retrieved data to select sequences of behaviors such as successful and unsuccessful contacts, scanning, and misconfigurations. The resulting network flow records are then displayed with tools such as `rwcut`, `rwuniq`, `rwcount`, and `rwstats`. These tools summarize and display network flow records using specified bins in order for analysts to verify and group data for traffic characterization and behavioral analysis. Top-N and bottom-N statistics, time series, event sequence, and record-by-record displays are a few examples depicted in this analysis.

Hosts that match specific characteristics or behaviors during an analysis are then saved to named SiLK IPsets. IPsets are data structures that represent an arbitrary collection of individual addresses, and are commonly named using a behavior, characteristic, or some other descriptive attribute. For example, `webservers.set` could be a IPset file of the source IP addresses obtained from querying network flow data for flows where the source IP address responded to a SYN scan on its port 80. These binary data structures enable analysts to use the SiLK tool suite to describe network traffic and save, display, or query the hosts that match those descriptions with tools such as `rwset`, `rwsetbuild`, `rwsetcat`, or `rwfilter`.

2.2 Single-path Analysis: Analytics

The commands, parameters, and examples described in this chapter serve as the building blocks for analyses with the SiLK tool suite.

2.2.1 Get a List of Sensors With `rwsiteinfo`

The first step in a basic, single-path network analysis of the dataset described in Section 1.7 is to find out which sensor recorded the data to be analyzed and narrow down the time period for our analysis. Since routing is relatively static, data from a specific IP address generally enters or leaves through the same sensor. You need to identify the sensor that covers the affected network and figure out when this sensor recorded network flow data.

Use the `rwsiteinfo` command to view this information for the sensors on your network. `rwsiteinfo` prints SiLK configuration file information for a site, its sensors, and the traffic they collect. The `--fields` parameter is required and specifies what information is displayed. Run `rwsiteinfo` twice to do the following:

1. List the names and descriptions of all the sensors on the network. This helps to locate the sensor that covers the affected network.
2. For the sensor of interest, list the types of SiLK traffic that it carries, the number of data files stored in the SiLK repository for each type of traffic, and the start and end times for storing network flow data in the repository. This identifies the direction and type of network traffic that the sensor recorded and the time period when it was actively storing data.

Example 2.1 shows the two `rwsiteinfo` commands and their output. The results of these two calls to `rwsiteinfo` will be used in Section 2.2.2 to build a query with the `rwfilter` command to select the network flow records for our analysis.

Determine Which Sensor Covers the Affected IP Addresses

To start, run the `rwsiteinfo` command to find the names and locations of the sensors in the network.

```
rwsiteinfo --fields=sensor,describe-sensor
```

The `--fields` parameters requests the following information:

- `sensor` displays the name of each sensor in plain text.
- `describe-sensor` displays the description of each sensor from the site configuration file (normally `silk.conf` in the root of the repository). A site's owner can specify information about the sensor configuration in this file. This gives you information (such as the sensor's location) that can help you to find which sensors recorded network traffic for the affected address block. (If the site's owner did not include this information in the site configuration file, nothing is displayed for this parameter.)

The output at the top of Example 2.1 lists the names and locations of the sensors. You need to find the sensor that covers the affected network. We are interested in traffic through the subnetwork `Div1Ext`. The sensor `S1` is associated with this subnetwork, which we will examine more closely.

Find Traffic Types and Repository Storage Times

Once you have found the sensor of interest (`S1`), you can find out what kinds of traffic the sensor carries and when it wrote data to the SiLK repository.

```
rwsiteinfo --sensor=S1 --fields=type,repo-file-count,repo-start-date,repo-end-date
```

- `--sensor` specifies which sensor to examine. In this example, it is the name of the sensor identified via the first `rwsiteinfo` command (`S1`).
- `--fields` displays the following information in table format for sensor `S1`:

```
<1>$ rwsiteinfo --fields=sensor,describe-sensor
Sensor|Sensor-Description|
    S0|           Div0Ext|
    S1|           Div1Ext|
    S2|           Div0Int|
    S3|          Div1Int1|
    S4|          Div1Int2|
    S5|          Div1log1|
    S6|          Div1log2|
    S7|          Div1log3|
    S8|          Div1log4|
    S9|          Div1ops1|
   S10|          Div1ops2|
   S11|          Div1ops3|
   S12|           Div1svc|
   S13|           Div1dhq|
   S14|           Div1dmz|
   S15|           Div1mar|
   S16|           Div1med|
   S17|          Div1nusr|
   S18|           Div1mgt|
   S19|        Div1intel1|
   S20|        Div1intel2|
   S21|        Div1intel3|
<2>$ rwsiteinfo --sensor=S1 \
   --fields=type,repo-file-count,repo-start-date,repo-end-date
   Type|File-Count|         Start-Date|           End-Date|
     in|       441|2015/06/02T13:00:00|2015/06/18T18:00:00|
    out|       512|2015/06/02T13:00:00|2015/06/18T18:00:00|
  inweb|       328|2015/06/02T13:00:00|2015/06/18T18:00:00|
 outweb|       446|2015/06/02T13:00:00|2015/06/18T18:00:00|
 innull|         0|                   |                   |
outnull|         0|                   |                   |
int2int|       511|2015/06/02T13:00:00|2015/06/18T18:00:00|
ext2ext|       204|2015/06/02T13:00:00|2015/06/18T18:00:00|
 inicmp|         0|                   |                   |
outicmp|         0|                   |                   |
  other|         0|                   |                   |
```

Example 2.1: Using `rwsiteinfo` to List Sensors, Display Traffic Types, and Show Repository Information

`type`—the types of enterprise network traffic that are associated with `S1`. This tells you the direction and origin of the network traffic it carries. It is also useful for splitting off data of interest (for instance, separating inbound Web traffic from other inbound traffic), which can speed up SiLK queries. (To learn more about the basic SiLK network types, see Sections 1.2.6 and 1.2.8.)

`repo-file-count`—the number of files that `S1` stored in the SiLK repository for each type of network traffic. Each file represents one hour of recorded data.

`repo-start-date`—the time and date of the oldest file that `S1` stored in the SiLK repository.

`repo-end-date`—the time and date of the most recent file that `S1` stored in the SiLK repository.

The output at the bottom of Example 2.1 lists the different types of network traffic carried by `S1`. The bulk of this traffic was recorded from `2015/06/02T13:00:00` through `2015/06/18T18:00:00`. In the next step of our analysis, we will therefore retrieve network flow records from `S1` within this time period.

The output from Example 2.1 can also tell us whether `S1` recorded enough data to support a meaningful network analysis. The repository contains 441 files of inbound traffic from the ISP to the network (`in`), representing 441 hours of recorded inbound traffic to the IP addresses covered by `S1`. Similarly, the repository contains 512 hours of outbound traffic from these IP addresses to the ISP (`out`), 328 hours of inbound Web traffic (`inweb`), and 446 hours of outbound web traffic (`outweb`). This is sufficient for our analysis.

Other Useful `rwsiteinfo` Options

Keep the following in mind when using this command:

- You must always specify parameters with `rwsiteinfo`; there is no default output.
- Enter `rwsiteinfo --fields` options in the order that you would like them to be displayed. For instance, to view the sensor description before the sensor name, specify `--fields=describe-sensor,sensor`
- To find the classes and types supported by an installation, run `rwsiteinfo --fields=class,type,mark-defaults`. This produces three columns labeled `Class`, `Type`, and `Defaults`. The Defaults column shows plus signs (`+`) for all the types in the default class and asterisks (`*`) for the default types in each class.
- The `rwsiteinfo` command supports optional parameters to control the formatting of its output (disable column spaces, change separation character, disable column headers, change field separators). It can also limit output to specific network types of interest. For these and other commonly-used parameters, see Appendix C.2. For a full list of `rwsiteinfo` options, type `rwsiteinfo --help`.

2.2.2 Choose Flow Records With `rwfilter`

A key step in performing a network analysis is to find and retrieve network flow records associated with the event from the SiLK repository. Use the `rwfilter` command to pull network flow records that were recorded by the sensor of interest (`S1`) during the time period of interest. These records will be used in subsequent steps in our analysis.

During this step in the analysis, `rwfilter` will be used to save network flow records of interest to a file. Later, we'll use `rwfilter` in conjunction with other SiLK commands to partition and explore this data.

About the `rwfilter` command

`rwfilter` is the most commonly used SiLK command and serves as the cornerstone for building a network analysis. It selects records from the SiLK repository, then directs the output to either files or other SiLK commands. Alternatively, `rwfilter` can select records from a pipe or file in a working directory (for instance, the output of a prior `rwfilter` command). It can optionally compute basic statistics about the flow records it reads from the repository or a file. `rwfilter` can be used on its own or in conjunction with other SiLK analysis tools, including additional invocations of `rwfilter`.

The following is a high-level view of the `rwfilter` command and its options:

`rwfilter` {*selection* | *input*} *partition output*

Specify input to `rwfilter` by using either selection or input parameters.

- *Selection* parameters read (or pull) network flow records of interest that were recorded by sensors and stored in the SiLK flow repository. They specify the attributes of records to be read from the repository, such as the sensor that recorded the data, the type of network data, the start and end dates for retrieving data, and the location of the repository.

- *Input* parameters read network flow records from pipes and/or named files in working directories containing records previously extracted from the repository or created by other means. They can be filenames (e.g., `infile.rw`) or pipe names (e.g., `stdin` or `/tmp/my.fifo`) to specify locations from which to read records. As many names as desired may be given, with both files and pipes used in the same command.

In this step of our network analysis, we will use `rwfilter`'s selection parameters to retrieve records from the SiLK repository. In future steps, we will use `rwfilter`'s input parameters to read flow records from a file or pipe.

Partitioning parameters create the "filter" part of `rwfilter`. These parameters specify which records pass the filter and which fail. This enables you to find and isolate network flow records that match the partitioning criteria you specify. `rwfilter` offers a variety of filtering parameters for specifying the criteria for pass/fail filtering, including time period, value ranges for packets and bytes, IP address, protocol, source and destination ports, and more.

Hint 2.1: Minimum Partitioning Parameters for `rwfilter`

An analysis will involve at least one call to `rwfilter` unless you are looking at records saved from a previous analysis. Each `rwfilter` call must include at least one partitioning parameter unless `--all-destination` is specified as an output parameter. Note that the partitioning parameter does not have to filter anything; it just needs to be present. The partitioning parameter `--protocol=0` is often used in this situation since it will not filter any records.

In this step of our network analysis, we will specify just one partitioning parameter: the IP address that is associated with the event. In future steps, we will specify additional partitioning parameters to identify records of interest and isolate them for further exploration with other SiLK commands.

Output parameters specify which group of records is returned from the call to `rwfilter`: those that "pass" the filter, those that "fail" the filter, both, or neither. These records can be written to pipes and/or named files in a working directory via the output parameters. (This also applies to statistics computed with `rwfilter`.) Each call to `rwfilter` must have at least one output parameter.

In this step of our network analysis, we will use output parameters to specify the name of the file where records are stored. In future steps, we will use pipes to direct `rwfilter` output to other SiLK commands for further investigation and processing.

Figure 2.2.2 shows how the `rwfilter` parameters interact.

Retrieving network flow records and saving them to a file

Our sample single-path analysis pulls network flow records from the SiLK repository with `rwfilter`, saves them to a binary file, then examines the data in the file. This is often much faster and more efficient than pulling fresh data from the repository at every step in the analysis. `rwfilter` queries into large repositories can take a long time to run—especially if you are investigating activity over an extended period of time. To look at another group of records from the repository (for instance, from a different sensor or time period), simply run `rwfilter` again to retrieve the desired records and create additional files for analysis.

Use the `rwfilter` command as follows to pull network flow records associated with the sensor, time period, and IP address of interest to our analysis:

```
rwfilter --start=2015/06/17T14 --end=2015/06/17T14 --sensor=S1 --type=all
--any-address=192.168.70.10 --pass=flows.rw
```

- `--start` and `--end` specify the time period for retrieving records from the SiLK repository (which was found in Section 2.2.1). Times can be expressed in the form *YYYY/MM/DD*T*hh:mm:ss.mmm*. This example uses an abbreviated time form. Since the `--start` and `--end` parameters only specify time down to the hour (e.g., `2015/06/17T14`), `rwfilter` retrieves an entire hour's worth of network flow data. One hour of traffic is pulled from the repository, starting at UTC 14:00:00.000 and ending at UTC 14:59:59.999 on June 17, 2015

Hint 2.2: SiLK Parameter Abbreviations

The full parameter names are `--start-date` and `--end-date`. SiLK will recognize a parameter as long as you specify enough of its name to uniquely identify it.

- `--sensor` specifies which sensor's records to retrieve (sensor `S1`, which was identified in Section 2.2.1)
- `--type` specifies the types of SiLK network traffic to retrieve. We will pull records for `all` network traffic.
- `--any-address` sets up a simple pass/fail filter for partitioning the selected network flow records. We are interested in traffic associated with the IP address 192.168.70.10. Records that match the specified IP address pass the filter; records that do not, fail it.
- `--pass` specifies the destination of the selected records that pass the filter. In this case, they are stored in the local disk file `flows.rw`.

Hint 2.3: `rwfilter` Output File Performance

Be aware that saving `rwfilter` output to a network disk file can slow down this command considerably. The speed at which records are written to the file is limited by the speed of the network. Saving to a local file is faster.

The resulting binary file, `flows.rw`, contains network flow records from the time period, sensor, traffic types, and IP address of interest. In other words, the records in this file are a snapshot of the event that we will be investigating over the course of our network analysis.

Other Useful `rwfilter` Options

Keep the following in mind when using `rwfilter`:

- Some selection parameters (such as `--sensor` and `--type`) can be used as partitioning parameters when `rwfilter` is pulling network flow records from a file or pipe. See Table C.3 for a complete list of parameters that can perform double duty for selecting and partitioning records.
- When specifying selection parameters, experienced analysts include a `--start-date` to avoid having `rwfilter` implicitly pull all records from the current day, potentially leading to inconsistent results.
- `rwfilter` partitioning parameters give analysts great flexibility in describing which flow records pass or fail the filter. Figuring out how to partition data to filter out unwanted records can be the most difficult part of using this command. Many commonly-used parameters are listed in Appendix C.3; see `rwfilter --help` for a full listing.
- Narrowing the selection of files from the repository always improves the performance of a query. On the other hand, increasing the specificity of partitioning options could improve or diminish performance. Increasing the number of partitioning parameters means more processing must be performed on each flow record. Most partitioning options involve minimal processing, but some involve considerable processing.

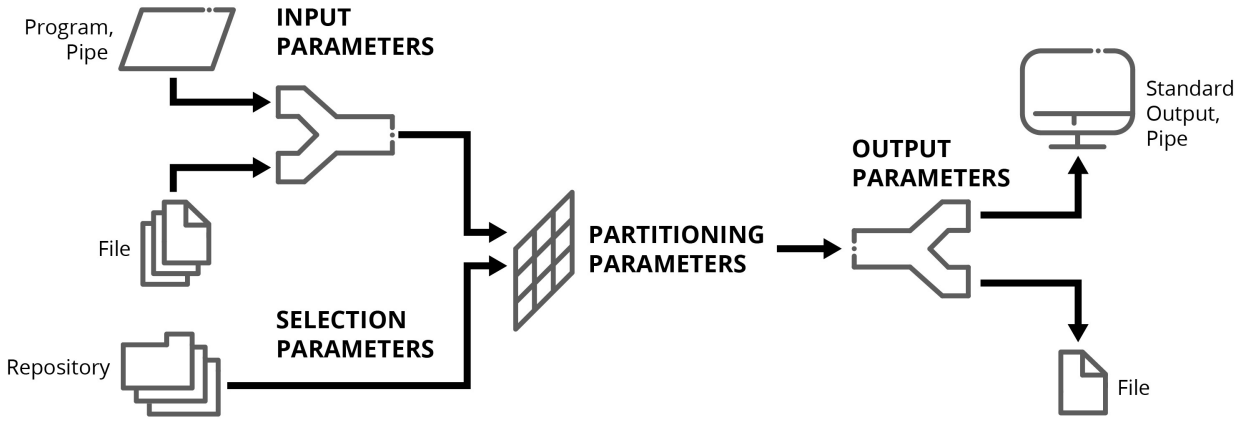

Figure 2.2: `rwfilter` Parameter Relationships

```
<1>$ rwfilter --start=2015/06/17T14 --end=2015/06/17T14 \
   --sensor=S1 --type=all --any-address=192.168.70.10 \
   --pass=flows.rw
<2>$ ls -l flows.rw
-rw-r--r--. 1 analyst analyst 365935 Nov  3 14:48 flows.rw
```

Example 2.2: Using `rwfilter` to Retrieve Network Flow Records From The SiLK Repository

Generally, processing partitioning options is much less of a concern than the number of output operations, especially disk operations, and most especially network disk operations. Choosing to output both the "pass" and "fail" sets of records will involve more output operations than choosing only one set.

- The parameter `--print-filenames` lists, on the standard error file, the name of each file as `rwfilter` opens it for reading. This provides assurance that the expected files were read and indicates the command's progress. (This is especially useful when many files are used as data sources and the command will take a long time to complete.)

- `rwfilter` can take multiple files and pipes as input. If the number of files exceeds what is convenient to put in the command line, use the `--xargs` parameter. It specifies the name of a file containing filenames from which to read flow records. This parameter also is used when another UNIX process is generating the list of input files, as in

```
find . -name '*.rw' | rwfilter --xargs=stdin ...
```

2.2.3 View Flow Records With `rwcut`

Translating network flow records from binary format into human-readable text is a helpful part of a network analysis. Use the `rwcut` command to translate the binary network flow records selected via the `rwfilter` command as tables of ASCII text.

SiLK uses binary data to speed up queries, file manipulation, and other operations. However, these data cannot be read using any of the standard text-processing UNIX tools. `rwcut` reads SiLK flow records and translates this binary data into pipe-delimited (`|`) text output. You can then view the data directly in a terminal window or read it into a text-processing, graphing, or mathematical analysis tool.

Hint 2.4: Keep Data in Binary Format Where Possible

Keep data in binary format (i.e., `*.rw` files) for as long as possible while performing an analysis. Binary SiLK network flow records are more compact and offer faster performance than the ASCII representation of these records. Use `rwcut` to inspect records or export data to other tools for further analysis.

`rwcut` can be invoked in two ways: by reading a file or by connecting it with another SiLK tool (such as `rwfilter` or `rwsort`) via a pipe. When reading a file, specify the file name in the command line. The `--fields` parameter selects, reorders, and formats SiLK data fields as text and separates them in different ways.

Displaying Flow Records

As part of the network analysis, we will use `rwcut` to take a closer look at a set of flow records from the file `flows.rw`.

```
rwcut --fields=sip,dip,sport,dport,protocol,stime --num-recs=10 flows.rw
```

- The `--fields` parameter specifies which fields in a SiLK record are shown. Field names are case-insensitive. This example displays the following fields:

  `sip`—source IP address for the flow

  `dip` —destination IP address for the flow

  `sport`—source port for the flow

  `dport`—destination port for the flow

  `protocol`—transport-layer protocol for the flow

  `stime`—start time of the flow, formatted as *YYYY/MM/DD*T*hh*:*mm*:*ss.mmm*

- The `--num-recs` parameter determines how many records `rwcut` displays. In this example, up to ten records are shown (regardless of how many records are actually in the file). If the file contains no records, `rwcut` only displays the column heading for each field.

- `flows.rw` is the name of the file containing SiLK network flow records.

The six fields specified with the `rwcut` command are displayed in the order in which they are listed. Each field is in a separate column with its own header. The source IP addresses (`sip`) for each record vary; two addresses are shown in this example. The destination IP address (`dip`) is the same for all of these records since we only pulled records associated with that IP address.

Hint 2.5: Format IP Addresses with SiLK Environment Variables

Your output may contain additional spaces in the IP address field. The environment variable `SILK_IPV6_POLICY=ignore` ignores any flow record marked as IPv6, regardless of the IP addresses it contains. Only records marked as IPv4 will be printed. Setting this environment variable has the same effect as invoking `rwcut` with the `--ipv6-policy=ignore` parameter.

Other Useful `rwcut` Options

Keep the following in mind while using the `rwcut` command:

- The `--fields` parameter selects which network flow record fields appear in `rwcut` output. Each field is associated with a number as well as a name. Table 1.2.2 lists the field numbers and their corresponding field names. Numbers can be specified individually or as ranges. Field names and numbers can be combined and can be listed in arbitrary order. For instance, `--fields=1-4,9,protocol` produces the same output as `--fields=sip,dip,sport,dport,stime,protocol`

- The `--fields` parameter also specifies the order in which fields are shown in output. Fields can be displayed in any order. Example 2.4 displays the output fields in this order: source IP address, source port, start time, destination IP address.

- If `--fields` is not specified, `rwcut` prints the source and destination IP address, source and destination port, protocol, packet count, byte count, TCP flags, start time, duration, end time, and the sensor name.

```
<1>$ rwcut --fields=sip,dip,sport,dport,protocol,stime \
   --num-recs=10 --ipv6-policy=ignore flows.rw
            sIP|            dIP|sPort|dPort|pro|                  sTime|
     10.0.40.83|  192.168.70.10|53981| 8082|  6|2015/06/17T14:00:02.631|
     10.0.40.20|  192.168.70.10|   53|58887| 17|2015/06/17T14:00:04.619|
     10.0.40.20|  192.168.70.10|   53|55004| 17|2015/06/17T14:00:04.621|
     10.0.40.83|  192.168.70.10|53982| 8082|  6|2015/06/17T14:00:12.673|
     10.0.40.20|  192.168.70.10|   53|64408| 17|2015/06/17T14:00:14.685|
     10.0.40.20|  192.168.70.10|   53|57734| 17|2015/06/17T14:00:14.689|
     10.0.40.83|  192.168.70.10|53983| 8082|  6|2015/06/17T14:00:22.709|
     10.0.40.20|  192.168.70.10|   53|63770| 17|2015/06/17T14:00:24.753|
     10.0.40.20|  192.168.70.10|   53|53374| 17|2015/06/17T14:00:24.755|
     10.0.40.83|  192.168.70.10|53984| 8082|  6|2015/06/17T14:00:32.741|
```

Example 2.3: `rwcut` for Displaying the Contents of Ten Flow Records

```
<1>$ rwfilter flows.rw --protocol=6 --max-pass-records=4 \
   --pass=stdout | rwcut --fields=1,3,sTime,2
            sIP|sPort|                  sTime|            dIP|
     10.0.40.83|53981|2015/06/17T14:00:02.631|  192.168.70.10|
     10.0.40.83|53982|2015/06/17T14:00:12.673|  192.168.70.10|
     10.0.40.83|53983|2015/06/17T14:00:22.709|  192.168.70.10|
     10.0.40.83|53984|2015/06/17T14:00:32.741|  192.168.70.10|
```

Example 2.4: `rwcut --fields` to Rearrange Output

- The `--delimited=C` parameter changes the separator from a pipe (|) to any other single character, where *C* is the delimiting character. It also removes spacing between fields. This is particularly useful with `--delimited=','` which produces comma-separated-value (CSV) output for easy import into spreadsheet programs and other tools that accept CSV files. `--delimited` is the equivalent of specifying `--no-columns --no-final-delimiter --column-sep=C`.

- When output is sent to a terminal, `rwcut` (and other text-outputting tools) automatically invoke the command listed in the user's `PAGER` environment variable to paginate the output. The command given in the `SILK_PAGER` environment variable will override the user's `PAGER` environment. If `SILK_PAGER` contains the empty string, no paging will be performed. The paging program can be specified for an individual command invocation by using its `--pager` parameter.

- For a list of the most commonly-used `rwcut` parameters and options, see Appendix C.6. For a complete list of all `rwcut` parameters, enter `rwcut --help`.

2.2.4 Viewing File Information with `rwfileinfo`

Analyses using the SiLK tool suite can become quite complex, with several intermediate files created while isolating the behavior of interest. The `rwfileinfo` displays a variety of characteristics for each file format produced by the SiLK tool suite, which helps you to manage these files. Use this command to find out more information about the file `flows.rw`, which contains the SiLK records associated with the IP address of interest.

For most analysts, the three most important file characteristics are the number of records in the file, the size of the file, and the SiLK commands that produced the file. Enter the following `rwfileinfo` command to view this information for `flows.rw`:

```
rwfileinfo --fields=count-records,file-size,command-lines flows.rw
```

- `--fields` specifies which SiLK file characteristics are displayed.

  `count-records`—the total number of network flow records in a flow record file.

  `file-size`—the size of the file in bytes.

  `command-lines`—the commands used to generate the file. This can be very helpful when performing an analysis that involves many steps and repeated applications of commands such as `rwfilter`.

- `flows.rw` is the name of the file containing SiLK network flow records.

Output is shown in Example 2.5. `flows.rw` contains 21,864 network flow records; its size is 365,935 bytes. This gives us an idea of how much network traffic is stored there. The SiLK command that generated the file is the `rwfilter` command described in Section 2.2.2.

Other Useful `rwfileinfo` Options

Keep the following in mind while using the `rwfileinfo` command:

- While `rwfileinfo` is generally associated with flow record files, it can also show information on sets, bags, and prefix maps (or pmaps). For more information, see Section 2.2.8, Section 4.2.4, and Section 6.2.7, respectively.

- Be sure to use the `--fields` parameter to choose which network flow record fields are displayed. If no fields are specified, `rwfileinfo` defaults to displaying a dozen fields—many of which are of no use to analysts.

- For flow record files, the record count is the number of flow records in the file. For files with variable-length records (indicated by a `record-length` of one) the field does *not* reflect the number of records; instead it is the uncompressed size (in bytes) of the data section. Notably, `count-records` does not reflect the number of addresses in an IPset file.

- Appendix C.26 lists the most commonly-used options for the `rwfileinfo` command. For a complete list of all parameters, enter `rwfileinfo --help`.

2.2.5 Profile Flows With `rwuniq` and `rwstats`

The next step in our network analysis is to investigate network flows to and from the IP address of interest. We will determine the most common protocols associated with these flows and find flows with low, medium, and high byte counts.

Two SiLK commands can perform these tasks.

- `rwuniq` is a general-purpose counting tool. It reads binary SiLK flow records from a file (or standard input) and counts the records, bytes, and packets for any combination of fields. `rwuniq` also groups (or *bins*) the records by a time interval specified by the analyst. In our example, this command is used to identify the hour-long time bins containing flows with low, medium, and high byte counts.

- `rwstats` provides a collection of statistical summary and counting facilities that organize and rank traffic according to various attributes. It reads binary SiLK flow records from a file (or standard input) and groups them according to a key composed of user-specified flow attributes, such as bytes, records, and packets. It then bins the records by a user-specified time interval, sums up the values of the key attributes, and sorts the bins. `rwstats` can compute statistics for each SiLK data type or for the n highest or n lowest bins. It also sums up the attribute values across all of the records it counts and displays the count for each bin as a percentage of the total. In our example, the `rwstats` command is used to identify the most commonly-used protocols associated with traffic to and from the IP address of interest.

`rwuniq` and `rwstats` overlap in their functions. Both assign flows to time bins whose length is set by the analyst. The bin size represents the length of time in seconds during which each group of records was collected, not the number of records in each bin. For each value of a key (specified by the `--fields` parameter), a bin contains counts of flows, packets, or bytes, or some other measure (specified with the `--values` parameter). `rwuniq` displays one row of output for every bin that falls within a threshold specified by the analyst. `rwstats` displays one row of output for each bin in the top N or bottom N of the total count, and computes the percentages of each data types. For a more detailed discussion of when to use each command, see Comparing `rwstats` to `rwuniq` (later in this section).

Finding Low, Medium, and High-Byte Flows with `rwuniq`

First, use the `rwuniq` command to profile flows by byte count. It can find out how many network flow records within an hour-long period have a low byte count (between zero and 300 bytes), a medium byte count (between 300 and 100,000 bytes), or a high byte count (more than 100,000 bytes). This gives you an estimate of the volume of network activity associated with the IP address of interest.

To perform this analysis, use the `rwuniq` command in conjunction with the `rwfilter` command.

1. Run `rwfilter` on the `flows.rw` file. This file contains all traffic to and from the IP address of interest during the time period of interest; it was extracted in Section 2.2.2. Running `rwfilter` on it a second time pulls all of the records in the file with the specified byte ranges.
2. Use the Unix pipe (`|`) command to direct the resulting output to the `rwuniq` command. This command counts the number of records with each range of bytes and directs the output to a file.

```
<1> $  rwfilter flows.rw --bytes=0-300 --pass=stdout \
| rwuniq --bin-time=3600 --fields=stime,type  --values=records --sort-output \
> low-byte.txt
<2> $  rwfilter flows.rw --bytes=300-100000 --pass=stdout \
| rwuniq --bin-time=3600 --fields=stime,type  --values=records --sort-output \
> medium-byte.txt
<3> $  rwfilter flows.rw --bytes=100000- --pass=stdout --values=records \
| rwuniq --bin-time=3600 --fields=stime,type  --sort-output \
> high-byte.txt
```

Parameters for the `rwfilter` command include the following:

- `flows.rw` contains the network flow records of interest.
- `--bytes` specifies the range of byte counts for selecting records. Ranges are specified using a dash (e.g., `0-300` selects all flows with byte counts between zero and 300). To specify an open-ended range, do not include an upper bound on the range (e.g., `100000-` selects all flows with byte counts greater than 100000).
- `--pass=stdout` sends all records that pass the filter to standard output.

Parameters for the `rwuniq` command include the following:

- `flows.rw` is the name of the file containing SiLK network flow records.
- `--bin-time=3600` defines a time bin that is one hour (3600 seconds) long.
- `--fields=stime,type` specifies the fields to use as keys for counting network flows. This parameter is required. We are looking at the values for `stime` (start time for the flow) and `type` (network flow type).
- `--values=records` counts the number of records that passed the `rwfilter` command.
- `--sort-output` sorts the output of the `rwuniq` command in numerical order according to the value (or values) of the key specified via the `--fields` parameter.

- The shell command `>` directs the output of `rwuniq` into the file `low-byte.txt`.

Hint 2.6: Use Unix Pipes To Improve SiLK Performance

We could have saved the `rwfilter` output to a file and run `rwuniq` on that file instead of using the UNIX pipe (`|`) command to send the output directly to the `rwuniq` command. However, one problem with generating such temporary files is that they slow down the analysis. The `rwfilter` command would have written all the data to disk, and then the subsequent `rwuniq` command would have read the data back from disk. Using UNIX pipes to pass records from one process to another skips the time-consuming steps of writing and reading data, speeding this up considerably. The SiLK tools can operate concurrently, using memory (when possible) to pass data between them. Setting up an unnamed pipe between processes is described in Appendix B.2.

Additional techniques for improving SiLK performance are described in Chapter 9.

Example 2.6 shows the output from this series of SiLK commands.

Other useful `rwuniq` options

- The `--value` parameter specifies which flow attributes are counted for a time bin. In addition to counting bytes, `rwuniq` can count records, packets, and source and destination IP addresses.
- Flow records need not be sorted before being passed to `rwuniq`. If the records are sorted in the same order as indicated by the `--fields` parameter to `rwuniq`, using the `--presorted-input` parameter may reduce memory requirements for `rwuniq`.
- For a list of the most commonly-used `rwuniq` parameters, see Appendix C.8. For a complete list of all `rwuniq` parameters, enter `rwuniq --help`.

Finding the Most Commonly-Used Protocols With `rwstats`

Another way to characterize network flows is by protocol usage. By looking at the most commonly-used protocols, we can get a sense of what types of traffic the network carries.

Use the `rwstats` command to identify the 10 most common protocols associated with traffic into and out of the IP address of interest. `rwstats` groups records into time bins by field (or fields), similar to `rwuniq`. However, `rwstats` can list the top N or bottom N bins and compute summary percentages for each item.

```
rwstats --fields=protocol --count=10 flows.rw
```

- `--fields=protocol` counts the records that carry traffic with each protocol.
- `--count=10` computes statistics for the 10 bins with the most common protocols.
- `flows.rw` is the name of the file containing SiLK network flow records.

```
<1>$ rwfileinfo --fields=count-records,file-size,command-lines \
   flows.rw
flows.rw:
  count-records       21864
  file-size           365935
  command-lines
                   1  rwfilter --start=2015/06/17T14 --end=2015/06/17T14 \
  --sensor=S1 --type=all --any-address=192.168.70.10 --pass=flows.rw
```

Example 2.5: `rwfileinfo` Displays Flow Record File Characteristics

```
<1>$ rwfilter flows.rw --bytes=0-300 --pass=stdout \
| rwuniq --bin-time=3600 --fields=stime,type \
   --values=records --sort-output >low-byte.txt
<2>$ cat low-byte.txt
              sTime|   type|   Records|
2015/06/17T14:00:00|     in|      1449|
2015/06/17T14:00:00|    out|      1500|
2015/06/17T14:00:00|  inweb|        12|
2015/06/17T14:00:00| outweb|      8339|
<3>$ rwfilter flows.rw --bytes=300-100000 --pass=stdout \
| rwuniq --bin-time=3600 --fields=stime,type \
   --values=records --sort-output >medium-byte.txt
<4>$ cat medium-byte.txt
              sTime|   type|   Records|
2015/06/17T14:00:00|     in|        66|
2015/06/17T14:00:00|    out|        96|
2015/06/17T14:00:00|  inweb|       346|
2015/06/17T14:00:00| outweb|     10051|
<5>$ rwfilter flows.rw --bytes=100000- --pass=stdout \
| rwuniq --bin-time=3600 --fields=stime,type \
   --values=records --sort-output >high-byte.txt
<6>$ cat high-byte.txt
              sTime|   type|   Records|
2015/06/17T14:00:00|    out|         3|
2015/06/17T14:00:00| outweb|         2|
```

Example 2.6: Characterizing flow byte counts with `rwuniq`

```
<1>$ rwstats --fields=protocol --count=10 flows.rw
INPUT: 21864 Records for 3 Bins and 21864 Total Records
OUTPUT: Top 10 Bins by Records
pro|   Records|  %Records|   cumul_%|
  6|     18854| 86.233077| 86.233077|
 17|      2909| 13.304976| 99.538053|
  1|       101|  0.461947|100.000000|
```

Example 2.7: Finding the top protocols with `rwstats`

Example 2.7 shows the output from this command.

Notice that the output lists just three protocols, not ten. This is because only three protocols were used during the time period of interest. `rwstats` also computes the number of records for each protocol and summarizes the percentage of traffic for each protocol.

- Protocol 6 (Transmission Control Protocol, or TCP) makes up approximately 86% of the traffic; it is used by popular applications such as the World Wide Web, email, remote administration, and file transfer programs.
- Protocol 17 (User Datagram Protocol, or UDP) makes up approximately 13% of the traffic; it is used by the Domain Name System (DNS), the Routing Information Protocol (RIP), the Simple Network Management Protocol (SNMP), and the Dynamic Host Configuration Protocol (DHCP). Voice and video is also transmitted using UDP.
- Protocol 1 (Internet Control Message Protocol, or ICMP) makes up less than 1% of the traffic; it is used by network devices (such as routers) to transmit error messages and other information.

Other useful `rwstats` options

- Each call to `rwstats` *must* include exactly one of the following:
  - a key containing one or more fields via the `--fields` parameter and an option to determine the number of key values to show via `--count` (shown in Example 2.7), `--percentage`, or `--threshold`
  - one of the summary parameters (`--overall-stats` or `--detail-proto-stats`)
- For a list of the most commonly-used `rwstats` parameters, see Appendix C.4. For a complete list of all `rwstats` parameters, enter `rwstats --help`.

Comparing `rwstats` to `rwuniq`

`rwstats` in top or bottom mode and `rwuniq` have much in common, especially since SiLK version 3.0.0. An analyst can perform many tasks with either tool. Some guidelines follow for choosing the tool that best suits a task. Generally speaking, `rwstats` is the workhorse data description tool, but `rwuniq` does have some features that are absent from `rwstats`.

- Like `rwcount`, `rwstats` and `rwuniq` assign flows to bins. For each value of a key, specified by the tool with the `--fields` parameter, a bin summarizes counts of flows, packets, or bytes, or some other measure determined by the analyst with the `--values` parameter. `rwuniq` displays one row of output for every bin except those not achieving optional thresholds specified by the analyst. `rwstats` displays one row of output for each bin in the top N or bottom N, where N is determined directly by the `--count` parameter or indirectly by the `--threshold` or `--percentage` parameters.
- If `rwstats` or `rwuniq` is initiated with multiple counts in the `--values` parameter, the first count is the primary count. `rwstats` can apply a threshold only to the primary count, while `rwuniq` can apply thresholds to any or several counts.
- For display of all bins, `rwuniq` is easiest to use. However, a similar result can be obtained with `rwstats --threshold=1`. `rwstats` will run more slowly than `rwuniq` because it must sort the bins by their summary values.

- `rwstats` always sorts bins by their primary count. `rwuniq` optionally sorts bins by their key.
- `rwstats` normally displays the percentage of all input traffic accounted for in a bin, as well as the cumulative percentage for all the bins displayed so far. This output can be suppressed with `--no-percents` to be more like `rwuniq` or when the primary count is not bytes, packets, or records.
- `rwuniq` has two counts that are not available with `rwstats`: `sTime-Earliest` and `eTime-Latest`.
- Network traffic frequently can be described as exponential, either increasing or decreasing. `rwstats` is good for looking at the main part of the exponential curve, or the tail of the curve, depending on which is more interesting. `rwuniq` provides more control of multi-dimensional data slicing, since its thresholds can specify both a lower bound and an upper bound. `rwuniq` will be better at analyzing multi-modal distributions that are commonly found when the x-axis represents time.

2.2.6 Characterize Traffic by Time Period With `rwcount`

A typical network analysis will examine network traffic by time period to see how it varies throughout the event of interest. Unusual volumes of traffic, changes in byte and packet counts, and other deviations from normal activity can help you to figure out what is causing the event to occur.

The `rwcount` command captures network activity that occurs during the time interval (or bin) that you specify. It counts the number of records, bytes, and packets for flows occurring during a bin's assigned time period. You can then view these counts in a terminal window or graph them in a plotting package such as gnuplot, a spreadsheet package such as Microsoft Excel, or another analysis tool.

Our analysis will examine network traffic to and from the target IP address during the time period of interest. We will use `rwcount` to show this activity in ten-minute time bins.

```
rwcount --bin-size=600 flows.rw
```

- `--bin-size` specifies the time bin in seconds. In this example, the time bin is 600 seconds or ten minutes.
- `flows.rw` contains the network flow records of interest.

Example 2.8 shows the output from this command. It counts the flow volume information gleaned from the `flows.rw` file by ten-minute bins.

By default, `rwcount` produces the table format shown in Example 2.8.

- The first column is the timestamp for the earliest moment in the bin.
- The net three columns show the number of flow records, bytes, and packets counted in the bin.

Examining Bytes, Packets, and Flows

Counting by bytes, packets, and flows can reveal different traffic characteristics. As noted at the beginning of this manual, the majority of traffic crossing wide area networks has very low packet counts. However, this traffic, by virtue of being so small, does not make up a large volume of bytes crossing the enterprise network.

Certain activities, such as scanning and worm propagation, are more visible when considering packets, flows, and various filtering criteria for flow records.

The traffic into and out of the IP address of interest (captured in the file `flows.rw`) jumps significantly during the ten-minute time bins `2015/06/17T14:40:00` and `2015/06/17T14:50:00`. Byte, packet, and record counts all rise during this 20-minute time period.

Examining Traffic Over a Period of Time

`rwcount` is used frequently to provide graphs showing activity over long periods of time, giving a visual representation of shifts in network traffic. Count data can be read by most plotting (graphing) applications.

The data from Example 2.8 is plotted using Microsoft Excel in Figure 2.2.6. The traffic spike that we saw in the tabular data shows up clearly in the plots on the left-hand side of this figure.

For a more detailed look at network activity during this time period, we can change the `--bin-size` from 600 seconds (ten minutes) to 60 seconds (one minute).

```
rwcount --bin-size=60 flows.rw
```

Plots of this data are shown on the right-hand side of Figure 2.2.6. Looking at the data on a minute-by-minute basis shows the variation in data flows during this event.

Hint 2.7: Data Resolution Versus Bin Size

Whether you use a larger bin size or smaller bin size depends on your data. Smaller bin sizes provide more data points to capture subtleties in traffic. If the bin size is too small, however, it becomes harder to spot trends in the data. Larger bin sizes make it easier to spot regular traffic patterns. If the bin size is too large, however, there will not be enough resolution in the data to see what is happening on your network at a given point in time.

Other Useful `rwcount` Information

Keep the following in mind when using `rwcount`.

- The default bin size is 30 seconds.
- Bin counts that have zero flows, packets, and bytes can be suppressed by the `--skip-zeroes` option to reduce the length of the listing. However, do not skip rows with zero flows if the output is being passed to a plotting program; if they are, those data points will not be plotted.

2.2.7 Sort Flow Records With `rwsort`

Sorting flow records can help you to organize them according to protocol, IP address, start time, and other attributes. Use the `rwsort` command to sort binary flow records according to the value of the field(s) you select.

`rwsort` is a high-speed sorting tool for SiLK flow records. It reads binary SiLK flow records from a file (or standard input) and outputs the same records in a user-specified order. The output records are also in binary (non-text) format and are not human-readable without interpretation by another SiLK tool such as `rwcut`. `rwsort` is faster than the standard UNIX `sort` command, handles flow record fields directly with understanding of the fields' types, and is capable of handling very large numbers of SiLK flow records provided sufficient memory and storage are available.

The following example sorts the network flow records in `flows.rw` by byte count, destination IP, and protocol from the highest to the lowest value in each field, then displays the first ten records.

```
rwsort flows.rw --fields=dip,protocol,bytes --reverse
| rwcut --fields=dip,protocol,bytes,stime --num-recs=10
```

- `--fields` specifies the sort order. It identifies the fields that are used as sort keys and specifies their precedence. In this example, `rwsort` first sorts the records by destination IP address (`dip`), then protocol (`protocol`), then byte count (`bytes`).
- By default, `rwsort` sorts from the lowest to the highest values of each sort key. `--reverse` sorts the records from the highest to the lowest values.
- The file `flows.rw` contains the SiLK record files to be sorted.
- The Unix pipe command (`|`) sends the output of the `rwsort` command to the `rwcut` command.
- The `rwcut` command and its parameters are described in Section 2.2.3.

Example 2.9 shows the results of this command. The records are first sorted from the highest destination IP address to the lowest. They are then sorted according to their protocols, then their sizes in bytes. This gives you an idea of the volume and types of traffic associated with the destination IPs.

Behavioral Analysis with `rwsort`, `rwcut`, and `rwfilter`

A behavioral analysis of protocol activity relies heavily on basic `rwcut` and `rwfilter` parameters. The analysis requires the analyst to have a thorough understanding of how protocols are meant to function. Some concept of baseline activity for a protocol on the network is needed for comparison.

To monitor the behavior of protocols, first take a sample of a particular protocol. Use `rwsort --fields=sTime`, and convert the results to ASCII text with `rwcut`. To produce byte and packet fields only, try `rwcut` with `--fields=bytes` and `--fields=packets`. Then, perform the UNIX commands `sort` and `uniq -c`.

Cutting in this manner (sorting by field or displaying select fields) can answer a number of questions:

1. Is there a standard bytes-per-packet ratio?
2. Do any bytes-per-packet ratios fall outside the baseline?
3. Do any sessions' byte counts, packet counts, or other fields fall outside the norm?

There are many such questions to ask, but keep the focus of exploration on the behavior being examined. Chasing down weird cases is tempting but can add little to your understanding of general network behavior.

```
<1>$ rwcount --bin-size=600 flows.rw
                Date|         Records|               Bytes|           Packets|
2015/06/17T14:00:00|          466.00|            798757.00|           3423.00|
2015/06/17T14:10:00|          394.00|            104668.00|           1622.00|
2015/06/17T14:20:00|          382.43|            104159.18|           1621.86|
2015/06/17T14:30:00|          393.57|            107100.82|           1670.14|
2015/06/17T14:40:00|         9335.01|          15559931.61|         191709.67|
2015/06/17T14:50:00|        10885.11|          16541697.17|         187619.55|
2015/06/17T15:00:00|            7.70|             75830.56|            897.45|
2015/06/17T15:10:00|            0.17|             21466.66|            383.33|
```

Example 2.8: Counting Bytes, Packets and Flows with Respect to Time

```
<1>$ rwsort flows.rw --fields=dip,protocol,bytes --reverse \
| rwcut --fields=dip,protocol,bytes,stime --num-recs=10
            dIP|pro|     bytes|                  sTime|
  216.207.68.32|  6|       960|2015/06/17T14:53:15.707|
  216.207.68.32|  6|       960|2015/06/17T14:54:30.604|
  216.207.68.32|  6|       120|2015/06/17T14:54:14.405|
  216.207.68.32|  6|       120|2015/06/17T14:55:29.333|
  209.66.102.50|  6|       960|2015/06/17T14:55:26.586|
  209.66.102.50|  6|       960|2015/06/17T14:56:42.465|
  209.66.102.50|  6|       120|2015/06/17T14:57:41.186|
  209.66.102.50|  6|       120|2015/06/17T14:56:25.264|
  208.206.41.61|  6|       960|2015/06/17T14:58:20.666|
  208.206.41.61|  6|       960|2015/06/17T14:46:17.427|
```

Example 2.9: Sorting by Destination IP Address, Protocol, and Byte Count

Other Useful `rwsort` Information

Keep the following in mind when using `rwsort`.

- Sort keys can be specified by field numbers as well as field names; see Table 1.2.2 for a complete list.
- Sort keys can be specified in any order. For example, `--fields=1,3` results in flow records being sorted by source IP address (1) and by source port (3) for each source IP address. `--fields=3,1` results in flow records being sorted by source port and by source IP address for each source port. (Since flow records are not always entered into the repository in the order in which they were initiated, analyses often involve sorting by start time at some point.)
- `rwsort` can also be used to sort multiple SiLK record files. If the flow records in the input files are already ordered in each file, using the `--presorted-input` parameter can improve efficiency significantly by just merging the files.
- If `rwsort` is processing large input files, disk space in the default temporary system space may be insufficient or not located on the fastest storage available. To use an alternate space, specify the `--temp-directory` parameter with an argument specifying the alternate space. This may also improve data privacy by specifying local, private storage instead of shared storage.

2.2.8 Use IPsets to Gather IP Addresses

Up to this point, our single-path analysis has focused on selecting, storing, and examining flow records. However, another common goal of single-path analysis is to compile lists of IP addresses that exhibit criteria of interest to the analyst. This section will continue our analysis by gathering and summarizing single-path criteria using named sets of IP addresses, or *IPsets*.

Create IPsets With `rwset` and `rwsetbuild`

`rwset` and `rwsetbuild` are two SiLK tools for creating sets of IP addresses (IPsets). `rwset` creates sets from flow records. `rwsetbuild` creates them from lists of IP addresses in text files. Expanding on the profiling in Section 2.2.5, `rwfilter` can be used to profile network flows by bytes. When combined, `rwset` and `rwfilter` summarize the IP addresses that exhibit byte-threshold profiles to files with descriptive names.

```
rwfilter flows.rw --bytes=0-300 --pass=stdout \
| rwset --any-file=low-byte.set
```

Parameters for the `rwfilter` command include the following:

- `flows.rw` contains the network flow records of interest.
- `--bytes=0-300` specifies the range of byte counts for selecting records (0-300 for this example).
- `--pass=stdout` sends all records that pass the filter to standard output.

Parameters for the `rwset` command include the following:

- `--any-file=low-bytes.set` specifies source and destination IP addresses from flow records with a range of 0-300 bytes to the IPset file `low-bytes.set`. Because `--any-file` was used above, the IPset file will include the IP address itself as well as any IP addresses that communicated with it.

Example 2.10 shows the output from this series of `rwfilter` and `rwset` commands.

Analysis requiring defined IP addresses should use the `rwsetbuild` tool. `rwsetbuild` creates SiLK IPsets from textual input, including canonical IP addresses, CIDR notation, and IP ranges. This approach is useful for creating whitelists and blacklists of IP addresses that may reside in network flow records presently or in the future.

```
rwsetbuild --ip-ranges servers.txt servers.set
```

Parameters for the `rwsetbuild` command include the following:

- `--ip-ranges` specifies allowing the textual input file to contain IP ranges.
- `servers.txt` specifies the textual input file name.
- `servers.set` specifies the binary IPset output file name.

Example 2.11 shows the output from the `rwsetbuild` command.

Other Useful `rwset` and `rwsetbuild` Options

Keep the following in mind while using the `rwset` command:

- `rwset` can assign IP addresses to IPsets by source, destination, and both source and destination simultaneously.
- `rwset` and `rwsetbuild` can read input from files on disk or standard input (`stdin`).
- `rwsetbuild` supports SiLK IP address wildcard notation (10.x.1-2.4,5). This notation is not supported when the `--ip-ranges` switch is specified.
- Appendix C.14 lists the most commonly-used options for the `rwset` command. For a complete list of all parameters, enter `rwset --help` or `rwsetbuild --help`.

Display IP Addresses, Counts, and Network Information With `rwsetcat`

Single-path analysis often requires the IP addresses in an IPset to be counted and displayed. This gives you an opportunity to inspect the IP addresses that met specified analytic criteria, such as behavior and network topology. `rwsetcat` can display the IP addresses in an IPset, count the number of IP addresses, display information about the network, and show minimum and maximum IP addresses as well as other summary data for the IPset.

We will continue our analysis of the low byte IP addresses from Section 2.2.8 by counting, listing, and computing summary statistics for the IP addresses in the `low-bytes.set` IPset file.

To count the number of IP addresses that exhibited 0-300 byte flow records with the IP address `192.168.70.10`, enter the following command:

```
rwsetcat --count-ips low-byte.set
```

Parameters for the `rwsetcat` command include the following:

- `--count-ips` specifies counting the number of IP addresses.
- `low-byte.set` specifies the binary IPset file for counting (containing IP addresses that exhibited 0-300 byte flow records with `192.168.70.10`.)

Example 2.12 shows the count of IP addresses contained in `low-byte.set`.

Although general counting is helpful, an analysis commonly requires additional context regarding the networks and hosts contained in the IPset. `rwsetcat` prints analyst-specified subnet ranges and the number of hosts in each subnet.

To summarize the /24 networks contained in `low-byte.set`:

```
rwsetcat --network-structure=24 low-byte.set
```

Parameters for the `rwsetcat` command include the following:

- `--network-structure` groups IP addresses by specified structure and prints the number of hosts
- `low-byte.set` specifies the binary IPset file for counting (containing IP addresses that exhibited 0-300 byte flow records with `192.168.70.10`.)

Example 2.13 shows the first four /24 networks contained in `low-byte.set` and their respective host counts.

Complete statistical summaries are also common during an analysis and can be printed with `rwsetcat`. Our previous /24 summary only prints the specified CIDR range and would require iterative commands to determine multiple CIDR network ranges that may be contained in an IPset. Therefore, `rwsetcat` provides the `--print-statistics` switch for full statistical summaries of an IPset.

```
rwsetcat --print-statistics low-byte.set
```

Parameters for the `rwsetcat` command include the following:

- `--print-statistics` specifies printing a statistical summary of IP addresses contained in an IPset.
- `low-byte.set` specifies the binary IPset file for counting (containing IP addresses that exhibited 0-300 byte flow records with `192.168.70.10`.)

Example 2.14 shows the statistical summary of IP addresses in the `low-byte.set` file.

Other Useful `rwsetcat` Options

Keep the following in mind while using the `rwsetcat` command:

- `rwsetcat` can print CIDR blocks without specifying a desired network mask. `rwsetcat` will group sequential IPs into the largest possible CIDR block and prints individual IP addresses. This switch cannot be combined with the `--network-structure` switch.

```
<1>$ rwfilter flows.rw --bytes=0-300 --pass=stdout \
| rwset --any-file=low-byte.set
<2>$ file low-byte.set
low-byte.set: SiLK, IPSET v2, Little Endian, LZO compression
```

Example 2.10: Using `rwset` to Gather IP Addresses

```
<1>$ cat servers.txt
# Text file of servers
192.168.2.1 # Single
192.168.3.0/24 # CIDR
192.168.4.1-192.168.4.128 # IP range
<2>$ rwsetbuild --ip-ranges servers.txt servers.set
<3>$ file servers.set
servers.set: SiLK, IPSET v2, Little Endian, LZO compression
```

Example 2.11: Using `rwsetbuild` to Gather IP Addresses

```
<1>$ rwsetcat --count-ips low-byte.set
574
```

Example 2.12: Using `rwsetcat` to Count Gathered IP Addresses

```
<1>$ rwsetcat --network-structure=24 low-byte.set | head -n 4
        4.2.0.0/24| 1
        6.7.1.0/24| 1
        8.1.7.0/24| 1
      10.0.20.0/24| 1
```

Example 2.13: Using `rwsetcat` to Print Networks and Host Counts

```
<1>$ rwsetcat --print-statistics low-byte.set
Network Summary
        minimumIP =         4.2.0.58
        maximumIP =    216.207.68.32
               574 hosts (/32s),    0.000013% of 2^32
                87 occupied /8s,   33.984375% of 2^8
               381 occupied /16s,   0.581360% of 2^16
               521 occupied /24s,   0.003105% of 2^24
               551 occupied /27s,   0.000411% of 2^27
```

Example 2.14: Using `rwsetcat` to Print IP Address Statistical Summaries

- The `--network-structure` switch supports multiple CIDR masks for a single command execution.
- Appendix C.15 lists the most commonly-used options for the `rwsetcat` command. For a complete list of all parameters, enter `rwsetcat --help`.

2.2.9 Resolve IP Addresses to Domain Names With `rwresolve`

Use the `rwresolve` command to display the hostnames associated with the IP addresses of interest to our network analysis. This command performs a reverse Domain Name Service (DNS) lookup on a list of IP addresses to retrieve their host names. If the lookup is successful, it prints the name of the host; if not, it prints the IP address. If an IP address resolves to multiple host names, it prints the first one found. The result is a human-readable list of hostnames that is useful for further investigation and analysis.

`rwresolve` takes delimited text as input, not binary flow records. It is designed for use with the `rwcut` command, although it can be used with any SiLK tool that produces delimited text.

Hint 2.8: Use `rwresolve` with Small Datasets

Since performing reverse DNS lookups is a time-consuming process, we strongly recommend that you use `rwresolve` only on small datasets.

```
rwcut --fields=1,1 flows.rw | rwresolve --ip-field=2
```

This command first uses the `rwcut` command to generate a list of source and destination IP addresses (`--fields=1,1`). It redirects the resulting output to the `rwresolve` command, which looks up the host names associated with the destination IP addresses.

Example 2.15 shows the default behavior of `rwresolve`. The output of the `rwcut` command is passed as input to the `rwresolve` command. By default, `rwresolve` will attempt to resolve source and destination IP addresses without the `--ip-field` option. However, this example shows that DNS was not able to resolve all source IP addresses.

`rwresolve` supports the *c-ares* and *adns* asynchronous DNS libraries and will automatically select what is available when the SiLK tool suite is installed. The *getnameinfo* and *gethostbyaddr* C libraries are also supported, however, these may impact DNS resolution speed. Analysts can select the desired resolver using the `--resolver` switch.

Example 2.16 shows how to display the destination IP address field with `rwresolve`. It is important to note that field 2 is the default position for destination IP addresses in SiLK network flow records. Therefore, if analysts decide to append a source IP address to `rwcut` output as a method for displaying the IP and hostname (such as `rwcut --fields=1-12,1`), the `--ip-fields=13` would be a required option for `rwresolve` to determine that the 13th flow record field should be resolved.

```
<1>$ rwcut --fields=sip,dip,sport,dport,protocol --num-recs=10 \
   --ipv6-policy=ignore flows.rw \
| rwresolve
                 sIP|                       dIP|sPort|dPort|pro|
          10.0.40.83|  divpx02un00001.div1.net|53981| 8082|  6|
soca1202un1.div0.net|  divpx02un00001.div1.net|   53|58887| 17|
soca1202un1.div0.net|  divpx02un00001.div1.net|   53|55004| 17|
          10.0.40.83|  divpx02un00001.div1.net|53982| 8082|  6|
soca1202un1.div0.net|  divpx02un00001.div1.net|   53|64408| 17|
soca1202un1.div0.net|  divpx02un00001.div1.net|   53|57734| 17|
          10.0.40.83|  divpx02un00001.div1.net|53983| 8082|  6|
soca1202un1.div0.net|  divpx02un00001.div1.net|   53|63770| 17|
soca1202un1.div0.net|  divpx02un00001.div1.net|   53|53374| 17|
          10.0.40.83|  divpx02un00001.div1.net|53984| 8082|  6|
```

Example 2.15: Looking Up Source and Destination Hostnames with `rwresolve`

```
<1>$ rwcut --fields=sip,dip,sport,dport,protocol --num-recs=10 \
   --ipv6-policy=ignore flows.rw \
| rwresolve --ip-fields=2
       sIP|                       dIP|sPort|dPort|pro|
10.0.40.83|  divpx02un00001.div1.net|53981| 8082|  6|
10.0.40.20|  divpx02un00001.div1.net|   53|58887| 17|
10.0.40.20|  divpx02un00001.div1.net|   53|55004| 17|
10.0.40.83|  divpx02un00001.div1.net|53982| 8082|  6|
10.0.40.20|  divpx02un00001.div1.net|   53|64408| 17|
10.0.40.20|  divpx02un00001.div1.net|   53|57734| 17|
10.0.40.83|  divpx02un00001.div1.net|53983| 8082|  6|
10.0.40.20|  divpx02un00001.div1.net|   53|63770| 17|
10.0.40.20|  divpx02un00001.div1.net|   53|53374| 17|
10.0.40.83|  divpx02un00001.div1.net|53984| 8082|  6|
```

Example 2.16: Looking Up Destination Hostnames with `rwresolve`

Figure 2.3: Displaying `rwcount` Output Using 10-Minute and 1-Minute Bins

2.3 Summary of SiLK Commands in Chapter 2

Command	Section Name	Page
`rwsiteinfo`	Get a List of Sensors With `rwsiteinfo`	17
`rwfilter`	Choose Flow Records With `rwfilter`	21
`rwcut`	View Flow Records With `rwcut`	25
`rwfileinfo`	Viewing File Information with `rwfileinfo`	28
`rwuniq` and `rwstats`	Profile Flows With `rwuniq` and `rwstats`	29
`rwcount`	Characterize Traffic by Time Period With `rwcount`	34
`rwsort`	Sort Flow Records With `rwsort`	35
`rwset` and `rwsetbuild`	Create IPsets With `rwset` and `rwsetbuild`	38
`rwsetcat`	Display IP Addresses, Counts, and Network Information With `rwsetcat`	39
`rwresolve`	Resolve IP Addresses to Domain Names With `rwresolve`	42

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Chapter 3

Case Studies: Basic Single-path Analysis

The previous chapter introduced the process of single-path analysis and covered some of the commands that are used in such analyses. This chapter walks through several detailed cases that serve as examples of single-path analyses.

Upon completion of this chapter you will be able to

- describe a sequence of steps that analysts may use in approaching a task
- apply those steps to several tasks relevant to network traffic
- use SiLK tools to automate the analysis

The case studies in this chapter use the FCCX dataset described in Section 1.7.

3.1 Profile Traffic Around an Event

One view of a network security event is that some specific activity occurs on a particular host at an identified time. In terms of the analysis in this handbook, a host is indicated by its IP address, and time is, at first consideration, associated with a given hour. With this as a starting point, the analyst needs to develop a high-level assessment of possible changes in behavior which then provides a guide to more detailed follow-on assessments. The end goal is to answer some basic questions about the event:

- Did the event impact network performance or services?
- Was the impact sufficient to warrant dedicating resources to respond?
- Was the event malicious?
- Did it demonstrate weaknesses that could enable malicious activity?
- Which entities were involved (both internal and external)?

Frequently, trying to answer such questions in detail involves too much effort. The alternative is to proceed in a staged manner, and at each stage determine if analysis should proceed further. This section describes an initial high-level analysis that can be done rapidly. It helps you to determine whether there could have been some impact from the event, along with a rough feel as to the magnitude of that impact.

Working from the target IP address and the time frame as a start, there are several possible approaches to gaining a high level indication of impact from the event:

- **traffic**—look at traffic on the targeted network and search for shifts in the size and frequency of contacts involving the target, measuring before and after the event
- **response time**—look at the overall response time for service requests (the average interval between request and response) into the network, then determine if it has increased during and following the event
- **contact rate**—look at the relative rate of contact with services (indicated by port and protocol) on the targeted network, searching for shifts in the contact rate and the size of traffic on those services
- **hosts**—look at the set of hosts in contact with the target, and determine if it has shifted unusually during and after the event.

This section will explore the first of these alternatives: looking at traffic shifts. (The other alternatives may be useful to analysts, but are not covered here.)

3.1.1 Examining Shifts in Traffic

We can apply the Formulate-Model-Analyze steps in the SiLK workflow to perform a single-path analysis that looks at shifts in network traffic around the event. First, we will filter for network flow records associated with the targeted host around the time of the event (the Formulate step from Section 1.5). This involves pulling records from the appropriate parts of the repository and isolating those that involve the targeted host. This set of records can then be divided into bins according to volumes, and then into counts for each bin before, during, and after the event (the Model step). Finally, the counts can then be interpreted to assess the potential impact of the event (the Analyze step).

Filter Traffic Around the Event

The filter portion of the analysis is structured as a query using the `rwfilter` tool. The appropriate parts of the repository are determined by date-hour (using the parameters `--start` and `--end`) and type (using the `--type` parameter). The association with the target host is indicated by the host's IP address (using the `--any-address` parameter). The filtered records are then stored in a file (using the `--pass` parameter) for later parts of the analysis.

Summarize Records

Once the records are pulled via the query, they are summarized by using `rwuniq`. The goal is to filter out the appropriate group of flows to summarize. We will create volume-based groups at low, medium, and high values for both byte volume and flow duration.

For each group, the analysis uses another call to `rwfilter` to pull records from the file generated previously. It extracts those with the volume measure for each group (using either `--bytes` or `--duration`). The output goes to `rwuniq` to count the records. Separate counts are generated for each hour and type of flow record (using `--fields=stime,type` and `--bin-time=3600`). The number of records in each group are counted (using `--values=records`). This provides a high-level view of the variation in activity from an hour before the event to an hour after it.

3.1.2 How to Profile Traffic

The resulting set of commands for this analysis are shown in Example 3.1. Command 1 is the initial query. It filters records from the repository that are associated with a specific IP address and saves them to the file `traffic.rw` in the local directory. Commands 2 through 7 are the processing steps to summarize each group of records. They produce text files with hourly counts for each type in each group.

The results of these commands are collated in Example 3.2. The counts show that there was a marked increase in low-to-medium byte and short-to-medium duration web traffic during and after the event. There was no corresponding increase in high byte or long duration traffic. Based on this, the analyst may start to focus to look for what common factors exist in the increased traffic. The goal is to build awareness of the impact of the event in a way that helps responders to deal with that impact.

```
<1>$ rwfilter --start=2015/06/17T13 --end=2015/06/17T15 \
   --sensor=S1 --type=in,inweb,out,outweb \
   --any-address=192.168.70.10 --pass=traffic.rw
<2>$ rwfilter traffic.rw --bytes=0-300 --pass=stdout \
| rwuniq --bin-time=3600 --fields=stime,type \
   --values=records --sort-output >low-byte.txt
<3>$ rwfilter traffic.rw --bytes=301-100000 --pass=stdout \
| rwuniq --bin-time=3600 --fields=stime,type \
   --values=records --sort-output >med-byte.txt
<4>$ rwfilter traffic.rw --bytes=100001- --pass=stdout \
| rwuniq --bin-time=3600 --fields=stime,type \
   --values=records --sort-output >high-byte.txt
<5>$ rwfilter traffic.rw --duration=0-60 --pass=stdout \
| rwuniq --bin-time=3600 --fields=stime,type \
   --values=records --sort-output >short-duration.txt
<6>$ rwfilter traffic.rw --duration=61-120 --pass=stdout \
| rwuniq --bin-time=3600 --fields=stime,type \
   --values=records --sort-output >med-duration.txt
<7>$ rwfilter traffic.rw --duration=121- --pass=stdout \
| rwuniq --bin-time=3600 --fields=stime,type \
   --values=records --sort-output >long-duration.txt
```

Example 3.1: Using `rwfilter` and `rwuniq` to Profile Traffic Around an Event

```
              stime|   type| sbyte| mbyte| hbyte|  sdur| mdur| ldur|
 2015/06/17T13:00:00|     in|   720|   160|      |   880|     |     |
 2015/06/17T13:00:00|  inweb|     5|   352|      |   357|     |     |
 2015/06/17T13:00:00|    out|   764|   192|     9|   960|    5|     |
 2015/06/17T13:00:00| outweb|     1|   400|      |   401|     |     |
 2015/06/17T14:00:00|     in|  1449|    66|      |  1515|     |     |
 2015/06/17T14:00:00|  inweb|    12|   346|      |   358|     |     |
 2015/06/17T14:00:00|    out|  1500|    96|     3|  1595|    1|    1|
 2015/06/17T14:00:00| outweb|  8339| 10051|     2| 18382|    9|    1|
 2015/06/17T15:00:00|     in|  2528|   550|      |  3077|    1|     |
 2015/06/17T15:00:00|  inweb|    14|   345|      |   359|     |     |
 2015/06/17T15:00:00|    out|  2520|   558|     5|  3076|    3|    3|
 2015/06/17T15:00:00| outweb| 10309| 11072|     7| 21366|   12|    9|
```

Example 3.2: Collated Profile of Traffic Around an Event

3.2 Generate Top *N* Lists

Filtering flow records by time, sensor, type, and volume characteristics often produces groups that contain flow records of interest. However, these groups also contain extraneous flows that produce noise, which makes it more difficult to spot patterns in the data.

One strategy for removing these extraneous flows is to identify the largest sub-groups, validate each sub-group, and either set it aside or include it in the collection of flows of interest. The sub-groups are identified by a combination of flow characteristics, such as the IP address of the source, the TCP flags present in the flow, or the network service involved. The contribution of each sub-group is measured by the total bytes or packets per sub-group, the number of records per sub-group, the number of distinct values present for some field in the flow record, or another summary statistic.

The overall process of pulling a collection of flow records and then removing flows not related to the analysis is sometimes referred to as *top-down analysis*. There is also a *bottom-up analysis* that involves starting with a minimal set of records that are of interest, then basing further queries to isolate more records of interest based on the field values in the minimal set.

3.2.1 Using `rwstats` to Create Top *N* Lists

To identify the identity and relative size of the sub-groups, use the `rwstats` command. It explicitly includes parameters to limit output to the largest contributors and describes the contribution of those categories to the overall flow collection[5]. Without `rwstats`, an analyst could load flow records into a spreadsheet, then generate a pivot table to identify the most common characteristics. `rwstats` is much faster and easier to use than a spreadsheet. It deals with high numbers of flow records very efficiently in terms of storage and memory usage.

Removing Unwanted Flows

In generating top-*N* lists, the Formulate stage involves eliminating flow records for network activity that is not of interest. This activity, sometimes referred to as network chaff, may include connections with not enough data exchanged to be significant, those involving services that are not important for an analysis, or, in general, anything that could obfuscate the results by contaminating the flow records retrieved for the event.

In Example 3.3, Command 1 looks at the first few flows in the `traffic.rw` file generated in Example 3.1. The sequence of flows shown are DNS queries. There is not enough information at the flow level to indicate whether they are relevant to the event that occurred.

Command 2 in the example uses a new call to `rwfilter` to exclude the unneeded flows, both saving a copy to a new flow file and sending it to `rwcut` for further examination. The examination shows that the host at 192.168.70.10 is doing a lot of communication on TCP port 8082, associated with a file management utility known as Utilistore, and the larger-volume flows appear to be associated with the host at 10.0.40.83.

Command 3 queries the flow repository to look for flows showing communication on this port with at least 150 average bytes per packet across the full data set. The results of this query are then passed to `rwuniq` to profile all of the locations to which data has been sent. The results of this profile show three hosts receiving this traffic, including both 192.168.70.10 and another host at 192.168.200.10.

[5] `rwstats` has further functions that facilitate describing collections of flows statistically, which are described in Appendix C.4

```
<1>$ rwcut --fields=1-3,protocol,bytes --num-recs=5 traffic.rw
            sIP|            dIP|sPort|pro|     bytes|
     10.0.40.20|  192.168.70.10|   53| 17|       242|
     10.0.40.20|  192.168.70.10|   53| 17|       242|
     10.0.40.20|  192.168.70.10|   53| 17|       242|
     10.0.40.20|  192.168.70.10|   53| 17|       242|
     10.0.40.20|  192.168.70.10|   53| 17|       242|
<2>$ rwfilter traffic.rw --aport=0,53 --fail=stdout \
| rwcut --fields=1-5,bytes --num-rec=5
            sIP|            dIP|sPort|dPort|pro|     bytes|
     10.0.40.27|  192.168.70.10|44358| 8082|  6|       332|
     10.0.40.27|  192.168.70.10|44383| 8082|  6|       332|
     10.0.40.83|  192.168.70.10|53596| 8082|  6|       838|
     10.0.40.83|  192.168.70.10|53597| 8082|  6|       551|
     10.0.40.83|  192.168.70.10|53598| 8082|  6|      1080|
<3>$ rwfilter --start=2015/06/13 --end=2015/06/18 --type=all \
   --proto=6 --dport=8082 --bytes-per=150- --pass=stdout \
| rwuniq --fields=dip --values=flows,distinct:bytes
            dIP|   Records|bytes-Dist|
      155.6.3.1|         1|         1|
 192.168.200.10|       804|        32|
  192.168.70.10|      1132|        37|
<4>$ rwfilter --start=2015/06/13 --end=2015/06/18 \
   --type=all --scidr=10.0.40.83/32,192.168.200.10/32 \
   --dcidr=10.0.40.83/32,192.168.200.10/32 \
   --pass=traffic2.rw
<5>$ rwstats --fields=dip,dport --values=flows,bytes --count=6 \
   traffic2.rw
INPUT: 11846 Records for 1954 Bins and 11846 Total Records
OUTPUT: Top 6 Bins by Records
            dIP|dPort|   Records|     Bytes|  %Records|   cumul_%|
 192.168.200.10| 8082|      5906|   8252849| 49.856492| 49.856492|
     10.0.40.83|56018|        45|      6357|  0.379875| 50.236367|
     10.0.40.83|55026|        18|      4653|  0.151950| 50.388317|
 192.168.200.10|  137|        15|      3510|  0.126625| 50.514942|
     10.0.40.83|  771|        15|      2520|  0.126625| 50.641567|
     10.0.40.83|56348|         3|      3390|  0.025325| 50.666892|
<6>$ rwstats --fields=dip,dport --values=bytes,flows --count=6 \
   traffic2.rw
INPUT: 11846 Records for 1954 Bins and 39548165 Total Bytes
OUTPUT: Top 6 Bins by Bytes
            dIP|dPort|     Bytes|   Records|    %Bytes|   cumul_%|
     10.0.40.83|49375|  13139355|         3| 33.223678| 33.223678|
 192.168.200.10| 8082|   8252849|      5906| 20.867843| 54.091521|
     10.0.40.83|54964|   1488312|         3|  3.763290| 57.854811|
     10.0.40.83|49408|   1488312|         3|  3.763290| 61.618100|
     10.0.40.83|54345|    328470|         3|  0.830557| 62.448657|
     10.0.40.83|54404|    328470|         3|  0.830557| 63.279214|
```

Example 3.3: Removing Unneeded Flows for Top N

Command 4 uses a further call to `rwfilter` to pull all the traffic associated with the newly located addresses 10.0.40.83 and 192.168.70.10. The addresses appear twice in the `rwfilter` call in order to specify that both the source and destination are constrained to these addresses. The results are then stored in the file `traffic2.rw` to be examined further.

Note that the addresses are specified with `--scidr` (Source CIDR block) and `--dcidr` (Destination CIDR block) instead of `--saddress` (source address), `--daddress` (destination address), or `--any-address` (both source and destination addresses). The `--scidr` and `--dcidr` parameters accept comma-separated lists of addresses in CIDR notation, whereas the other parameters accept only a single address. The /32 CIDR notation specifies a single address and thus permits us to use a list of addresses.

Summarizing Destination Port Usage By Records and Bytes

After we query and filter the flow records to isolate those of interest, we can calculate values to clarify our understanding of these data (the Model step). We could use either `rwuniq` or `rwstats` to understand the contributors to these data, which fed into the filtering process. `rwstats` allows for more explicit limits on the number of bins that are displayed. In contrast, `rwuniq` shows all of the bins for the input dataset. `rwstats` also shows the percentage contribution to the overall input of each bin and cumulatively across bins. These limits are often expressed as a count of bins, but they can also be expressed in terms of percentage contribution or a threshold on the count. The percentages are calculated based only on the first value specified for the bin. This allows `rwstats` to be used flexibly to profile the contributors to the data.

In Example 3.3, Command 5 uses `rwstats` to profile the records in `traffic2.rw`, looking at the destination port utilization in these data by the flow count (as a rough measure for how often communication takes place), with bytes also calculated as a supplementary value.

In the results, the largest contributor accounts for very close to half of the data. This is not surprising since the analyst used this port to identify these hosts as being of interest during the filtering process. Three of the other ports shown are ephemeral ports (officially, ports numbering 49,152 or more, although some Linux versions use 32,768 to 61,000, and some Windows versions use 1,025-5,000). This use indicates that 192.158.200.10 is the server and 10.0.40.83 is the client. These two IP addresses account for at most a little over a third of one percent of the records. Port 137 is the Windows netbios name service port, and port 771 is an ICMP data artifact that will be discussed below.

For a contrasting look at the data, Command 6 calls `rwstats` to summarize port utilization by the number of bytes (as a rough measure of the size of the communication taking place). By this measure, the largest contributor is not the traffic on port 8082, but rather traffic on an ephemeral port. This illustrates the need for analysts to examine the data from several perspectives to clarify its interpretation.

3.2.2 Interpreting the Top-N Lists

One key to interpreting the results shown in Example 3.3 is provided in the output from Command 3. The last column of results is the count of distinct values for the bytes in each flow that is assigned to that bin. In this case, it is the number of bytes in each flow going to a specific IP address. For the last two entries, the value is less than 10 percent of the record count, indicating that communication with the same number of bytes is common, which in turn suggests that this is automated, rather than human-driven, traffic.

In this light, the results shown from Command 5 suggest that this traffic averages about 1,400 bytes per flow to the server, with smaller acknowledgement traffic being returned to the client via the ephemeral ports. This suggestion, however, is contradicted by the results shown from command 6, which indicate that

several very large-byte flows occur to the clients on the ephemeral port, indicating that data transfer is bi-directional. Confirming the data transfer dynamics and determining if any indications of threat are present requires further analysis—pulling more traffic to see if these hosts shift behavior across time as threats in their contacts to additional hosts.

In the results for Command 5, the traffic to UDP port 137 (name service) is not answered with service traffic. Instead, it is responded to with messages using protocol 1, ICMPv4 (which appears with a 771 port number, although ICMP does not use ports). This is suggested by the common number of flows associated with these ports. It was confirmed by an inspection of the data using `rwcut` that was too long to show in the example. The flow generators encode the ICMP message type and code in the dPort field of NetFlow and IPFIX records.

In the example, the value of 771 corresponds to a message indicating that name service is unreachable. While the number of repetitions is not extensive (15 across 3 days of traffic), that repetition despite unreachable service indicates that the server is generating the port 137 traffic automatically.

Chapter 4

Intermediate Multi-path Analysis with SiLK: Explaining and Investigating

This chapter introduces intermediate multi-path analysis through application of the analytic development process with the SiLK tool suite. It discusses iteration, conditional analysis steps, categorization, and behavior identification.

Upon completion of this chapter you will be able to

- describe intermediate multi-path analysis and how it maps to the analytic development process
- describe SiLK tools commonly used with intermediate multi-path analysis
- provide example multi-path network flow analysis workflows

4.1 Multi-path Analysis: Concepts

4.1.1 What Is Multi-path Analysis?

Some network behaviors are not visible within the single view of the network flow data provided by single-path analysis. Finding them requires investigating and integrating several different views of the data. This type of analysis is known as *multi-path analysis*.

A multi-path analysis involves a deeper, multi-pronged dive into network flow data than can be accomplished with a single-path analysis. While a single-path analysis may involve looking at summary data or just one part of a data set, multi-path analysis explores different aspects of the data set (ports, IP addresses, protocols, packet and byte volumes, flow types and volumes, etc.) to find trends, leftovers, and groupings that are not necessarily visible in a single view of the data. Multi-path analysis builds upon single-path analysis; often, a single-path analysis is performed as just one phase of a multi-path analysis.

Multi-path analysis follows the general analysis framework described in Section 1.5. The overall process includes several steps:

1. Formulate the problem and gather context about the data. Is this event similar to other incidents? Which aspects of the data set should be investigated? How should we classify and group the data?

2. Model and test the data. What network behaviors are we looking for? Which statistics and metrics give us insight into these behaviors of interest?

3. Analyze the results. What did we find? How can we integrate the results of our different investigations into the data? Is our model of the event borne out by the results of our analysis?

4. Refine the analysis. Now that we have an idea of what might be going on, we can optionally take another look at the data and our assumptions to improve the analysis.

In multi-path analysis, the Formulate and Model steps are performed on multiple categories of data, each associated with aspects of the overall behavior of interest. After gathering context about the data, retrieving the data from the SiLK repository, building a model, and summarizing the data, a multi-path analysis includes an integration and analysis step that ties together the separate results to further characterize network behavior. The analyst can then iterate these steps to further refine the analysis.

4.1.2 Example of a Multi-path Analysis: Examining Web Service Traffic

A short example of a multi-path analysis is shown in Example 4.1. It looks at statistics on ports related to web traffic.

During the Formulate step of our multi-path analysis, we gather information about related categories of data. Multiple ports are used for web traffic: the normal HTTP port (TCP port 80), the HTTP secure port (TCP port 443), the alternate web ports (TCP ports 8080 and 8443), and so forth. We would like to examine traffic on each of these ports.

A single-path analysis would gather flows from all of these ports into one pool of data to produce a composite model in the next step. In contrast, the multi-path analysis in Example 4.1 gathers traffic from each port as a separate pool of data. It investigates each pool individually in the Model step, profiling individual characteristics and summarizing variations.

1. Command 1 uses the `mkfifo` command to create a set of named pipes, or FIFO (first-in-first-out) files, to support a complex series of `rwfilter` calls in Command 2. Each one is named after a port number (e.g., `multi-port8080.fifo`) to indicate that it carries data related to that port.

Hint 4.1: Use Named Pipes for Efficient Analytics

Named pipes efficiently transfer data from one SiLK command to another without the overhead of writing data to a disk file at each step, making the analytic run more quickly. Using named pipes also makes the analytic easier to script. Unlike regular operating system pipes (`|`), named pipes persist after a command finishes executing and can therefore be used as a source of input data for subsequent SiLK commands.

See Chapter 9 for additional tips on how to improve the performance of your SiLK analytics. Appendix B.2.5 has more information on named pipes.

```
<1>$ mkfifo /tmp/multi-port8080.fifo; \
     mkfifo /tmp/multi-port443.fifo; \
     mkfifo /tmp/multi-port8443.fifo
<2>$ rwfilter --start=2015/06/15 --end=2015/06/21 \
   --type=out,outweb --proto=6 --flags-all=SAF/SAF,SAR/SAR \
   --packets=4- --bytes-per=65- --pass=stdout \
| rwfilter stdin --aport=8080 \
   --pass=/tmp/multi-port8080.fifo --fail=stdout \
| rwfilter stdin --aport=443 --pass=/tmp/multi-port443.fifo \
   --fail=stdout \
| rwfilter stdin --aport=8443 \
   --pass=/tmp/multi-port8443.fifo --fail=stdout \
| rwfilter stdin --aport=80 --pass=stdout \
| rwbag --bag-file=sipv4,bytes,./output/tmp80.bag &
<3>$ rwbag --bag-file=sipv4,bytes,./output/tmp443.bag \
   /tmp/multi-port443.fifo &
<4>$ rwbag --bag-file=sipv4,bytes,./output/tmp8443.bag \
   /tmp/multi-port8443.fifo &
<5>$ rwbag --bag-file=sipv4,bytes,./output/tmp8080.bag \
   /tmp/multi-port8080.fifo &
<6>$ wait
<7>$ rwbagcat --print-stat=./output/out80.txt \
   ./output/tmp80.bag
<8>$ rwbagcat --print-stat=./output/out8080.txt \
   ./output/tmp8080.bag
<9>$ rwbagcat --print-stat=./output/out443.txt \
   ./output/tmp443.bag
<10>$ rwbagcat --print-stat=./output/out8443.txt \
   ./output/tmp8443.bag
<11>$ grep 'mean' ./output/out{80,8080,443,8443}.txt
./output/out80.txt:              mean:  5.471e+06
./output/out8080.txt:              mean:  4.707e+07
./output/out443.txt:              mean:  2.585e+07
./output/out8443.txt:              mean:  1.367e+08
<12>$ grep 'standard' ./output/out{80,8080,443,8443}.txt
./output/out80.txt:standard deviation:  2.021e+07
./output/out8080.txt:standard deviation:  6.655e+07
./output/out443.txt:standard deviation:  5.704e+07
./output/out8443.txt:standard deviation:  9.266e+06
```

Example 4.1: Examining Flows for Web Service Ports

2. Commands 2 through 5 set up an analytical structure known as a *manifold*, which is discussed in more detail in section 4.2.1. The pipelined series of `rwfilter` calls in Command 2 first pulls from the repository all outbound complete TCP flows (shown in the selection and partitioning commands in the first `rwfilter` call). These outbound flows (selected by `--type=out,outweb`) include traffic produced by the monitored network. Selecting complete TCP flows (partitioned by a combination of `--proto`, `--flags-all`, `--packets`, and `--bytes-per`) avoids data that includes scans, extended sessions, redundant flow termination, and other data artifacts—all of which might confuse the analysis.

   The subsequent `rwfilter` calls in Command 2 then divide the retrieved flow records into separate pools, one for each of the web-related ports using both standard output and the FIFO files. Each of these `rwfilter` calls culminates (at the end of Command 2 and in Commands 3 through 5) in a call to `rwbag` to generate a summary set of byte counts per source IP address in each pool. Section 4.2.4 describes more about the bag tools.

3. To make all of this work in Linux, these commands have to operate in a producer-consumer manner as background processes. Command 6 is a shell command that causes the script to wait until the producer-consumer processes have finished, so that the counts are all complete.

4. Commands 7 through 10 use `rwbagcat` to calculate descriptive statistics for each of the pool of data. They send each set of statistics to a separate text file.

5. Commands 11 and 12 show two of these statistics, mean and standard deviation, across the pools of data to produce integrated summaries of outbound web traffic on these ports.

4.1.3 Exploring Relationships and Behaviors With Multi-path Analysis

Many possible relationships in network traffic can be explored during multi-path analyses, in addition to the port-protocol alternatives in the web traffic analysis shown in Example 4.1.

- **Address relationships** can be explored by looking at the behavior of a block of addresses as seen by varying sensors, looking at variations in behavior between addresses within a block, or looking at behaviors of several blocks within a given Autonomous System that is handled by a common route. These address relationships might be useful for analysis tasks such as confirming suspected malware propagation or isolating targeted scanning from more general scanning.
- **Timing relationships** can be explored by separately summarizing and examining behavior before, during, and after the times associated with network events. They can also be explored by profiling behavior around an event in comparison to a period of normal activity that goes on for a similar period of time. These timing relationships could be useful to identify more subtle intrusions, for example, or to isolate activity that might indicate malicious pivoting between parts of the network.
- **Volumetric relationships** can be explored to find more complex relationships between pools of data depending on byte volumes or transfer rates. These volumetric relationships could help to indicate covert data exfiltration, for example, or detect when services are exploited to support malicious activity.

4.1.4 Integrating and Interpreting the Results of Multi-path Analysis

During the Model phase of the analysis, the focus is often about determining values to provide insight on the relationships in the data. Measures of central tendency (such as averages) are frequently useful. They should be extended by measures of extent (such as range or standard deviation) to provide context for variation

between pools of data. With these measures calculated, a range of activity can be specified. In the web traffic analysis shown in Example 4.1, for instance, each pool of network traffic associated with a port is profiled into an output text file using the `rwbagcat --print-stat` command, which computes a variety of descriptive statistical measures, including mean and standard deviation.

Once the measures are calculated, integrate them by matching them across the pools of data to establish trends or contrast values for the identified relationships. In Example 4.1, the standard deviations are almost all larger than the mean values, indicating that the count distribution has a long tail. More traffic values are lower than the mean than higher, but the higher ones go quite high.

Interpreting the results involves examining the statistics given and applying what insight the analyst can provide. Consider a variety of explanations for the behavior. If necessary, refine and iterate the analysis to support or deny these explanations.

Generally, consider benign interpretations for behavior first, and only reject them if appropriate contradiction can be found. In Example 4.1, the benign interpretation is that much of the traffic across these ports cannot be readily differentiated; the main difference is which port it was sent on. An alternative interpretation is that the large bulk of relatively low-byte traffic and the long tail of relatively high-byte traffic should be examined separately to determine if suspicious traffic is present. This would involve iterating the analysis to partition and separately examine low-byte and high-byte traffic for each port.

4.1.5 "Gotchas" for Multi-path Analysis

While it is quite possible to explore combinations of relationships within a given analysis, some care is needed. As the number of relationships being combined increases, so does both the size and the complexity of the results. This raises several concerns in performing combined multi-path analyses:

- Interpreting the results can require a lot of rather tedious effort for limited results. It is likely that the number of data combinations that need to be evaluated will yield many cases that are not of interest to the investigation, but may still need to be explored either for completeness or to be sure that all interesting cases are dealt with. If the combination of data relationships is not carefully chosen, analysts may spend a lot of time without much compensating insight.
- The amount of data required to fully explore combinations of relationships can be extensive, which will both slow the gathering step and require iteration across cases. Finding appropriate data to cover combinations can involve effort—for example, establishing that "normal" network activity does not itself contain malicious activity!
- As the number of combinations involved in analysis increases, so does the possibility that observed differences may occur by coincidence. This can lead to unintended "cooking" of the results, focusing on combinations that confirm the analysts' preconceptions, rather than on a more holistic view of the behaviors.

Based on these concerns, we recommend that you **keep your multi-path analyses as simple as possible**, given the behaviors being studied. It may well be preferable to perform a series of simpler analyses rather than a single, complex, multi-factor analysis—both more manageable in action and producing more easily understood results.

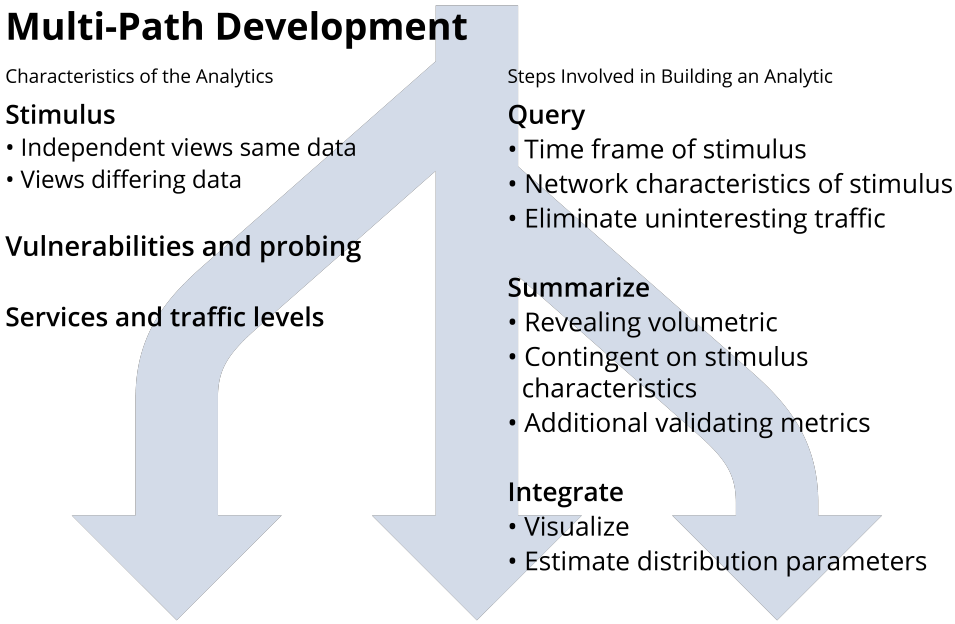

Figure 4.1: Multi-Path Analysis

4.2 Multi-path Analysis: Analytics

The SiLK commands, parameters, and examples described in this chapter can be employed with any analysis method. However, they involve more complex uses of the SiLK tool suite than the commands described in Chapter 2. Multi-path analyses frequently make use of these commands to construct analytics and store intermediate and final results.

4.2.1 Complex Filtering With `rwfilter`

Complex filtering combines operating system pipes with `rwfilter` output parameters to perform large-scale, multi-path flow analyses. It is an important concept to adopt and incorporate into the multi-path analysis process discussed in Section 4.1 and the overall SiLK workflow described in Section 1.5.

The conditional steps, refinement, and iteration of multi-path analysis usually require multiple `rwfilter` queries. Wide time periods, large network ranges, and increasing network traffic are a few examples that complicate this process. Unfortunately, the increasing `rwfilter` directory and file searches needed to support such analyses also impact disk input/output (I/O) performance and latency.

To address these trade-offs, `rwfilter` provides three output parameters to optimize repository queries and classify traffic behavior.

- `--pass-destination` writes flow records that pass *all* partitioning criteria to a path.
- `--fail-destination` writes flow records that fail *any* partitioning criteria to an alternate path.
- `--all-destination` writes *all partitioned flow records* to a third path.

These parameters are so commonly used that the remainder of this handbook will refer to them by their common abbreviations (`--pass`, `--fail`, and `--all`). All three can be combined and repeated within the same `rwfilter` statement. They can write network flow records to a newly-created file, a named pipe, standard output (`stdout`), or standard error (`stderr`).

Multi-level Filtering With Pipes and Manifolds

A *manifold* combines several `rwfilter` commands to categorize traffic. By using operating system pipes and switches with the `--pass` and `--fail` parameters, analysis can chain multiple `rwfilter` statements together to reduce an initial broad data pull into smaller sets of results that isolate traffic of interest for further analysis. After examining your manifold's initial categorization of network flow data, you can adjust the parameters of subsequent `rwfilter` calls to re-categorize data and find additional records of interest.

Chaining `rwfilter` calls into a manifold also can reduce the number of files saved to disk, since the output from each `rwfilter` call is passed to the next one via UNIX pipes. This can improve the analytic's performance.

Manifolds perform complex traffic categorization by filtering data into overlapping and non-overlapping traffic categories.

Manifolds with Non-overlapping Traffic. If the categories are *non-overlapping*, the manifold uses the `--pass` parameter to write matching traffic to a file, as shown in Figure 4.2.1. The shaded arrows indicate data flows from the SiLK repository to the series of `rwfilter` commands that comprise the manifold. Each `rwfilter` command uses the `--pass` parameter to save the records that meet the filtering criteria to a file. It also uses the `--fail` parameter to transfer the remaining traffic to the next `rwfilter` command for further filtering. The final `rwfilter` command in Figure 4.2.1 saves the last category and uses the `--fail` parameter to discard the remaining uncategorized traffic. (Alternatively, the manifold could save the discarded traffic to a file.)

Manifolds with Overlapping Traffic. If the categories are *overlapping*, the manifold again uses the `--pass` parameter to filter traffic in a category. But it would use the `--all` parameter as shown in Figure 4.2.1 to transfer *all* traffic to the next call to `rwfilter`. With overlapping categories, the manifold is not done with a record just because it assigned a first category to it. The record may belong to other categories as well, which would be identified by subsequent calls to `rwfilter`.

Figure 4.2.1 also shows how records can be passed to subsequent `rwfilter` calls via the `--fail` parameter. Using successive `rwfilter` calls that combine the `--pass`, `--fail`, and `--all` parameters gives you a high degree of control over how your network traffic is categorized for analysis.

Simple Manifold: Filtering Incoming Client and Server Traffic

In Example 4.2, we look for inbound flows from external servers and clients. The manifold sorts these flows into two separate files. This is an example of a non-overlapping manifold, since incoming client and server traffic have independent characteristics.

- The first `rwfilter` command in the manifold filters out all incoming client traffic.
  - The `--start` and `--sensor` selection parameters specify the time period and network sensor of interest.
  - `--protocol=6` selects Transmission Control Protocol (TCP) traffic.
  - `--flags-initial=SA/SA` selects traffic where TCP flags on the first packet of the flow record are set to "SYN/ACK", indicating that the source IP address is a server.
  - `--packets=3-` selects flow records with three or more packets to identify TCP sockets.
  - `--pass=incoming-client.rw` stores flow records that match the filtering criteria to the file `incoming-client.rw`.
  - `--fail=stdout` sends all records that do not match the filtering criteria to the second part of the manifold.

- The second `rwfilter` command in the manifold selects incoming server traffic.
  - `stdin` tells the `rwfilter` command to process flow records from standard input (i.e., the output from the previous `rwfilter` command).
  - The command does not filter on Sensor, Type and Protocol. It looks at traffic that does not meet those criteria.
  - `--flags-initial=S/SA` selects traffic where TCP flags on the first packet of the flow record are set to "SYN" with no "ACK," indicating the source IP address is a client.

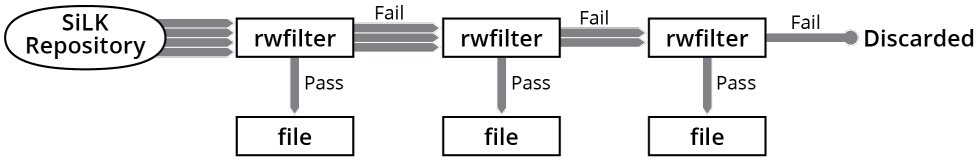

Figure 4.2: Diagram of a Simple, Non-overlapping Manifold

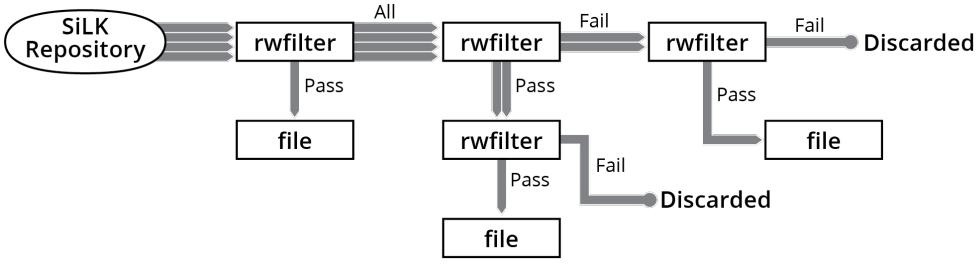

Figure 4.3: Diagram of a Complex, Overlapping Manifold

```
<1>$ rwfilter --start=2015/06/17T15 --sensor=S5 --type=in \
   --protocol=6 --flags-initial=SA/SA --packets=3- \
   --fail=stdout --pass=inbound-clients.rw \
| rwfilter stdin --flags-initial=S/SA --packets=3- \
   --pass=inbound-servers.rw
```

Example 4.2: Simple Manifold to Select Inbound Client and Server Flows

- `--packets=3-` selects flow records with three or more packets, which is the minimum number required to open a TCP socket.
- `--pass=incoming-server.rw` stores flow records that match the filtering criteria to the file `incoming-server.rw`
- Notice that the second `rwfilter` command did not specify a `--fail` destination. We are only interested in the records that pass the filtering criteria in the second part of the manifold, so there is no need to save the ones that fail.

Hint 4.2: An Example TCP Session

Figure 4.2.1 shows the TCP flags for client and server communication. The client first sends a packet with the SYN flag to initiate the TCP connection. The server responds with a packet with SYN and ACK flags to acknowledge the client request. The client then sends a packet with the ACK flag to acknowledge receipt of the server SYN/ACK packet; it follows with one or more packets that have PSH and ACK flags. The server responds to each client PSH/ACK packet with packets that also have PSH and ACK flags. At this stage of client/server communication, they have established a TCP socket and exchanged data.

To complete the session, the client sends the server a packet with FIN and ACK flags. The server responds to the client with a packet that has an ACK flag to acknowledge receipt of the client's FIN/ACK packet. The server follows with a packet that has FIN and ACK flags. The client then responds by sending a packet with a ACK flag, responding to the server's FIN/ACK packet, ending the session. For more detailed information about TCP flags, see Appendix A.5.2.

Expanding the Simple Manifold: Filtering for Incoming and Outgoing Client and Server Traffic

To expand the simple manifold in the previous example to partition both inbound and outbound traffic, we make three modifications as shown in Example 4.3.

1. Prefilter traffic to ignore flows that we know are unwanted. These consist of non-TCP flow types other than `in` and `out` plus flows with fewer than three packets.
2. Filter traffic from internal and outgoing servers and clients into files.
3. Store the leftover flows in a file for later use.

- The first `rwfilter` command in the manifold filters out unwanted traffic.

  `--start` and `--sensor` selection specify the time period and network sensor of interest.

  `--protocol=6` selects Transmission Control Protocol (TCP) traffic.

  `--packets=3-` selects flow records with three or more packets indicating TCP sockets.

  `--pass=stdout` sends all records that match the filtering criteria to the second part of the manifold. Records that do not match are ignored.

- The second `rwfilter` command in the manifold filters out inbound server traffic.

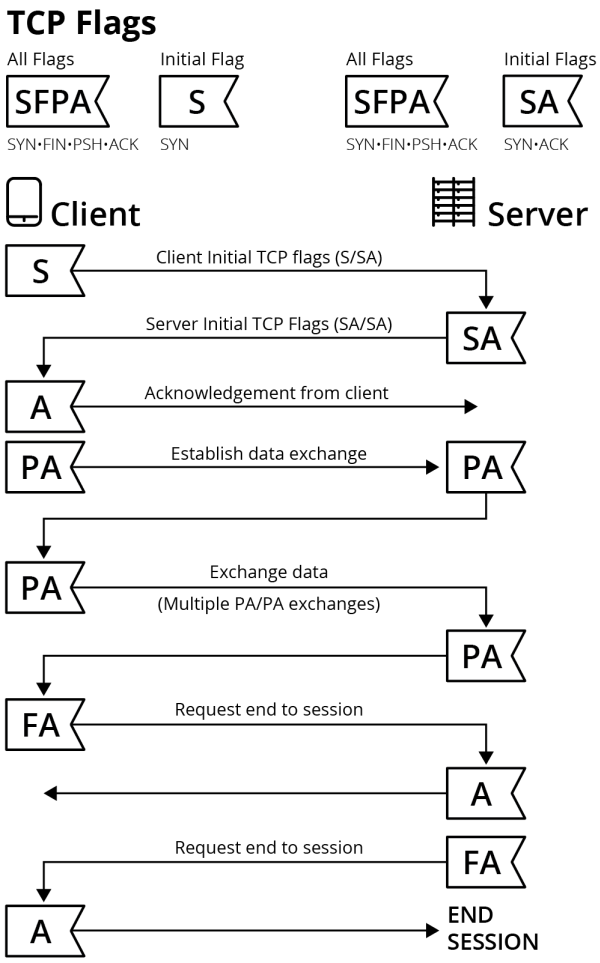

Figure 4.4: Client and Server TCP flags

```
<1>$ rwfilter --start=2015/06/17T15 --sensor=S5 --type=in,out \
   --protocol=6 --packets=3- --pass=stdout \
| rwfilter stdin --type=in --flags-initial=SA/SA \
   --pass=incoming-server.raw --fail=stdout \
| rwfilter stdin --type=in --flags-initial=S/SA \
   --pass=incoming-client.raw --fail=stdout \
| rwfilter stdin --type=out --flags-initial=SA/SA \
   --pass=outgoing-server.raw --fail=stdout \
| rwfilter stdin --type=out --flags-initial=S/SA \
   --pass=outgoing-client.raw --fail=leftover.raw
<2>$ for f in incoming-server.raw incoming-client.raw \
   outgoing-server.raw outgoing-client.raw leftover.raw; \
     do echo -n "$f: "; \
     rwfileinfo --fields=count-records $f; \
     done
incoming-server.raw: incoming-server.raw:
  count-records       1001
incoming-client.raw: incoming-client.raw:
  count-records       41
outgoing-server.raw: outgoing-server.raw:
  count-records       41
outgoing-client.raw: outgoing-client.raw:
  count-records       1002
leftover.raw: leftover.raw:
  count-records       2
```

Example 4.3: Complex Manifold to Select Inbound Client and Server Flows

`stdin` tells the `rwfilter` command to process flow records from standard input (i.e., the output from the previous `rwfilter` command).

`--type=in` selects inbound traffic.

`--flags-initial=SA/SA` selects traffic where TCP flags on the first packet of the flow record are set to "SYN/ACK", indicating that the source IP address is a server.

`--pass=incoming-server.raw` stores flow records that match the filtering criteria to the file `incoming-server.raw`

`--fail=stdout` sends all records that do not match the filtering criteria to the next part of the manifold.

- The third `rwfilter` command in the manifold filters out inbound client traffic.

  `--type=in` selects inbound traffic.

  `--flags-initial=S/SA` selects traffic where TCP flags on the first packet of the flow record are set to "SYN", indicating the source IP address is a client.

  `--pass=outgoing-client.raw` stores flow records that match the filtering criteria to the file `outgoing-client.raw`.

- The fourth `rwfilter` command in the manifold filters out outbound server traffic.

  `--type=out` selects outbound traffic.

  `--flags-initial=SA/SA` selects traffic where TCP flags on the first packet of the flow record are set to "SYN/ACK", indicating the source IP address is a server.

  `--pass=outgoing-server.raw` stores flow records that match the filtering criteria to the file `outgoing-server.raw`

- The fifth (and final) `rwfilter` command in the manifold filters out outbound client traffic.

  `--type=out` selects outbound traffic.

  `--flags-initial=S/SA` selects traffic where TCP flags on the first packet of the flow record are set to "SYN", indicating the source IP address is a client.

  `--pass=outgoing-client.raw` stores flow records that match the filtering criteria to the file `outgoing-client.raw`

  `--fail=leftover.rw` saves all records that do not match the filtering criteria in the file `leftover.raw`.

4.2.2 Finding Low-Packet Flows with `rwfilter`

The TCP state machine is complex (see Figure A.5.2). As described in Appendix A.5, legitimate service requests require a minimum of three (more commonly four) packets in the flow from client to server. Flows from server to client may only have two packets.

Several types of illegitimate traffic (such as port scans and responses to spoofed-address packets) involve TCP flow records with low numbers of packets. Although legitimate TCP flow records occasionally have low numbers of packets (such as continuations of previously timed-out flow records, contact attempts on hosts that do not exist or are down, services that are not configured, and RST packets on already closed connections), this behavior is relatively rare. Understanding where low-packet TCP network traffic comes

from and when such flow records are collected most frequently can therefore help you to identify traffic that is potentially illegitimate.

Example 4.4 shows how to use the manifold concept from Section 4.2.1 to find low-packet traffic. It illustrates how `rwfilter` can be used to refine selections to isolate flow records of interest.

1. The first call to `rwfilter` in Command 1 selects all incoming flow records in the repository on 6/17/2015, that describe TCP traffic, and that had one to three packets in the flow record. It is the only `rwfilter` call that pulls data directly from the SiLK repository; as such, it is the only one that uses selection parameters.

   This call also uses a combination of partitioning parameters (`--protocol` and `--packets`) to isolate low-packet TCP flow records from the selected time range. It uses the `--pass` switch twice: once to save the selected records to the file `/.Ex4-data/lowpacket.rw` and once to direct the selected records to standard output (`stdout`) for use by the next `rwfilter` command in the manifold.

   The `--print-statistics` parameter saves information about the `rwfilter` call to the file `temp-all.txt`, including the number of repository files retrieved by `rwfilter`, the total number of flow records, and the number of records that passed or failed the filter.

2. The second call to `rwfilter` in Command 1 uses `--flags-all` as a partitioning parameter to pull out flow records of interest. It passes flow records that had the SYN flag set in any of their packets, but do not have the ACK, RST, and FIN flags set in any of their packets. It fails those that did not show this flag combination. It saves statistics to the file `temp-syn.txt`. Records that fail this filter are passed to the next `rwfilter` call via the `--fail=stdout` parameter.

3. The third call to `rwfilter` extracts the flow records that have the RST flag set, but had the SYN and FIN flags not set. It saves statistics to the file `temp-rst.txt`.

4. Command 2 displays the statistics information saved at each step in the manifold. We can see how the succession of calls to `rwfilter` progressively refine the data, and how data passes from one filter to the next.

4.2.3 Time Binning, Options, and Thresholds With `rwstats`, `rwuniq` and `rwcount`

Approximating Flow Behavior Over Time

SiLK flow records do not contain information about the time distribution of packets and bytes during a flow. Grouping packets into flow records results in a loss of timing information; specifically, it is not possible to tell how the packets in a flow are distributed over time. Even at the sensor, the information about the time distribution of packets in a flow is lost.

By default, SiLK distributes the packets and bytes equally across all the milliseconds in the flow's duration. This approximation works well for investigating overall trends in network behavior.

However, some types of analysis benefit from intentionally changing the time distribution of packets. For example, incident analysis investigates behavior during specific time bands. Changing the time distribution of packets and bytes (or *load-scheme*) emphasizes different flow characteristics of interest.

Analysts can impose a specific time distribution on `rwcount` by using the `--load-scheme` parameter. `rwcount` can assign one of seven time distributions of packets and bytes in the flow to allocate the volume to time bins.

Figure 4.2.3 illustrates the allocation of flows, packets, and bytes to time bins under different load-schemes (which are described more fully in Table C.5). The squares depict a fixed number of packets or bytes. The partial squares are proportional to the complete squares. The wide, solidly filled rectangles depict entire flows, along with their packets and bytes. They appear once in schemes 1, 2, and 3 (where one bin receives the entire flow with its packets and bytes) and in every bin for scheme 5 (where every bin receives the entire flow). The wide, hollow rectangles only appear in scheme 6 and represent whole flows with no packets or bytes.

Using Thresholds to Profile a Slice of Flows

`rwuniq` allows you to set thresholds to segregate IP addresses by the number of flows, sizes of flows, and other values. Recall that `rwuniq` reads SiLK flow records, groups them according to a key composed of user-specified flow attributes, then computes summary values for each group (or bin), such as the sum of the bytes fields for all records that match the key. Thresholding limits the output of `rwuniq` to bins where the summary value meets user-specified minimum or maximum values.

The `--bytes`, `--packets`, and `--flows` parameters are all threshold operators for filtering. For example, to show only the source IP addresses with 200 flow records or more, use the `--flows=200-` parameter as shown in Example 4.5.

```
<1>$ rwfilter --start-date=2015/06/17 \
   --type=in,inweb --protocol=6 --packets=1-3 \
   --print-statistics=temp-all.txt \
   --pass=./Ex4-data/lowpacket.rw --pass=stdout \
| rwfilter --flags-all=S/SARF \
   --print-statistics=temp-syn.txt \
   --pass=./Ex4-data/synonly.rw --fail=stdout stdin \
| rwfilter --flags-all=R/SRF \
   --print-statistics=temp-rst.txt \
   --pass=./Ex4-data/reset.rw stdin
<2>$ cat temp-all.txt output/temp-syn.txt output/temp-rst.txt
Files    415.   Read     9083613.   Pass      906016.  Fail      8177597.
Files      1.   Read      906016.   Pass       97279.  Fail       808737.
Files      1.   Read      808737.   Pass      130145.  Fail       678592.
```

Example 4.4: Extracting Low-Packet Flow Records

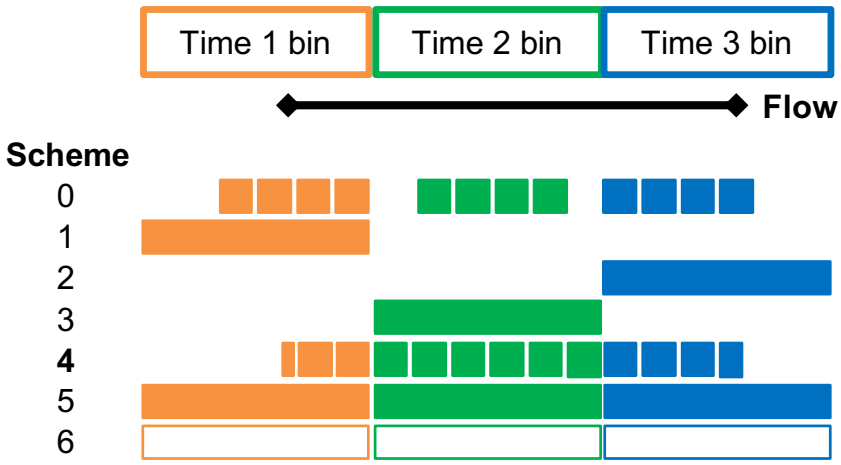

Figure 4.5: Allocating Flows, Packets and Bytes via `rwcount` Load-Schemes

In addition, `rwuniq` can count bytes and packets for a flow threshold through the `bytes` and `packets` values in the `--values` parameter, as shown in Example 4.6. This example counts the byte and packet volumes for all IP addresses that exceed a minimum flow threshold of 2000 records (`--values=Bytes,Packets,Flows --flows=2000-`).

If a range (such as `--flows=2000-`) is not specified, the parameter simply adds the named count to the list started by the `--values` parameter. We recommend using the `--values` parameter for this purpose. `--values` provides greater control over the order in which the values are displayed than the other thresholding parameters.

Hint 4.3: How to Specify Ranges with `rwuniq`

`rwuniq` provides three ways to specify ranges: with the low and high bounds separated by a hyphen (e.g., 200–2000); with a low bound followed by a hyphen (e.g., 200–) denoting that there is no upper bound; and with a low bound alone (e.g., 200). Unlike `rwfilter` partitioning values, the last method denotes a range with no upper bound, not just a single value. **We do not recommend using this method because it can lead to confusion.**

If multiple threshold parameters are specified, `rwuniq` will print all records that meet *all* of the threshold criteria, as shown in Example 4.7.

Profiling With Compound Keys

Profiling can also be done by counting and thresholding combinations of fields, in addition to the simple counting shown previously. Both the `rwuniq` and `rwstats` commands support compound keys.

Using Compound Keys with `rwuniq`. To use a compound key, specify it using a comma-separated list of values or ranges in the `rwuniq --fields` parameter. Keys can be manipulated in the same way as with `rwcut`: `--fields=3,1` is a different key than `--fields=1,3`.

In Example 4.8, the `--fields` parameter is used to identify communication between clients and specific services only when the number of flows for the key exceeds a threshold. It counts and thresholds incoming traffic to identify those source IP addresses with the highest number of flow records that connect to specific TCP ports (`--fields=sIP,sPort`).

Using Compound Keys with `rwstats`. Alternatively, you can perform this analysis by running the `rwstats` command with compound keys. In Example 4.9, the `--fields` parameter is similarly used to count incoming traffic and identify the eleven source IP addresses with the highest number of flow records that connect to specific TCP ports (`--fields=sIP,sPort`). In addition to counting and displaying these records, `rwstats` computes their cumulative statistics. This allows you to directly compare the amount of traffic carried by each source IP-port combination.

Isolating Behaviors of Interest

`rwuniq` can be used in conjunction with `rwfilter` to profile flow records for a variety of behaviors:

```
<1>$ rwfilter --start-date=2015/06/17T15 --type=in --protocol=0- \
   --pass=./Ex4-data/in_month.rw
<2>$ ls -l ./Ex4-data/in_month.rw
-rw-r--r--. 1 analyst analyst 7409538 Apr 25 17:22 ./Ex4-data/in_month.rw
<3>$ rwuniq ./Ex4-data/in_month.rw --field=sIP --value=Flows \
   --flows=200- \
| head -n 10
            sIP|   Records|
 192.168.143.57|       481|
 192.168.161.26|       443|
  192.168.40.51|       254|
     10.0.40.23|      5128|
 192.168.165.83|       378|
  192.168.40.25|     11951|
192.168.162.160|       401|
     10.0.40.92|      1838|
192.168.143.162|       635|
```

Example 4.5: Constraining Counts to a Threshold by using `rwuniq --flows`

```
<1>$ rwfilter --start-date=2015/06/17T15 --type=in --protocol=0- \
   --pass=./Ex4-data/in_month.rw
<2>$ ls -l ./Ex4-data/in_month.rw
-rw-r--r--. 1 analyst analyst 7409538 Apr 25 17:22 ./Ex4-data/in_month.rw
<3>$ rwuniq ./Ex4-data/in_month.rw --field=sIP \
   --values=Bytes,Packets,Flows --flows=2000- \
| head -n 10
            sIP|               Bytes|         Packets|   Records|
     10.0.40.23|             9331109|          108622|      5128|
  192.168.40.25|             6066944|           58819|     11951|
  192.168.20.58|             4128957|           54314|     28189|
     10.0.40.53|            64029248|          281180|     33917|
 192.168.200.10|             6089612|           20535|      8816|
     10.0.40.54|             6131060|           42785|      7075|
     10.0.40.20|            36120528|          345466|    149284|
     10.0.20.58|             4043680|           55644|     21253|
     67.215.0.8|          1499433280|         6096359|     30549|
```

Example 4.6: Setting Minimum Flow Thresholds with `rwuniq --values`

```
<1>$ rwfilter --start-date=2015/06/17T15 --type=in --protocol=0- \
   --pass=./Ex4-data/in_month.rw
<2>$ ls -l ./Ex4-data/in_month.rw
-rw-r--r--. 1 analyst analyst 7409538 Apr 25 17:23 ./Ex4-data/in_month.rw
<3>$ rwuniq ./Ex4-data/in_month.rw --field=sIP \
   --values=Bytes,Packets,Flows --flows=2000- \
   --packets=100000-
           sIP|               Bytes|         Packets|   Records|
     10.0.40.23|             9331109|          108622|      5128|
     10.0.40.53|            64029248|          281180|     33917|
     10.0.40.20|            36120528|          345466|    149284|
     67.215.0.8|          1499433280|         6096359|     30549|
  192.168.40.20|            67729921|          283002|    106848|
```

Example 4.7: Constraining Flow and Packet Counts with `rwuniq --flows` and `--packets`

```
<1>$ rwfilter --start-date=2015/06/17T15 --type=in --protocol=6 \
   --pass=./Ex4-data/in_month.rw
<2>$ ls -l ./Ex4-data/in_month.rw
-rw-r--r--. 1 gtsanders domain users 2059092 May 14 12:15 ./Ex4-data/in_month.rw
<3>$ rwuniq --fields=sIP,sPort --value=Flows --flows=20- \
   ./Ex4-data/in_month.rw \
| head -n 11
           sIP|sPort|   Records|
192.168.143.162|  591|        26|
192.168.111.131|  591|        28|
192.168.122.141|  591|        26|
     10.0.40.20|   88|       476|
     10.0.40.20|  139|      1189|
192.168.164.119|  591|        26|
  192.168.40.20|60309|        20|
  192.168.40.25|  445|       120|
192.168.165.216|  591|        26|
  192.168.40.20|  135|       265|
```

Example 4.8: Profiling IP addresses with `rwuniq --fields`

1. Use `rwfilter` to filter records for the behavior of interest. (To filter for multiple behaviors, set up a manifold as described in Section 4.2.1.)
2. Use `rwuniq` to count the records that exhibit that behavior.

This can help you to understand the behavior of hosts that use or provide a variety of services. Example 4.10 shows how to generate data that compare hosts showing DNS (domain name system) and non-DNS behavior among a group of flow records. We can find DNS servers by filtering the file `in_month.rw` (created in Example 4.8) for hosts that carry traffic on port 53 with the UDP protocol (17).

1. Command 1 first isolates the set of hosts of interest by using `rwfilter` to filter records from `in_month.rw` with UDP traffic on port 53 (`--protocol=17 --aport=53`). It then uses `rwset` to generate an IPset (`interest.set`) from the records that pass the filter.
2. Command 2 uses `interest.set` to filter `in_month.rw` again to distinguish IP addresses with general UDP traffic from the set of hosts that carry DNS traffic on port 53. It then uses `rwuniq` to count the DNS flow records and sorts them by source address.

   Although `rwuniq` will correctly sort the output rows by IP address without zero-padding, the upcoming `join` command will not understand that the input is properly sorted without `rwuniq` first preparing the addresses with the `--ip-format=zero-padded` parameter.
3. Command 3 counts the non-DNS flow records created with the `--fail` switch in Command 2 and sorts them by source address.
4. Command 4 merges the two count files by source address and then sorts them by number of DNS flows with the results shown. Hosts with high counts in both columns should be either workstations or gateways. Hosts with high counts in DNS and low counts in non-DNS should be DNS servers.[6]

For more complex summaries of behavior, use the `rwbag` command and its related utilities as described in Section 4.2.4.

4.2.4 Summarizing Network Traffic with Bags

IPsets contain lists of IP addresses. However, it's often useful to associate a value with each address in an IPset. For instance, you may want to associate the IP addresses that engage in web traffic with the volume of flows, packets, or bytes of web traffic that each address carries. *Bags* are extended sets that contain these types of key-value pairs.

Where IPsets record the presence or absence of key values, bags add the ability to count the number of instances of a particular key value—that is, the number of bytes, the number of packets, or the number of flow records associated with that key. Bags also allow the analyst to summarize traffic on characteristics other than IP addresses—specifically on protocols and ports.[7]

Bags can be thought of as enhanced IPsets. Like IPsets, they are binary structures that can be manipulated using a collection of tools. As a result, operations that are performed on IPsets have analogous bag operations, such as addition (the equivalent to union). Analysts can also extract a cover set (the set of all IP addresses in the bag) for use with `rwfilter` and the IPset tools.

[6] The full analysis to identify DNS servers is more complex and will not be dealt with in this handbook.

[7] PySiLK allows for even more general bag key values and count values. See the documentation *PySiLK: SiLK in Python* for more information.

```
<1>$ rwfilter --start-date=2015/06/17T15 --type=in --protocol=6 \
   --pass=./Ex4-data/in_month.rw
<2>$ ls -l ./Ex4-data/in_month.rw
-rw-r--r--. 1 analyst analyst 2059092 May 14 12:26 ./Ex4-data/in_month.rw
<3>$ rwstats --count=11 --fields=sIP,sPort --value=Flows \
   ./Ex4-data/in_month.rw \
INPUT: 124356 Records for 11637 Bins and 124356 Total Records
OUTPUT: Top 11 Bins by Records
            sIP|sPort|   Records|  %Records|   cumul_%|
     10.0.40.53| 5723|     33103| 26.619544| 26.619544|
     67.215.0.8|11009|     12479| 10.034900| 36.654444|
     67.215.0.8|11007|     10714|  8.615588| 45.270031|
     67.215.0.8|  135|      7181|  5.774550| 51.044582|
     10.0.40.23| 8443|      5128|  4.123645| 55.168227|
  192.168.40.20|   88|      3296|  2.650455| 57.818682|
     10.0.40.20|  445|      1986|  1.597028| 59.415710|
     10.0.40.20|  389|      1367|  1.099263| 60.514973|
     10.0.40.20|  139|      1189|  0.956126| 61.471099|
  192.168.70.10| 8082|      1077|  0.866062| 62.337161|
     10.0.40.20|49158|      1071|  0.861237| 63.198398|
```

Example 4.9: Profiling IP addresses with `rwstats --fields`

```
<1>$ rwfilter in_month.rw --protocol=17 --aport=53 --pass=stdout \
| rwset --sip-file=interest.set
<2>$ rwfilter in_month.rw --sipset=interest.set --protocol=17 \
   --pass=stdout \
| rwfilter stdin --aport=53 --fail=not-dns.rw --pass=stdout \
| rwuniq --fields=sIP --no-titles --ip-format=zero-padded \
   --sort-output --output-path=dns-saddr.txt
<3>$ rwuniq not-dns.rw --fields=sIP --no-titles \
   --ip-format=zero-padded --sort-output \
   --output-path=not-dns-saddr.txt
<4>$ echo '            sIP|       DNS||   not DNS|' \
; join -t'|' dns-saddr.txt not-dns-saddr.txt \
| sort -t'|' -nrk2,2 \
| head -n 5
            sIP|       DNS||   not DNS|
010.000.040.020|    124652||     14322|
192.168.040.020|     98128||       797|
192.168.200.010|      7123||        64|
192.168.040.025|      5188||      5127|
192.168.165.216|       508||        47|
```

Example 4.10: Isolating DNS and Non-DNS Behavior with `rwuniq`

Generating Bags from Network Flow Data

The `rwbag` command creates bags from raw network flow data, either directly output from the `rwfilter` command or stored in a file. The *key* parameter specifies the network flow record field that serves as the key for the bag. Examples of keys include source IP address (`sIPv4`, `sIPv6`), destination IP address (`dIPv4`, `dIPv6`), source port (`sPort`), destination port (`dport`), `protocol`, `packets`, and `bytes`.

The *counter* parameter sums up the number of `records`, `flows`, `packets`, or `bytes` for the flow record field specified by *key*. *outputfile* is the name of the file where the bag is stored, such as `mybag.bag`. Bags are stored in binary format to make analysis tasks faster and more efficient. Use the `rwbagcat` command to display the contents of a bag.

Example 4.11 shows an example of how to use `rwbag` in conjunction with `rwfilter`. You may specify multiple `--bag-file` parameters when you issue the `rwbag` command.

```
<1>$ rwfilter --type=in,inweb --start-date=2015/06/18T12 \
   --protocol=6 --pass=stdout \
| rwbag --sip-packets=x.bag --dip-flows=y.bag
<2>$ file x.bag y.bag
x.bag: data
y.bag: data
```

Example 4.11: Generating Bags with `rwbag`

See Appendix C.18 for more information about the `rwbag` command. To view a complete list of command options, type `rwbag --help` at the command line.

Summarizing Network Traffic with Bags

To show how useful bags can be, we return to the task mentioned earlier in this section: analyzing outgoing web traffic. We want to find out which IP addresses engage in web traffic and will narrow our study to outgoing TCP flows on ports 80 and 443. We can find these IP addresses by using the `rwfilter` and `rwuniq` commands as shown in Example 4.12.

```
<1>$ rwfilter --start-date=2015/06/17 --sensors=S1 --type=outweb \
   --protocol=6 --sport=80,443 --packets=3- --pass=stdout \
| rwuniq --fields=sip --values=bytes
            sIP|               Bytes|
  192.168.40.24|              877782|
  192.168.20.59|             1392516|
  192.168.40.91|              124548|
  192.168.40.92|              124548|
```

Example 4.12: Summarizing Network Traffic with rwuniq

This provides us with addresses and byte counts in text format. However, we would like to use this information during further analysis with SiLK—for example, as an IPset with the addresses and some way to store the number of bytes for each address. To store such a list, we need to create a bag with the `rwbag` command as shown in Example 4.13. We want the key to be the IP address and the value to be the number of bytes of outbound web traffic.

```
<1>$ rwfilter --start-date=2015/06/17 --sensors=S1 --type=outweb \
   --protocol=6 --sport=80,443 --packets=3- --pass=stdout \
| rwbag --bag-file=sipv4,sum-bytes,outgoingweb.bag \
<2>$ file outgoingweb.bag
outgoingweb.bag: SiLK, RWBAG v3, Little Endian, LZO compression
<3>$ rwbagcat outgoingweb.bag
  192.168.20.59|             1392516|
  192.168.40.24|              877782|
  192.168.40.91|              124548|
  192.168.40.92|              124548|
```

Example 4.13: Summarizing Network Traffic with Bags

The file `outgoingweb.bag` contains the list of IP addresses that carry outgoing web traffic and the volume of outbound traffic in bytes that flows through each address. Unlike the output of the `rwuniq` command, this information is stored in a single binary file, as shown in 4.13. We can now use this file during further analysis of outbound web traffic.

Generating Bags From IP Sets or Text: A Scanning Example

You can create a bag from an existing set or a text file by using the `rwbagbuild` tool. This allows you to associate counts with items in a set or file. It also gives you more flexibility with creating bags than the `rwbag` command does. For instance, you can use `rwbagbuild` to count something other than bytes, packets, or flow records for an address.

`rwbagbuild` takes either an IPset (as specified in `--set-input`) or a text file (as specified in `--bag-input`), but not both.

- For IPset input, the `--default-count` parameter specifies the count value for each set element in the output bag. If no `--default-count` value is provided, the count will be set to one.
- For text-file input, the lines of the file are expected to consist of a key value, a delimiter (by default the vertical bar), and a count value. Keys can be IP addresses (including canonical forms, CIDR blocks, and SiLK address wildcards) or unsigned integers.

See Appendix C.19 for more information about the `rwbagbuild` command. To view a complete list of command options, type `rwbagbuild --help` at the command line.

Example 4.14 shows how to use the `rwbagbuild` command in conjunction with the `rwscan` command to create a bag that contains IP addresses that show evidence of scanning activity and the number of flows associated with them.

`rwscan` analyzes SiLK flow records for signs of network scanning—when an external host gathers information about a network during the reconnaissance phase of an attack. It takes sorted network flow records as input and outputs in columnar text format any IP addresses that show signs of network scanning. This is useful for identifying hosts that are conducting reconnaissance and the ports and protocols of interest to them. Pairing this command with `rwbagbuild` allows you to create a bag that stores scanner IP addresses and attributes of their activity for further investigation.

1. Command 1 uses `rwfilter` to pull inbound TCP traffic (`--proto=6 --type=in,inweb`).

2. The `rwscan` command requires input to be pre-sorted by source IP address, protocol, and destination IP address. Command 1 therefore calls `rwsort --fields=sip,proto,dip` to sort the selected records.
3. Command 1 then uses `rwscan` to search for IP addresses that show signs of scanning activity. It pipes the output through the operating system `cut` command to remove the delimiters (`|`) in the `rwscan` output.
4. Finally, Command 1 uses the `rwbagbuild` command to create a bag (`scanners.bag`) from the `rwscan` output. It uses the scanning IP addresses as the key and the number of flow records as the associated count for the bag entries.
5. Commands 2 and 3 display the list of scanners created in Command 1. Command 2 uses the `rwbagcat` command to create a text file that contains the contents of `scanners.bag`. (`rwbagcat` is described later in this section.) Command 3 shows that file.

Specifying IP addresses with `rwbagbuild`. The `rwbagbuild` command does not support mixed input of IP addresses and integer values, since there is no way to specify whether the number represents an IPv4 address or an IPv6 address. (For example, does `1` represent `::FFFF.0.0.0.1` or `::1`?) `rwbagbuild` also does not support symbol values in its input, so some types commonly expressed as symbols (TCP flags, attributes) must be translated into an integer form.

Similarly, `rwbagbuild` does not support formatted time strings. Times must be expressed as unsigned integer seconds since UNIX epoch (i.e., the number of seconds since midnight, January 1, 1970). If the delimiter character is present in the input data, it must be followed by a count. If the `--default-count` parameter is used, its argument will override any counts in the text-file input; otherwise the value in the file will be used. If no delimiter is present, either the `--default-count` value will be used or the count will be set to 1 if no such parameter is present. If the key value cannot be parsed or a line contains a delimiter but no count, `rwbagbuild` prints an error and exits.

Displaying the Contents of Bags

To view or summarize the contents of a bag, use the `rwbagcat` command. By default, it displays the contents of a bag in sorted order as shown in Example 4.15.

See Appendix C.20 for more information about the `rwbagcat` command. To view a complete list of command options, type `rwbagcat --help` at the command line.

Thresholding Bags. In Example 4.15, the *counts* (the number of elements that match a particular IP address) are printed per key. `rwbagcat` can also print values within ranges of both counts and keys, as shown in Example 4.16.

These thresholding values can be used in any combination.

Counting Keys in Bags. In addition to thresholding, `rwbagcat` can also reverse the index; that is, instead of printing the number of counted elements per key, it can produce a count of the number of keys matching each count using the `--bin-ips` parameter. This reverse count is shown in Example 4.17.

- In Command 1, it is shown using linear binning—one bin per value, with the counts showing how many keys had that value.

```
<1>$ rwfilter --start-date=2015/06/02 --end-date=2015/06/18 \
   --proto=6 --type=in,inweb --pass=stdout \
| rwsort --fields=sip,proto,dip \
| rwscan --scan-model=2 --output-path=stdout --no-title \
| cut -f1,5 -d'|' \
| rwbagbuild --bag-input=stdin --key-type=sIPv4 \
   --counter-type=records >scanners.bag
<2>$ echo 'Scanner        |               Flows|' >scanners.txt \
; rwbagcat scanners.bag >>scanners.txt
<3>$ cat scanners.txt
Scanner        |               Flows|
  192.168.181.8|               45428|
```

Example 4.14: Creating a Bag of Network Scanners with `rwbagbuild` and `rwscan`

```
<1>$ rwbagcat x.bag \
      | head -n 5
    192.0.2.198|                1281|
    192.0.2.227|                  12|
    192.0.2.249|                  90|
 198.51.100.227|                   3|
 198.51.100.244|                 101|
```

Example 4.15: Viewing the Contents of a Bag with `rwbagcat`

```
<1>$ rwbagcat --mincounter=100 --maxcounter=600 kerbserv.bag
     10.0.40.20|                 574|
     67.215.0.5|                 245|
<2>$ rwbagcat --minkey=10.0.0.0 --maxkey=192.168.255.255 \
   kerbserv.bag
     10.0.40.20|                 574|
     67.215.0.5|                 245|
  192.168.40.20|                4596|
```

Example 4.16: Thresholding Results with `rwbagcat --mincounter`, `--maxcounter`, `--minkey`, and `--maxkey`

- In Command 2, it is shown with binary binning—values collected by powers of two and with counts of keys having summary volume values in those ranges.
- In Command 3, it is shown with decimal logarithmic binning—values collected in bins that provide one bin per value below 100 and an even number of bins for each power of 10 above 100, arranged logarithmically and displayed by midpoint. This option supports logarithmic graphing options.

The `--bin-ips` parameter can be particularly useful for distinguishing between sites that are hit by scans (where only one or two packets may appear) from sites that are engaged in legitimate activity.

Formatting Key Values for Bags. If the bag is not keyed by IP address, the optional `--key-format` parameter makes it *much* easier to read the output of `rwbagcat`. Example 4.18 shows the difference in output for a sIP-keyed bag counting bytes, where the IP addresses are shown in decimal and hexadecimal formats.

Comparing the Contents of Bags

Once you have created bags to store key-value pairs, you can compare their contents to identify common values and trends. For example, you may want to compare the traffic volumes associated with two groups of IP addresses, each in a separate bag file. Use the `rwbagtool --compare` parameter to compare the contents of two bags. It stores the output from this comparison in a new bag file.

For each *key* that appears in both bag files, the `--compare` option compares the value of the key's associated *counter* (i.e., the number of bytes, packets, or records summed up by the `rwbag` or `rwbagbuild` command) in the first file to the value of the key's counter in the second file.

- If the comparison is *true*, the key appears in the resulting bag file with a counter of 1.
- If the comparison is *false*, the key is not present in the output file.
- Keys that appear in only one of the input bag files are ignored.

`rwbagtool --compare` can perform the following comparisons:

`lt` Finds keys in the first bag file whose counters are less than those in the second bag file.

`le` Finds keys in the first bag file whose counters are less than or equal to those in the second bag file.

`eq` Finds keys whose counters are equal in both files.

`ge` Finds keys in the first bag file whose counters are greater than or equal to those in the second bag file.

`gt` Finds keys in the first bag file whose counters are greater than those in the second bag file.

See Appendix C.21 for more information about the `rwbagtool` command. To view a complete list of command options, type `rwbagtool --help` at the command line.

4.2.5 Working with Bags and IPsets

Since bags are essentially enhanced IPsets, SiLK provides operations that enable you to create IPsets from bags and compare the contents of bags with those of IPsets.

```
<1>$ rwbagcat --bin-ips dns.bag \
| head -n 5
                  1|                   1|
                  3|                   1|
                 14|                   1|
                 18|                   1|
                 30|                   1|
<2>$ rwbagcat --bin-ips=binary dns.bag \
| head -n 5
      2^00 to 2^01-1|                   1|
      2^01 to 2^02-1|                   1|
      2^03 to 2^04-1|                   1|
      2^04 to 2^05-1|                   2|
      2^09 to 2^10-1|                   3|
<3>$ rwbagcat --bin-ips=decimal dns.bag \
| head -n 5
                  1|                   1|
                  3|                   1|
                 14|                   1|
                 18|                   1|
                 30|                   1|
```

Example 4.17: Displaying Unique IP Addresses per Value with `rwbagcat --bin-ips`

```
<1>$ rwbagcat kerbserv.bag
     10.0.40.20|              751382|
     67.215.0.5|              395218|
  192.168.40.20|             5510424|
<2>$ rwbagcat --key-format=decimal kerbserv.bag
 167782420|              751382|
1138163717|              395218|
3232245780|             5510424|
<3>$ rwbagcat --key-format=hexadecimal kerbserv.bag
 a002814|              751382|
43d70005|              395218|
c0a82814|             5510424|
```

Example 4.18: Displaying Decimal and Hexadecimal Output with `rwbagcat --key-format`

Extracting IPsets from Bags

Sometimes you will want to extract an IPset from a bag—for instance, if you used the `rwbagtool --compare` command to compare traffic associated with IP addresses in two bags and want to analyze the set of IP addresses in the new bag. Use the `rwbagtool --coverset` parameter to generate a *cover set*: the set of IP addresses in a bag. The resulting IPset file can be used with `rwfilter` and manipulated with any of the `rwset` commands.

Example 4.19 shows how to extract an IPset from a bag file. The `rwsetcat` command displays the contents of the resulting set and the `rwbagcat` command displays the contents of the original bag—showing that the IP addresses that comprise the set are identical to those in the bag.

Hint 4.4: How to Use `rwbagtool --coverset` with Bag Files

Be careful of bag contents when using `rwbagtool --coverset`. Since `rwbagtool` does not limit operations by the type of keys contained within a bag, the `--coverset` parameter will interpret the keys as IP addresses even if they are actually protocol or port keys. This will lead to confusion and analysis errors!

Intersecting Bags and IPsets

You may want to find out whether the IP addresses in an IPset are also contained in a bag. You may also want to limit the contents of a bag to a specific group of IP addresses—for instance, those on a specific subnet.

The `rwbagtool --intersect` and `--complement-intersect` parameters are used to intersect an IPset with a bag. Example 4.20 shows how to use these parameters to extract a specific subnet.

4.2.6 Masking IP Addresses

When working with IP addresses and utilities such as `rwuniq` and `rwstats`, you may want to analyze activity across *networks* rather than individual IP addresses. For example, you may wish to examine all of the activity originating from the /24s constituting the enterprise network rather than generating an individual entry for each address. To perform this type of analysis, use the `rwnetmask` command to reduce IP addresses to prefix values of a parameterized length. See Appendix C.9 for more information about `rwnetmask` or type `rwnetmask --help` at the command line.

The query in Example 4.21 is followed by an `rwnetmask` call to retain only the first 24 bits (three octets) of source IPv4 addresses, as shown by the `rwcut` output.

As Example 4.21 shows, `rwnetmask` replaces the last 8 bits[8] of the source and destination IP addresses with zero, so all IP addresses in the 10.0.40/24 block (for example) will be masked to produce the same IP address. This replaces both source and destination IP addresses with zero. With `rwnetmask`, an analyst can use any of the standard SiLK utilities on networks in the same way the analyst would use the utilities on individual IP addresses.

[8] 32 bits total for an IPv4 address minus the 24 bits specified in the command for the prefix length leaves 8 bits to be masked.

```
<1>$ rwbagtool outgoingweb.bag --coverset \
   --output-path=outgoingweb.set
<2>$ rwsetcat outgoingweb.set \
| head -n 3
192.168.20.59
192.168.40.24
192.168.40.91
<3>$ rwbagcat outgoingweb.bag \
| head -n 3
  192.168.20.59|             1392516|
  192.168.40.24|              877782|
  192.168.40.91|              124548|
```

Example 4.19: Creating an IP Set from a Bag with `rwbagtool --coverset`

```
<1>$ echo '10.0.20.x' >f.set.txt
<2>$ rwsetbuild f.set.txt f.set
<3>$ rwbagtool x.bag --intersect=f.set --output-path=xf.bag
<4>$ rwbagcat x.bag
     10.0.20.58|                 522|
     10.0.20.59|                1652|
    67.215.0.55|                  88|
   117.34.28.84|                  12|
     155.6.3.10|                  30|
     155.6.4.10|                  30|
 192.168.200.10|                3913|
<5>$ rwbagcat xf.bag
     10.0.20.58|                 522|
     10.0.20.59|                1652|
```

Example 4.20: Using `rwbagtool --intersect` to Extract a Subnet

```
<1>$ rwfilter --type=out,outweb --start-date=2015/06/02 \
   --end-date=2015/06/18 --sensors=S0,S1 --protocol=6 \
   --max-pass-records=3 --pass=stdout \
| rwnetmask --4sip-prefix-length=24 --4dip-prefix-length=24 \
| rwcut --fields=1-5
            sIP|            dIP|sPort|dPort|pro|
      10.0.40.0|  192.168.124.0| 1065|  591|  6|
      10.0.40.0|  192.168.166.0| 1066|  591|  6|
      10.0.40.0|   192.168.40.0|58083|   88|  6|
```

Example 4.21: Abstracting Source IPv4 addresses with `rwnetmask`

4.2.7 Working With IPsets

Iterative multi-path analyses commonly result in multiple SiLK IPset files. These files are usually named to describe their association with a specific aspect of analysis, such as byte thresholds as discussed in Section 2.2.8. As analyses progress, however, it is necessary to understand how IPsets compare and contrast. `rwsetbuild`, `rwsettool`, and `rwsetmember` are three important SiLK IPset tools that are often used together to identify network infrastructure and traffic flow.

Creating IPsets from Text Files

`rwsetbuild` creates binary IPsets from text input files. It can be used to build reference sets to start an analysis, as previously discussed in Section 2.2.8. See Appendix C.17 for a command summary or type `rwsetbuild --help` at the command line.

Example 4.22 shows how to build an IPset of the FCCX-15 internal network reference from the `ipblocks` statements in the `sensors.conf` configuration file. Command 1 displays the first five lines of the `monitored_nets.set.txt` textual input file. Command 2 shows the use of the `rwsetbuild` to build the binary IPset from text. Finally, Command 3 shows the file command to verify the `monitored_nets.set` filetype.

Example 4.23 shows a similar approach to build an IPset of the broadcast address space with `rwsetbuild`.

Manipulating IPsets: DNS Server Example

Once you have constructed SiLK IPsets, use the `rwsettool` command for manipulating them. It provides common algebraic set operations for arbitrary numbers of IPset files. See Appendix C.16 for a summary of its syntax and most of its parameters or type `rwsettool --help` at the command line.

Example 4.24 shows an example of how to combine two sets to create a comprehensive IPset of the FCCX-15 internal network. It uses the `rwsettool --union` operation to combine both input set files, resulting in a summary set file, `internal_nets.set`. This file represents the FCCX-15 internal network addresses, including IP broadcasts that should not route to public IP space.

Analysts should determine the time period required for an analysis after creating reference sets. Example 4.25 shows how to use `rwsiteinfo` with the `--fields=repo-start-date,repo-end-date` parameter to determine the full time range of FCCX-15 data: `2015/06/02T13:00:00` to `2015/06/18T18:00:00`.

The dates identified in Example 4.25 are then used as input to the `rwfilter` command to inventory all `out` type Domain Name System (DNS) servers, as shown in Example 4.26. Command 1 shows how to use `rwfilter` to query the entire FCCX-15 repository for DNS servers, which carry `out` type traffic on port 53 (`--dport=53`) with the UDP protocol (`--protocol=17`). It saves those IP addresses to the `dns_servers_out.set` file. Command 2 shows that there were outbound requests to 22 DNS servers on port 53/UDP during the period 2015/06/02 to 2015/06/18.

Although Example 4.26 generated a comprehensive IPset of outbound DNS servers (`dns_servers_out.set`), it contains all servers that carry `out` type traffic. This means that DNS servers that are contained within the network perimeter may also reside in the resulting IPset. To differentiate between the internal and external network, IP addresses of internal DNS servers must be removed from the set.

Example 4.27 shows how to use the `rwsettool --difference` option to remove the IP addresses of internal DNS servers from the set of DNS servers that reside outside the network perimeter. Command 1 shows how to create the `external_dns_servers.set` set file by finding the difference between the DNS servers

```
<1>$ head -n 5 monitored_nets.set.txt
# Text file of monitored networks
# Build from sensor.conf ipblocks
10.0.10.0/24
10.0.20.0/24
10.0.30.0/24
<2>$ rwsetbuild monitored_nets.set.txt monitored_nets.set
<3>$ file monitored_nets.set
monitored_nets.set: SiLK, IPSET v2, Little Endian, LZO compression
```

Example 4.22: Generating a Monitored Address Space IPset with `rwsetbuild`

```
<1>$ echo 255.255.255.255 >broadcast.set.txt
<2>$ rwsetbuild broadcast.set.txt broadcast.set
<3>$ file broadcast.set
broadcast.set: SiLK, IPSET v2, Little Endian, LZO compression
```

Example 4.23: Generating a Broadcast Address Space IPset with `rwsetbuild`

```
<1>$ rwsettool --union monitored_nets.set broadcast.set \
   >internal_nets.set
```

Example 4.24: Performing an IPset Union with `rwsettool`

```
<1>$ rwsiteinfo --fields=repo-start-date,repo-end-date
         Start-Date|           End-Date|
2015/06/02T13:00:00|2015/06/18T18:00:00|
```

Example 4.25: Displaying Repository Dates with `rwsiteinfo`

```
<1>$ rwfilter --start-date=2015/06/02 --end-date=2015/06/18 \
   --protocol=17 --type=out --dport=53 --pass=stdout \
| rwset --dip-file=dns_servers_out.set
<2>$ rwsetcat --count dns_servers_out.set
22
```

Example 4.26: Counting Outbound DNS Servers with `rwset`

contained in `dns_servers_out.set`, but not contained in `internal_nets.set`. Command 2 shows a total of 16 DNS servers that reside external to the network in the FCCX-15 data.

The remaining internal DNS servers can be identified with the `rwsettool --symmetric-difference` option. A symmetric difference is the elements of two sets that are members of either set, but not members of both. Example 4.28 shows how the `internal_dns_server.set` set file is generated from a symmetric difference of the `external_dns_servers.set` and `dns_servers_out.set` files, finding a total of 6 internal DNS servers.

Using Set Membership to Understand Traffic Flow

Once DNS server infrastructure is identified, multi-path analyses may also require identifying traffic flow to specific DNS servers. Use the `rwsetmember` command to identify if an IP address or pattern is contained within one or more IPset files. This command shows how network traffic flows through a network infrastructure.

`rwsetmember` begins by building per-sensor IPset inventories of outbound traffic to DNS servers, as shown in Example 4.29.

Command 1 shows how to use `rwsiteinfo` to generate a list of sensors for the FCCX-15 dataset. This list of sensors is then used in Commands 2 and 3 of the `dns_servers_by_sensor.sh` script to loop through each sensor name and build an IPset of the DNS servers that are monitored by each sensor.

After creating the per-sensor DNS server IPsets, we can use the `rwsetmember` command as shown in Example 4.30 to identify sensors that monitor specific external DNS servers.

- Command 1 shows how to use `rwsetmember` to identify the sensors that monitor 8.8.x.x DNS servers. The results indicate that sensors `S0`, `S1`, `S2`, `S3`, and `S12` logged DNS requests to 8.8.x.x IP addresses.
- Command 2 shows how these sensors can be combined into a list with `rwsiteinfo` to display their descriptions. The output from the `rwsiteinfo` command shows that DNS clients in the `Div0Ext`, `Div1Ext`, `Div0Int`, `Div1Int1`, and `Div1svc` monitored networks execute DNS queries to 8.8.x.x internet servers.

The `rwsettool --intersection` option can also be used to identify infrastructure that shares traffic flows. This option intersects IP addresses that are members of two sets. Command 1 of Example 4.31 shows using `rwsettool` with `--intersection` to identify the DNS servers that both the `S0` and `S1` sensors monitor.

Displaying the Contents of IPsets

Use the `rwsetcat` command to view the contents of IPsets. It reads one or more set files, then displays the IP addresses in each file or prints out statistics about the set in each file. See Appendix C.15 for a command summary or type `rwsetcat --help` at the command line.

In Example 4.32, the call to `rwsetcat` prints out all the addresses in the set; IP addresses appear in ascending order.

In addition to printing out IP addresses, `rwsetcat` can also perform counting and statistical reporting, as shown in Example 4.33. These features are useful for describing the set without dumping out all the IP addresses in the set. Since sets can have any number of addresses, counting with `rwsetcat` tends to be much faster than counting via text tools such as `wc`.

```
<1>$ rwsettool --difference dns_servers_out.set \
   internal_nets.set >external_dns_servers.set
<2>$ rwsetcat --count external_dns_servers.set
16
```

Example 4.27: Finding IPset Differences with `rwsettool`

```
<1>$ rwsettool --symmetric-difference external_dns_servers.set \
   dns_servers_out.set >internal_dns_servers.set
<2>$ rwsetcat --count internal_dns_servers.set
6
```

Example 4.28: Finding IPset Symmetric Difference with `rwsettool`

```
<1>$ rwsiteinfo --fields=sensor:list
                                                                    Sensor:list|
S0,S1,S2,S3,S4,S5,S6,S7,S8,S9,S10,S11,S12,S13,S14,S15,S16,S17,S18,S19,S20,S21|
<2>$ cat dns_servers_by_sensor.sh
SDATE="2015/06/02"
EDATE="2015/06/18"
SENSORS="S0 S1 S2 S3 S4 S5 S6 S7 S8 S9 S10 S11 S12 S13 S14"
SENSORS+=" S15 S16 S17 S18 S19 S20 S21"
for SENSOR in $SENSORS; do
  rwfilter --start-date=$SDATE --end-date=$EDATE --type=out \
  --proto=17 --dport=53 --sensor=$SENSOR --pass=stdout \
  | rwset --dip-file="$SENSOR"_dns_servers_out.set
done
<3>$ sh dns_servers_by_sensor.sh
```

Example 4.29: Grouping Outbound DNS Servers by Sensor

```
<1>$ rwsetmember 8.8.x.x S*.set
S0_dns_servers_out.set
S12_dns_servers_out.set
S1_dns_servers_out.set
S2_dns_servers_out.set
S3_dns_servers_out.set
<2>$ rwsiteinfo --fields=sensor,describe-sensor \
   --sensors=S0,S1,S2,S3,S12
Sensor|Sensor-Description|
    S0|           Div0Ext|
    S1|           Div1Ext|
    S2|           Div0Int|
    S3|          Div1Int1|
   S12|           Div1svc|
```

Example 4.30: Identifying DNS Traffic Flow

```
<1>$ rwsettool --intersect S0_dns_servers_out.set \
   S1_dns_servers_out.set | rwsetcat
8.8.4.4
8.8.8.8
67.215.0.5
128.8.10.90
128.63.2.53
192.5.5.241
192.33.4.12
192.36.148.17
192.58.128.30
192.112.36.4
192.203.230.10
192.228.79.201
193.0.14.129
198.41.0.4
199.7.83.42
202.12.27.33
```

Example 4.31: Identifying Shared DNS Monitoring

```
<1>$ rwsetcat medtcp-dest.set | head -n 5
192.168.45.27
192.168.61.26
```

Example 4.32: Displaying the Contents of IP Sets with `rwsetcat`

- Command 1 shows how many IP addresses are in the IPset.
- Command 2 shows summary statistics and network structure for the addresses in the IPset.

Example 4.33 also shows the wide variety of network information that can be displayed by using the `--network-structure` parameter.

- In Command 3, there are no *list-lengths* and no *summary-lengths*. As a result, a default array of summary lengths is supplied.
- In command 4 there is a *list-length*, but no slash (`/`) introducing *summary-lengths*, so the netblock with the specified prefix length is listed, but no summary is produced.
- In Command 5, a prefix length is supplied that is sufficiently large to list multiple netblocks.
- Command 6 shows two prefix lengths in *list-lengths*.
- Command 7 shows that a prefix length of zero (no network bits, so no choice of networks) treats the entire address space as a single network and labels it `TOTAL`.
- Command 8 shows that summarization occurs not only for the *summary-lengths* but also for every prefix length in *list-lengths* that is larger than the current list length.
- In Command 9, the slash introduces *summary-lengths*, but the array of summary lengths is empty; as a result, the word "hosts" appears as if there will be summaries, but there aren't any.
- In Command 10, the `S` replaces the slash and summary lengths, so default summary lengths are used.
- In Command 11, the list length is larger than the smallest default summary length, so that summary length does not appear.
- In Command 12, `H` (host) is used for a list length.
- command 13 shows that `H` is equivalent to 32 for IPv4.

```
<1>$ rwsetcat medtcp-dest.set --count-ips
93
<2>$ rwsetcat medtcp-dest.set --print-statistics
Network Summary
        minimumIP =       10.0.40.20
        maximumIP =  192.168.166.233
                93 hosts (/32s),    0.000002% of 2^32
                 2 occupied /8s,    0.781250% of 2^8
                 2 occupied /16s,   0.003052% of 2^16
                20 occupied /24s,   0.000119% of 2^24
                66 occupied /27s,   0.000049% of 2^27
<3>$ rwsetcat medtcp-dest.set --network-structure
TOTAL| 93 hosts in 2 /8s, 2 /16s, 20 /24s, and 66 /27s
<4>$ rwsetcat medtcp-dest.set --network-structure=4
        0.0.0.0/4| 10
      192.0.0.0/4| 83
<5>$ rwsetcat medtcp-dest.set --network-structure=18
       10.0.0.0/18| 10
    192.168.0.0/18| 15
```

```
   192.168.64.0/18| 27
  192.168.128.0/18| 41
<6>$ rwsetcat medtcp-dest.set --network-structure=4,18
  10.0.0.0/18       | 10
0.0.0.0/4           | 10
  192.168.0.0/18    | 15
  192.168.64.0/18   | 27
  192.168.128.0/18  | 41
192.0.0.0/4         | 83
<7>$ rwsetcat medtcp-dest.set --network-structure=0,18
  10.0.0.0/18       | 10
  192.168.0.0/18    | 15
  192.168.64.0/18   | 27
  192.168.128.0/18  | 41
TOTAL               | 93
<8>$ rwsetcat medtcp-dest.set --network-structure=4,18/24
  10.0.0.0/18       | 10 hosts in 2 /24s
0.0.0.0/4           | 10 hosts in 1 /18 and 2 /24s
  192.168.0.0/18    | 15 hosts in 3 /24s
  192.168.64.0/18   | 27 hosts in 6 /24s
  192.168.128.0/18  | 41 hosts in 9 /24s
192.0.0.0/4         | 83 hosts in 3 /18s and 18 /24s
<9>$ rwsetcat medtcp-dest.set --network-structure=4/
        0.0.0.0/4| 10 hosts
      192.0.0.0/4| 83 hosts
<10>$ rwsetcat medtcp-dest.set --network-structure=4S
        0.0.0.0/4| 10 hosts in 1 /8, 1 /16, 2 /24s, and 4 /27s
      192.0.0.0/4| 83 hosts in 1 /8, 1 /16, 18 /24s, and 62 /27s
<11>$ rwsetcat medtcp-dest.set --network-structure=12S
       10.0.0.0/12| 10 hosts in 1 /16, 2 /24s, and 4 /27s
    192.160.0.0/12| 83 hosts in 1 /16, 18 /24s, and 62 /27s
<12>$ rwsetcat medtcp-dest.set --network-structure=H \
| head -n 5
     10.0.40.20|
     10.0.40.23|
     10.0.40.53|
     10.0.40.83|
     10.0.50.11|
<13>$ rwsetcat medtcp-dest.set --network-structure=32 \
| head -n 5
     10.0.40.20|
     10.0.40.23|
     10.0.40.53|
     10.0.40.83|
     10.0.50.11|
```

Example 4.33: `rwsetcat` Options for Showing Structure

4.2.8 Indicating Flow Relationships

A useful step in a multi-path analysis is to identify a set of flow records that have common attributes—for instance, records that are part of the same TCP session. Use `rwgroup` and `rwmatch` to label a set of flow

records that share attributes. This identifier, or group ID, is stored in the next-hop IP (`nhIP`) field. It can be manipulated as an IP address (that is, either by directly specifying a group ID or by using IPsets). The two tools generate group IDs in different ways.

- `rwgroup` scans a file of flow records and groups records with common attributes, such as source or destination IP address pairs.
- `rwmatch` groups records of different types (typically, incoming and outgoing types), creating a file containing groups that represent TCP sessions or groups that represent other behavior.

Hint 4.5: Scale Grouping Tools with Sorted Data

To improve scalability, the grouping tools require the data they process to first be sorted using `rwsort`. The sorted data must be sorted on the criteria fields: in the case of `rwgroup`, the ID field and delta fields; in the case of `rwmatch`, start time and the fields specified in the `--relate` parameter(s).

Labeling Flow Records Based on Common Attributes

The `rwgroup` command groups flow records that have common field values. Grouped records can be output separately (with each record in the group having a common ID) or summarized by a single record. Applications of `rwgroup` include the following:

- grouping together all flow records for a long-lived session: By specifying that records are grouped together by their port numbers and IP addresses, an analyst can assign a common ID to all of the flow records that make up a long-lived session.
- reconstructing web sessions: Due to diversified hosting and caching services such as Akamai®, a single webpage on a commercial website is usually hosted on multiple servers. For example, the images may be on one server, the HTML text on a second server, advertising images on a third server, and multimedia on a fourth server. An analyst can use `rwgroup` to tag web traffic flow records from a single user that are closely related in time and then use that information to identify individual webpage fetches.
- counting conversations: An analyst can group all the communications between two IP addresses together and see how much data was transferred between both sites regardless of port numbers. This is particularly useful when one site is using a large number of ephemeral ports.

See Appendix C.30 for a command summary or type `rwgroup --help` at the command line.

Flow records are grouped when the fields specified by `--id-fields` are identical and the field specified by `--delta-field` matches within a value less than or equal to the value specified by `--delta-value`.

Creating a group is a two-step process:

1. Sort the records using `rwsort` as described in Section 2.2.7. `rwgroup` requires input records to be sorted by the fields specified in `--id-fields` and `--delta-field`.
2. Run `rwgroup` to create a group that matches the grouping criteria specified by `--id-fields`, `--delta-field`,and `--delta-value`. Records in the same group are assigned a common group ID.

`rwgroup` outputs a stream of flow records. Each record's next-hop IP address field is set to the value of the group ID.

Grouping Records By Session. The most basic use of `rwgroup` is to group together flow records that constitute a single longer session, such as the components of a single FTP session (or, in the case of Example 4.34, a Microsoft® Distributed File System Replication Service session). To do this, the example does the following:

1. Command 1 uses `rwfilter` to pull the desired flow records from the repository. It then uses the `rwsort` command to sort these records by source and destination IP address, source and destination port, and start time.
2. Command 2 uses `rwgroup` to group together flow records that have closely-related start times.
3. Command 3 uses the `rwfilter` and `rwcut` commands to display grouped records. It filters for records with `--next-hop-id=0.0.0.1,28` (the group IDs), then displays the source and destination IP addresses, source and destination ports, and the group ID (nhIP).

This creates a group of records that comprise a session.

Thresholding Groups By Number of Records. By default, `rwgroup` outputs one flow record for every flow record it receives as input. You can set a threshold for flow record output by using the `--rec-threshold` parameter, as shown in Example 4.35. This parameter specifies that `rwgroup` only passes records that belong to a group with at least as many records as given in `--rec-threshold`. All other records are dropped silently.

This allows you to filter out smaller groups of records. For instance, if you are only interested in grouping significant amounts of traffic, you could drop groups with low flow counts. Example 4.35 shows how this thresholding works. In the first case, there are several low-flow-count groups. When `rwgroup` is invoked with `--rec-threshold=4`, these groups are discarded by `rwgroup`, while the groups with 4 or more flow records are output.

Generating a Single Summary Record for a Group. `rwgroup` can also generate a single summary record with the `--summarize` parameter. When this parameter is used, `rwgroup` only produces a single record for each group. The summary record uses the first record in the group for its addressing information (IP addresses, ports, and protocol). The total number of bytes and packets for the group is recorded in the summary record's corresponding fields, and the start and end times for the record will be the extrema for that group.[9]

Example 4.36 shows how summarizing works: The 10 original records are reduced to two group summaries, and the byte totals for those records are equal to the sum of the byte values of all the records in the group.

Grouping Records via IPsets. For any data file, calling `rwgroup` with the same `--id-fields` and `--delta-field` values will result in the same group IDs being assigned to the same records. As a result, an analyst can use `rwgroup` to manipulate groups of flow records where the group has a specific attribute. This can be done by using `rwgroup` and IPsets, as shown in Example 4.37.

[9] This is only a quick version of condensing long flows—TCP flags, termination conditions, and application labeling may not be properly reflected in the output.

```
<1>$ rwfilter --type=in,out --start-date=2015/06/02 \
   --end-date=2015/06/18 --packets=4- --protocol=6 \
   --bytes-per-packet=60- --duration=1000- --pass=stdout \
| rwsort --fields=1,2,3,4,sTime --output-path=sorted.rw
<2>$ rwgroup sorted.rw --id-fields=1,2,3,4 --delta-field=sTime \
   --delta-value=3600 --output-path=grouped.rw
<3>$ rwfilter grouped.rw --next-hop-id=0.0.0.1,28 --pass=stdout \
| rwcut --fields=1-4,nhIP
            sIP|            dIP|sPort|dPort|           nhIP|
     10.0.40.20|  192.168.40.20|55425| 5722|        0.0.0.1|
     10.0.40.20|  192.168.40.20|55425| 5722|        0.0.0.1|
     10.0.40.20|  192.168.40.20|55425| 5722|        0.0.0.1|
  192.168.40.20|     10.0.40.20| 5722|55425|       0.0.0.28|
  192.168.40.20|     10.0.40.20| 5722|55425|       0.0.0.28|
  192.168.40.20|     10.0.40.20| 5722|55425|       0.0.0.28|
```

Example 4.34: Grouping Flows of a Long Session with `rwgroup`

```
<1>$ rwgroup sorted.rw --id-fields=1,2,3,4 --delta-field=sTime \
   --delta-value=3600 \
| rwcut --num-recs=10 --field=1-5,nhIP
            sIP|            dIP|sPort|dPort|pro|           nhIP|
     10.0.40.20|  192.168.40.20| 5722|60309|  6|        0.0.0.0|
     10.0.40.20|  192.168.40.20|55425| 5722|  6|        0.0.0.1|
     10.0.40.20|  192.168.40.20|55425| 5722|  6|        0.0.0.1|
     10.0.40.20|  192.168.40.20|55425| 5722|  6|        0.0.0.1|
     10.0.50.12| 192.168.40.100| 3088| 8005|  6|        0.0.0.2|
     10.0.50.12| 192.168.40.100| 3088| 8005|  6|        0.0.0.2|
     10.0.50.12| 192.168.40.100| 3088| 8005|  6|        0.0.0.2|
     10.0.50.12| 192.168.40.100| 3088| 8005|  6|        0.0.0.2|
     10.0.50.12| 192.168.40.100| 3088| 8005|  6|        0.0.0.2|
     10.0.50.12| 192.168.40.100| 3088| 8005|  6|        0.0.0.2|
<2>$ rwgroup sorted.rw --id-fields=1,2,3,4 --delta-field=sTime \
   --delta-value=3600 --rec-threshold=4 \
| rwcut --num-recs=10 --field=1-5,nhIP
            sIP|            dIP|sPort|dPort|pro|           nhIP|
     10.0.50.12| 192.168.40.100| 3088| 8005|  6|        0.0.0.2|
     10.0.50.12| 192.168.40.100| 3088| 8005|  6|        0.0.0.2|
     10.0.50.12| 192.168.40.100| 3088| 8005|  6|        0.0.0.2|
     10.0.50.12| 192.168.40.100| 3088| 8005|  6|        0.0.0.2|
     10.0.50.12| 192.168.40.100| 3088| 8005|  6|        0.0.0.2|
     10.0.50.12| 192.168.40.100| 3088| 8005|  6|        0.0.0.2|
     10.0.50.12| 192.168.40.100| 3088| 8005|  6|        0.0.0.2|
     10.0.50.12| 192.168.40.100| 3088| 8005|  6|        0.0.0.2|
     10.0.50.12| 192.168.40.100| 3088| 8005|  6|        0.0.0.2|
     10.0.50.12| 192.168.40.100| 3088| 8005|  6|        0.0.0.2|
```

Example 4.35: Dropping Trivial Groups with `rwgroup --rec-threshold`

1. Command 1 uses `rwfilter` to filter for traffic with the TCP protocol (`--protocol=6`) and destination ports 20 and 21 (`--dport=20,21`). It then calls `rwsort` to sorts the data and uses `rwgroup` to convert the results into a file, `out.rw`, grouped as FTP communications between two sites. All TCP port 20 and 21 communications between two sites are part of the same group.

2. Command 2 filters through the collection of groups for those group IDs (as next-hop IP addresses stored in `control.set`) that use FTP control.

3. Finally, Command 3 uses that next-hop IPset to pull out all the flows (ports 20 and 21) in groups that had FTP control (port 21) flows.

Labeling Matched Groups of Flow Records

As part of a larger analysis, you may want to group network flow records. For instance, you could group records from both sides of a bidirectional session, such as HTTP requests and responses, for further examination. You may also wish to create groups with more flexible matching, such as matching groups across protocols to identify `traceroute` messages, which use the UDP and ICMP protocols.

Use the `rwmatch` to create *matched groups*. A matched group consists of an initial record (usually a *query*) followed by one or more *responses* and (optionally) additional queries. (For more information about this command's syntax and common options, see Appendix C.29 or type `rwmatch --help` at the command line.)

A response is a record that is related to the query (as specified in the `rwmatch` command). However, it is collected from a different direction or from a different router. As a result, the fields relating the two records may be different. For example, the source IP address in one record may match the destination IP address in another record.

A relationship in `rwmatch` is established using the `--relate` parameter, which takes two numeric field IDs separated by a comma (e.g., `--relate=3,4` or `--relate=5,5`). The first value corresponds to the field ID in the query file,. The second value corresponds to the field ID in the response file. For example, `--relate=1,2` states that the source IP address in the query file must match the destination IP address in the response file. The `rwmatch` tool will process multiple relationships, but each field in the query file can be related to, at most, one field in the response file.

The two input files to `rwmatch` must be sorted before matching. The same information provided in the `--relate` parameters, plus `sTime`, must be used for sorting. The first fields in the `--relate` value pairs, plus `sTime`, constitute the sort fields for the query file. The second fields in the `--relate` value pairs, plus `sTime`, constitute the sort fields for the response file.

The `--relate` parameter always specifies a relationship from the query to the responses, so specifying `--relate=1,2` means that the records match if the source IP address in the query record matches the destination IP address in the response. Consequently, when working with a protocol where there are implicit relationships between the queries and responses, especially TCP, these relationships must be fully specified. Example 4.38 shows the impact that not specifying all of the fields has on TCP data. Note that the match relationship specified (the source IP address of the query matches the destination IP address of the response) results in all of the records in the response matching the initial query record, even though the source ports in the query file may differ from a response's destination port (as seen with the third matched record).

Example 4.39 shows the relationships that could be specified when working with TCP or UDP. This example specifies a relationship between the query's source IP address and the response's destination IP address, the query's source port and the response's destination port, and the reflexive relationships between query and response.

```
<1>$ rwgroup sorted.rw --id-fields=1,2,3,4 --delta-field=sTime \
   --delta-value=3600 --rec-threshold=3 \
| rwcut --fields=1-5,bytes,nhIP --num-recs=10
            sIP|            dIP|sPort|dPort|pro|     bytes|           nhIP|
     10.0.40.20|  192.168.40.20|55425| 5722|  6|      5523|        0.0.0.1|
     10.0.40.20|  192.168.40.20|55425| 5722|  6|     21084|        0.0.0.1|
     10.0.40.20|  192.168.40.20|55425| 5722|  6|     11500|        0.0.0.1|
     10.0.50.12| 192.168.40.100| 3088| 8005|  6|    977689|        0.0.0.2|
     10.0.50.12| 192.168.40.100| 3088| 8005|  6|    977689|        0.0.0.2|
     10.0.50.12| 192.168.40.100| 3088| 8005|  6|    977689|        0.0.0.2|
     10.0.50.12| 192.168.40.100| 3088| 8005|  6|    977689|        0.0.0.2|
     10.0.50.12| 192.168.40.100| 3088| 8005|  6|    977689|        0.0.0.2|
     10.0.50.12| 192.168.40.100| 3088| 8005|  6|    977689|        0.0.0.2|
     10.0.50.12| 192.168.40.100| 3088| 8005|  6|    959308|        0.0.0.2|
<2>$ rwgroup sorted.rw --id-fields=1,2,3,4 --delta-field=sTime \
   --delta-value=3600 --rec-threshold=3 --summarize \
| rwcut --fields=1-5,bytes,nhIP --num-recs=5
            sIP|            dIP|sPort|dPort|pro|     bytes|           nhIP|
     10.0.40.20|  192.168.40.20|55425| 5722|  6|     38107|        0.0.0.1|
     10.0.50.12| 192.168.40.100| 3088| 8005|  6|  46529266|        0.0.0.2|
     10.0.50.12| 192.168.40.100| 3089| 8005|  6|  46726003|        0.0.0.3|
     10.0.50.12| 192.168.40.100| 3090| 8005|  6|  46497279|        0.0.0.4|
     10.0.50.12| 192.168.40.100| 3091| 8005|  6|  46448588|        0.0.0.5|
```

Example 4.36: Summarizing Groups with `rwgroup --summarize`

```
<1>$ rwfilter --start-date=2015/06/02 --end-date=2015/06/18 \
   --protocol=6 --type=out --dport=20,21 --pass=stdout \
| rwsort --fields=1,2,sTime \
| rwgroup --id-fields=1,2 --output-path=out.rw
<2>$ rwfilter out.rw --dport=21 --pass=stdout \
| rwset --nhip-file=control.set
<3>$ rwfilter out.rw --nhipset=control.set --pass=stdout \
| rwcut --fields=1-5,sTime --num-recs=5
            sIP|            dIP|sPort|dPort|pro|                 sTime|
  192.168.70.10|     10.0.40.83|65360|   21|  6|2015/06/16T20:38:57.018|
  192.168.70.10|     10.0.40.83|65360|   21|  6|2015/06/16T20:38:57.018|
  192.168.70.10|     10.0.40.83|65360|   21|  6|2015/06/16T20:38:57.146|
  192.168.70.10|     10.0.40.83|57096|   21|  6|2015/06/17T04:41:35.525|
  192.168.70.10|     10.0.40.83|57096|   21|  6|2015/06/17T04:41:35.525|
```

Example 4.37: Using `rwgroup` to Identify Specific Sessions

```
<1>$ rwfilter --type=in,out --start-date=2015/06/02 \
   --end-date=2015/06/18 --protocol=6 --dport=88 \
   --pass=stdout \
| rwsort --fields=1 --output-path=query.rw
<2>$ rwfilter --type=in,out --start-date=2015/06/02 \
   --end-date=2015/06/18 --protocol=6 --sport=88 \
   --pass=stdout \
| rwsort --fields=2 --output-path=response.rw
<3>$ rwcut query.rw --fields=1-4,sTime --num-recs=4
            sIP|            dIP|sPort|dPort|                  sTime|
     10.0.40.26|  192.168.40.20|57288|   88|2015/06/17T17:06:38.871|
     10.0.40.26|  192.168.40.20|57287|   88|2015/06/17T17:06:38.865|
     10.0.40.26|  192.168.40.20|52176|   88|2015/06/16T16:22:08.659|
     10.0.40.26|  192.168.40.20|57287|   88|2015/06/17T17:06:38.856|
<4>$ rwcut response.rw --fields=1-4,sTime --num-recs=4
            sIP|            dIP|sPort|dPort|                  sTime|
  192.168.40.20|     10.0.40.26|   88|57390|2015/06/17T17:32:21.501|
  192.168.40.20|     10.0.40.26|   88|52724|2015/06/16T18:54:21.810|
  192.168.40.20|     10.0.40.26|   88|52725|2015/06/16T18:54:21.818|
  192.168.40.20|     10.0.40.26|   88|57389|2015/06/17T17:32:21.493|
<5>$ rwmatch --relate=1,2 query.rw response.rw stdout \
| rwcut --fields=1-4,nhIP --num-recs=10
            sIP|            dIP|sPort|dPort|           nhIP|
     10.0.40.26|  192.168.40.20|57390|   88|        0.0.0.1|
  192.168.40.20|     10.0.40.26|   88|57390|      255.0.0.1|
  192.168.40.20|     10.0.40.26|   88|52724|      255.0.0.1|
  192.168.40.20|     10.0.40.26|   88|52725|      255.0.0.1|
  192.168.40.20|     10.0.40.26|   88|57389|      255.0.0.1|
  192.168.40.20|     10.0.40.26|   88|51466|      255.0.0.1|
  192.168.40.20|     10.0.40.26|   88|57321|      255.0.0.1|
  192.168.40.20|     10.0.40.26|   88|57320|      255.0.0.1|
  192.168.40.20|     10.0.40.26|   88|52030|      255.0.0.1|
  192.168.40.20|     10.0.40.26|   88|52031|      255.0.0.1|
```

Example 4.38: Using `rwmatch` with Incomplete Relate Values

`rwmatch` is designed to handle not just protocols where source and destination are closely associated, but also where partial associations are significant.

To establish a match group, a response record must first match a query record. For that to happen all the fields of the query record specified as first values in relate pairs must match all the fields of the response record specified as second values in the relate pairs. Additionally, the start time of the response record must fall in the interval between the query record's start time and its end time extended by the value of `--time-delta`. Alternatively, if the `--symmetric-delta` parameter is specified, the query record's start time may fall in the interval between the response record's start time and its end time extended by `--time-delta`. The record whose start time is earlier becomes the base record for further matching.

Additional target records from either file may be added to the match group. If the base and target records come from different files, field matching is performed with the two fields specified for each relate pair. If the base and target records come from the same file, field matching is done with the same field for both records.

In addition to matching the relate pairs, the target record's start time must fall within a time window beginning at the start time of the base record. If `--absolute-delta` is specified, the window ends at the base record's end time extended by `--time-delta`. If `--relative-delta` is specified, the window ends `--time-delta` seconds after the maximum end time of any record in the match group so far. If `--infinite-delta` is specified, time matching is not performed.

As with `rwgroup`, `rwmatch` sets the next-hop IP address field to an identifier common to all related flow records. However, `rwmatch` groups records from two distinct files into single groups. To indicate the origin of a record, `rwmatch` uses different values in the next-hop IP address field. Query records will have an IPv4 address where the first octet is set to zero; in response records, the first octet is set to 255. `rwmatch` *only* outputs queries that have a response grouped with all the responses to that query.

`rwmatch` discards queries that do not have a response and responses that do not have a query unless `--unmatched` is specified. It tells `rwmatch` to write unmatched query and/or response records to an output file or standard output.

- `q` writes query records. Unmatched query records have their next hop IPset to 0.0.0.0.
- `r` writes response records. Unmatched response records have their next hop IPset to 255.0.0.0.
- `b` writes both query and response records.

As a result, the output from `rwmatch` usually contains fewer records than the total of the two source files. `rwgroup` can be used to compensate for this by merging all of the query records for a single session into one record.

Example 4.39 matches all addresses and ports in both directions. As with `rwgroup`, `rwmatch` requires sorted data, and in the case of `rwmatch`, there is always an implicit time-based relationship controlled using the `--time-delta` parameter. As a consequence, *always* sort `rwmatch` data on the start time. (Example 4.38 generated the query and response files from a query that might not produce sorted records; Example 4.39 corrected this by sorting the input files before calling `rwmatch`.)

4.2.9 Managing IPset, Bag, and Prefix Map Files

During a multi-path analysis, an analyst typically performs many intermediate steps while isolating the behavior of interest. The `rwfileinfo` command prints information about binary SiLK files, helping you to manage the files generated as part of this process.

`rwfileinfo` can display information about all types of binary SiLK files: flow record files, IPset files, bag files, and prefix map (or pmap) files. Section 2.2.4 describes how to use `rwfileinfo` for viewing information about flow record files. The current section describes how to use `rwfileinfo` to view information about set, bag, and pmap files, such as the record count, file size, and the SiLK command(s) that created the file. Additionally, `rwfileinfo` displays information specific to each type of file. This information is displayed by default along with the rest of the file information, or can be explicitly viewed by using the `--fields` parameter.

- For IPset files, it shows the nodes, branches and leaves of the IPset (`--fields=ipset`).
- For bag files, it shows the key-value pairs that make up the bag (`--fields=bag`).
- For pmap files, it shows the internal prefix map name (`--fields=prefix-map`). If a prefix map was created without a map name, `rwfileinfo` returns an empty result for the prefix-map-specific field.

Example 4.40 show how `rwfileinfo` handles these files.

1. Commands 1, 2 and 3 create a set, a bag, and a pmap for the example.
2. Command 4 shows a full `rwfileinfo` result for the set file.
3. Commands 5, 6 and 7 show just the specific information for the IPset, bag, and pmap file, respectively.

```
<1>$ rwsort query.rw --fields=1,2,sTime \
   --output-path=squery.rw
<2>$ rwsort response.rw --fields=2,1,sTime \
   --output-path=sresponse.rw
<3>$ rwmatch --relate=1,2 --relate=2,1 --relate=3,4 --relate=4,3 \
   squery.rw sresponse.rw stdout \
| rwcut --fields=1-4,nhIP --num-recs=5
            sIP|            dIP|sPort|dPort|           nhIP|
     10.0.40.26|  192.168.40.20|52396|   88|        0.0.0.1|
  192.168.40.20|     10.0.40.26|   88|52396|      255.0.0.1|
     10.0.40.26|  192.168.40.20|51466|   88|        0.0.0.2|
  192.168.40.20|     10.0.40.26|   88|51466|      255.0.0.2|
     10.0.40.26|  192.168.40.20|51466|   88|        0.0.0.3|
```

Example 4.39: Using `rwmatch` with Full TCP Fields

```
<1>$ rwfilter --start-date=2015/06/02 --end-date=2015/06/18 \
   --sensors=S0,S1 --type=out,outweb --protocol=0- \
   --pass=stdout \
| rwbag --bag-file=sIPv4,flows,internal.bag
<2>$ rwbagtool --coverset --ipset-record-version=4 \
   --output-path=internal.set internal.bag
<3>$ rwpmapbuild --input-file=internal.pmap.txt \
   --output-file=internal.pmap
<4>$ rwfileinfo internal.set
internal.set:
  format(id)          FT_IPSET(0x1d)
  version             16
  byte-order          littleEndian
  compression(id)     lzo1x(2)
  header-length       56
  record-length       1
  record-version      4
  silk-version        3.16.1
  count-records       1184
  file-size           506
  ipset               IPv4
<5>$ rwfileinfo internal.set --fields=ipset
internal.set:
  ipset               IPv4
<6>$ rwfileinfo internal.bag --fields=bag
internal.bag:
  bag                 key: sIPv4 @ 4 octets; counter: records @ 8 octets
<7>$ rwfileinfo internal.pmap --fields=prefix-map
internal.pmap:
  prefix-map          v1: internal
```

Example 4.40: `rwfileinfo` for Sets, Bags, and Prefix Maps

4.3 Summary of SiLK Commands in Chapter 4

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Chapter 5

Case Studies: Intermediate Multi-path Analysis

This chapter features detailed case studies of multi-path analyses, using concepts from previous chapters. They employ the SiLK workflow, `rwfilter` and other SiLK tools, UNIX commands, and networking concepts to provide practical examples of multi-path analyses with network flow data.

Upon completion of this chapter you will be able to

- describe how to combine several tasks to form a multi-path analyses
- execute multi-path analyses with various SiLK tools in one automated program
- associate sets of IP addresses (IPsets) with network flow sensors

5.1 Building Inventories of Network Flow Sensors With IPsets

Flow sensors commonly monitor strategic points in enterprise networks where different network environments meet. This environmental complexity affects sensor flow collection and analyst knowledge as network infrastructure evolves. For example, multiple sensors may overlap their flow collection for failover purposes; as the network routes traffic, analysts may need to determine which sensor is the primary flow collector.

To mitigate these issues, analysts can create and maintain inventories of network sensors, making it easier to review and validate them. These sensor inventories consist of SiLK IPsets that contain internal network addresses monitored by a flow sensor. They are generated by applying the following multi-path analysis workflow.

1. Path 1 associates network addresses with a single sensor.
2. Path 2 associates network addresses of the remaining sensors.
3. Path 3 associates network shared addresses.
4. Finally, the results of each part of the multi-path analysis are merged to create a complete inventory of sensors.

This case is an example of how a multi-path analysis can be built from successive single-path analyses. It demonstrates how to build IPset inventories by merging the results of three single-path analyses into a single IPset inventory. Like the case study and command examples earlier in this guide, it uses the FCCX dataset described in Section 1.7. All analysis steps are shown in Example 5.1. Each part of the multi-path analysis is described in its own section.

5.1.1 Path 1: Associate Addresses with a Single Sensor

To begin generating IPsets, you must select a sensor for the inventory (referenced as an *inventory sensor* for this case study).

1. Command 1 of Example 5.1 shows how to use the `rwfilter` command to select all outbound traffic on inventory sensor `S0` from the repository.
2. Command 1 then calls the `rwset` command to generate a source IPset of internal addresses (`S0-out.set`) that pass the `rwfilter` query. This IPset contains all outbound source IP addresses monitored by sensor `S0` for the defined time period.
3. The `rwset --copy` switch copies the `rwfilter` results to `rwbag`, generating a SiLK bag of flow counts per source IP address for the same time period (`S0-out.bag`).

The resulting IPset and bag provide a detailed inventory of all source IP addresses and their flow volumes monitored by sensor `S0`.

5.1.2 Path 2: Associate Addresses of Remaining Sensors

Command 2 of Example 5.1 shows the next path in the multi-path analysis: associating the addresses for non-inventory sensors in the repository. This procedure is similar to that of Command 1. However, Command 2 selects outbound traffic for the remaining repository sensors (`S1` through `S21`) and generates source IP address sets and bag files for the same time period (`S0-other.set`, `S0-oth.bag`).

5.1.3 Path 3: Associate Shared Addresses

The third path of the multi-path analysis associates the addresses that may be monitored (or *shared*) by multiple sensors.

Identify Uniquely-Monitored Addresses

To begin path three, you need to identify addresses that are uniquely monitored by the inventory sensor, `S0`.

1. Command 3 of Example 5.1 shows how to use `rwsettool --difference` to generate an IPset of addresses that are uniquely monitored by sensor `S0` (`S0-only.set`). This command compares the set of addresses from Command 1 that are monitored by `S0` (`S0-out.set`) to the set of addresses from Command 2 that are monitored by all the other sensors (`S0-other.set`), and saves the IP addresses that are only found in `S0-out.set` to `S0-only.set`.

```
<1>$ rwfilter --sensor=S0 --type=out,outweb --start=2015/06/01 \
   --end=2015/06/30 --proto=0- --pass=stdout \
| rwset --sip-file=S0-out.set --copy=stdout \
| rwbag --bag-file=sipv4,flows,S0-out.bag
<2>$ rwfilter \
   --sensor=S1,S2,S3,S4,S5,S6,S7,S8,S9,S10,S11,S12,S13,S14,S15,\
   S16,S17,S18,S19,S20,S21 \
   --type=out,outweb --start=2015/06/01 --end=2015/06/30 \
   --proto=0- --pass=stdout \
| rwset --sip-file=S0-other.set --copy=stdout \
| rwbag --bag-file=sipv4,flows,S0-oth.bag
<3>$ rwsettool --difference S0-out.set S0-other.set \
   --output=S0-only.set
<4>$ rwbagtool --compare=ge S0-out.bag S0-oth.bag \
   --output=S0-most.bag
<5>$ rwbagtool --coverset S0-most.bag --output=S0-most.set
<6>$ rwsetcat --net=27 S0-most.set S0-only.set \
| cut -f1 -d '|' \
| rwsetbuild stdin cand.set
<7>$ rwfilter --sensor=S0 --type=in,inweb --start=2015/06/01 \
   --end=2015/06/30 --dipset=cand.set --pass=stdout \
| rwset --dip-file=S0-in.set
<8>$ rwsettool --difference S0-in.set S0-most.set S0-only.set \
   --output=S0-close.set
<9>$ rwsettool --union S0-only.set S0-most.set S0-close.set \
   --output=S0.set
```

Example 5.1: Building an IPset Inventory for Sensor S0

2. Command 4 of Example 5.1 checks to see if the inventory sensor `S0` is the primary flow collection sensor. It compares the IP address flow volumes of the inventory sensor to those of the other sensors to determine if `S0` monitors the majority of network traffic for an IP address. To perform this comparison, it uses `rwbagtool` to compare the bag files created in commands 1 and 2 (`S0-out.bag` and `S0-oth.bag`). IP addresses that are monitored by the inventory sensor and have flow volumes greater than or equal to those monitored by the non-inventory sensors are saved to the *S0-most.bag* file.

3. Command 5 shows how to use `rwbagtool --coverset` to generate an IPset (`S0-most.set`) from the `S0-most.bag` file.

Find Asymmetric and Missing Flow Data

To continue Path 3 of the multi-path analysis, you must account for asymmetric and missing network flow data. Causes of this include outages, routing, and network backdoors. To address each case, the third path should identify inbound network traffic to internal hosts closely adjacent to other inventory sensor addresses. This can be accomplished using a small CIDR range, such as /27.

1. Command 6 of Example 5.1 shows how to use the `rwsetcat` and `rwsetbuild` commands to build a `cand.set` candidate set from the `S0-only` and `S0-most` IPset files. The `--net=27` parameter specifies the CIDR range for closely adjacent addresses in the two sets.

2. This candidate set is then used as a destination IPset (`--dipset=cand.set`) for the `rwfilter` query in command 7 to identify any remaining addresses not previously found in commands 1 and 2.

3. Command 8 then uses `rwsettool --difference` to create the `S0-close.set` IPset, which contains IP addresses that are closely adjacent to inventory sensor addresses.

5.1.4 Merge Address Results

After completing the third path of the multi-path analysis, you will have three subsets of the sensor inventory: `S0-only.set`, `S0-most.set`, and `S0-close.set`. To complete the full sensor inventory, all three subsets must be merged together into a single IPset that contains the inventory of IP addresses associated with the inventory sensor, `S0`.

Command 9 of Example 5.1 shows how to generate the final sensor inventory with the `rwsettool --union` switch. This command performs an algebraic *union* on `S0-only.set`, `S0-most.set`, and `S0-close.set` to produce `S0.set`, which contains all of the IP addresses in the sensor inventory.

Analysts can use and maintain the sensor inventory IPset to gain a better understanding of the networks monitored by a specific network flow sensor (in this example, `S0`) and identify any situational awareness changes.

5.2 Automating IPset Inventories of Network Flow Sensors

Section 5.1 described how to manually generate a sensor IPset inventory by performing a multi-path analysis. This process is fine if you only need to inventory a single sensor. However, what if you need to inventory all of the sensors in the SiLK repository? Manually executing this workflow for every sensor would quickly become time consuming and represents an inefficient use of analyst time and resources.

Instead, create a shell program to automatically execute this workflow. An automated program can use the `rwsiteinfo` command to compile a list of *all* sensors in the repository, then execute the analytic from Section 5.1 for every sensor. Automating the workflow is more efficient and accurate than manually executing it for each sensor. It makes compiling and updating a complete sensor inventory much easier: simply run the program as needed to automatically generate a new inventory for all sensors that are currently in the SiLK repository. This improves your situational awareness of the network.

This section discusses Example 5.2, a simple Bash shell program that automates the process of building sensor IPset inventories. This program consists of two main sections, a *header* and *loop*, that are discussed in detail below.

5.2.1 Program Header

The first section of this automated program is the *header*, which contains information used throughout program execution.

Line 1 of Example 5.2, commonly known as the *she-bang*, identifies this as a *Bourne-again (Bash)* shell program to the system shell. The comment in Line 2 helps users to understand the overall purpose of the program.

Lines 5-8 define variables that are referenced throughout the remainder of the program.

- The `START` and `END` variables specify the dates that are used with `rwfilter --start-date` and `--end-date` switches.
- The `INBOUND` and `OUTBOUND` variables specify the options for inbound and outbound `rwfilter` queries that are executed in the program's *for loop*.

5.2.2 Program Loop

The remainder of the program, a Bash *for loop*, executes most of the program's automated tasks.

Line 11 of Example 5.2 loops through the sensors in the SiLK repository. The `rwsiteinfo --sensor` command generates a complete list of sensors in the repository. The for loop cycles through this list to generate an inventory for each sensor.

Lines 13-15 define a variable (`FILES` in this example) of temporary files that will be deleted at the end of the for loop (Line 47).

Line 17 follows with a visual output of the current inventory sensor using the UNIX `echo` command. This indicates that the program has started building an IPset inventory for that sensor.

With the exception of Lines 23-25, the remainder of the program repeats the analytic in Example 5.1 using the variables defined in the program header. Lines 23-25 are an addition to the original analytic. They call `rwsiteinfo` with the `--fields=sensor:list` option to generate a comma-delimited list of sensors. This list of sensors is then passed to a series of `sed` commands to remove the inventory sensor, effectively building an `OTHERS` variable that contains a list of non-inventory sensors. The `OTHERS` variable is then used to build the set of non-inventory sensors used in the rest of the analytic.

Line 49 again displays the name of the current sensor and indicates that the program has finished building an inventory for that sensor.

```
#!/bin/bash
# Script to automate sensor IPSet inventories

# Variables
START="2015/06/01"
END="2015/06/30"
OUTBOUND="--type=out,outweb --start=$START --end=$END --proto=0-"
INBOUND="--type=in,inweb --start=$START --end=$END --dipset=cand.set"

# Loop through each sensor in the repository
for SEN in $(rwsiteinfo --no-titles --no-final --fields=sensor); do

  FILES="$SEN-out.set $SEN-out.bag $SEN-close.set $SEN-other.set"
  FILES+=" $SEN-oth.bag $SEN-only.set cand.set"
  FILES+=" $SEN-most.set $SEN-in.set $SEN-most.bag"

  echo "Sensor: $SEN -- Start"

  rwfilter --sensor=$SEN $OUTBOUND --pass=stdout \
   | rwset --sip-file=${SEN}-out.set --copy=stdout \
   | rwbag --bag-file=sipv4,flows,${SEN}-out.bag

  OTHERS=$(rwsiteinfo --no-titles --no-final --fields=sensor:list \
   | sed -e "s/,$SEN,/,/" \
   | sed -e "s/^$SEN,//" | sed -e "s/,$SEN$//")

  rwfilter --sensor=$OTHERS $OUTBOUND --pass=stdout \
   | rwset --sip-file=${SEN}-other.set --copy=stdout \
   | rwbag --bag-file=sipv4,flows,${SEN}-oth.bag

  rwsettool --difference ${SEN}-out.set ${SEN}-other.set \
   --output=${SEN}-only.set
  rwbagtool --compare=ge ${SEN}-out.bag ${SEN}-oth.bag \
   --output=${SEN}-most.bag
  rwbagtool --coverset ${SEN}-most.bag --output=${SEN}-most.set

  rwsetcat --net=27 ${SEN}-most.set ${SEN}-only.set \
    | sed -e 's/|.*//'     | rwsetbuild stdin cand.set

  rwfilter --sensor=$SEN $INBOUND --pass=stdout \
    | rwset --dip-file=${SEN}-in.set

  rwsettool --difference ${SEN}-in.set ${SEN}-most.set \
  ${SEN}-only.set --output=${SEN}-close.set
  rwsettool --union ${SEN}-only.set ${SEN}-most.set \
  ${SEN}-close.set --output=${SEN}.set
  rm -f $FILES

  echo "Sensor: $SEN -- End"
done
```

Example 5.2: Automating IPset Inventories

Chapter 6

Advanced Exploratory Analysis with SiLK: Exploring and Hunting

This chapter introduces advanced exploratory analysis through application of the analytic development process with the SiLK tool suite. It discusses the exploratory analysis process, starting points for exploration, and advanced SiLK commands and techniques that can be employed during an analysis.

Upon completion of this chapter you will be able to

- describe advanced exploratory analysis and how it maps to the analytic development process
- describe SiLK tools that often are used during exploratory analysis
- provide example workflows for exploratory network flow analysis

6.1 Exploratory Analysis: Concepts

The *exploratory* approach is the most open-ended of the analysis workflows described in this guide. It provides a framework for investigating more complex questions about network traffic. As the name suggests, exploratory analysis involves asking questions about trends, processes, and dynamic behavior that do not necessarily have fixed or obvious answers. Often the analysis leads to more questions!

Exploratory analysis uses single-path and multi-path analyses as building blocks to provide insight into network events. It typically considers more than one indicator of network behavior to provide a more complete understanding of what happened. Each building block represents a question (or part of a question) whose answer feeds into subsequent steps in the analysis. Analysts can assemble these building blocks by hand to prototype an analysis or examine one-time phenomena, iterating if necessary. This manual analysis can then transition to scripted analysis to save time, make it easier to repeat the analysis, and ensure more consistent results.

As Figure 6.1 indicates, this form of analysis rarely proceeds directly from initial question to final result. Instead, it gathers a variety of contextual information, and goes forward in a search pattern to reach the result.

6.1.1 Exploring Network Behavior

Exploratory analysis follows the general SiLK analysis workflow described in Figure 1.5. The overall course of exploratory analysis generally follows these steps:

1. come up with initial questions as the starting point (the Formulate stage)
2. apply a set of analyses to provide insight into a given question (the Model and Test stages)
3. integrate the results of these analyses with previously-available data (the Analyze stage)
4. refine the results (the Refine stage)
5. identify new questions to be investigated with further analyses (return to the Formulate stage to begin another iteration of the exploratory analysis)

In contrast to single-path and multi-path analysis, analysts explore with iterations of questions and their associated analyses. We may not have a specific set of behaviors, known event, or identified service in mind at the start of an exploratory analysis. Instead, we start with a general question and seek a clearer target during the iterations of the analysis.

As the exploration progresses, the scope of these questions often becomes more associated with any features of interest that are identified in the data. These features can be identified during the initial stages of establishing context for the network behavior to be investigated and gathering data about it. They also can emerge from the results of preliminary single-path or multi-path analyses of the data, which help to refine the scope of the exploratory analysis.

Exploratory analysis often takes a deep dive into the data to examine the possible causes or conditions related to the features of interest. The analyst may form, test, and either continue to investigate or abandon hypotheses about sources of the behavior. This exploration continues until the analyst reaches a sufficient level of confidence in understanding the features to either identify the causes of the event and share the results, or close the hypothesis. When all threatening hypotheses have been closed, we can close the investigation and associate the behavior with unremarkable network activity.

6.1.2 Starting Points for Exploratory Analysis

The first question that normally arises during an exploratory analysis is, “Where should it start?”

One set of starting points for exploratory analyses involves investigating unexplained activity on the monitored network. This produces initial questions such as

- What activity is present that could be malicious or damaging?
- What is the impact of this unexpected activity?
- What led to this unexpected activity?

The initial stage of the investigation may be a relatively straightforward profiling analysis or an inventory of traffic of interest across specific servers. Further iterations use the results of these profiles and inventories to identify outliers, inconsistencies, and behaviors exhibited by the unexplained activity. These outliers, inconsistencies, and behaviors then become the focus of exploration for the next iteration. At this point in the analysis, a case-by-case frequency summary or time-based trends can provide insight into the activity.

The iterations of analysis continue until the analyst identifies a reasonable explanation of the activity, rejecting alternate explanations.

Another set of starting points for exploratory analyses involves unusual levels or directions of network services. This produces initial questions such as

- What led to these services?
- Is there a change in the population of external hosts employing these services?
- Does this change in service match with a model of network attack?

Analyses for these questions often summarize network activities via time series or service-by-service counts of incoming activity versus outgoing activity. The analyst integrates and examines these summaries and counts, looking for points of significant change in trends or traffic levels. These points of change, and the hosts involved in those changes, become the focus of the next iteration of the exploratory analysis.

6.1.3 Example Exploratory Analysis: Investigating Anomalous NTP Activity

As an example of an exploratory analysis, consider an investigation into Network Time Protocol (NTP) usage. NTP is associated with UDP port 123, so our starting point would be to find out what level of activity is observed on this port.

Compare Inbound and Outbound UDP Activity on Port 123

The `rwfilter` commands in Example 6.1 provide an initial view of UDP activity on port 123. Command 1 profiles the outgoing activity to UDP/123. Command 2 profiles the incoming activity from this port. The size of the outgoing activity is surprisingly large (almost double the flow records, and one third larger in bytes) and worth looking at more closely.

Differentiate Benign and Malicious Traffic

The second phase of this sample exploratory analysis examines the UDP activity on port 123 more closely to look for patterns that might differentiate between benign and malicious traffic. `rwuniq` is well suited for this task, since it allows us to look at the traffic over a variety of contingencies. RFC 5905[10] specifies that NTP packets must have a byte size of 76 bytes for a request and 96 bytes for a response. We would therefore expect to find flow bytes that are a multiple of either of these two values.

Example 6.2 runs `rwuniq` on the output files from Example 6.1. Command 1 shows an excerpt of the various byte counts for outgoing flows. Command 2 shows a similar excerpt for the incoming flows. The byte sizes are the ones expected: 76, 96, $152 = 2 \times 76$, $192 = 2 \times 96$. (While not shown in the excerpt, all of the other byte sizes are multiples of either 76 or 96.)

What is surprising are the further columns on the last line of the excerpts in Example 6.2. NTP is a protocol where machines on a network make queries to a few servers for time values, then adjust their clocks based on the answers received. We would therefore expect outgoing traffic to come from only a few addresses but go to multiple hosts in the local network.

[10] Internet Engineering Task Force (IETF) Request for Comments 5905 (https://www.ietf.org/rfc/rfc5905.txt)

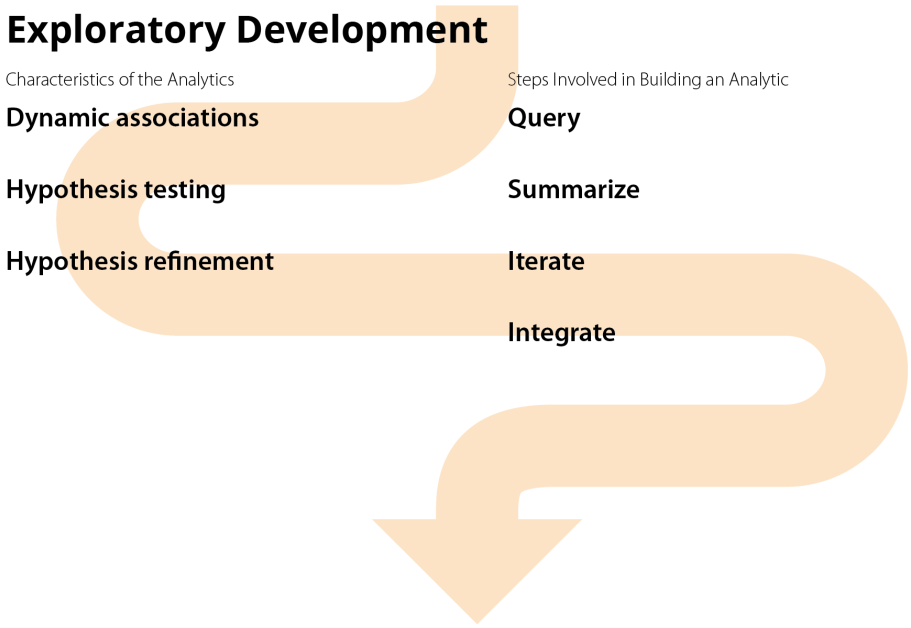

Figure 6.1: Exploratory Analysis

```
<1>$ rwfilter --start=2015/06/16 --sensor=S0,S1,S2,S3,S4 \
   --type=out --proto=17 --dport=123 --pass=NTP-out.raw \
   --print-vol=stdout
     |              Recs|           Packets|               Bytes|     Files|
Total|           5566807|          15791472|          2646290347|        60|
 Pass|              7040|              8410|              659800|         |
 Fail|           5559767|          15783062|          2645630547|         |
<2>$ rwfilter --start=2015/06/16 --sensor=S0,S1,S2,S3,S4 \
   --type=in --proto=17 --sport=123 --pass=NTP-in.raw \
   --print-vol=stdout
     |              Recs|           Packets|               Bytes|     Files|
Total|           3549008|          15506147|          3118288427|        60|
 Pass|              3936|              6148|              493968|         |
 Fail|           3545072|          15499999|          3117794459|         |
```

Example 6.1: Using `rwfilter` to Profile NTP Activity

For flows with byte size 192 (double the response value), the number of local hosts and the number of remote hosts are nearly equal, which is unusual. Additionally, the number of incoming packets is larger than the number of outgoing requests. This disparity is also unusual, indicating that further exploration of this traffic is needed.

Plot Anomalous Flows

Now that we have identified the anomalous flows, it's time to take a more detailed look at them. Example 6.3 uses `rwfilter` to isolate the incoming 192-byte flows, then calls `rwcount` to generate a time series of that traffic. The results are somewhat lengthy, since the `rwcount` command splits a day of traffic into five-minute bins.

Command 1 uses `rwcount` options to generate a comma-separated-value file (CSV), which can be fed into Microsoft Excel or another graphing program. The resulting time series plot is shown in Figure 6.1.3.

NTP traffic is normally expected to either cluster around the point at which computers are connecting to the network, or occur periodically thereafter as the computers adjust their clocks. As can be seen in the figure, while there are regular pulses of traffic (visible more to the right end of the timeline), there are also irregular collections of traffic earlier in the day.

```
<1>$ rwuniq --fields=bytes \
   --values=Flows,packets,distinct:dip,distinct:sip --sort \
   NTP-out.raw \
| head -5
     bytes|   Records|         Packets|dIP-Distin|sIP-Distin|
        76|      5728|            5728|         2|        17|
        96|       362|             362|         6|        75|
       152|       563|            1126|         1|         1|
       192|       323|             646|        50|        46|
<2>$ rwuniq --fields=bytes \
   --values=Flows,packets,distinct:dip,distinct:sip --sort \
   NTP-in.raw \
| head -5
     bytes|   Records|         Packets|dIP-Distin|sIP-Distin|
        76|      2083|            2083|        16|         1|
        96|        66|              66|        27|         5|
       152|      1126|            2252|         1|         1|
       192|       615|            1230|        50|        46|
```

Example 6.2: Using `rwuniq` to examine NTP Activity

```
<1>$ rwfilter NTP-in.raw --bytes=192-192 --pass=stdout \
| rwcount --bin-size=300 --delim=',' >NTP-in.csv
```

Example 6.3: Using `rwcount` to generate NTP Timelines

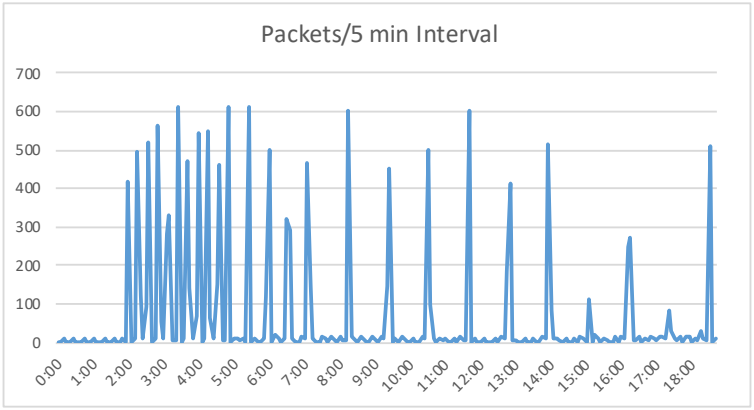

Figure 6.2: Time Series Plot of NTP Traffic

Is the Irregular NTP Traffic Related to Client-side Initialization?

To determine if this early irregular traffic is related to initialization of the client side of the NTP traffic, Example 6.4 generates summary bags for the hosts involved. Command 1 starts this process by identifying the earliest start time for each client (internal recipient) of the NTP traffic, using a combination of `rwfilter` and `rwuniq`. The output of the `rwuniq` is formatted for easy parsing in Command 3, then saved to the file `source-fields.txt`.

An obvious approach at this point would be to issue another call to `rwfilter` to pull traffic prior to the start of the NTP traffic for the destinations involved, then call `rwuniq` to summarize the traffic. One complication to this approach is that the start times for the NTP traffic are not aligned. Rather than setting a fixed time (such as the minimum start time), it seems wise to analyze client traffic on a one-by-one basis. This individual approach has two disadvantages: it requires more programming (14 lines of commands, as opposed to two or three), and it is somewhat slower in execution (for the data being examined, about five seconds, rather than an immediate result). However, these disadvantages are outweighed by the increased precision of the results.

Command 2 of Example 6.4 prepares to analyze traffic for individual clients by creating an empty bag.

Command 3 is the loop that reads the start time information for each client (shown by the redirection at the end and the `read` call in the `while` statement's condition). The body of the loop then uses `date` as the NTP start time for the client and calculates a ten minute time window prior to the start time (using shell arithmetic and `awk` to reformat the range elements as SiLK formatted date-time values).

The bag initialized in Command 2 (`cur.bag`) is updated for each source IP address. The loop in Command 3 calls `rwfilter` using the time range for each address to find activity prior to the NTP traffic, using `rwbagtool` to add the results to the bag. Since `cur.bag` is initially empty but keyed by the client IP address, the prior activity is calculated for each client in turn. Although the `rwbagtool` call adds the bags, it is really just inserting the new entry in the summary bag, using `temp.bag` as an intermediate that is renamed in the `mv` call to overwrite the summary bag.

After all of the clients are summarized, Command 4 displays the first few entries in `cur.bag`. They represent a brief sample of the 48 lines of full output.

- Low values (in the tens) would support the hypothesis that the host in question is in the process of initialization, as is possible for `192.168.50.11`.
- High values (in the hundreds to thousands) would support that the host in question is in ongoing use, as is the case for most of the hosts.

Possible Explanations for Anomalous NTP Traffic

While it is clear that there is a range of flow counts during the ten-minute time window prior to the start of NTP traffic, the numbers are large enough to eliminate the idea that the anomalous NTP traffic is due to initialization of the clients. The irregular traffic could be due to a variety of causes:

- It could be a covert means of mapping clients: send NTP results to the clients, then see which ones respond with an `ICMP host unreachable` message.
- It could be a covert signaling or command interface for malicious software that is running on the clients.

```
<1>$ rwfilter NTP-in.raw --bytes=192-192 --pass=stdout \
| rwuniq --fields=dip --values=stime-earliest --no-titles \
   --delim=' ' --output=source-fields.txt
<2>$ rwbagbuild --bag-input=/dev/null --key-type=sipv4 \
   --counter-type=records --output=cur.bag
<3>$ while IFS="" read -r line || [[ -n "$line" ]]; \
do srcArray=($line); \
    StEpoch=$( date -d ${srcArray[1]} +"%s"); \
    StTimeE=$(echo $(( $StEpoch - 1 )) \
    | awk '{print strftime("%Y/%m/%dT%T",$1)}'); \
    StTimeS=$(echo $(( $StEpoch - 600 )) \
    | awk '{print strftime("%Y/%m/%dT%T",$1)}'); \
    rwfilter --start=2015/06/16 --sensor=S0,S1,S2,S3,S4 \
    --type=out,outweb --saddress=${srcArray[0]} \
    --stime=${StTimeS}-${StTimeE} --pass=stdout \
    | rwbag --bag-file=sipv4,flows,stdout \
    | rwbagtool --add cur.bag stdin --output=temp.bag; \
    mv temp.bag cur.bag; \
done < source-fields.txt
<4>$ rwbagcat cur.bag | head -10
     10.0.40.54|                1452|
  192.168.40.25|                1777|
  192.168.40.50|                 183|
  192.168.40.51|                 123|
  192.168.50.11|                  63|
192.168.111.109|                 211|
192.168.111.131|                 319|
 192.168.121.57|                 325|
 192.168.121.77|                 291|
192.168.121.145|                 248|
```

Example 6.4: Using `rwuniq` and Bags to Summarize Prior Traffic on NTP Clients

- It could reflect some flaw in the NTP implementation on the network. However, the relative maturity of NTP and its implementations and the halting of the irregular traffic discount this possibility.
- It could be a reflection attack against the target network. However, the nature of the exercise under way and the overall level of traffic involved discount that possibility.

Testing and evaluating these possibilities is left for further rounds of exploratory analysis!

6.1.4 Observations on Exploratory Analysis

The initial examination of inbound and outbound data in an exploratory analysis is the basis for all that follows. It is the starting point for an accumulating body of experience that aids the analyst in interpreting the results.

The odd behavior shown in Example 6.2 reflects a general aspect of exploratory analysis: it is shaped by the dynamics of network behavior. Since the analyst is exploring previously-unexamined behaviors, the process incorporates consideration of new behaviors and trends. This is done by both noting results that are expected in a given situation and those that are surprising.

Surprising results (such as those in Example 6.2) often serve as starting points for further rounds of analysis. Networks are not static: the traffic they carry constantly changes over time. Analysts therefore must build an evolving understanding of their behavior.

The exploratory analysis in this section uses a variety of SiLK tools. It also employs tabular data, graphical summary, and calculation of specific values. This diverse set of tools and techniques reflects the open-ended nature of exploratory analysis. Analysts need to obtain different views into the data to obtain a good understanding of the target of the analysis.

The outcome of an exploratory analysis can take several forms. As the analysis proceeds, it produces more and more background information on the network hosts and their traffic. As this information is captured, it aids in interpreting both results obtained later in the analysis and the results of other analyses.

Background information is not the only thing that can be reused in an exploratory analysis! Its component parts can be applied in other analyses as filters or analytics. For example, the date math portion of Example 6.4 is also incorporated into the case study discussed in Chapter 7. As the body of such filters and analytics expands, you can perform further exploratory analyses more easily—simply reuse those developed for earlier analyses.

6.2 Exploratory Analysis: Analytics

The SiLK commands described in this chapter involve sophisticated uses of the SiLK tool suite that are often appropriate for exploratory analyses. However, they can be used with any analysis method.

6.2.1 Using Tuple Files for Complex Filtering

Partitioning criteria for many analyses comprise specific combinations of field values, any one of which can be considered as *passing*. While you can make repeated `rwfilter` calls and merge them later, this approach is often inefficient as it may involve pulling the same records from the repository several times.

For example, consider an analysis that is looking for a Simple Network Management Protocol (SNMP) call generated from viewing a malicious email message. SNMP is associated with UDP port 161, email receipt with TCP port 25. The naive approach would be a call to `rwfilter` that simply merges these two ports:

```
rwfilter --protocol=6,17 --dport=25,161
```

This call to `rwfilter` actually uses four permutations of the selection parameters to select records (protocol 6 and dport 25, protocol 6 and dport 161, protocol 17 and dport 25, protocol 17 and dport 161), not just the two that apply for this example (protocol 6 and dport 25, protocol 17 and dport 161).

As shown in Example 6.5, you could use two calls to `rwfilter` to pull the desired port-protocol permutations separately, then combine the data files with the `rwappend` command. However, this approach involves two calls to `rwfilter` that re-read the input flow records. If the analysis includes many cases, the same data would be read many times. On top of that, if the data set is large, each pull from the repository could take a significant amount of time.

A more efficient approach is to store partitioning criteria as a *tuple file* and use that file with `rwfilter` to pull the records in a single operation. A tuple file is a text file consisting of the five-tuple fields (`sIP`, `dIP`, `sPort`, `dPort`, `protocol`) delimited by vertical bars (`|`). `rwfilter` pulls the flow records that match the entries in the tuple file from the SiLK repository.

To select the protocol-dport combinations of (6,25) and (17,161), you could create a tuple file that contains both combinations:

```
protocol|dport
       6|25
      17|161
```

Running `rwfilter` with the `--tuple-file` switch set to the name of this tuple file will select only those flow records with (protocol 6, dport 25) and (protocol 17, dport 161). Only one call to `rwfilter` would be needed to pull these records, not two (as in Example 6.5).

Using Tuple Files to filter Web Servers

Example 6.6 shows a tuple file that is used to choose web server addresses on different ports.

- Command 1 shows the tuple file, `webservers.tuple`. The first line contains headers that identify the fields associated with the columns, `dIP` and `dPort`. The rest of the tuple file lists the destination IP address and destination port combinations of interest.
- This file can then be used with `rwfilter` as shown in Command 2. The `--tuple-file` option need not be the only partitioning option. In Command 2, the `--protocol` parameter also is specified as a partitioning criterion.

In some cases, you can obtain results more quickly by using seemingly redundant command-line options to duplicate some of the values from the tuple file. For instance, adding `--dport=80,443,8443` to the `rwfilter` call in Example 6.6 reduces the number of records that need to be examined with the tuple file. No matter where they appear in the `rwfilter` call, tuple files are always processed after the parameters that partition based on individual flow record fields, and before those using plug-ins or Python. However, filtering by multiple destination ports is not a substitute for the tuple file in Example 6.6, as these criteria are not sufficiently restrictive to produce the desired results.

```
<1>$ rwfilter --start=2015/06/17 --type=in,out --protocol=6 \
   --dport=25 --pass=result.raw
<2>$ rwfilter --start=2015/06/17 --type=in,out --protocol=17 \
   --dport=161 --pass=part2.raw
<3>$ rwappend result.raw part2.raw
<4>$ rm part2.raw
```

Example 6.5: Using Multiple Data Pulls to Filter on Multiple Criteria

```
<1>$ cat <<EOF >webservers.tuple
            dIP|dPort
     10.0.40.21|  443
     10.0.40.23| 8443
     10.0.20.59|   80
  192.168.20.59|   80
     10.0.40.21|   80
  192.168.40.24|  443
  192.168.40.27|  443
  192.168.40.91|  443
  192.168.40.92|  443
EOF
<2>$ rwfilter --type=in,inweb --start-date=2015/06/02 \
   --end-date=2015/06/18 --dport=80,443,8443 \
   --protocol=6 --flags-all=SAF/SAF,SAR/SAR \
   --tuple-file=webservers.tuple --sensors=S0,S1 \
   --pass=stdout \
| rwuniq --fields=dIP,dPort --value=Records
            dIP|dPort|   Records|
     10.0.20.59|   80|     29720|
     10.0.40.21|  443|    355791|
     10.0.40.23| 8443|     30934|
  192.168.40.91|  443|         6|
  192.168.40.27|  443|         9|
  192.168.40.92|  443|         3|
  192.168.20.59|   80|     10652|
     10.0.40.21|   80|      1565|
  192.168.40.24|  443|        24|
```

Example 6.6: Filtering on Multiple Criteria with a Tuple File

6.2.2 Manipulating Bags

Using bags to store key values and counts (as described in Section 4.2.4) can be very helpful to store the intermediate and final results of a multi-path analysis. SiLK supports several advanced options for working with bags. In addition to comparing bags with `rwbagtool` (Section 4.2.4) and extracting sets from bags (Section 4.2.5), you can use `rwbagtool` to do the following:

- add and subtract bags (analogous to the SiLK set operations)
- multiply bags by scalar numbers
- divide bags
- threshold bags (filter bags on volume)

The result of these operations is a bag with new volumes.

Adding and Subtracting Bags

Suppose you want to find the total number of records associated with the IP addresses that are stored in two bags. You can add the contents of the two bags together to create a new bag that holds the sum of their contents.

To add bags together, use the `rwbagtool --add` parameter. The `--output-path` parameter specifies where to deposit the results. Most of the results from `rwbagtool` are bags themselves. Example 6.7 shows how to use bag addition to find the total number of flows of inbound web traffic over a two-day period.

1. The `rwbagcat` calls in commands 1 and 2 display the contents of the two bags to be added, `web-20150616.bag` and `web-20150617.bag`. Each bag contains a day's worth of inbound web traffic flows.
2. Command 3 adds the two bags with the `rwbagtool --add` parameter.
3. The results of the addition are stored in `web-sum.bag`, which is shown in Command 4.
    - If an IP address appears in both bags, the `rwbagtool --add` command sums up the number of flows in the two bags. For instance, the IP address `10.0.20.59` appears in both bags. The number of flows for this IP address in `web-sum.bag` is the sum of the flows in the two bags.
    - If an IP address appears in just one bag, the `rwbagtool --add` command still includes it in the results. For instance, the IP address `190.168.40.27` only appears in the bag `web-20150616.bag` but is included in the results stored in `web-sum.bag`.

Similarly, you may want to subtract the byte counts in one bag from those stored in another bag to find out how many are left over after a step in your analysis. Use the `rwbagtool --subtract` command to subtract the contents of bags.

Bag subtraction operates in the same fashion as bag addition, but all bags after the first are subtracted from the first bag specified in the command. Bags cannot contain negative values: any subtraction resulting in a negative number causes `rwbagtool` to omit the corresponding key from the resulting bag.

```
<1>$ rwbagcat web-20150616.bag
     10.0.20.59|                7977|
     10.0.40.21|              135757|
     10.0.40.23|               11700|
  192.168.20.59|                3980|
  192.168.40.24|                  17|
  192.168.40.27|                   9|
  192.168.40.91|                   3|
<2>$ rwbagcat web-20150617.bag
     10.0.20.59|               15248|
     10.0.40.21|              221599|
     10.0.40.23|               19234|
  192.168.20.59|                6672|
  192.168.40.24|                   7|
  192.168.40.91|                   3|
  192.168.40.92|                   3|
<3>$ rwbagtool --add web-20150616.bag web-20150617.bag \
   >web-sum.bag
<4>$ rwbagcat web-sum.bag
     10.0.20.59|               23225|
     10.0.40.21|              357356|
     10.0.40.23|               30934|
  192.168.20.59|               10652|
  192.168.40.24|                  24|
  192.168.40.27|                   9|
  192.168.40.91|                   6|
  192.168.40.92|                   3|
```

Example 6.7: Merging the Contents of Bags Using `rwbagtool --add`

Hint 6.1: Be Aware of Bag Types with `rwbagtool`

Bags do store information in the file header about which types of keys and counts they contain. However, the information is not used to restrict bag operations. Consequently, `rwbagtool` will add or subtract byte bags and packet bags without warning, producing meaningless results.

If unequal but compatible types are added or subtracted, a meaningful result type will be produced. For example, keys of `sIPv4` and `dIPv4` will produce a result key of type `any-IPv4`. When incompatible types are combined, the resulting type will be `custom` (the most generic bag type). Use `rwfileinfo --fields=bag` to view this information, as described in Section 4.2.9.

Multiplying and Dividing Bags

You can multiply the values in a bag by a scalar number and divide the contents of a bag by the contents of another bag. This is useful for operations such as computing percentages (for instance, to compare traffic levels during different time periods).

- Use the `rwbagtool --scalar-multiply` command to multiply all of the counter values in a bag by a scalar value. Bags can only be multiplied by a scalar value.

- Use the `rwbagtool --divide` command to divide the counter values in one bag by those of another.

Hint 6.2: Use Caution when Dividing Bags with `rwbagtool`

Be very careful when dividing bags. **The second (denominator) bag must contain every key found in the first (numerator) bag—do not divide by zero!** To ensure that the elements of the two bags match, use the `rwbagtool --intersect` command to remove mismatched elements.

1. Extract the set of IP addresses from the denominator bag by using `rwbagtool --coverset` as described in Section 4.2.5.
2. Run `rwbagtool --intersect` on the numerator bag to remove all elements that are not found in the denominator bag as described in Section 4.2.5.
3. Use `rwbagtool --divide` to divide the contents of the numerator bag by those of the denominator bag.

Example 6.8 shows how to use scalar multiplication and division. The example computes the percentage change in traffic between the two bags from Example 6.7. It uses `rwbagtool --coverset` to remove the IP addresses that do not appear in both bags, then uses the `rwbagtool` options `--scalar-multiply` and `--divide` to compute the percentage change in traffic between the IP addresses in both bags.

```
<1>$ rwbagtool --coverset 20150616.bag >20150616.set
<2>$ rwbagtool --coverset 20150617.bag >20150617.set
<3>$ rwsettool --intersect 20150616.set 20150617.set \
   >common.set
<4>$ rwbagtool --scalar-multiply=100 --intersect=common.set \
   20150616.bag >multiply.bag
<5>$ rwbagcat multiply.bag
     10.0.20.59|              797700|
     10.0.40.21|            13575700|
     10.0.40.23|             1170000|
  192.168.20.59|              398000|
  192.168.40.24|                1700|
  192.168.40.91|                 300|
<6>$ rwbagcat 20150617.bag
     10.0.20.59|               15248|
     10.0.40.21|              221599|
     10.0.40.23|               19234|
  192.168.20.59|                6672|
  192.168.40.24|                   7|
  192.168.40.91|                   3|
  192.168.40.92|                   3|
<7>$ rwbagtool --intersect=common.set 20150617.bag \
   >predivide.bag
<8>$ rwbagtool --divide multiply.bag predivide.bag >divide.bag
<9>$ rwbagcat divide.bag
     10.0.20.59|                  52|
     10.0.40.21|                  61|
     10.0.40.23|                  61|
  192.168.20.59|                  60|
  192.168.40.24|                 243|
  192.168.40.91|                 100|
```

Example 6.8: Using `rwbagtool` to Generate Percentages

Thresholding Bags with Count and Key Parameters

Sometimes, you may want to threshold the contents of a bag to items that are larger than a minimum value or smaller than a maximum value. This thresholding can be used to limit key values (e.g., eliminating IP addresses that are lower or higher than the specified address value) as well as count values (e.g., eliminating IP addresses with packet counts that are lower than the desired volume).

The `--minkey`, `--maxkey`, `--mincounter`, and `--maxcounter` parameters supported by `rwbagcat` are also supported by `rwbagtool`. In this case, they specify the minimum and maximum key and count values for output. They can optionally be combined with an operation parameter (e.g., `--add`, `--subtract`) or a masking parameter (i.e., `--intersect` or `--complement-intersect`) to perform other operations on a bag. Example 6.10 shows an example of thresholding by minimum and maximum counts.

6.2.3 Sets Versus Bags: A Scanning Example

Both sets and bags can be employed to search for network scanners. This section provides some examples of each and contrasts how they are used within an analysis.

Fine-tuning IP Sets to Find Scanners

Using IP sets can focus on alternative representations of traffic and identify network scanning and other activities. Example 6.9 drills down on IP sets themselves and provides a different view of this traffic.

This example isolates the set of hosts that exclusively scan from a group of flow records using `rwfilter` to separate the set of IP addresses that complete legitimate TCP sessions from the set of IP addresses that never complete sessions. As this example shows, the `final.set` set file consists of two IP addresses in contrast to the set of thirty-six that produced low-packet flow records—these addresses are consequently suspicious.[11]

Using Bags to Find Scanners

To show how bags differ from sets, let's revisit the scanning filter presented in Example 6.9. The difficulty with that code is that if a scanner completed *any* handshake, it would be excluded from the `low.set` file. Many automated scanners would fall under this exclusion if any of their potential victims responded to the scan. It would be more robust to include as scanners hosts that complete only a small number of their connections (10 or fewer) and have a reasonable number of flow records covering incomplete connections (10 or more).

By using bags, Example 6.10 is able to incorporate counts, resulting in the detection of more potential scanners.

1. The calls to `rwfilter` in commands 1 through 3 are piped to `rwbag` to create bags for incomplete, FIN-terminated, and RST-terminated traffic.
2. Commands 4 and 5 use `rwbagtool --coverset` to generate the cover sets for these bags. These commands also use thresholding to generate two sets: `fast-low.set`, which contains only IP addresses

[11] While this might be indicative of scanning activity, the task of scan detection is more complex than shown in Example 6.9. Scanners sometimes complete connections to hosts that respond (to exploit vulnerable machines); non-scanning hosts sometimes consistently fail to complete connections to a given host (contacting a host that no longer offers a service). A more complete set of scan detection heuristics is implemented in the `rwscan` tool, which is discussed in Section 4.2.4.

with fewer than 10 low-packet connections (`--mincounter=10`) and `fast-high.set`, which contains only IP addresses with more than 10 incomplete connections (`--maxcounter=10`).

3. Command 6 uses `rwsettool --difference` to find the set of IP addresses that are members of `fast-low.set` but not members of `fast-high.set`. The result, `scan.set`, represents the set of IP addresses that responded to the scans.

4. Command 7 uses `rwsetcat` to count the number of IP addresses in each bag.

6.2.4 Manipulating SiLK Files

Combining Flow Record Files to Provide Context

When you are profiling flow records, you may want to drill down into the data to find specific behaviors. This is especially useful for analyzing traffic with large volumes (for example, by the duration of transfer and by protocol). Issuing repeated `rwfilter` calls subdivides large data sets into smaller ones that are easier to examine and manipulate. However, sometimes this obscures the "big picture" of what is happening during an event. Combining flow record files is one way to provide this kind of context.

Use one of the following SiLK commands to merge multiple flow record files:

- `rwcat` concatenates flow record files in the order in which they are listed. It creates a new flow record file that contains the merged records.
- `rwappend` places the contents of the flow record files at the end of the first specified flow record file. It does not create a new file.

Hint 6.3: SiLK Tools Can Use Multiple Flow Files

As an alternative to combining flow files, many of the SiLK tools accept multiple flow record files as input to a single call. For example, `rwfilter` can accept several flow files to filter during a single call and `rwsort` can accept several flow files to merge and sort during a single call. Very often, it is more convenient to use multiple inputs than to combine flow files.

In Example 6.11, `rwcat` is used to combine previously filtered flow record files to permit the counting of overall values.

1. The initial call to `rwfilter` in Command 1 pulls out all records in the period of interest: 2015/6/10 through 2015/6/24. Subsequent calls to `rwfilter` split these records into three files, depending on the duration of the flow:
   - slow flows of at least 20 minutes duration (i.e., those that match the partitioning criteria of `--duration=1200-`)
   - medium flows of 1–20 minutes duration (i.e., those that match the partitioning criteria of `--duration=60-1199`),
   - fast flows of less than 1 minute duration (the remainder of the flows, which had failed both partitioning criteria and must therefor be less than one minute long)

```
<1>$ rwfilter --start-date=2015/06/02 --protocol=6 \
   --type=in,inweb --packets=1-3 --pass=stdout \
| rwset --sip-file=low.set
<2>$ rwfilter --start-date=2015/06/02 --protocol=6 \
   --type=in,inweb --packets=4- --pass=stdout \
| rwset --sip-file=high.set
<3>$ rwsettool --difference low.set high.set \
   --output-path=final.set
<4>$ rwsetcat low.set --count-ips
36
<5>$ rwsetcat final.set --count-ips
2
```

Example 6.9: Using `rwset` to Filter for a Set of Scanners

```
<1>$ rwfilter --start-date=2015/06/02 --end-date=2015/06/18 \
   --type=in,inweb --bytes=2048- --pass=stdout \
| rwfilter stdin --duration=1200- --pass=slowfile.rw \
   --fail=fastfile.rw
<2>$ rwfilter fastfile.rw --protocol=6 --flags-all=S/SRF \
   --packets=1-3 --pass=stdout \
| rwbag --sip-flows=fast-low.bag
<3>$ rwfilter fastfile.rw --protocol=6 \
   --flags-all=SAF/SARF,SR/SRF --pass=stdout \
| rwbag --sip-flows=fast-high.bag
<4>$ rwbagtool fast-low.bag --mincounter=10 --coverset \
   --output-path=fast-low.set
<5>$ rwbagtool fast-high.bag --maxcounter=10 --coverset \
   --output-path=fast-high.set
<6>$ rwsettool --difference fast-low.set fast-high.set \
   --output-path=scan.set
<7>$ rwsetcat fast-low.set fast-high.set scan.set --count-ips
fast-low.set:40
fast-high.set:104
scan.set:37
```

Example 6.10: Using `rwbagtool` to Filter Out a Set of Scanners

2. The calls to `rwfilter` in Commands 2 through 4 split each of the initial divisions based on protocol: UDP (17), TCP (6), and ICMPv4 (1). They are saved to files whose names correspond to their speed and protocol (e.g., `slow17.rw`, `med17.rw`, `fast17.rw`).
3. The calls to `rwcat` in commands 5–7 combine the three splits for each protocol into one overall file per protocol (e.g., `all17.rw`).
4. Command 8 is a short script that produces a summary output reflecting the volume of records in each of the composite files.

When using the `rwfileinfo` command, be aware that `rwcat` creates a new file and can record annotation (using `--note-add` and `--note-file-add`) in the output file header. However, it does not preserve this information from its input files. `rwappend` cannot add annotations and command history to the output file.

For more information about the `rwcat` command, see Appendix C.10 or enter the command `rwcat --help`.

For more information about the `rwappend` command, see Appendix C.11 or enter the command `rwappend --help`.

Dividing or Sampling Flow Record Files with `rwsplit`

In addition to being able to join flow record files, some analyses are facilitated by dividing or sampling flow record files. To facilitate coarse parallelization, one approach is to divide a large flow record file into pieces and concurrently analyze each piece separately. For extremely high-volume problems, analyses on a series of robustly taken samples can produce a reasonable estimate using substantially fewer resources. `rwsplit` is a tool that facilitates both of these approaches to analysis.

Each call to `rwsplit` requires the `--basename` switch to specify the base file name for output files. In addition, one of these parameters must be present:

- `--ip-limit` specifies the IP address count at which to begin a new output file
- `--flow-limit` specifies the flow count at which to begin a new output file
- `--packet-limit` specifies the packet count at which to begin a new output file
- `--byte-limit` specifies the byte count at which to begin a new output file

Example 6.12 is an example of a coarsely parallelized process.

1. Command 1 pulls a large number of flow records with the `rwfilter` command, then use the `rwsplit` command to divide those records into a series of 400,000-record files with a base name of `part`.
2. Command 2 initializes a list of generated filenames. It then uses the `rwfilter` command to separate the records in each file based on sets that contain IP addresses of interest (`mission.set`, `threat.set`, `casual.set`).
3. In Command 3, each of these files is then fed into an `rwfileinfo` call to count the number of records that fall into the selection categories (`mission`, `threat`, and `casual`).

For an additional example of how to use `rwsplit` to improve SiLK performance, see Section 9.6.

Example 6.13 is an example of a sampled-flow process. These commands estimate the percentage of UDP traffic moving across a large infrastructure over a workday.

```
<1>$ rwfilter --type=in,inweb --start-date=2015/6/10 \
   --end-date=2015/6/24 --protocol=0- --note-add='example' \
   --pass=stdout \
| rwfilter stdin --duration=1200- --pass=slowfile.rw \
   --fail=stdout \
| rwfilter stdin --duration=60-1199 --pass=medfile.rw \
   --fail=fastfile.rw
<2>$ rwfilter slowfile.rw --protocol=17 --pass=slow17.rw \
   --fail=stdout \
| rwfilter stdin --protocol=6 --pass=slow6.rw --fail=stdout \
| rwfilter stdin --protocol=1 --pass=slow1.rw
<3>$ rwfilter medfile.rw --protocol=17 --pass=med17.rw \
   --fail=stdout \
| rwfilter stdin --protocol=6 --pass=med6.rw --fail=stdout \
| rwfilter stdin --protocol=1 --pass=med1.rw
<4>$ rwfilter fastfile.rw --protocol=17 --pass=fast17.rw \
   --fail=stdout \
| rwfilter stdin --protocol=6 --pass=fast6.rw --fail=stdout \
| rwfilter stdin --protocol=1 --pass=fast1.rw
<5>$ rwcat slow17.rw med17.rw fast17.rw --output-path=all17.rw
<6>$ rwcat slow1.rw med1.rw fast1.rw --output-path=all1.rw
<7>$ rwcat slow6.rw med6.rw fast6.rw --output-path=all6.rw
<8>$ echo -e "\nProtocol, all, fast, med, slow"; \
for p in 6 17 1; \
   do rm -f ,c.txt ,t.txt ,m.txt
   echo " count-records -" >,c.txt
   for s in all fast med slow; \
     do rwfileinfo $s$p.rw --fields=count-records \
     | tail -n1 >,t.txt
     join ,c.txt ,t.txt >,m.txt
     mv ,m.txt ,c.txt
   done
   sed -e "s/^ *count-records - */$p,/" \
         -e "s/\([^, ]*\),* */\1, /g" ,c.txt
done

Protocol, all, fast, med, slow
6, 6327373, 6280726, 46274, 373,
17, 7304579, 7258750, 45029, 800,
1, 131843, 124221, 6271, 1351,
```

Example 6.11: Combining Flow Record Files with `rwcat` to Count Overall Volumes

```
<1>$ rwfilter --type=inweb,outweb --start-date=2015/6/10 \
   --end-date=2015/6/24 --bytes-per-packet=45- \
   --pass=stdout \
| rwsplit --flow-limit=400000 --basename=part
# keep track of files generated
<2>$ s_list=(skip); \
for f in part*; \
do n=$(basename $f); \
t=${n%.*}; \
rm -f $t{-miss,-threat,-casual,-other}.rw; \
rwfilter $f --anyset=mission.set --pass=$t-miss.rw \
   --fail=stdout \
| rwfilter stdin --anyset=threat.set --pass=$t-threat.rw \
   --fail=stdout \
| rwfilter stdin --anyset=casual.set --pass=$t-casual.rw; \
s_list=(${s_list[*]} $t{-miss,-threat,-casual}.rw); \
done
<3>$ echo -e "\nPart-name, mission, threat, casual"; \
prev=" "; \
for f in ${s_list[*]}; \
do if [ "$f" = skip ]; \
then continue; \
fi; \
cur=${f%-*}; \
if [ "$prev" != " " ]; \
then if [ "$cur" != "$prev" ]; \
then echo; \
echo -n "$cur, "; \
fi; \
else echo -n "$cur, "; \
fi; \
prev=$cur; \
echo -n $(rwfileinfo --fields=count-records $f | tail -n1 \
| sed -e "s/^ *count-records *//")", "; \
done; \
echo

Part-name, mission, threat, casual
part.00000000, 342291, 2191, 5741,
part.00000001, 337363, 2331, 6036,
part.00000002, 351400, 1365, 3403,
part.00000003, 324637, 1438, 4880,
part.00000004, 59355, 9590, 45748,
part.00000005, 32648, 9042, 43983,
part.00000006, 42775, 13484, 56446,
part.00000007, 52733, 11759, 62119,
part.00000008, 45304, 13089, 60488,
part.00000009, 61153, 3854, 19262,
```

Example 6.12: `rwsplit` for Coarse Parallel Execution

1. Command 1 invokes `rwfilter` to perform the initial data pull, retrieving a very large number of flow records. It then uses the `rwsplit` command to pull 100 samples of 1,000 flow records each (`--flow-limit=1000 --sample-ratio=100`), with a 1% rate of sample generation (that is, of 100 samples of 1,000 records, only one sample is retained).

2. Commands 2 through 4 create a file to store the summary results (`udpsample.txt`), then use the `rwstats` command to summarize each sample and isolate the percentage of UDP traffic (protocol 17) in the sample. The results in `udpsample.txt` are then sorted using the operating system `sort` command.

3. Commands 5 through 7 profile the resulting percentages to report the minimum, maximum, and median percentages of UDP traffic.

For more information about the `rwsplit` command, see Appendix C.12 or enter the command `rwsplit --help`.

6.2.5 Generate Flow Records From Text

The `rwtuc` (Text Utility Converter) tool creates SiLK flow record files from columnar text. `rwtuc` is effectively the inverse of `rwcut`, with additional parameters to supply values not given by the columnar input.

`rwtuc` is useful when you need to work with tools or scripting languages that manipulate text output. For example, some scripting languages (Perl in particular) have string-processing functions that may be useful during an analysis. However, for later processing, you may need to use a binary file format for compactness and speed. In this situation, you could use `rwcut` to convert the binary flow record files to text, process the resulting file with a scripting language, and then use `rwtuc` to convert the text output back to the binary flow record format.

If scripting can be done in the Python programming language, the programming interface contained in the `silk` module allows direct manipulation of the binary flow records without converting them to text (and back again). This binary manipulation is more efficient than text-based scripting.[12] See Chapter 8 for more information on using Python with SiLK.

On the other hand, `rwtuc` gives you complete control of the binary representation's content. This is very useful if you need to cleanse a flow record file before exchanging data[13] (for instance, to anonymize IP addresses). To ensure that unreleasable content is not present in the binary form, an analyst can convert binary flow records to text, perform any required edits on the text file, and then generate a binary representation from the edited text. Example 6.14 shows a sample use of `rwtuc` for anonymizing flow records. After `rwtuc` is invoked in Command 3, both the file-header information and non-preserved fields have generic or null values.

`rwtuc` expects input in the default format for `rwcut` output. The record fields should be identified either in a heading line or in a `--fields` parameter of the call. `rwtuc` has a `--column-separator` parameter, with an argument that specifies the character-separating columns in the input. For debugging purposes, input lines that `rwtuc` cannot parse can be written to a file or pipe which the `--bad-input-lines` option names. For fields not specified in the input, an analyst can either let them default to zero (as shown in Example 6.14,

[12] In several published examples, analysts encoded non-flow information as binary flow records using `rwtuc` or PySiLK so that SiLK commands could be used for the fast filtering and processing of that information.

[13] Ensuring that data content can be shared is quite complex, and involves many organization-specific requirements. `rwtuc` helps with mechanics, but often more transformations are required. The `rwsettool` command contains parameters ending in *-strip* that also help to cleanse IP sets.

especially for `sensor`) or use parameters of the form `--FixedValueParameter=FixedValue` to set a single fixed value for that field in all records, instead of using zero. Numeric field IDs are supported as arguments to the `--fields` parameter, not as headings in the input file.

For more information about the `rwtuc` command, see Appendix C.13 or enter the command `rwtuc --help`.

6.2.6 Using Aggregate Bags

Aggregate bags (aggbags for short) are the most complex in a progression of SiLK-related data structures. They are an extension of SiLK bags. Like bags, aggregate bags store key-value pairs. However, bags only store simple key-value pairs, each of which represents a single field or count. Aggregate bags store *composite* key-value pairs: both the key and value can be composed of one or more fields.

For example, the key in an aggregate bag could be a composite of IP address and protocol. The value could be counts of records and bytes for each IP/Protocol combination found in the provided flow records. An aggregate bag stores these combinations of field and count values in a single binary file, as opposed to multiple bag files. Use aggregate bags to summarize and store the results of complex operations in a single file.

Creating Aggregate Bags from Flow Records

To create an aggregate bag that stores the results of a SiLK operation, use the `rwaggbag` command. It creates aggregate bags directly from flow records.

You need to specify the flow record fields that contain the keys and values that are stored in the aggregate bag. For each flow record that `rwaggbag` reads, it extracts the values of the key fields (identified by the `--keys` switch), and combines those fields into a key. It searches for an existing bin that contains the specified key (creating a new bin for that key if none is found), then adds the values for each of the fields listed in the `--counters` switch to the bin's counter. The combined key-value counts are stored in the aggregate bag.

Example 6.15 shows how to use an aggregate bag to count the records associated with source IP addresses that have different protocol and destination port combinations. An ordinary bag can only store one key and one count, limiting it to counting the flow records associated with an IP address, a port, or a protocol. An aggregate bag can count the flow records associated with combinations of these three keys.

1. The `rwfilter` call in Command 1 pulls records with destination ports 1 through 1023.
2. It passes the output to the `rwaggbag` command, which counts the number of flow records associated with the combination of source IP address, destination port, and protocol (`--key=sipv4,dport,protocol --counter=records`).

The new aggregate bag is saved in the file `sim-dport-proto-aggbag`.

Hint 6.4: Sorting and counting aggregate bag keys

The contents of an aggregate bag are sorted and counted in the same order as its keys. For example, the contents of the aggregate bag in Example 6.15 are sorted and counted first by source IP address, then by destination port, and then by protocol.

For more information about the `rwaggbag` command, see Appendix C.22 or enter the command `rwaggbag --help`.

Viewing Aggregate Bags

Command 3 in Example 6.15 shows how to use the `rwaggbagcat` command to view the contents of a binary aggregate bag as text. The command displays the values of the three keys (`sIPv4`, `dPort`, `pro`) along with the count of records associated with each combination of the three keys.

For more information about the `rwaggbagcat` command, see Appendix C.24 or enter the command `rwaggbagcat --help`.

Comparing `rwaggbag` with `rwuniq`

The SiLK command that most closely matches the capability of `rwaggbag` is `rwuniq`. Command 4 in Example 6.15 compares the output of the `rwuniq` command with that of the `rwaggbag` command. The output from `rwuniq` is the same as the contents of the aggregate bag. The biggest difference is that `rwaggbag` outputs its multi-key counts in binary format; `rwuniq` outputs them as text.

Creating Aggregate Bags from Text

Sometimes, you may not want to use network flow data to create an aggregate bag. For instance, suppose you wish to study incoming ICMP usage on the network. Specifically, you'd like to find out what ICMP types and codes are in use. Are any hosts sending high volumes of ICMP packets?

To facilitate this analysis, you could create a file with the host's source IP, the ICMP type and code, and the count for that triple. An aggregate bag is the best choice, since bags only store pairs of one key and one count and you want to store three keys and a count. However, the man page for the `rwaggbag` command does not show ICMP type and code on the list of key fields.

Instead, use the `rwaggbagbuild` command to store these values and counts. It accepts SiLK key fields as text and produces an aggregate bag file with the desired count of the triple. This gives you more flexibility in creating aggregate bags than the `rwaggbag` command does.

Example 6.16 shows how to create an aggregate bag file that counts and stores the values of this triple.

1. Command 1 creates a text file with the desired fields. The `rwfilter` call pulls network flow data from the desired date range. It pipes the data to the `rwcut` command to output the desired fields as text. We want to include the following values: source IP, ICMP type, and ICMP code (`--fields=sip,itype,icode`). The `rwaggbagbuild` command does not accept a header line with the field names in the file, so we will also use the `--no-titles` option.
2. The `rwaggbagbuild` call in Command 2 takes the text output from `rwcut` and converts it to an aggregate bag. The three keys are specified by `--fields=sIPv4,icmpType,icmpCode`.
3. The `rwaggbagcat` command in Command 3 displays the values of the three keys and the number of flow records counted for each combination.

The IP addresses 10.0.40.20, 4.0.0.34, and 10.0.1.201 are sending high numbers of ICMP messages compared to the other hosts, and should be investigated.

For more information about the `rwaggbagbuild` command, see Appendix C.23 or enter the command `rwaggbagbuild --help`.

Thresholding Aggregate Values

The aggregate bag of ICMP type and code counts from Example 6.16 is rather long. We are interested in examining hosts that have produced the most ICMP traffic.

The `rwaggbagtool` command lets you manipulate aggregate bags, similar to how the `rwbagtool` command manipulates bags. Use the thresholding feature of `rwaggbagtool` to threshold aggregate bag entries by count.

`--min-field=`*`FIELD=VALUE`* selects entries where the specified field is above a minimum value.

`--max-field=`*`FIELD=VALUE`* selects entries where the specified field is below a maximum value.

In this case, we will specify that the value of the records field be greater than or equal to 1000—as shown in Example 6.17.

1. The call to `rwaggbagtool` sets a threshold of 1000 records (`--min-field=records=1000`) and creates a new aggregate bag, `top-icmp.aggbag`.
2. The call to `rwaggbagcat` displays the thresholded aggregate bag.

For more information about the `rwaggbagtool` command, see Appendix C.25 or enter the command `rwaggbagtool --help`.

Exporting Aggregate Bags to Bags and IPsets

You can also use the `rwaggbagtool` to export bags and IPsets from aggregate bags. The previous example created an aggregate bag that contains the source IP, ICMP type, and ICMP code triples with the highest record counts. Exporting it allows you to create a bag that holds only one key-value pair—for instance, if you only want to look at high ICMP traffic by source IP and not the other two keys.

Example 6.18 shows how to use the `rwaggbagtool` command to export a bag from an aggregate bag.

1. The call to `rwaggbagtool` selects the key and count to be exported—in this case, source IP and record count (`--to-bag=sIPv4,records`) It saves the exported key-value pairs to a bag file, `top-icmp.bag`.
2. The call to `rwbagcat` displays this file as text.

Similarly, Example 6.19 shows how to use the `rwaggbagtool` command to export an IPset from an aggregate bag. Creating an IPset of hosts that send the highest amount of ICMP messages can be useful for further analysis of their behavior.

1. The call to `rwaggbagtool` selects the IP addresses to be exported (`--to-ipset=sIPv4 `) to a new IPset file, `top-icmp.set`.
2. The `rwsetcat` command displays the contents of this set as text.

6.2.7 Labeling Data with Prefix Maps

Some analyses are easier to conceptualize and perform when you assign a text label to data of interest. You can identify this data and think of it in context by the label you've given it, not just as an abstract group of flow records. You can then filter and perform other operations on the data according to how it is labeled.

SiLK allows you to create a *prefix map* (often abbreviated as *pmap*) to assign user-defined text labels to ranges of IP addresses or protocols and ports. You can use the resulting pmap file to retrieve, partition, sort, count, and perform other operations on network flow records by their labels. This enables you to work with data semantically.

What Are Prefix Maps?

A prefix map file is a binary file that maps a value (either an IP address or a protocol-port pair) to a text label. SiLK supports two general types of prefix maps.

- **User-defined prefix maps** assign arbitrary text labels to IP addresses or protocol-port combinations.
- **Predefined prefix maps** are specialized prefix maps that are typically included with the SiLK distribution and facilitate analysis by country code or traffic direction.

Both types of pmap can be used interchangeably with the `rwfilter`, `rwcut`, `rwsort`, `rwuniq`, `rwstats`, `rwgroup`, and `rwpmaplookup` commands to perform operations on SiLK network data according to how it is labeled.

Comparing Prefix Maps to Sets, Bags, and Aggregate Bags. Like SiLK IP sets, bags, and aggregate bags, prefix maps allow you to create user-defined groups of IP addresses to facilitate further analysis. However, prefix maps are more generalized groupings than sets, bags, and aggregate bags. A set creates a binary association between an IP address and a condition (an address is either in the set or not in the set), a bag between an IP address and a single numeric value, and an aggregate bag between an IP address and a composite (or aggregate) value. However, a prefix map assigns arbitrary, user-defined text labels to many different address ranges. Prefix maps also expand the type of groupings to include assigning labels to protocol-port ranges. It is an entirely different way to identify and group data.

It is often easier to examine IP addresses by label rather than by whether they belong to a bag or set. For example, suppose you want to look at traffic from IP addresses that are linked to different types of malware. You could create multiple IP sets or bags that contain the addresses associated with each type of malware and compute traffic statistics individually for each set or bag. However, this would be cumbersome and time-consuming to script.

Alternatively, you could create a single, user-defined pmap file that labels the addresses by the type of malware that is associated with each address. You could then use the pmap file to filter network flow data and compute traffic statistics according to the type of malware, all in a single analytic. This is a more intuitive and easier way to perform that type of analysis.

Creating a User-defined Prefix Map From a Text File

To create a binary prefix map from a text file, use the `rwpmapbuild` tool. Creating a user-defined pmap is a two-step process:

1. Create a text file that contains the mapping of IP addresses or protocol-port pairs to their labels.
2. Use the `rwpmapbuild` command to translate this text-based file into a binary pmap file.

Creating the Text File. Each mapping line in the text file contains either an IP address or protocol-port pair range with a corresponding label. They are separated by whitespace (spaces and tabs). Include the following information when creating a text file for use with the `rwpmapbuild` command:

- The input file may specify a name for the pmap via the line `map-name` *mapname* where *mapname* is the name of the pmap. Pmap names cannot contain whitespaces, commas, or colons.
- `mode` specifies the type of pmap.
  - `ipv4` creates a pmap containing IPv4 addresses
  - `ipv6` creates a pmap containing IPv6 addresses
  - `proto-port` creates a pmap containing protocol-port pairs
- If you are creating an IP address pmap, specify an address range with either a CIDR block or a whitespace-separated low IP address and high IP address (formatted in canonical form or as integers). Specify a single host as a CIDR block with a prefix length of 32 for IPv4 or 128 for IPv6.
- If you are creating a protocol-port pmap, specify a range that is either a single protocol or a protocol and a port separated by a slash character (`/`). If the range is a single port, specify that port number as the starting and ending value of the range. For example, `17/17` specifies general UDP traffic; `17/53 17/53` specifies DNS traffic (UDP on port 53), and `17/67 17/68` specifies DHCP client and server traffic (UDP on ports 67 and 68). A detailed example of a protocol-port pmap is shown in Section 7.3.1.
- Do not use commas, which invalidate the pmap for use with `rwfilter`.
- Comment lines begin with the pound or hashtag character (`#`). Do not use this character in text labels.
- The input file may also contain a *default label* to be used when there is no matching range in the text file. This default is specified by the line `default` *deflabel*, where *deflabel* is the text label specified by the analyst for otherwise-unlabeled address ranges.

For more information about the `rwpmapbuild` command, see Appendix C.27 or enter the command `rwpmapbuild --help`.

Building the Prefix Map File. Example 6.20 shows an example of how to create an IPv4 prefix map of FCC network labels from the FCCX dataset described in Section 1.7. The FCC network description is contained in the file `fccnets.pmap.txt`. It associates network address ranges with text labels that identify their subnetwork locations (`Div0Ext`, `Div1Ext`, etc.).

In addition to the address list, the text file specifies the prefix map name (`map-name fccnets`). This name is used in SiLK commands to identify which prefix map is being used. Using the map name as the name of the text file and resulting pmap file helps you to keep track of and organize your user-defined prefix maps. Note also that the text file includes a default label (`default None`) that is assigned to IP addresses that are not listed in the FCC network description.

The `rwpmapbuild` command takes `fccnets.pmap.txt` as input to create a binary pmap file, `fccnets.pmap`.

```
<1>$ cat <<-EOF >fccnets.pmap.txt
map-name fccnets
default None

# FCC network descriptions
10.0.10.0/24 Div0Ext
10.0.20.0/24 Div0Ext
10.0.30.0/24 Div0Ext
10.0.40.0/24 Div0Ext
10.0.50.0/24 Div0Ext
192.168.10.0/24 Div1Ext
192.168.20.0/24 Div1Ext
192.168.30.0/24 Div1Ext
192.168.40.0/24 Div1Ext
192.168.50.0/24 Div1Ext
192.168.60.0/24 Div1Ext
192.168.70.0/24 Div1Ext
192.168.110.0/23 Div1Ext
192.168.120.0/23 Div1Ext
192.168.122.0/23 Div1Ext
192.168.124.0/24 Div1Ext
192.168.130.0/23 Div1Ext
192.168.140.0/23 Div1Ext
192.168.142.0/23 Div1Ext
192.168.150.0/23 Div1Ext
192.168.160.0/23 Div1Ext
192.168.162.0/23 Div1Ext
192.168.164.0/23 Div1Ext
192.168.166.0/24 Div1Ext
192.168.170.0/24 Div1Ext
10.0.40.0/24 Div0Int
10.0.50.0/24 Div0Int
192.168.20.0/24 Div1Int1
192.168.40.0/24 Div1Int1
192.168.50.0/24 Div1Int1
192.168.60.0/24 Div1Int1
192.168.70.0/24 Div1Int1
192.168.110.0/23 Div1Int1
192.168.120.0/23 Div1Int1
192.168.122.0/23 Div1Int1
192.168.124.0/24 Div1Int1
192.168.130.0/23 Div1Int1
192.168.140.0/23 Div1Int1
192.168.142.0/23 Div1Int1
192.168.150.0/23 Div1Int1
192.168.160.0/23 Div1Int1
192.168.162.0/23 Div1Int1
192.168.164.0/23 Div1Int1
192.168.166.0/24 Div1Int1
192.168.170.0/24 Div1Int1
192.168.60.0/24 Div1Int2
192.168.110.0/23 Div1Int2
192.168.120.0/23 Div1Int2
```

```
192.168.122.0/23 Div1Int2
192.168.124.0/24 Div1Int2
192.168.130.0/23 Div1Int2
192.168.140.0/23 Div1Int2
192.168.142.0/23 Div1Int2
192.168.150.0/23 Div1Int2
192.168.160.0/23 Div1Int2
192.168.162.0/23 Div1Int2
192.168.164.0/23 Div1Int2
192.168.166.0/24 Div1Int2
192.168.170.0/24 Div1Int2
192.168.121.0/24 Div1log1
192.168.122.0/24 Div1log2
192.168.123.0/24 Div1log3
192.168.124.0/24 Div1log4
192.168.141.0/24 Div1ops1
192.168.142.0/24 Div1Ext0
192.168.143.0/24 Div1Ext1
192.168.40.0/24 Div1Ext2
192.168.111.0/24 Div1Ext3
192.168.20.0/24 Div1Ext4
192.168.164.0/24 Div1Ext5
192.168.166.0/24 Div1Ext6
192.168.165.0/24 Div1Ext7
192.168.50.0/24 Div1Ext8
192.168.161.0/24 Div1Ext9
192.168.162.0/24 Div0Int0
192.168.163.0/24 Div0Int1
EOF
<2>$ rwpmapbuild --input-file=fccnets.pmap.txt \
   --output-file=fccnets.pmap
<3>$ file fccnets.pmap.txt fccnets.pmap
fccnets.pmap.txt: ASCII text
fccnets.pmap:     SiLK, PREFIXMAP v2, Little Endian, Uncompressed
```

Example 6.20: Using `rwpmapbuild` to Create a FCC Pmap File

Predefined Prefix Maps: Country Codes and Address Types

SiLK has two predefined prefix maps to facilitate common analyses: filtering by country codes and by address types (internal, external, non-routable). They can be used as input to SiLK commands just like user-defined pmaps.

Filtering by Country Code. Country codes identify the nations where IP addresses are registered and are used by the Root Zone Database (e.g., see https://www.iana.org/domains/root/db). They are described in a `country_codes.pmap` file in the `share` directory underneath the directory where SiLK was installed or in the file specified by the `SILK_COUNTRY_CODES` environment variable.

If the current SiLK installation does not have this file, either contact the administrator that installed SiLK or look up this information on the Internet.[14] Country code maps are not in the normal pmap binary format

[14] One such source is the GeoIP® Country database or free GeoLite™ database created by MaxMind® and available at

and cannot be built using `rwpmapbuild`.

Filtering Internal, External, and Non-routable Addresses. For common separation of addresses into specific types, normally internal versus external, a special pmap file may be built in the `share` directory underneath the directory where SiLK was installed. This file, `address_types.pmap`, contains a list of CIDR blocks that are labeled `internal`, `external`, or `non-routable`.

The `rwfilter` parameters `--stype` or `--dtype` use this pmap to isolate internal and external IP addresses. The `rwcut` parameter `--fields` specifies the display of this information when its argument list includes `sType` or `dType`. A value of 0 indicates `non-routable`, 1 is `internal`, and 2 is `external`. The default value is `external`.

Using Prefix Maps to Filter Flow Records

You can use prefix maps to filter network flow records with the `rwfilter` command. This allows you to pull and partition SiLK repository data based on how it is labeled.

The pmap provides context for filtering network traffic and allows you to perform complex filtering operations in a single analytic. For example, you could create a user-defined pmap that labels IP addresses in network spaces of interest (such as the one created in Example 6.20) and filter records based on their subnetworks. You could use the predefined country code pmap (`country_codes.pmap`) to filter source or destination IP addresses based on their country of origin. You could create a user-defined port-protocol pmap to filter records for specific port and protocol combinations in order to search for unusual protocols. These types of analysis are easier to perform with data that is labeled via prefix map.

`rwfilter` supports four pmap parameters.

- `--pmap-file` specifies which compiled prefix map file to use and optionally associates a mapname with that pmap. **This switch must be specified before the other prefix map switches.**
- `--pmap-any-`*mapname* specifies the the set of labels used to filter records based on both source and destination IP addresses. Any source or destination IP addresses that matches an IP address with the specified label passes the filter.
- `--pmap-src-`*mapname* and `--pmap-dst-`*mapname* specify the set of labels for filtering by source or destination IP address, respectively. *mapname* is the name given to the pmap during construction or in `--pmap-file`. The `--pmap-file` parameter must come before any use of the *mapname* in other parameters.

Example 6.21 shows how to use the `fccnets.pmap` file from Example 6.20 to select flow records associated with web traffic from hosts on the subnetwork `Div1Int1` in the FCC network.

1. The initial call to `rwfilter` pulls all flow records from the date of interest (`--start-date=2015/06/17`) that contain inbound and outbound web traffic (`--type=inweb,outweb`).
2. The output goes to a second `rwfilter` command that uses the `--pmap-file` parameter to load the file `fccnets.pmap` and create the mapname `fccnets`. The `--pmap-any-fccnets=Div1Int1` parameter filters for all flow records whose source IP address or destination IP address matches any of the IP addresses with the label `Div1Int1` in the pmap file. These source and destination IP addresses

https://www.maxmind.com/; the SiLK tool `rwgeoip2ccmap` converts this file to a country-code pmap.

represent traffic that flows into, within, and out of the hosts on the `Div1Int1` subnet. (Note that the `--pmap-file` parameter comes before the `--pmap-any` parameter.)

3. Records that pass the pmap-based filter are saved in `fccnets.rw`.

Displaying Prefix Values

To view the actual value of a prefix map label, use the `rwcut` command with the `--pmap-file` parameter. It takes an argument of a filename or a map name coupled to a filename with a colon. The map name typically comes from the argument for `--pmap-file`; if none is specified there, the name in the source file applies.

The `--pmap-file` parameter adds `src-`*`mapname`* and `dst-`*`mapname`* as arguments to `--fields`. Essentially, it tells `rwcut` to treat the pmap value as just another flow record field. The `--pmap-file` parameter must precede the `--fields` parameter. The two pmap fields display labels associated with the source and destination IP addresses.

Example 6.22 shows how to display the prefix labels for IP addresses in the flow record file `fccnets.rw` (created in Example 6.21). The names of the pmap and its file (`--pmap-file=fccnets:fccnets.pmap`) are specified.

Sorting, Counting, and Grouping Records with Prefix Maps

You can also count, sort, and group flow records by prefix value. This lets you work with network data according to how it is labeled in the prefix map, which can be easier and more intuitive than some of the other methods for summarizing data. The `rwsort`, `rwgroup`, `rwstats`, and `rwuniq` tools all work with prefix maps. The prefix map parameters are the same as those used in the `rwcut` command and sort, group, and count records according to the values in the prefix map file.

Example 6.23 sorts flow records by the prefix value defined in `fccnets.pmap` for source IP addresses and bytes (`--fields=src-fccnets,bytes`). It then uses the `rwcut` command to display the pmap labels and port numbers. The first five records in the data file are displayed.

Notice that the results in Example 6.23 list `None` as their label. This is the default label from Example 6.20 that was assigned to IP addresses that are not included in the pmap. It indicates that these source IP addresses do not belong to the FCC network space. However, they exchanged traffic with hosts that are labeled as belonging to `Div1Int1` on the FCC network. Because the `rwfilter` command in Example 6.21 filtered for *all* records that contained IP addresses labeled as `Div1Int1` in the pmap, it included records where either the source or destination IP address was not part of this subnetwork.

Example 6.24 shows how to count the number of records in the file `fccnets.rw` with labels defined in `fccnets.pmap`. Records without a label are listed as `None`. It also displays the destination port and the number of distinct destination IP addresses.

Again, the `rwuniq` command counts records with source or destination IP addresses that are not part of the `Div1Int1` subnet. Because these hosts communicated with hosts on the `Div1Int1` subnet, they are included in the count. The records in this case all are filtered to be TCP traffic, which makes the port numbers meaningful. TCP and UDP are the main protocols that use ports, and so are the most common ones for port-protocol pmaps. SiLK does encode ICMP type and Code into the destination port (sometimes the source port), so ICMP port-protocol pmaps are also used by some analysts.

Querying Prefix Map Labels

When using prefix maps, you may need to look up which labels correspond to specific IP addresses or protocol-port pairs. Use the `rwpmaplookup` command to query prefix map files—either user-defined pmaps or one of the two predefined pmaps that often are created as part of the SiLK installation (country codes and address types).

You can query a pmap with `rwpmaplookup` by doing one of the following:

- specify the addresses or protocol-port pairs in a text file (the default),
- use the `--ipset-files` parameter to query the addresses in one or more IP sets,
- use the `--no-files` parameter to list the addresses or protocol-port pairs to be queried directly on the command line.

In any of these cases, one and only one of `--country-codes`, `--address-types`, or `--map-name` is used.

IP addresses are specified as described earlier in this section. For protocol-port pmaps, only the names of text files having lines in the format *protocolNumber*`/`*portNumber* or the `--no-files` parameter followed by strings in the same format are accepted. *protocolNumber* must be an integer in the range 0–255, and *portNumber* must be an integer in the range 0–65,535.

If the prefix map being queried is a protocol-port pmap, it makes no sense to query it with an IP set. `rwpmaplookup` prints an error and exits if `--ipset-files` is given.

Example 6.25 shows how to use `rwpmaplookup`.

- Command 1 creates a list of IP addresses and stores it in the file `ips_to_find`.
- Command 2 uses `rwpmaplookup` to find the country codes associated with these addresses. If an IP address is not listed in the country code pmap, the command returns `--` as its value.
- Command 3 looks up the address types of the IP addresses. The first address has a value of 1, indicating an `internal` address. The second address has a value of 2, indicating an `external` address. The third address has a value of 0, indicating a `non-routable` address.
- Commands 4 and 5 build a protocol-port prefix map.
- Command 6 looks up protocol-port pairs from the command line.

For more information about the `rwpmaplookup` command, see Appendix C.28 or enter the command `rwpmaplookup --help`.

```
<1>$ rwfilter --type=in,inweb --start-date=2015/6/10 \
   --end-date=2015/6/24 --proto=0-255 --pass=stdout \
| rwsplit --flow-limit=1000 --sample-ratio=100 \
   --basename=sample --max-outputs=100
<2>$ echo -n >udpsample.txt
<3>$ for f in sample*rwf; \
do rwstats $f --values=records --fields=protocol --count=30 \
   --top \
| grep "17|" | cut -f3 "-d|" >>udpsample.txt
done
<4>$ sort -nr udpsample.txt >tmp.txt
<5>$ echo -n "Max UDP%: "; \
   head -n 1 tmp.txt
Max UDP%:  83.700000
<6>$ echo -n "Min UDP%: " ; \
   tail -n 1 tmp.txt
Min UDP%:   1.700000
<7>$ echo -n "Median UDP%: "; \
head -n 50 tmp.txt \
| tail -n 1
Median UDP%:  68.800000
```

Example 6.13: `rwsplit` to Generate Statistics on Flow Record Files

```
<1>$ rwfilter --sensor=S0 --type=in --start-date=2015/06/02 \
   --end-date=2015/06/18 --protocol=17 \
   --bytes-per-packet=100- --pass=bigflows.rw
<2>$ rwcut bigflows.rw --fields=1-5,stime --num-recs=20 \
| sed -re 's/([0-9]+\.){3}/192.168.200./g' \
   >anonymized.rw.txt
<3>$ rwtuc anonymized.rw.txt --output-path=anonymized.rw
<4>$ rwfileinfo anonymized.rw
anonymized.rw:
  format(id)          FT_RWIPV6ROUTING(0x0c)
  version             16
  byte-order          littleEndian
  compression(id)     lzo1x(2)
  header-length       88
  record-length       88
  record-version      1
  silk-version        3.16.0
  count-records       20
  file-size           512
  command-lines
                  1  rwtuc --output-path=anonymized.rw anonymized.rw.txt
<5>$ rwcut anonymized.rw --fields=sIP,dIP,sTime,sensor \
   --num-recs=4
            sIP|            dIP|                  sTime|sen|
192.168.200.205| 192.168.200.20|2015/06/16T12:50:02.144| S0|
  192.168.200.5| 192.168.200.20|2015/06/16T12:50:03.139| S0|
192.168.200.218| 192.168.200.20|2015/06/16T12:50:05.189| S0|
192.168.200.160| 192.168.200.20|2015/06/16T12:50:09.997| S0|
```

Example 6.14: Simple File Anonymization with `rwtuc`

```
<1>$ rwfilter --start-date=2015/06/17 --type=out --dport=0-1023 \
   --pass=stdout \
| rwaggbag --key=sipv4,dport,protocol --counter=records \
   --output-path=sip-dport-proto.aggbag
<2>$ ls -l sip-dport-proto.aggbag
-rw-r--r--. 1 analyst analyst 6766 Mar 18 14:30 sip-dport-proto.aggbag
<3>$ rwaggbagcat sip-dport-proto.aggbag \
| head -n 5
          sIPv4|dPort|pro|   records|
    10.0.10.254|    0| 89|        48|
     10.0.20.58|   53| 17|   1131799|
     10.0.20.58|  771|  1|       848|
     10.0.20.58|  778|  1|         2|
<4>$ rwfilter --start-date=2015/06/17 --type=out --dport=0-1023 \
   --pass=stdout \
| rwuniq --fields=sip,dport,protocol --sort-output \
| head -n 5
            sIP|dPort|pro|   Records|
    10.0.10.254|    0| 89|        48|
     10.0.20.58|   53| 17|   1131799|
     10.0.20.58|  771|  1|       848|
     10.0.20.58|  778|  1|         2|
```

Example 6.15: Summarizing Source IP, Destination Port, and Protocol with `rwaggbag`

```
<1>$ rwfilter --start-date=2015/06/17 --type=in --protocol=1 \
   --pass=stdout \
| rwcut --fields=sip,itype,icode --no-titles \
   --ipv6-policy=ignore >icmp-no-titles.txt
<2>$ rwaggbagbuild --fields=sIPv4,icmpType,icmpCode \
   --constant-field=record=1 --output-path=icmp.aggbag \
   icmp-no-titles.txt
<3>$ rwaggbagcat icmp.aggbag | head
          sIPv4|icm|icm|   records|
       4.0.0.34|  3|  1|      1459|
     10.0.1.101|  0|  0|       359|
     10.0.1.201|  0|  0|      1002|
      10.0.10.1|  0|  0|       263|
      10.0.10.1| 11|  0|         1|
     10.0.20.58|  3| 10|        19|
      10.0.30.1| 11|  0|         1|
     10.0.40.20|  0|  0|      9440|
     10.0.40.27|  3| 10|         6|
```

Example 6.16: Summarizing Source IP, ICMP Type, and ICMP Code with `rwaggbagbuild`

```
<4>$ rwaggbagtool --min-field=records=1000 \
   --output-path=top-icmp.aggbag icmp.aggbag
<5>$ rwaggbagcat top-icmp.aggbag | head
          sIPv4|icm|icm|   records|
       4.0.0.34|  3|  1|      1459|
     10.0.1.201|  0|  0|      1002|
     10.0.40.20|  0|  0|      9440|
     10.0.40.27|  8|  0|      2214|
  192.168.40.20|  0|  0|      1486|
  192.168.40.27|  8|  0|     17354|
  192.168.70.10|  3|  3|      2797|
192.168.110.254|  3|  1|      2856|
192.168.120.254|  3|  1|      2290|
```

Example 6.17: Thresholding an aggregate bag with `rwaggbagtool`

```
<6>$ rwaggbagtool --to-bag=sIPv4,records \
   --output-path=top-icmp.bag top-icmp.aggbag
<7>$ rwbagcat top-icmp.bag | head
       4.0.0.34|                1459|
     10.0.1.201|                1002|
     10.0.40.20|                9440|
     10.0.40.27|                2214|
  192.168.40.20|                1486|
  192.168.40.27|               17354|
  192.168.70.10|                2797|
192.168.110.254|                2856|
192.168.120.254|                2290|
192.168.130.254|                2032|
```

Example 6.18: Extracting a bag from an aggregate bag with `rwaggbagtool`

```
<8>$ rwaggbagtool --to-ipset=sIPv4 --output-path=top-icmp.set \
   top-icmp.aggbag
<9>$ rwsetcat top-icmp.set | head
4.0.0.34
10.0.1.201
10.0.40.20
10.0.40.27
192.168.40.20
192.168.40.27
192.168.70.10
192.168.110.254
192.168.120.254
192.168.130.254
```

Example 6.19: Extracting an IPset from an aggregate bag with `rwaggbagtool`

```
<1>$ rwfilter --start-date=2015/06/17 --type=inweb,outweb \
   --protocol=6 --pass=stdout \
| rwfilter stdin --pmap-file=fccnets:fccnets.pmap \
   --pmap-any-fccnets=Div1Int1 --pass=fccnets.rw
<2>$ rwfileinfo fccnets.rw --fields=count-records
fccnets.rw:
  count-records       722193
```

Example 6.21: Using Pmap Parameters with `rwfilter`

```
<1>$ rwcut fccnets.rw --pmap-file=fccnets:fccnets.pmap \
   --fields=src-fccnets,sPort,dIP,dPort --num-recs=5
src-fccnets|sPort|            dIP|dPort|
   Div1Int1|50373|     10.0.20.59|   80|
   Div1Int1|63440|     10.0.20.59|   80|
   Div1Int1|57862|     10.0.20.59|   80|
   Div1Int1|62669|     10.0.20.59|   80|
   Div1Int1|54211|     10.0.20.59|   80|
```

Example 6.22: Viewing Prefix Map Labels with `rwcut`

```
<1>$ rwsort fccnets.rw --pmap-file=fccnets:fccnets.pmap \
   --fields=src-fccnets,bytes \
| rwcut --pmap-file=fccnets.pmap --fields=src-fccnets,sport \
   --num-recs=5
src-fccnets|sPort|
       None|55862|
       None|55862|
       None|54392|
       None|54393|
       None|54394|
```

Example 6.23: Sorting by Prefix Map Labels

```
<1>$ rwuniq fccnets.rw --pmap-file=fccnets:fccnets.pmap \
   --fields=src-fccnets,dPort --values=flows,dIP-Distinct \
| head -n 5
src-fccnets|dPort|   Records|dIP-Distin|
    Div0Ext|52963|         8|         1|
       None|57113|         4|         1|
       None|58924|        12|         1|
   Div1Int1|55777|         2|         1|
```

Example 6.24: Counting Records by Prefix Map Labels

```
<1>$ cat <<END_FILE >ips_to_find
192.88.209.244
128.2.10.163
127.0.0.1
END_FILE
<2>$ rwpmaplookup --country-codes ips_to_find
            key|value|
 192.88.209.244|   us|
   128.2.10.163|   us|
      127.0.0.1|   --|
<3>$ rwpmaplookup --address-types ips_to_find
            key|value|
 192.88.209.244|    1|
   128.2.10.163|    2|
      127.0.0.1|    0|
<4>$ cat <<END_FILE >mini_icmp.pmap.txt
map-name miniicmp
default Unassigned
mode proto-port
1/0    1/0      Echo Response
1/768  1/768    Net Unreachable
1/769  1/769    Host Unreachable
1/2048 1/2048   Echo Request
END_FILE
<5>$ rwpmapbuild --input-file=mini_icmp.pmap.txt --output-file=mini_icmp.pmap
<6>$ rwpmaplookup --map-file=mini_icmp.pmap --no-files 1/769 1/1027
      key|           value|
    1/769|Host Unreachable|
   1/1027|      Unassigned|
```

Example 6.25: Query Addresses and Protocol/Ports with `rwpmaplookup`

6.3 Summary of SiLK Commands in Chapter 6

Command	Section Name	Page
`rwfilter`	Using Tuple Files for Complex Filtering	115
	Using Prefix Maps to Filter Flow Records	136
`rwbagtool`	Adding and Subtracting Bags	118
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	Thresholding Bags with Count and Key Parameters	122
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Chapter 7

Case Studies: Advanced Exploratory Analysis

This chapter features two detailed case studies of exploratory analysis, using concepts from previous chapters. Both employ the SiLK workflow, SiLK tools, UNIX commands, and networking concepts to provide a practical example of exploratory analyses with network flow data.

Upon completion of this chapter you will be able to

- describe how to use single-path and multi-path analyses as the building blocks of an exploratory analysis
- formulate an approach to exploratory analysis
- prepare a model of exploratory analysis
- execute these analyses with various SiLK tools in one automated program

Each level of an exploratory analysis case is posed as a question. The case studies build upon the answers to these questions to investigate unusual network traffic and revealing changes of network behavior.

7.1 Dataset for Exploratory Case Studies

Like the previous case studies and command examples, the exploratory analysis case studies uses the FCCX dataset described in Section 1.7. From the diagram in Figure 7.1, we know that sensors `S0` through `S4` monitor the operating network. These sensors are part of the inventory generated via the example in Chapter 5.

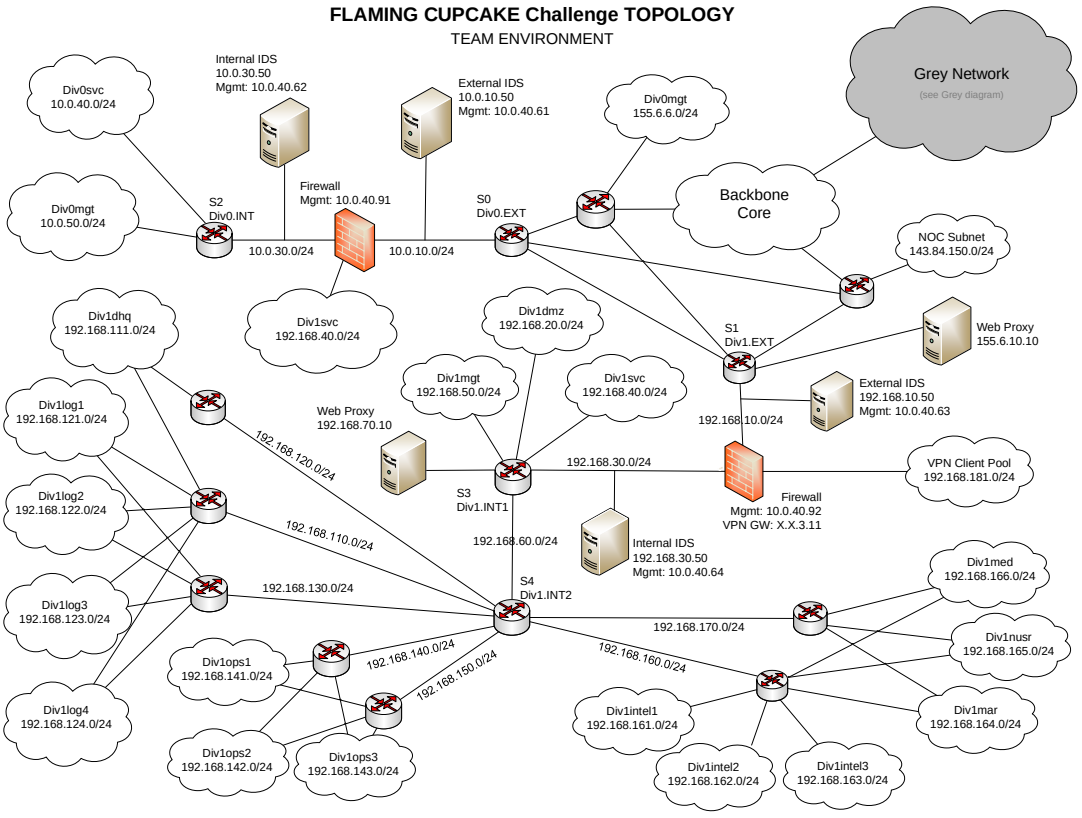

Figure 7.1: FCC Network Diagram

7.2 Case Study: Investigating Suspicious TCP Behavior

The first exploratory case study investigates TCP traffic for signs of illicit behavior. We'll first examine TCP requests to figure out which ones are legitimate and which ones are not. This will identify source and destination IPs for further investigation. Our overall goal is to figure out whether a pattern of activity is associated with this traffic—and if so, what it might indicate.

7.2.1 Level 0: Which TCP Requests are Suspicious?

In the initial phase of our exploratory analysis, we want to identify which TCP requests might represent illegitimate traffic. For most services, the flows containing client requests tend to be close in number with those containing responses to those requests. We will exploit this tendency to identify irregular traffic.

In particular, we want to look at traffic on service ports to find out which ports carry a much higher volume of inbound data than outbound data. This is one of the fingerprints (or indicators) of network scanning and several other behaviors that may be of concern. However, although this traffic imbalance is outside the range of typical behavior, it may not represent malicious activity. We need to identify these ports to take a closer look at their TCP traffic and to assess any impact it might have.

Example 7.1 shows how to find this type of data anomaly with SiLK. We will retrieve inbound and outbound TCP requests on all network ports, then find the ports that have a much higher level of inbound requests than outbound requests.

1. Command 1 uses `rwfilter` to pull inbound TCP (protocol 6) traffic for sensors `S0` through `S4` sent to all reserved ports (0 - 1023), which are dedicated to network services. It pipes the results to the `rwuniq` command, which counts flows and bytes for each destination port, then sorts the results to present the ports in ascending order.
2. Similarly, Command 2 uses `rwfilter` to pull outbound TCP traffic and `rwuniq` to count and sort traffic for each source port.
3. Comparing the corresponding ports in the results for commands 1 and 2, we see that most of the service ports carry similar levels of inbound and outbound TCP traffic. However, ports 21, 22, and 591 carry higher inbound than outbound TCP traffic.

Activity on these ports will be investigated further.

7.2.2 Level 1: How Can We Identify and React to Illegitimate Requests?

The nest step in our exploratory analysis is to separate normal and abnormal TCP requests on the service ports identified in Section 7.2.1. Specifically, we need to identify mismatched TCP flows: flows that have either no request or no response. These flows are odd, and worth examining to see if they are malicious. The goal is to describe this behavior in a way that supports further analysis.

Example 7.2 shows how to detect mismatched flows and identify the IP addresses of their sources, contrasting those addresses with sources of matched flows.

1. Command 1 uses `rwfilter` to pull inbound TCP traffic for sensors `S0` through `S4` on the suspect destination ports 21, 22, and 591. It then uses `rwsort` to sort this traffic by source IP address,

```
<1>$ rwfilter --sensor=S0,S1,S2,S3,S4 --start=2015/06/01 \
   --end=2015/06/30 --type=in --proto=6 --dport=0-1023 \
   --pass=stdout \
| rwuniq --fields=dport --values=flows,bytes --sort
dPort|   Records|               Bytes|
   21|      6184|              418452|
   22|      6180|              481760|
   53|        35|               88237|
   88|     47187|            74586782|
  135|      6996|             6940590|
  137|      6064|              364320|
  139|     57313|            93274792|
  389|     22095|           118221682|
  445|     81039|           363318703|
  591|    112702|            76762887|
<2>$ rwfilter --sensor=S0,S1,S2,S3,S4 --start=2015/06/01 \
   --end=2015/06/30 --type=out --proto=6 --sport=0-1023 \
   --pass=stdout \
| rwuniq --fields=sport --values=flows,bytes --sort
sPort|   Records|               Bytes|
   21|       200|               28288|
   22|       204|               99024|
   53|        35|               18860|
   88|     47184|            76069648|
  135|      6991|             4052306|
  137|        80|                3200|
  139|     51631|            47100178|
  389|     22214|           110222710|
  445|     75426|           205229733|
  591|     55161|            17580192|
```

Example 7.1: Looking for Service Ports with Higher Inbound than Outbound TCP Traffic

destination port, destination IP address, source port, protocol, and start time. The sorted inbound flow records are saved in the file `app-in.raw`. This sort order sets up the data for matching in Command 3.

2. Similarly, Command 2 uses `rwfilter` to pull outbound TCP traffic for the sensors and ports of interest. It sorts this traffic by destination IP address, source port, source IP address, protocol, and start time. The sorted outbound flow records are saved in the file `app-out.raw`. This sort order allows records to be matched efficiently with those from Command 1, using `rwmatch`.

3. To find mismatched flows, Command 3 uses `rwmatch` to match queries in the inbound TCP flows in `app-in.raw` to responses in the outbound TCP flows in `app-out.raw`. Mismatched flows that do not belong to sessions can indicate illegitimate activity.

   - `--relate=1,2` matches the inbound source IPs to the outbound destination IPs.
   - `--relate=2,1` matches the inbound destination IPs to the outbound source IPs.
   - `--relate=3,4` matches the inbound source ports to the outbound destination ports.
   - `--relate=4,3` matches the inbound destination ports to the outbound source ports.
   - `--relate=5,5` matches the inbound and outbound protocols.
   - `--unmatched=b` saves the unmatched inbound and outbound records instead of discarding them. These unmatched records are the ones we will want to investigate for illegitimate behavior.

   The matched records are indicated by setting the (mostly unused) next-hop IP address. Rather than a real IP address, `rwmatch` uses 0 followed by a positive integer value for a request, and 255 followed by the corresponding integer for a response. For a request without a response, `rwmatch` uses `0.0.0.0` for a response without a request, `rwmatch` uses `255.0.0.0`. Command 3 then calls `rwsort` to sort the matched records by start time and saves them in a temporary file, `temp-match.raw`.

4. Command 4 runs `rwfilter` on `temp-match.raw` to filter records that have a next-hop IP indicating unmatched inbound requests, then saves these records in `temp-noresp.raw`. A second call to `rwfilter` filters records that have a next-hop IP indicating unmatched outbound responses, then saves those records in `temp-noreq.raw`. The records that fail both filters represent flows with matching responses and are saved in `app-match.raw`.

5. Command 5 runs the `rwstats` command on `temp-noresp.raw` to display information about the top five source IP addresses and destination ports of flows with no response flows. Since there are only two source IP addresses in this data (one with two destination ports), only three are displayed.

6. Command 6 runs the `rwstats` command on `app-match.raw` to display information about the top five source IP addresses and source ports of flows that do have matching query and response flows. Since there are 3,848 source IP addresses for the matching records, the top five are shown. None of these are the sources for the unmatched records.

Given the distribution of source addresses between the matched and unmatched traffic, these sources are clearly worth investigating further.

7.2.3 Level 2: What are the Illegitimate Sources and Destinations Doing?

In the next part of our exploratory analysis, we will investigate the activities of the illegitimate source and destination hosts identified in Section 7.2.2 to see what patterns emerge.

```
<1>$ rwfilter --sensor=S0,S1,S2,S3,S4 --start=2015/06/01 \
   --end=2015/06/30 --type=in --proto=6 --dport=21,22,591 \
   --pass=stdout \
| rwsort --fields=sip,dport,dip,sport,protocol,stime \
   --output=app-in.raw
<2>$ rwfilter --sensor=S0,S1,S2,S3,S4 --start=2015/06/01 \
   --end=2015/06/30 --type=out --proto=6 --sport=21,22,591 \
   --pass=stdout \
| rwsort --fields=dip,sport,sip,dport,protocol,stime \
   --output=app-out.raw
<3>$ rwmatch --relate=1,2 --relate=2,1 --relate=3,4 --relate=4,3 \
   --relate=5,5 --unmatched=b app-in.raw app-out.raw stdout \
| rwsort --fields=stime --output=temp-match.raw
<4>$ rwfilter temp-match.raw --next=0.0.0.0 \
   --pass=temp-noresp.raw --fail=stdout \
| rwfilter stdin --next=255.0.0.0 --pass=temp-noreq.raw \
   --fail=app-match.raw
<5>$ rwstats --fields=sip,dport --values=flows --count=5 \
   temp-noresp.raw
INPUT: 69810 Records for 3 Bins and 69810 Total Records
OUTPUT: Top 5 Bins by Records
            sIP|dPort|   Records|  %Records|   cumul_%|
     10.0.40.21|  591|     57582| 82.483885| 82.483885|
  192.168.181.8|   22|      6180|  8.852600| 91.336485|
  192.168.181.8|   21|      6048|  8.663515|100.000000|
<6>$ rwstats --fields=sip,sport --values=flows --count=5 \
   app-match.raw
INPUT: 110478 Records for 3848 Bins and 110478 Total Records
OUTPUT: Top 5 Bins by Records
            sIP|sPort|   Records|  %Records|   cumul_%|
192.168.165.216|  591|      1708|  1.546009|  1.546009|
192.168.161.124|  591|      1691|  1.530621|  3.076631|
192.168.122.195|  591|      1663|  1.505277|  4.581908|
192.168.122.141|  591|      1657|  1.499846|  6.081754|
 192.168.121.57|  591|      1657|  1.499846|  7.581600|
```

Example 7.2: Identifying Abnormal TCP Flows and their Originating Hosts

Level 2A: What are the Illegitimate Source IPs Doing?

First, we will take a look at the activity of the illegitimate source IP addresses. As shown in Example 7.3, we will find the sources of illegitimate traffic and look at the network behavior associated with scanning. Scan queries typically have low byte counts and often lack corresponding responses, since the scanned hosts lack the service being sought.

1. Command 1 calls `rwbag` and `rwbagtool --coverset` to create a set of source IPs that did not have matching queries (`noresp.set`). As input, it uses the file of no-response flows created in Section 7.2.2 (`temp-noresp.raw`).
2. Command 2 calls `rwfilter` to pull records coming from the source IP addresses `noresp.set`—in other words, records with source IPs that produced unmatched flows. It saves these records in `sources.raw`.
3. To find the actual scanning flows, Command 3 uses `rwfilter` on `sources.raw` to filter flows with very low byte counts (0-60 bytes), indicating those with only a header, or with a header and optional extensions. It then uses the `rwuniq` command to profile these flows and saves the results in `source.txt`. This file is human readable, and contains a breakdown by protocol and bytes per flow, showing how many hosts were the destination of these flows, when the earliest of them started, and when the latest ended.

   A copy of the low-volume flows is sent to a second call to `rwuniq` to save the earliest start and latest end times of the flows from each source IP to the file `source-fields.txt`. The output here is generated without column headings and vertical bar delimiter to facilitate processing by commands 5-9. As it happens, all of these low-volume flows come from a single source IP address, so the `source-fields.txt` only contains one line.
4. Command 4 displays the contents of the human-readable profile. There are several features in this output:

   - There are few distinct byte sizes in these results: only one for TCP flows, and only two for UDP flows.
   - The TCP flows are by far the most numerous, and go to by far the most distinct addresses.
   - The earliest start times are all within a one minute range.
   - The latest end times are all within a five second span.

   These results support an interpretation of this behavior as scan traffic, and of a common direction behind this traffic. That all of these flows come from a single source IP address further supports this interpretation.

Level 2B: What Behavior Changes do Destination IPs Show?

Next, we will investigate traffic patterns on the destination hosts (the targets of the scans). Using the start times and end times of the scan from Example 7.3, we will look at traffic patterns before and afterwards as shown in Example 7.4.

1. Commands 1 through 5 locate the start times (`StTime`, `StEpoch`) and end times (`EnTime`, `EnEpoch`), using the `source-fields.txt` file created in Example 7.3. This identifies the "before" and "after" boundaries of the scan.

- Command 1 stores the contents of the file (one line) in a shell array for ease of reference to the fields.
- Command 2 converts the earliest start time of the scan into an integer UNIX epoch value (the number of seconds since midnight, January 1, 1970). This format is used to make it easy to calculate.
- Command 3 subtracts one from the epoch value to get a time briefly before the scan activity started, then uses the string processing language `awk` to convert the epoch date back into a SiLK formatted date.
- Commands 4 and 5 do an analogous process to commands 2 and 3, but with the ending time of the scanning activity, producing a value just after the scanning ended.

2. Command 6 uses `rwfilter` to pull inbound and outbound non-web traffic for the destination IPs in `noresp.set` in the time window *before* the start of the scan, saving these flows to `dest-before.raw`.

3. Command 7 uses `rwfilter` to pull inbound and outbound traffic for the illegitimate IPs in `noresp.set` in the time window *after* the end of the scan, saving these files to `dest-after.rw`.

4. For clarity of display, command 8 calls `rwuniq`, then uses the `head` command to pull off the column headers and store them in the file `myhead`.

5. After displaying the column headers with `cat`, command 9 uses `rwuniq` to calculate the counts of flows for each byte size in `dest-before.rw`, which contains data from the time period before the start of scanning. It sorts the byte sizes in ascending order, then calls `tail` to display the largest flows. (Because we use `tail` for this, we had to separately save and display the column headers; without that, no column labels would be shown.)

6. To profile network behavior after scanning, Command 10 uses `rwuniq` to find the flows with the largest byte sizes in the file `dest-after.rw`, which contains data from the time period after scanning ended.

7.2.4 Level 3: What are the Commonalities Across The Cases?

Our exploratory analysis of the network traffic shows likely scanning behavior during a tight time frame: a 28-minute interval, ending within a few seconds.

A further look at the results reveals a definite change in behavior of the suspected scanners. One IP address is active before and during the scan. Another is active after, with much larger flows to the destination after the scan completed. All of this is highly suspicious. Even more concerning, the large traffic after the scan is all ICMP traffic (which is normally quite modest in size). These large ICMP flows are highly unusual for any benign purpose.

Future areas for investigation include

- looking for additional hosts that exhibit behavior that is similar to the scan/exploit hosts, during the periods before and after the scan
- investigating the behavior of the scan and exploit hosts for further confirmation of their malicious character
- looking for other activities associated with the scan/exploit hosts. What else are they up to?

As the analysis continues, these areas will likely suggest others to be explored. One difficulty here is knowing when to stop. Analysts need to keep the desired level of output firmly in mind, steering their explorations to provide suitable results. They need to stop either when those results are found (a likely compromise is identified, a sufficient understanding of the service has resulted, or interactions across the network are understood), or when it is clear no such results will emerge (i.e., everything is benign).

In this case, having identified a definite change in behavior, the analysis has reached its end. Information about the affected hosts could then be passed to incident handlers or system administrators for response.

```
<1>$ rwbag --bag-file=sipv4,flows,stdout temp-noresp.raw \
| rwbagtool --coverset --output=noresp.set
<2>$ rwfilter --sensor=S0,S1,S2,S3,S4 --start=2015/06/01 \
   --end=2015/06/30 --type=in,out --sipset=noresp.set \
   --pass=sources.raw
<3>$ rwfilter sources.raw --bytes=0-60 --pass=stdout \
| rwuniq --fields=protocol,bytes \
   --values=flows,distinct:dip,stime-earliest,etime-latest \
   --sort --output=sources.txt --copy=stdout \
| rwuniq --fields=sip --values=stime-earliest,etime-latest \
   --no-titles --delim=' ' --output=source-fields.txt
<4>$ cat sources.txt
pro|     bytes|   Records|dIP-Distin|     sTime-Earliest|       eTime-Latest|
  6|        60|     29492|       768|2015/06/17T16:12:58|2015/06/17T16:41:21|
 17|        29|        68|        17|2015/06/17T16:13:54|2015/06/17T16:41:21|
 17|        42|       136|        17|2015/06/17T16:13:54|2015/06/17T16:41:26|
<5>$ srcArray=( $(cat source-fields.txt) )
```

Example 7.3: Finding Activity of Illegitimate Destination IP Addresses

```
<1>$ srcArray=( $(cat source-fields.txt) )
<2>$ StEpoch=$( date -d ${srcArray[1]} +"%s")
<3>$ StTime=$(echo $(( $StEpoch - 1 )) | awk '{print \
   strftime("%Y/%m/%dT%T",$1)}')
<4>$ EnEpoch=$( date -d ${srcArray[2]} +"%s")
<5>$ EnTime=$(echo $(( $EnEpoch + 1 )) | awk '{print \
   strftime("%Y/%m/%dT%T",$1)}')
<6>$ rwfilter --sensor=S0,S1,S2,S3,S4 --start=2015/06/01 \
   --end=2015/06/30 --type=in,out --dipset=noresp.set \
   --etime=2015/06/01-2015/06/17T09:12:57 \
   --pass=dest-before.raw
<7>$ rwfilter --sensor=S0,S1,S2,S3,S4 --start=2015/06/01 \
   --end=2015/06/30 --type=in,out --dipset=noresp.set \
   --stime=2015/06/17T09:41:27-2015/06/30 \
   --pass=dest-after.raw
<8>$ rwuniq --fields=bytes,protocol \
   --values=Flows,distinct:sip,distinct:dip dest-before.raw \
   | head -1 >myhead
<9>$ cat myhead; \
rwuniq --fields=bytes,protocol \
   --values=Flows,distinct:sip,distinct:dip --sort \
   dest-before.raw \
| tail -5
     bytes|pro|   Records|sIP-Distin|dIP-Distin|
       884| 17|         2|         1|         1|
       988|  1|         4|         1|         1|
      1028| 17|         5|         2|         1|
      1326| 17|         1|         1|         1|
      1976|  1|         3|         1|         1|
<10>$ cat myhead; \
rwuniq --fields=bytes,protocol \
   --values=Flows,distinct:sip,distinct:dip --sort \
   dest-after.raw \
| tail -5
     bytes|pro|   Records|sIP-Distin|dIP-Distin|
      5128|  1|         8|         2|         1|
      5488|  1|         4|         1|         1|
      5756|  1|         4|         1|         1|
      5844|  1|         4|         1|         1|
      6020|  1|         4|         1|         1|
```

Example 7.4: Finding Changed Behavior in Destination IPs

7.3 Case Study: Exploring Network Messaging for Information Exposure

The second exploratory case study discusses how to perform an exploratory analysis that investigates information exposure by examining use of the Internet Control Message Protocol (ICMP). For the purposes of this case study, *information exposure* is defined as the inadvertent exposure of network information due to relaxed security controls that are commonly exploited by attackers. The case study employs the SiLK workflow and tools, combined with networking concepts, to provide a practical example of how to explore network flow data and identify network configurations that require further investigation. It assumes the vantage point of an enterprise security operations analyst as depicted in the FCCX-15 sensor configuration file, `sensor.conf`.

7.3.1 Prepare a Model of the Enterprise Network and Protocols

As described in RFC 792[15], ICMP is a crucial component of the Internet Protocol (IP) for reporting errors in the processing of datagrams. Unfortunately, when relaxed security controls are implemented in a network, ICMP can leak information to attackers as they conduct network reconnaissance. For example, subnetwork gateways commonly respond to ICMP echo request messages (ping) with an echo response.

However, as the network perimeter continues to shrink due to technologies such as mobile devices and the Internet of things (IoT), hosts within a subnetwork should not respond to ICMP pings outside of their local subnetwork. If they do respond, attackers are able to gather information that supports their efforts. Therefore, analysis of ICMP network flow data provides analysts ground truth of how an enterprise network is configured, operating, and identifies security controls that may require further review.

Build a Port-Protocol Prefix Map

The first step in the exploratory analysis is to define a model of the enterprise network and the protocols under analysis. SiLK tools provide IPsets and prefix maps (pmaps) for this modeling. For the FCCX-15 dataset, these SiLK data structures can be created using the information in the network diagram and sensor configuration shown in Figure 7.1. RFC 792 provides some of the protocol information required for the model. The analyst must research and gather the remaining information!

This case study begins with building a port-protocol prefix map (also known as a proto-port pmap) of the ICMP protocol as defined by RFC standards. Example 7.5 shows the pmap and how it is created.

1. Create a text file with protocol-port mappings. The completed text file `icmp_code_official_pmap.txt` is shown in Command 1. Each entry in this text file defines an ICMP type, code, and a corresponding text label.

   By design, SiLK records do not store ICMP types and codes in individual flow record fields. Instead, an algorithm calculates the type and code and stores it in the flow record `dPort` field. The algorithm used for this is `(type x 256) + code`. For example, the prefix map entry of ICMP type 3 code 0 (network unreachable) is protocol 1, port 768 (3 x 256 + 0).

2. Convert the text file into a binary pmap for use with SiLK tools, as shown in Commands 2 and 3 of Example 7.5. The completed binary pmap will be used with other SiLK tools to count and sort records with the protocol and port combinations specified in the pmap.

[15] Internet Engineering Task Force (IETF) Request for Comments 792 (https://www.ietf.org/rfc/rfc792.txt)

```
<1>$ cat <<-EOF >icmp_code_official.pmap.txt
map-name icmp
mode proto-port

1/0     1/0     Echo Reply      # type 0 code 0

1/768   1/768   Net Unreachable # type 3 code 0
1/769   1/769   Host Unreachable # type 3 code 1
1/770   1/770   Protocol Unreachable # type 3 code 2
1/771   1/771   Port Unreachable # type 3 code 3
1/772   1/772   Frag Needed DF Set # type 3 code 4
1/773   1/773   Source Rte Failed # type 3 code 5
1/774   1/774   Dest Ntwk Unknown # type 3 code 6
1/775   1/775   Dest Host Unknown # type 3 code 7
1/776   1/776   Source Host Isolated # type 3 code 8
1/777   1/777   Dest Ntwk Admin Proh # type 3 code 9
1/778   1/778   Dest Host Admin Proh # type 3 code 10
1/779   1/779   Dest Ntwk Unreachable for TOS # type 3 code 11
1/780   1/780   Dest Host Unreachable for TOS # type 3 code 12
1/781   1/781   Administratively Prohibited # type 3 code 13
1/782   1/782   Host Precedence Violation # type 3 code 14
1/783   1/783   Precedence Cutoff # type 3 code 15

1/1024  1/1024  Source Quench # type 4 code 0 - DEPRECATED

1/1280  1/1280  Redirect Ntwk/Subnet # type 5 code 0
1/1281  1/1281  Redirect Host # type 5 code 1
1/1282  1/1282  Redirect TOS & Ntwk/Subnet # type 5 code 2
1/1283  1/1283  Redirect TOS & Host # type 5 code 3

1/1536  1/1536  Alternate Host Address # type 6 code 0

1/2048  1/2048  Echo request # type 8 code 0

1/2304  1/2304  Normal Router Advertisement # type 9 code 0
1/2320  1/2320  Router Adv not rte common traff # type 9 code 16

1/2560  1/2560  Router Selection # type 10 code 0

1/2816  1/2816  TTL exceeded # type 11 code 0
1/2817  1/2817  Frag Reassembly Time Exceeded # type 11 code 1

1/3072  1/3072  Parameter Prob - ptr indicates err # type 12 code 0
1/3073  1/3073  Missing Required Option # type 12 code 1
1/3074  1/3074  Bad Length # type 12 code 2

1/3328  1/3328  Timestamp request # type 13 code 0
1/3584  1/3584  Timestamp Reply # type 14 code 0
1/3840  1/3840  Information Request # type 15 code 0
1/4096  1/4096  Information Reply # type 16 code 0
1/4352  1/4352  Address Mask Request # type 17 code 0
1/4608  1/4608  Address Mask Reply # type 18 code 0
```

```
1/7680  1/7680  Traceroute pkt forwarded # type 30 code 0
1/7681  1/7681  Traceroute no rte for pkt; discarded # type 30 code 1

1/7936  1/7936  DG conv failed - unspecified # type 31 code 0
1/7937  1/7937  DG conv failed - Don't Convert option # type 31 code 1
1/7938  1/7938  DG conv failed - unk mandatory opt # type 31 code 2
1/7939  1/7939  DG conv failed - known unsupported opt # type 31 code 3
1/7940  1/7940  DG conv failed - unsupported transport proto # type 31 code 4
1/7941  1/7941  DG conv failed - length exceeded # type 31 code 5
1/7942  1/7942  DG conv failed - IP hdr len exceeded # type 31 code 6
1/7943  1/7943  DG conv failed - Transport proto > 255 # type 31 code 7
1/7944  1/7944  DG conv failed - Port conv out of range # type 31 code 8
1/7945  1/7945  DG conv failed - Transport hdr len exceeded # type 31 code 9
1/7946  1/7946  DG conv failed - 32bit Rollover missing & ACK set # type 31 code 10
1/7947  1/7947  DG conv failed - Unk mandatory transport opt # type 31 code 11

1/9472  1/9472  Domain Name Request # type 37 code 0
1/9728  1/9728  Domain Name Reply # type 38 code 0

1/10240 1/10240 Photuris bad SPI # type 40 code 0
1/10241 1/10241 Photuris Auth Failed # type 40 code 1
1/10242 1/10242 Photuris Decompression Failed # type 40 code 2
1/10243 1/10243 Photuris Decryption Failed # type 40 code 3
1/10244 1/10244 Photuris Need Authentication # type 40 code 4
1/10245 1/10245 Photuris Need Authorization # type 40 code 5

1/10496 1/10496 Seamoby CARD or CXTP # type 41 code 0 (RFC 4066/4067)
EOF
<2>$ rwpmapbuild --input-file=icmp_code_official.pmap.txt \
   --output-file=icmp_code_official.pmap
<3>$ file icmp_code_official.pmap.txt icmp_code_official.pmap
icmp_code_official.pmap.txt: ASCII text
icmp_code_official.pmap:     SiLK, PREFIXMAP v3, Little Endian, Uncompressed
```

Example 7.5: Building an RFC Compliant ICMP Type and Code Prefix Map

Define IP Address Roles

The next step in creating the model is to define IP address roles. We will look at IP addresses that are associated with internal subnetworks, internal subnetwork gateways, and network services. Example 7.6 shows how to define all the FCCX-15 internal subnetworks contained in `sensor.conf`.

1. The file `internal.set.txt` (shown in Command 1) lists the IP addresses of the internal networks from `sensor.conf`.

2. Command 2 calls the `rwsetbuild` command to convert this text list into a binary SiLK IPset, `internal.set` (shown in Command 3).

The resulting IPset, `internal.set`, can be used to filter hosts the sensor identifies as "internal" to the monitored network from hosts the sensor identifies as "external" to the network.

```
<1>$ cat <<-EOF >internal.set.txt
# Internal networks from FCCX-15 sensor.conf
10.0.x.x
192.168.x.x
EOF
<2>$ rwsetbuild internal.set.txt >internal.set
<3>$ file internal.set.txt internal.set
internal.set.txt: ASCII text
internal.set:     SiLK, IPSET v2, Little Endian, LZO compression
```

Example 7.6: Building an IPset of FCCX-15 Internal Subnetworks

Example 7.7 and Example 7.8 also use the `rwsetbuild` command to build IPsets that model internal subnetwork gateways (`gateways.set`) and network services (`services.set`). The gateway and services information comes from the FCCX-15 Flaming Cupcake Challenge network diagram shown in Figure 7.1.

```
<1>$ cat <<-EOF >gateways.set.txt
# FCCX-15 gateways commonly end in .1 or .254
10.0.x.1
10.0.x.254
192.168.x.1
192.168.x.254
EOF
<2>$ rwsetbuild gateways.set.txt >gateways.set
<3>$ file gateways.set.txt gateways.set
gateways.set.txt: ASCII text
gateways.set:     SiLK, IPSET v2, Little Endian, LZO compression
```

Example 7.7: Building an IPset of FCCX-15 Internal Subnetwork Gateways

```
<1>$ cat <<-EOF >services.set.txt
# Addresses of FCCX-15 internal network services
10.0.20.x # DMZ subnet
10.0.40.x # Services subnet
192.168.20.x # DMZ subnet
192.168.40.x # Services subnet
EOF
<2>$ rwsetbuild services.set.txt >services.set
<3>$ file services.set.txt services.set
services.set.txt: ASCII text
services.set:     SiLK, IPSET v2, Little Endian, LZO compression
```

Example 7.8: Building an IPset of FCCX-15 Internal Network Service Subnetworks

7.3.2 Pull Records Associated with ICMP Flows

After defining the network model, the next step is to pull the relevant network flow records from the SiLK repository. Example 7.9 shows how to use `rwfilter` to pull all ICMP traffic from the repository from 2015/06/02 through 2015/06/18 (the start and end dates of the exercise).

1. Command 1 shows that `rwfilter` statistics identified 436,648 records in the repository matched the query.
2. Command 2 shows the resulting SiLK raw file is less than 5 Mb in size.

Hint 7.1: Limiting `rwfilter` Query Size

If you are unsure about the number of records that might result from an `rwfilter` query, remove the `--pass=icmpall.rw` option from the `rwfilter` command. This displays information about the query without creating the raw file, allowing you to preview its results.

```
<1>$ rwfilter --start-date=2015/06/02 --end-date=2015/06/18 \
   --type=all --protocol=1 --pass=icmpall.rw \
   --print-statistics
Files  2442.  Read   39210497.  Pass     436648. Fail    38773849.
<2>$ ls -ahl icmpall.rw
-rw-r--r--. 1 analyst analyst 4.9M Feb 27 15:42 icmpall.rw
```

Example 7.9: Pulling ICMP Network Flow Data for a Specified Period

7.3.3 What Anomalies are in the ICMP Records?

To find potential cases of data exfiltration, examine the ICMP records for anomalies. SiLK's `rwuniq` command is a good tool for reviewing and examining data that's pulled from the repository. `rwuniq` provides an aggregate view of SiLK flow records. It can be used with prefix maps to label fields and display a visual summary of ICMP messaging.

Example 7.10 shows how to combine `rwuniq` with the prefix map from Section 7.3.1 to generate a sorted summary of ICMP types, codes, distinct source/destination IP address counts, and flow record counts.

- `--pmap-file=icmp:icmp_code_official.pmap` tells `rwuniq` to count and summarize flow records according to the labels defined in the pmap file from Example 7.5.
- `--fields=itype,icode,dst-icmp` identifies the flow fields that `rwuniq` selects and sorts upon. `itype` and `icode` represent the ICMP type and code computed for the flow record. `dst-icmp` is the record's label from the pmap.
- `--values=sip-distinct,dip-distinct` counts the distinct source and destination IP addresses for each pmap label.
- `icmpall.rw` contains the ICMP flow data (created in Example 7.9)

The `UNKNOWN` labels in Example 7.10 are a default feature of prefix maps. They are assigned to any attributes that do not have a corresponding pmap entry. This feature helps to identify ICMP protocol anomalies in flow data. The results from the `rwuniq` command contain ICMP echo reply anomalies (type (`iTy`) `0`, code (`iCo`) `1` and type 0, code 9) and ICMP echo request anomalies (type `8`, code `1` and type `8`, code `9`). Internet research[16] [17] indicates that these anomalies, when combined with the other ICMP types

[16] https://nmap.org/book/osdetect-methods.html#idm8844
[17] https://www.blackhat.com/presentations/bh-europe-00/OfirArkin/OfirArkin2.pdf

and codes displayed in the `rwuniq` summary, indicate a high probability of network reconnaissance in the data.

```
<1>$ rwuniq --pmap-file=icmp:icmp_code_official.pmap \
   --fields=itype,icode,dst-icmp \
   --values=sip-distinct,dip-distinct --flows --sort-output \
   icmpall.rw
iTy|iCo|            dst-icmp|sIP-Distin|dIP-Distin|   Records|
  0|  0|          Echo Reply|       106|        70|    101076|
  0|  1|             UNKNOWN|        13|        18|        39|
  0|  9|             UNKNOWN|        11|         1|        58|
  3|  0|     Net Unreachable|         3|         6|      1074|
  3|  1|    Host Unreachable|        12|        78|    142054|
  3|  2|Protocol Unreachable|        40|        27|      1890|
  3|  3|    Port Unreachable|       103|        63|     59335|
  3|  4|  Frag Needed DF Set|         1|        65|      6774|
  3| 10|Dest Host Admin Proh|         4|         5|       162|
  8|  0|        Echo request|        86|       862|    120618|
  8|  1|             UNKNOWN|        18|        36|        96|
  8|  9|             UNKNOWN|         1|       768|      3089|
 11|  0|        TTL exceeded|         4|         5|        26|
 13|  0|   Timestamp request|        18|        36|        96|
 14|  0|     Timestamp Reply|        26|        18|        69|
 15|  0| Information Request|        18|        36|        96|
 17|  0|Address Mask Request|        18|        36|        96|
```

Example 7.10: Exploring Unique ICMP Types/Codes in a SiLK Raw File

- `Echo Request` and `Echo Reply` are used for network host enumeration.
- `Net Unreachable`, `Host Unreachable`, `Port Unreachable`, and `Protocol Unreachable` messages are common responses to port and protocol enumeration.
- `Frag Needed DF Set` messages can result from operating system fingerprinting.

Many of the ICMP types and codes in Example 7.10 serve legitimate purposes as well. However, the likelihood of deprecated type requests without responses and small counts of source IP addresses "sweeping" the network with anomalous types and codes is low. The results of the `rwuniq` command contain one distinct source IP address sending ICMP echo requests with code 9 to 768 destination IP addresses.

7.4 Exploring Attributes of ICMP Messaging

One approach to exploring the data in this case study is to analyze common and uncommon attributes of ICMP messaging. Further review of Example 7.10 indicates three logical groups of common and uncommon ICMP behavior that would be useful for understanding information exposure and to identify follow-on exploratory analyses:

- deprecated types
- uncommon types

- uncommon behavior of common types

Executing the exploratory analysis involves looking at the three logical groupings of ICMP behavior identified in Section 7.3.3 .

Exploring Deprecated ICMP Types

Deprecated ICMP types no longer have official support from standards committees and, in many cases, are discouraged due to previous use. The IETF issues both individual and bulk deprecation notices for standards that the body has introduced. For example, RFC 6633[18] deprecates ICMP source quench message types; RFC 6918[19] deprecates multiple message types. Searching for these message types in ICMP traffic help analysts to identify anomalous traffic. If deprecated types are seen in monitored traffic, they should be validated and cataloged for future analysis. Internet research[20] supports this analysis approach.

The results in Example 7.10 show that deprecated type requests are present in our data. However, there are no corresponding responses. This indicates that information exposure from deprecated types didn't occur on the network for the time period under analysis.

Follow-on exploratory analysis could identify the sources of deprecated ICMP type requests in the data. It could also explore how security operations could automate this analysis and display events on a situational awareness dashboard.

Exploring Uncommon ICMP Types

Uncommon ICMP types continue to have official standards committee support, but do not commonly occur in network traffic. Example 7.10 data show that timestamp request and reply traffic occurred during the exploratory analysis period.

ICMP timestamp types are uncommon on most networks[21] and can be used for reconnaissance[22]. Analysts may want to determine how many hosts are sending ICMP timestamp reply messages to begin assessing the risk of information exposure.

Example 7.11 shows how to use SiLK tools to count the number of unique source IP addresses sending timestamp reply messages.

1. The `rwfilter` call in Command 1 partitions ICMP type 14 messages from the exploratory analysis data (`--icmp-type=14`) and passes these records to a file, `icmp_14_all.rw`. This file contains all records that include ICMP timestamp reply messages.
2. The `rwset` call in Command 2 builds an IPset file in memory from the file in Command 1. The `rwsetcat` call counts the number of distinct source IP addresses (26).

CAPEC-295 lists a low severity for timestamp messages, therefore, analysts should determine if such messages are exiting the subnetwork address space. Example 7.12 shows how to use SiLK tools to count the number of source IP addresses that are sending timestamp message replies outside the local subnetworks.

[18] Internet Engineering Task Force (IETF) Request for Comments 6633 (https://www.ietf.org/rfc/rfc6633.txt)
[19] Internet Engineering Task Force (IETF) Request for Comments 6918 (https://www.ietf.org/rfc/rfc6918.txt)
[20] Common Attack Pattern Enumeration and Classification 296 (https://capec.mitre.org/data/definitions/296.html)
[21] Cisco Security ICMP Timestamp Request Signature (https://tools.cisco.com/security/center/viewIpsSignature.x?signatureId=2007&signatureSubId=0)
[22] Common Attack Pattern Enumeration and Classification 295 (https://capec.mitre.org/data/definitions/295.html)

1. The `rwfilter` call in Command 1 partitions the outbound ICMP timestamp messages (`--type=out`) in the file `icmp_14_all.rw` (created in Example 7.11).
2. The output is piped to the `rwset` command to build an IPset that contains the source IP addresses for these outbound messages.
3. Finally, the `rwsetcat` command counts the number of source IP addresses in the set.

The resulting count of zero source IP addresses indicates that all timestamp replies are contained within the local subnetworks.

Example 7.13 shows how to use SiLK tools to verify the subnetworks that contain these message types.

1. The `rwfilter` call in Command 1 sends all ICMP traffic in the file `icmp_14_all.rw` to standard output.
2. The `rwnetmask` command masks the last 8 bits of the source and destination IP addresses. This provides a subnetwork-level view into the data.
3. Finally, the `rwuniq` command counts the number of subnetworks that sent ICMP timestamp replies.

Follow-on analyses can verify whether these message types should occur within the identified subnetworks.

Exploring Uncommon Behavior of Common ICMP Types

Common ICMP types observed in network traffic are echo request (type `8`), echo reply (type `0`), and destination unreachable (type `3`). Uncommon behavior of these types should be analyzed for information exposure. For example, it would be common for gateway devices or hosts providing network services to respond to echo requests. However, it would be *uncommon* to see these messages from hosts within subnetwork address ranges. Many organizations do not enforce these types of security controls, which introduces the vulnerability of information exposure.

Are internal hosts sending echo reply messages to external hosts? Example 7.14 shows how to use SiLK tools to identify internal hosts that are sending echo reply messages to external IP addresses.

1. The `rwfilter` call in Command 1 partitions the `icmpall.rw` file, which contains all ICMP traffic. It filters outbound echo reply traffic (`--type=out --icmp-type=0`), and uses `internal.set`, the set of IP addresses in internal networks (see Example 7.6) to select both source IP addresses (`--sipset=internal.set`) and IP addresses that aren't destination addresses (`--not-dipset=internal.set`). The records that pass this filter are saved in `icmp_00_external.rw`.
2. The `rwset` call in Command 2 counts the number of receiving destination IP addresses. First, it creates a set of the IP addresses in `icmp_00_external.rw` that are destination addresses.

   It then pipes the results to `rwsetcat`, which counts the number of IP addresses in the set.

One IP address receives ICMP echo reply messages. A count of one or more hosts should be reviewed to determine if hosts are exposing information outside the enterprise network. This could result from improper access control lists or other configuration issues.

```
<1>$ rwfilter icmpall.rw --type=all --icmp-type=14 \
   --pass=icmp_14_all.rw
<2>$ rwset --sip-file=stdout icmp_14_all.rw \
| rwsetcat stdin --count
26
```

Example 7.11: Counting Hosts that Send ICMP Timestamp Reply Messages

```
<1>$ rwfilter icmp_14_all.rw --type=out --pass=stdout \
| rwset --sip-file=stdout \
| rwsetcat stdin --count
0
```

Example 7.12: Counting Hosts that Send ICMP Timestamp Reply Messages Outside their Subnetwork

```
<1>$ rwfilter icmp_14_all.rw --type=all --pass=stdout \
| rwnetmask --sip-prefix-length=24 --dip-prefix-length=24 \
| rwuniq --fields=sip,dip --flows
            sIP|            dIP|   Records|
  192.168.142.0|  192.168.142.0|        24|
  192.168.165.0|  192.168.165.0|         6|
   192.168.40.0|   192.168.40.0|         7|
  192.168.164.0|  192.168.164.0|        11|
  192.168.143.0|  192.168.143.0|        15|
  192.168.141.0|  192.168.141.0|         6|
```

Example 7.13: Identifying Networks that Send ICMP Timestamp Reply Messages

```
<1>$ rwfilter icmpall.rw --type=out --icmp-type=0 \
   --sipset=internal.set --not-dipset=internal.set \
   --pass=icmp_00_external.rw
<2>$ rwset --dip-file=stdout icmp_00_external.rw \
| rwsetcat --count stdin
1
```

Example 7.14: Counting External Networks that Receive ICMP Echo Reply Messages

Example 7.15 shows how to validate the hosts that are sending and receiving echo reply messages from Example 7.14. The `rwuniq` call in Command 1 counts the hosts in `icmp_00_external.rw` to find out which ones serve as sources and destinations for echo reply messages. Source IP address 10.0.40.21 resides in a service subnetwork, while destination IP address 155.6.3.11 resides in the `Divnet3` subnetwork. This behavior could be considered normal because the `Divnet3` subnetwork is internal to a theater gateway. However, it should be reviewed in follow-on analyses to verify this trust relationship.

Are internal non-gateway hosts sending echo reply messages outside their subnetworks? Example 7.16 shows how to identify internal non-gateway hosts that are sending echo reply messages outside their subnetworks.

1. The `rwfilter` call in Command 1 partitions `icmpall.rw` to filter all internal source IP addresses that send outbound echo reply messages (`--type=out --icmp-type=0`), using `internal.set`, the set of IP addresses in internal networks (see Example 7.6) to select both. It removes gateway and service hosts as sources and saves the results to the `icmp_00_internal.rw` raw file.
2. The `rwset` and `rwsetcat` calls in Command 2 count the number of source IP addresses that exhibit this behavior.

Example 7.16 found 20 non-gateway source IP addresses that send echo reply messages outside their subnetworks.

Before reviewing the specific hosts identified in Example 7.16 further, analysts may want to label the results to help them with the exploratory analysis. Example 7.17 shows how to build an IPv4 prefix map that provides labels for various internal network services. It labels the subnetworks that host the `DMZ`, `SERVICES`, and `VPNPOOL` services.

Example 7.18 shows how to use this pmap with `rwuniq` to analyze host behavior. Echo reply messages from source IP address 192.168.70.10 (proxy device) to destination IP address 10.0.40.27 (Nagios server) are likely to be legitimate. However, the remaining results should be considered suspicious. The multiple internal subnetwork host echo reply messages to a `VPNPOOL` host (192.168.181.8) and a domain controller (10.0.40.20) are not considered to be common ICMP echo reply behavior and should be investigated.

7.4.1 Identify Follow-On Analyses

This case study shows how network flow data, SiLK tools, and exploratory analysis of ICMP traffic helps analysts assess information exposure. The results of this exploratory analysis show that information exposure from ICMP messaging appears to not be widespread across the enterprise.

However, as with most exploratory efforts, additional follow-on analyses have been identified: trust relationships between internal subnetworks and potential malicious activity. The follow-on analyses may also require support and data from outside the security operations group.

```
<1>$ rwuniq --fields=sip,dip --flows icmp_00_external.rw
            sIP|            dIP|   Records|
     10.0.40.21|     155.6.3.11|        66|
```

Example 7.15: Identifying External Networks that Receive ICMP Echo Reply Messages

```
<1>$ rwfilter icmpall.rw --type=out --icmp-type=0 \
   --sipset=internal.set --pass=stdout \
| rwfilter stdin --not-sipset=gateways.set --pass=stdout \
| rwfilter stdin --not-sipset=services.set \
   --pass=icmp_00_internal.rw
<2>$ rwset --sip-file=stdout icmp_00_internal.rw \
| rwsetcat --count stdin
20
```

Example 7.16: Counting Internal Non-Gateway Hosts that Send ICMP Echo Reply Messages Outside their Subnetwork

```
<1>$ cat <<-EOF >servicenets.pmap.txt
# Service Network Descriptions
map-name services
mode ipv4

10.0.20.0/24     DMZ      # DMZ subnet
10.0.40.0/24     SERVICES # Services subnet
192.168.20.0/24  DMZ      # DMZ subnet
192.168.40.0/24  SERVICES # Services subnet
192.168.181.0/24 VPNPOOL  # VPN pool
EOF
<2>$ rwpmapbuild --input-file=servicenets.pmap.txt \
   --output-file=servicenets.pmap
<3>$ file servicenets.pmap.txt servicenets.pmap
servicenets.pmap.txt: ASCII text
servicenets.pmap:     SiLK, PREFIXMAP v2, Little Endian, Uncompressed
```

Example 7.17: Building a Prefix Map of Service Subnetworks

```
<1>$ rwuniq --pmap-file=services:servicenets.pmap \
   --fields=sip,dip,itype,icode,dst-services --flows \
   icmp_00_internal.rw
           sIP|            dIP|iTy|iCo|dst-services|   Records|
 192.168.121.77|  192.168.181.8|  0|  0|      VPNPOOL|         5|
 192.168.166.55|  192.168.181.8|  0|  0|      VPNPOOL|         5|
  192.168.121.2|  192.168.181.8|  0|  0|      VPNPOOL|         5|
 192.168.166.12|  192.168.181.8|  0|  0|      VPNPOOL|         5|
  192.168.111.2|  192.168.181.8|  0|  0|      VPNPOOL|         5|
  192.168.121.2|  192.168.181.8|  0|  9|      VPNPOOL|         5|
192.168.111.223|  192.168.181.8|  0|  0|      VPNPOOL|         5|
192.168.111.212|  192.168.181.8|  0|  0|      VPNPOOL|         5|
 192.168.166.15|  192.168.181.8|  0|  0|      VPNPOOL|         5|
192.168.111.109|  192.168.181.8|  0|  0|      VPNPOOL|         5|
  192.168.70.10|     10.0.40.27|  0|  0|    SERVICES|      1013|
192.168.121.158|  192.168.181.8|  0|  0|      VPNPOOL|         5|
192.168.124.218|  192.168.40.20|  0|  0|    SERVICES|         2|
 192.168.166.43|  192.168.181.8|  0|  0|      VPNPOOL|         5|
 192.168.121.57|  192.168.181.8|  0|  0|      VPNPOOL|         5|
192.168.111.131|  192.168.181.8|  0|  0|      VPNPOOL|         5|
 192.168.166.43|  192.168.40.20|  0|  0|    SERVICES|         2|
  192.168.111.2|  192.168.181.8|  0|  9|      VPNPOOL|         5|
192.168.121.145|  192.168.181.8|  0|  0|      VPNPOOL|         5|
 192.168.111.94|  192.168.181.8|  0|  0|      VPNPOOL|         5|
192.168.166.233|  192.168.181.8|  0|  0|      VPNPOOL|         5|
192.168.121.244|  192.168.181.8|  0|  0|      VPNPOOL|         5|
192.168.124.205|     10.0.40.20|  0|  0|    SERVICES|         4|
```

Example 7.18: Identifying Internal Non-Gateway Hosts that Send ICMP Echo Reply Messages Outside their Subnetwork

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Chapter 8

Extending the Reach of SiLK with PySiLK

This chapter discusses how to use PySiLK, the SiLK Python extension, to support analyses that are difficult to implement within the normal constraints of the SiLK tool suite. Sometimes, an analyst needs to use parts of the SiLK suite's native functionality in a modified way. The capabilities of PySiLK simplify these analyses.

This chapter does not discuss the issues involved in composing new PySiLK scripts or how to code in the Python programming language. Several example scripts are shown, but the detailed design of each script will not be presented here.

Upon completion of this chapter, you will be able to

- explain the purpose of PySiLK in analysis
- use and modify PySiLK plug-ins to match records in `rwfilter`
- use and modify PySiLK plug-ins to add fields for `rwcut` and `rwsort`
- use and modify PySiLK plug-ins to add key fields and summary values for `rwuniq` and `rwstats`

Additional PySiLK and Python programming language resources include

- a brief guide to coding PySiLK plug-ins, provided by the `silkpython` manual page (see `man silkpython` or Section 3 of *The SiLK Reference Guide* at https://tools.netsa.cert.org/silk/reference-guide.pdf)
- detailed descriptions of the PySiLK structures, provided in *PySiLK: SiLK in Python* (https://tools.netsa.cert.org/silk/pysilk.pdf)
- generic programming in the Python programming language, as described in many locations on the web, particularly on the Python official website (https://www.python.org/doc/)

8.1 Using PySiLK

PySiLK is an extension to the SiLK tool suite that expands its functionality via scripts written in the Python programming language. The purpose of PySiLK is to support analytical use cases that are difficult to express, implement, and support with the capabilities natively built into SiLK, while using those capabilities where appropriate.

To extend the SiLK tools with PySiLK, first write a Python file that calls Python functions defined in the `silk.plugin` Python module. To use this Python file, specify the `--python-file` switch for one of the SiLK tools that supports PySiLK. (The `rwfilter`, `rwstats`, `rwuniq`, `rwcut`, and `rwsort` tools can all make use of PySiLK extensions.) The tool then loads the Python file and makes the new functionality available.

8.1.1 PySiLK Requirements

To use PySiLK:

1. Install the appropriate version of the Python language[23] on your system.
2. Load the PySiLK library (a directory named `silk`) in the `site-packages` directory of the Python installation.
3. To ensure that the PySiLK library works properly, set the `PYTHONPATH` environment variable to include the `site-packages` directory.

8.1.2 PySiLK Scripts and Plug-ins

PySiLK code comes in two forms: standalone Python programs and plug-ins for SiLK tools. Both of these forms use a Python module named `silk` that is provided as part of the PySiLK library. PySiLK provides the capability to manipulate SiLK objects (flow records, IPsets, bags, etc.) with Python code.

For analyses that will not be repeated often or that are expected to be modified frequently, the relative brevity of PySiLK renders it an efficient alternative. As with all programming, analysts need to use algorithms that meet the speed and space constraints of the project. Often (but not always), building upon the processing of the SiLK tools by use of a plug-in yields a more suitable solution than developing a stand-alone script.

PySiLK plug-ins for SiLK tools use an additional component called `silkpython`, which is also provided with the PySiLK library. The `silkpython` component creates the application programming interfaces (APIs), simple and advanced, that connect a plug-in to SiLK tools. Currently, `silkpython` supports the following SiLK tools: `rwfilter`, `rwcut`, `rwgroup`, `rwsort`, `rwstats`, and `rwuniq`.

- For `rwfilter`, `silkpython` permits a plug-in to provide new types of partitioning criteria.
- For `rwcut`, plug-ins can create new flow record fields for display.
- For `rwgroup` and `rwsort`, plug-ins can create fields to be used as all or part of the key for grouping or sorting records.

[23] Python 2.7.x for SiLK Version 3.8.

- For `rwstats` and `rwuniq`, two types of fields can be defined: *key* fields used to categorize flow records into bins and *summary value* fields used to compute a single value for each bin from the records in those bins.

- For all of the tools, `silkpython` allows a plug-in to create new SiLK tool switches (parameters) to modify the behavior of the aforementioned partitioning criteria and fields.

The `silkpython` module provides only one function for establishing (registering) partitioning criteria (filters) for `rwfilter`. The simple API provides four functions for creating key fields for the other five supported SiLK tools and three functions for creating summary value fields for `rwstats` and `rwuniq`. The advanced API provides one function that can create either key fields or summary value fields, and permits a higher degree of control over these fields.

8.2 Extending `rwfilter` with PySiLK

PySiLK extends the capabilities of `rwfilter` by letting the analyst create new methods for partitioning flow records.[24]

For a single execution of `rwfilter`, PySiLK is much slower than using a combination of `rwfilter` parameters and usually slower than using a C-language plug-in. However, there are several ways in which using PySiLK can replace a series of several `rwfilter` executions with a single execution and ultimately speed up the overall process.

Without PySiLK, `rwfilter` has limitations using its built-in partitioning parameters:

- Each flow record is examined without regard to other flow records. That is, no state is retained.

- There is a fixed rule for combining partitioning parameters: Any of the alternative values within a parameter satisfies that criterion (i.e., the alternatives are joined implicitly with a logical *or* operation). All parameters must be satisfied for the record to pass (i.e., the parameters are joined implicitly with a logical *and* operation).

- The types of external data that can assist in partitioning records are limited. IP sets, tuple files, and prefix maps are the only types provided by built-in partitioning parameters.

PySiLK is useful to expand the capabilities of `rwfilter` in these cases:

- Information from prior records may help to partition subsequent records into the pass or fail categories.

- A series of nontrivial alternatives form the partitioning condition.

- The partitioning condition employs a control structure or data structure.

[24] These partitioning methods may also calculate values not normally part of `rwfilter`'s output, typically emitting those values to a file or to the standard error stream to avoid conflicts with flow record output.

8.2.1 Using PySiLK to Incorporate State from Previous Records: Eliminating Inconsistent Sources

For an example of where some information (or *state*) from prior records may help in partitioning subsequent records, consider Example 8.1. This script (`ThreeOrMore.py`) passes all records that have a source IP address used in two or more prior records. This can be useful if you want to eliminate casual or inconsistent sources of particular behavior. The `addrRefs` variable is the record of how many times each source IP address has been seen in prior records. The `threeOrMore` function holds the Python code to partition the records. If it determines the record should be passed, it returns `True`; otherwise it returns `False`.

In Example 8.1, the call to `register_filter` informs `rwfilter` (through `silkpython`) to invoke the specified Python function (`threeOrMore`) for each flow record that has passed all the built-in SiLK partitioning criteria. In the `threeOrMore` function, the `addrRefs` dictionary is a container that holds entries indexed by an IP address and whose values are integers.

When the `get` method is applied to the dictionary, it obtains the value for the entry with the specified key, `keyval`, if such an entry already exists. If this is the first time that a particular key value arises, the `get` method returns the supplied default value, zero. Either way, one is added to the value obtained by `get`. The `return` statement compares this incremented value to the `bound` threshold value and returns the Boolean result to `silkpython`, which informs `rwfilter` whether the current flow record passes the partitioning criterion in the PySiLK plug-in.

In Example 8.1, the `set_bound` function is not required for the partitioning to operate. It provides the capability to modify the threshold that the `threeOrMore` function uses to determine which flow records pass. The call to `register_switch` informs `rwfilter` (through `silkpython`) that the `--limit` parameter is acceptable in the `rwfilter` command after the `--python-file=ThreeOrMore.py` parameter, and that if the user specifies the parameter (e.g., `--limit=5`) the `set_bound` function will be run to modify the `bound` variable before any flow records are processed. The value provided in the `--limit` parameter will be passed to the `set_bound` function as a string that needs to be converted to an integer so it can participate later in numerical comparisons.

If the user specifies a string that is not a representation of an integer, the conversion will fail inside the `try` statement, raising a `ValueError` exception and displaying an error message; in this case, `bound` is not modified.

8.2.2 Using PySiLK to Incorporate State from Previous Records: Detecting Port Knocking

For an example in which some information (or *state*) from prior records may help in partitioning subsequent records, consider *port knocking*. This is a technique used to thwart port scanning. Port scanning involves sending single packets to particular ports on a target host to see what response, if any, is returned by the target. The response, or lack of one, is interpreted to determine if there is a service available on that port on the target host. Port knocking is employed by the administrator of the target host to make all ports look as if there are no services available on any of them.

Port knocking requires legitimate users (or their software) to know the secret combination of actions that must be taken before an attempt is made to connect to a service port. These actions consist of attempts to connect (or *knocks*) to certain other ports in the correct order right before attempting a connection to the service port. Achieving the correct sequence of knocks creates a temporary rule in the firewall to allow the sender of the knocks to connect to a particular service. Profiling a network to obtain situational awareness could include port knocking detection to explain what would otherwise look like strange traffic.

```
import sys   # stderr

bound = 3    # default threshold for passing record
addrRefs={}  # key = IP address, value = reference count

def threeOrMore(rec):
  global addrRefs  # allow modification of addrRefs

  keyval = rec.sip  # change this to count on different field
  addrRefs[keyval] = addrRefs.get(keyval, 0) + 1
  return addrRefs[keyval] >= bound

def set_bound(integer_string):
  global bound

  try:
    bound = int(integer_string)
  except ValueError:
    print >>sys.stderr, '--limit value, %s, is not an integer.' % integer_string

def output_stats():
  AddrsWithEnufFlows = len([1 for k in addrRefs.keys()
                            if addrRefs[k] >= bound])
  print >>sys.stderr, 'SIPs: %d;  SIPs meeting threshold: %d' % (len(addrRefs),
                                                                 AddrsWithEnufFlows)

register_filter(threeOrMore, finalize=output_stats)
register_switch('limit', handler=set_bound, help='Threshold for passing')
```

Example 8.1: `ThreeOrMore.py`: Using PySiLK for Memory in `rwfilter` Partitioning

Example 8.2 implements a plug-in for `rwfilter` that takes a simple approach. The plug-in requires that its input be sorted by IP addresses and time. That way the port knocks appear in the input right before the service connection attempt. This means that the plug-in needs to retain state for only one connection attempt at a time, simplifying the code and greatly reducing the memory requirements.

The plug-in looks for three consecutive flow records where the first two (the port knocks) attempt to initiate TCP connections to different ports, but there are no following packets with the ACK flag that would indicate the connection had been established. After the two port knock flows, there must be a flow for a third port which does have additional packets with the ACK flag.

These criteria are somewhat simple. We could add constraints such as specifying that the three ports must have a certain ordinal relationship (e.g., lower-higher-lower). However, Example 8.2 shows the essential elements. When the three-flow sequence is found, the third flow passes the filter and a text record is displayed.

```
import datetime # timedelta()
import sys # stdout

REQDKNOCKS = 2  # number of required knocks with distinct port numbers
INTERVAL = datetime.timedelta(seconds=5)  # knocks & conn this close in time
TCP = 6  # protocol number

portListWidth = REQDKNOCKS * 7
lastsip = None

def note_first_knock(rec):
   global lastsip, lastdip, portlist, lastetime
   lastsip = rec.sip
   lastdip = rec.dip
   portlist = [rec.dport]
   lastetime = rec.etime
   return

def examine_flow(rec):
   global lastsip, lastdip, portlist, lastetime
   if (rec.protocol == TCP and rec.initial_tcpflags is not None and
       rec.initial_tcpflags.matches('S/SA')):  # initial SYN (client to server)
      if lastsip is not None and rec.sip == lastsip and rec.dip == lastdip:
         if rec.stime - lastetime <= INTERVAL:
            if rec.session_tcpflags.ack:  # established connection
               # connected to knocked port or insufficient knocks?
               if rec.dport in portlist or len(portlist) < REQDKNOCKS:
                  lastsip = None
               else:  # enough prior knocks?
                  sys.stdout.write('%15s %15s %*s %5d\n' % (lastsip, lastdip,
                                       portListWidth, portlist, rec.dport))
                  lastsip = None
                  return True  # flow record passes filter
            else:  # connection not established; just a knock
               if rec.dport in portlist:  # already seen this port
                  note_first_knock(rec)  # start over as 1st knock
               else:
                  if len(portlist) >= REQDKNOCKS:  # add a knock
                     del portlist[0]  # delete oldest knock, make room for new
                  portlist.append(rec.dport)
```

```
                lastetime = rec.etime
        # last knock was too long ago
        elif rec.session_tcpflags.ack:  # established connection
            lastsip = None
        else:  # too long ago and connection not established; just a knock
            note_first_knock(rec)  # start over as 1st knock
    # new sip and/or dip
    elif not rec.session_tcpflags.ack: # conn not established; just a knock
        note_first_knock(rec)  # start over as 1st knock
  return False  # flow record fails filter

def show_heading():
  sys.stdout.write('%15s %15s %*s %5s\n' % ('sIP', 'dIP', portListWidth,
                                            'Knock-Ports', 'Estab'))

register_filter(examine_flow, initialize=show_heading)
```

Example 8.2: `portknock.py`: Using PySiLK to Retain State in `rwfilter` Partitioning

8.2.3 Using PySiLK with `rwfilter` in a Distributed or Multiprocessing Environment

An analyst could use a PySiLK script with `rwfilter` by first calling `rwfilter` to retrieve the records that satisfy a given set of conditions, then piping those records to a second `rwfilter` call that uses the `--python-file` parameter to invoke the script. This is shown in Example 8.3. This syntax is preferred to simply including the `--python-file` parameter on the first call, since its behavior is more consistent across execution environments. If `rwfilter` is running on a multiprocessor configuration, running the script on the first `rwfilter` call cannot be guaranteed to behave consistently for a variety of reasons, so running PySiLK scripts via a piped `rwfilter` call is more consistent.

8.2.4 Simple PySiLK with `rwfilter --python-expr`

Some analyses that do not lend themselves to solutions with just the SiLK built-in partitioning parameters may be so simple with PySiLK that they center on an expression that evaluates to a Boolean value. Using the `rwfilter --python-expr` parameter will cause `silkpython` to provide the rest of the Python plug-in program.

Example 8.4 partitions flow records that have the same port number for their source port and destination port (`sport` and `dport`). Although the name for the flow record object is specified by a function parameter in user-written Python files, with `--python-expr`, the record object is always called `rec`. The source port and destination port therefore can be specified as `rec.sport` and `rec.dport`. Checking whether their values are equal becomes very simple.

With `--python-expr`, it is not possible to retain state from previous flow records as in Example 8.1. Nor is it possible to incorporate information from sources other than the flow records. Both of these require a plug-in invoked by `--python-file`.

8.2.5 PySiLK with Complex Combinations of Rules

Example 8.5 shows an example of using PySiLK to filter for a condition with several alternatives. This code is designed to identify virtual private network (VPN) traffic in the data, using IPsec, OpenVPN®, or VPNz® . This involves having several alternatives, each matching traffic either for a particular protocol (50 or 51) or for particular combinations of a protocol (17) and ports (500, 1194, or 1224). This could be done using a pair of `rwfilter` calls (one for UDP [17] and one for both ESP [50] and AH [51]) and `rwcat` to put them together, but this is less efficient than using PySiLK.

8.2.6 Use of Data Structures in Partitioning

Example 8.6 shows the use of a data structure in an `rwfilter` condition. This particular case identifies internal IP addresses responding to contacts by IP addresses in certain external blocks. The difficulty is that the response is unlikely to go back to the contacting address and likely instead to go to another address on the same network. Matching this with conventional `rwfilter` parameters is very slow and repetitive. By building a list of internal IP addresses and the networks they've been contacted by, `rwfilter` can partition records based on this list using the PySiLK script in Example 8.6, called `matchblock.py`.

In Example 8.6, lines 1 and 2 import objects from two modules. Line 3 sets a constant (with a name in all uppercase by convention). Line 4 creates a global variable to hold the name of the file containing external netblocks and gives it a default value. Lines 6, 10, and 32 define functions to be invoked later. Line 42 informs `silkpython` of two things: (1) that the `open_blockfile` function should be invoked after all command-line switches (parameters) have been processed and before any flow records are read and (2) that in addition to any other partitioning criteria, every flow record must be tested with the `match_block` function to determine if it passes or fails. Line 43 tells `silkpython` that `rwfilter` should accept a `--blockfile` parameter on the command line and process its value with the `change_blockfile` function before the initialization function, `open_blockfile`, is invoked.

When `open_blockfile` is run, it builds a list of external netblocks for each specified internal address. Line 25 converts the specified address to a PySiLK address object; if that's not possible, a `ValueError` exception is raised, and that line in the blockfile is skipped. Line 26 similarly converts the external netblock specification to a PySiLK IP wildcard object; if that's not possible, a `ValueError` exception is raised, and that line in the file is skipped. Line 26 also appends the netblock to the internal address's list of netblocks; if that list does not exist, the `setdefault` method creates it.

When each flow record is read by `rwfilter`, `silkpython` invokes `match_block`, which tests every external netblock in the internal address's list to see if it contains the external, destination address from the flow record. If an external address is matched to a netblock in line 35, the test passes. If no netblocks in the list match, the test fails in line 39. If there is no list of netblocks for an internal address (because it was not specified in the blockfile), the test fails in line 38.

Example 8.7 uses command-line parameters to invoke the Python plug-in and pass information to the plug-in script (specifically the name of the file holding the block map). Command 1 displays the contents of the block map file. Each line has two fields separated by a comma. The first field contains an internal IP address; the second field contains a wildcard expression (which could be a CIDR block or just a single address) describing an external netblock that has communicated with the internal address. Command 2 then invokes the script using the syntax introduced previously, augmented by the new parameter.

```
<1>$ rwfilter --start-date=2015/06/02 --end-date=2015/06/18 \
   --type=inweb --protocol=6 --dport=443 \
   --bytes-per-packet=65- --packets=4- \
   --flags-all=SAF/SAF,SAR/SAR --pass=stdout \
| rwfilter stdin --python-file=ThreeOrMore.py \
   --pass=web.rw
SIPs: 81;  SIPs meeting threshold: 81
```

Example 8.3: Calling `ThreeOrMore.py`

```
<1>$ rwfilter flows.rw --protocol=6,17 --python-expr='rec.sport==rec.dport' \
              --pass=equalports.rw
```

Example 8.4: Using `--python-expr` for Partitioning

```
def vpnfilter(rec):
  return ((rec.protocol == 17 and  # UDP
         (rec.dport in (500, 1194, 1224) or   # IKE, OpenVPN, VPNz
          rec.sport in (500, 1194, 1224)   ) )
       or rec.protocol in (50, 51) )  # ESP, AH

register_filter(vpnfilter)
```

Example 8.5: `vpn.py`: Using PySiLK with `rwfilter` for Partitioning Alternatives

```
from silk import IPAddr,IPWildcard
import sys  # exit(), stderr
PLUGIN_NAME = 'matchblock.py'
blockname='blocks.csv'

def change_blockfile(block_str):
  global blockname
  blockname = block_str

def open_blockfile():
  global blockfile, blockdict
  try:
    blockfile = open(blockname)
  except IOError, e_value:
     sys.exit('%s: Block file: %s' % (PLUGIN_NAME, e_value))
  blockdict = dict()
  for line in blockfile:
    if line.lstrip()[0] == '#':  # recognize comment lines
      continue                   # skip entry
    fields = line.strip().split(',') # remove NL and split fields on commas
    if len(fields) < 2:  # too few fields?
      print >>sys.stderr, '%s: Too few fields: %s' % (PLUGIN_NAME, line)
      continue           # skip entry
    try:
      idx = IPAddr(fields[0].rstrip())
      blockdict.setdefault(idx, []).append(IPWildcard(fields[1].strip()))
    except ValueError:   # field cannot convert to IPAddr or IPWildcard
      print >>sys.stderr, '%s: Bad address or wildcard: %s' % (PLUGIN_NAME, line)
      continue           # skip entry
  blockfile.close()

def match_block(rec):
  try:
    for netblock in blockdict[rec.sip]:
      if rec.dip in netblock:
        return True
  except KeyError:  # no such inside addr
    return False
  return False  # no netblocks match

#  M A I N
register_filter(match_block, initialize=open_blockfile)
register_switch('blockfile', handler=change_blockfile,
  help='Name of file that holds CSV block map.  Def. blocks.csv')
```

Example 8.6: `matchblock.py`: Using PySiLK with `rwfilter` for Structured Conditions

```
<1>$ cat blockfile.csv
198.51.100.17, 192.168.0.0/16
203.0.113.178, 192.168.x.x
<2>$ rwfilter out_month.rw --protocol=6 --dport=25 --pass=stdout \
      | rwfilter stdin --python-file=matchblock.py \
                  --blockfile=blockfile.csv --print-statistics
Files     1.  Read     375567.  Pass          8. Fail      375559.
```

Example 8.7: Calling `matchblock.py`

8.3 Extending SiLK with Fields Defined with PySiLK

Five SiLK tools support fields defined with PySiLK: `rwcut`, `rwgroup`, `rwsort`, `rwstats`, and `rwuniq`. All five support newly defined *key* fields, although for `rwcut` these fields are not really the key to any sorting or grouping operation; they are simply available for display. Two of the tools, `rwstats` and `rwuniq`, support newly defined *summary value* fields. For fields that require the use of the advanced API, the programmer will want to determine which of the five tools will be used with these fields to avoid unnecessary programming. By examining the characteristics of the new field the programmer can determine which tools can take advantage of the field.

`rwcut` can make use of any key field that produces character strings (text). It does not matter if field values can be used in computations, comparisons, or sorting. As long as the field can be represented as text, `rwcut` can use it. When registering such fields, a function to produce a text value must be provided.

For `rwgroup` and `rwsort` to utilize a field defined with PySiLK, the field registration must provide a function that produces binary (non-text) values that can be compared. For `rwgroup`, the comparison is only for equality to determine if two consecutive records belong in the same group. For `rwsort` the comparison must also determine the order of unequal values.

For `rwstats` and `rwuniq`, a key field not only needs a binary representation for grouping purposes, it also needs a function to convert the binary key (bin) to text for display purposes. Furthermore, it must make sense semantically for the field to produce a many-to-one mapping from its inputs to its value. This is necessary for the field to make a good key (or partial key) for bins. A field makes a poor binning key if nearly every record produces a unique field value, or if nearly every record produces the same field value.

8.4 Extending `rwcut` and `rwsort` with PySiLK

PySiLK is useful with `rwcut` and `rwsort` in these cases:

- An analysis requires a value based on a combination of fields, possibly from a number of records.
- An analyst chooses to use a function on one or more fields, possibly conditioned by the value of one or more fields. The function may incorporate data external to the records (e.g., a table of header lengths).

8.4.1 Computing Values from Multiple Records

Example 8.8 shows the use of PySiLK to calculate a value from the same field of two different records in order to provide a new column to display with `rwcut`. This particular case, which will be referred to as `delta.py`, introduces a `delta_msec` column, with the difference between the start time of two successive records. Potential uses for this column including ready identification of flows that occur at very stable intervals, such as keep-alive traffic or beaconing.

The plug-in uses global variables to save the IP addresses and start time between records and then returns to `rwcut` the number of milliseconds between start times. The `register_int_field` call allows the use of `delta_msec` as a new field name and gives `rwcut` the information that it needs to process the new field.

To use `delta.py`, Example 8.9 sorts the flow records by source address, destination address, and start time after pulling them from the repository. After sorting, the example passes them to `rwcut` with the `--python-file=delta.py` parameter before the `--fields` parameter so that the `delta_msec` field name is

defined. Because of the way the records are sorted, if the source or destination IP addresses are different in two consecutive records, the latter record could have an earlier `sTime` than the prior record. Therefore, it makes sense to compute the time difference between two records only when their source addresses match and their destination addresses match. Otherwise, the delta should display as zero.

8.4.2 Computing a Value Based on Multiple Fields in a Record

Example 8.10 shows the use of a PySiLK plug-in for both `rwsort` and `rwcut` that supplies a value calculated from several fields from a single record. In this example, the new value is the number of bytes of payload conveyed by the flow. The number of bytes of header depends on the version of IP as well as the Transport-layer protocol being used (IPv4 has a 20-byte header, IPv6 has a 40-byte header, and TCP adds 20 additional bytes, while UDP adds only 8 and GRE [protocol 47] only 4, etc.).

The `header_len` variable holds a mapping from protocol number to header length. Protocols omitted from the mapping contribute zero bytes for the Transport-layer header. This is then multiplied by the number of packets and subtracted from the flow's byte total. This code assumes no packet fragmentation is occurring. The same function is used to produce both a value for `rwsort` to compare and a value for `rwcut` to display, as indicated by the `register_int_field` call.

Example 8.11 shows how to use Example 8.10 with both `rwsort` and `rwcut`. The records are sorted into payload-size order and then output, showing both the bytes and payload values.

8.4.3 Defining a Character String Field for `rwcut`

PySiLK has no function in the simple API for creating character-string fields. Do not be tempted to use an enumeration where there are many possible strings produced for the field; an enumeration can be quite memory-intensive. It will not sort correctly in `rwsort` or in `rwuniq` with the `--sort-output` parameter.

Creating a character-string field with the advanced API (`register_field` function) is not difficult. Starting with an example of a string field that works only with `rwcut`, Example 8.12 is a PySiLK plug-in that makes large values in the built-in `duration` field more understandable by breaking it down into days, hours, minutes, and seconds (including milliseconds). This field does not provide a binary value, so the field has no usefulness with `rwsort` or `rwgroup`, which produce non-text output. Since this field embodies the same information as the built-in `duration` field, the built-in field is better suited for use with these tools as it will yield much better performance. The usefulness of `decode_duration` with `rwstats` and `rwuniq` is dubious as well; although these tools produce textual output, the lack of a many-to-one mapping makes this field an ideal candidate for use only with `rwcut`.

Example 8.13 shows both the built-in `duration` field and the associated `decode_duration` field for several flow records.

8.4.4 Defining a Character String Field for Five SiLK Tools

A plug-in to create a character-string field not only for `rwcut`, but also for `rwgroup`, `rwsort`, `rwstats`, and `rwuniq` needs a little more code. In Example 8.14 a regular expression is used to provide a pattern for the site-name portion of a sensor name. Since the regular expression does not permit numeric digits as part of the site name, the pattern matching ends when a digit is reached in the sensor name. In addition to defining a function that derives a string from a SiLK flow record, we need a function to pad the strings so their lengths are the same for all records, and a function to strip the padding.

```
last_sip = None

def compute_delta(rec):
    global last_sip, last_dip, last_time
    if last_sip is None or rec.sip != last_sip or rec.dip != last_dip:
        last_sip = rec.sip
        last_dip = rec.dip
        last_time = rec.stime_epoch_secs
        deltamsec = 0
    else:  # sip and dip same as previous record
        deltamsec = int(1000. * (rec.stime_epoch_secs - last_time))
        last_time = rec.stime_epoch_secs
    return deltamsec

register_int_field ('delta_msec', compute_delta, 0, 4294967295)
#                    fieldname      function    min     max
```

Example 8.8: `delta.py`

```
<1>$ rwfilter --type=out --start-date=2015/06/02 \
   --end-date=2015/06/18 --protocol=17 --packets=1 \
   --pass=stdout \
| rwsort --fields=sIP,dIP,sTime \
| rwcut --python-file=delta.py \
   --fields=sIP,dIP,sTime,delta_msec --num-recs=20
            sIP|            dIP|                  sTime|delta_msec|
     10.0.20.58|    128.8.10.90|2015/06/17T20:50:50.725|         0|
     10.0.20.58|    128.8.10.90|2015/06/17T20:50:50.725|         0|
     10.0.20.58|    128.8.10.90|2015/06/17T20:50:50.725|         0|
     10.0.20.58|    199.7.83.42|2015/06/17T20:50:46.717|         0|
     10.0.20.58|    199.7.83.42|2015/06/17T20:50:46.717|         0|
     10.0.40.20|     10.0.20.58|2015/06/16T12:48:08.030|         0|
     10.0.40.20|     10.0.20.58|2015/06/16T12:48:08.268|       237|
     10.0.40.20|     10.0.20.58|2015/06/16T12:48:08.580|       312|
     10.0.40.20|     10.0.20.58|2015/06/16T12:48:08.580|         0|
     10.0.40.20|     10.0.20.58|2015/06/16T12:48:08.674|        94|
     10.0.40.20|     10.0.20.58|2015/06/16T12:48:09.015|       341|
     10.0.40.20|     10.0.20.58|2015/06/16T12:48:09.043|        27|
     10.0.40.20|     10.0.20.58|2015/06/16T12:48:09.215|       171|
     10.0.40.20|     10.0.20.58|2015/06/16T12:48:09.397|       182|
     10.0.40.20|     10.0.20.58|2015/06/16T12:48:10.228|       830|
     10.0.40.20|     10.0.20.58|2015/06/16T12:48:10.620|       391|
     10.0.40.20|     10.0.20.58|2015/06/16T12:48:10.622|         2|
     10.0.40.20|     10.0.20.58|2015/06/16T12:48:10.622|         0|
     10.0.40.20|     10.0.20.58|2015/06/16T12:48:11.069|       447|
     10.0.40.20|     10.0.20.58|2015/06/16T12:48:11.415|       345|
```

Example 8.9: Calling `delta.py`

```
#            ICMP  IGMP  IPv4    TCP    UDP    IPv6   RSVP
header_len={1:8, 2:8, 4:20, 6:20, 17:8, 41:40, 46:8,
            47:4, 50:8, 51:12, 88:20, 132:12}
#             GRE    ESP     AH    EIGRP    SCTP

def bin_payload(rec):
    transport_hdr = header_len.get(rec.protocol, 0)
    if rec.is_ipv6():
        ip_hdr = 40
    else:
        ip_hdr = 20
    return rec.bytes - rec.packets * (ip_hdr + transport_hdr)

register_int_field('payload', bin_payload, 0, (1 << 32) - 1)
#                   fieldname    function  min       max
```

Example 8.10: payload.py: Using PySiLK for Conditional Fields with rwsort and rwcut

```
<1>$ rwsort inbound.rw --python-file=payload.py --fields=payload \
      | rwcut --python-file=payload.py --fields=5,packets,bytes,payload
pro|   packets|     bytes|   payload|
  6|      1007|     40280|         0|
  1|         1|        28|         0|
  6|         2|        92|        12|
  6|         8|       332|        12|
  1|         1|        48|        20|
 17|         1|        51|        23|
  1|        14|       784|       392|
 80|         3|       762|       702|
 50|        16|      1920|      1472|
 17|         1|      2982|      2954|
 47|       153|     12197|      8525|
 50|        77|     11088|      8932|
 17|       681|    212153|    193085|
  6|       309|    398924|    386564|
 51|      5919|    773077|    583669|
 51|     10278|   1344170|   1015274|
  6|       820|   1144925|   1112125|
 97|   2134784|2770949632|2728253952|
```

Example 8.11: Calling payload.py

```
'''Define a field for rwcut which formats the flow duration as a string
   representation of days, hours, minutes, seconds, and milliseconds.
'''

SECPERHOUR = 3600
SECPERMIN = 60

def decode_duration(rec):
  (hours, seconds) = divmod(rec.duration.seconds, SECPERHOUR)
  (minutes, seconds) = divmod(seconds, SECPERMIN)
  return '%02dd%02dh%02dm%02d.%03ds' % (rec.duration.days, hours, minutes,
                                        seconds, rec.duration.microseconds // 1000)

register_field('decode_duration', column_width=16, rec_to_text=decode_duration,
               description='Decomposition of duration into days, hours,'
                           ' minutes, seconds, and milliseconds')
```

Example 8.12: `decode_duration.py`: A Program to Create a String Field for `rwcut`

```
<1>$ rwcut flows.rw --python-file=decode_duration.py \
                    --fields=decode_duration,duration
 decode_duration| duration|
01d07h32m49.161s|113569.161|
00d00h29m00.450s| 1740.450|
00d19h05m22.667s|68722.667|
00d00h00m03.000s|    3.000|
```

Example 8.13: Calling `decode_duration.py`

The functions provided here should work for other string-field plug-ins, except for the call to `get_site`, which derives the string from the record. Then we must establish the maximum length of the field, and supply a few additional parameters to the `register_field` call. Example 8.15 shows how use of the derived field reduces the output to fewer lines than the number of sensors.

```
import re  # compile(), SRE_Pattern.match(), SRE_Match.group()

# Global variables that may be modified for the enterprise.
MAX_FIELD_LEN = 8
regex = re.compile(r"^[-A-Za-z]+")

def get_site(rec):
  '''Derive site name from sensor field in flow record.'''

  return regex.match(rec.sensor).group()

def remove_padding(bin):
  '''Remove padding from fixed-length string.'''

  # for Python 3.x, change "bin" to "str(bin, 'UTF-8')"
  return bin.rstrip('\0')

def pad_to_fixed_length(rec):
  '''Make site names all the same length.'''

  # for Python 3.x, enclose the entire expression in "bytes( , 'UTF-8')"
  return get_site(rec).ljust(MAX_FIELD_LEN, '\0')

register_field('Site',
               bin_bytes=MAX_FIELD_LEN,
               bin_to_text=remove_padding,
               column_width=MAX_FIELD_LEN,
               description='Site name derived from sensor.',
               rec_to_bin=pad_to_fixed_length,
               rec_to_text=get_site)
```

Example 8.14: `sitefield.py`: A Program to Create a String Field for Five SiLK Tools

```
<1>$ rwcut flows.rw --python-file=sitefield.py --fields=sensor,Site
  sensor|    Site|
NewYork1| NewYork|
NewYork2| NewYork|
 London0|  London|
London1a|  London|
NewYork1| NewYork|
NewYork2| NewYork|
NewYork3| NewYork|
 London0|  London|
London1a|  London|
London1a|  London|
London1a|  London|
NewYork2| NewYork|
NewYork2| NewYork|
NewYork3| NewYork|
NewYork3| NewYork|
NewYork2| NewYork|
London1a|  London|
<2>$ rwuniq flows.rw --python-file=sitefield.py --field=Site --sort-output
    Site|   Records|
  London|         7|
 NewYork|        10|
```

Example 8.15: Calling `sitefield.py`

8.5 Defining Key Fields and Summary Value Fields for `rwuniq` and `rwstats`

In addition to defining key fields that `rwcut` can use for display, `rwsort` can use for sorting, and `rwgroup` can use for grouping, `rwuniq` and `rwstats` can make use of both key fields and summary value fields. Key fields and summary fields use different registration functions in the simple API, however the registered callback functions do not have to be different. In Example 8.16, the same function, `rec_bpp`, is used to compute the bytes-per-packet ratio for a flow record for use in binning records by a key and in proposing candidate values for the summary value.

In Example 8.17, command 2 uses the Python file, `bpp.py`, to create a key field for binning records. Command 3 creates an summary value field instead. The summary value in the example finds the maximum value of all the records in a bin, but there are simple API calls for minimum value and sum as well. For additional summaries, the analyst can use the advanced API function, `register_field`.

As shown in this chapter, PySiLK simplifies several previously difficult analyses, without requiring coding large scripts. While the programming involved in creating these scripts has not been described in much detail, the scripts shown (or simple modifications of these scripts) may prove useful to analysts.

```
def rec_bpp(rec):
    return int(round(float(rec.bytes) / float(rec.packets)))

register_int_field('bpp', rec_bpp, 0, (1<<32) - 1)
register_int_max_aggregator('maxbpp', rec_bpp, (1<<32) - 1)
```

Example 8.16: bpp.py

```
<1>$ rwfilter --type=in --start-date=2015/06/02 \
   --end-date=2015/06/18 --protocol=0- \
   --max-pass-records=70 --pass=tmp.rw
<2>$ rwuniq tmp.rw --python-file=bpp.py --fields=protocol,bpp \
   --values=records
pro|       bpp|   Records|
 17|        70|         1|
  6|       132|         2|
  6|       410|         1|
 17|        74|         2|
  6|       201|         1|
  6|       116|         1|
 17|        72|         1|
 17|        85|         1|
  6|       409|         1|
  6|       217|         1|
 17|       213|         1|
 17|        84|         1|
  6|       434|         1|
  6|       140|         1|
  6|        40|        15|
  6|       160|         1|
  6|        46|         1|
  6|       236|         1|
  6|        45|        29|
 17|        73|         1|
  6|       174|         5|
  6|       154|         1|
<3>$ rwuniq tmp.rw --python-file=bpp.py --fields=protocol \
   --values=maxbpp
pro|    maxbpp|
  6|       434|
 17|       213|
```

Example 8.17: Calling bpp.py

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Chapter 9

Tuning SiLK for Improved Performance

While the SiLK tool suite offers a lot of expressive power and can accommodate a wide variety of analyses, processing network flow records can take a long time. This delay comes from retrieving a large number of records and analyzing those records through a complex series of steps. The time it takes to perform an analysis can be reduced by exploiting features of the SiLK suite, the data being processed, and the processing environment.

Upon completion of this chapter you will be able to

- develop a plan to reduce analysis time
- exploit features of the processing environment to reduce analysis time
- exploit data characteristics to reduce analysis time
- employ features of the SiLK suite to reduce analysis time

Hint 9.1: Response Times and Processor Architectures

This chapter presents a series of examples showing the various strategies, with observed response times. Variations on host load, processor and disk configuration, storage organization, repository structure, repository file sizes, and operating system versions all will affect the time values. The amount of gain for any strategy cannot be guaranteed for all data sets. However, these techniques do allow retrieval and filtering to be done faster on modern multiprocessor architectures.

The specific results presented here were obtained on a sixteen-processor shared-memory architecture, with two cores per processor. Other processor architectures likely will produce differing amounts of improvement. The times in this chapter are presented to compare and illustrate response time improvements and may not represent the expected times for your environment.

9.1 Introduction

This chapter is organized around strategies to improve analysis response time. While not all strategies will be appropriate everywhere, some of them may be applicable to your environment.

As an ongoing example through this chapter, we are looking for evidence of data transfer using transport protocols that are not TCP, UDP, or ICMP and present several variations on this analysis. We will examine different ways to reduce the time it takes to perform this analysis. In many of the examples, output files are silently deleted (omitted for page formatting in the handbook) between calls to prevent over-writing existing files.

Two of the processing attributes that bound the performance gain (particularly of strategies involving parallelization) are processor contention and data contention.

- *Processor contention* is when the number of running processes exceeds the available processor resources, forcing the operating system to delay (wait for an open processor) or time-slice (force temporary waits to share processors) execution. This increases response time and limits the improvement due to parallelization.
- *Data contention* is when multiple processes are competing for transfer of data from the same storage resource (either disk, the network interface, or less commonly, memory). In data contention, one process using the resource blocks its availability to other processes, forcing them to wait. This increases the response time and limits the improvement due to parallelization. While modern disk and network interfaces support some degree of sharing, there is still some waiting involved.

For many SiLK tools, particularly `rwfilter`, `rwsort`, `rwuniq`, and `rwstats`, data contention is a more significant factor on most architectures than processor contention—a phenomenon known as *being I/O bound*. In order to reduce the impact of being I/O bound, an analyst needs to organize the concurrent queries to use different storage resources. For SiLK queries, this means accessing types individually to pull the separate storage in parallel. While the separate access does not completely eliminate being I/O bound, it does provide more gain in response times.

9.2 Spreading the Load Across Processors

One approach to improving command performance is to make more efficient use of the available processing resources. This generally means to structure the query so as to keep the processor busy, in a way that provides results concurrently on separate data. These data can then be combined to produce a final results.

9.2.1 Parallelizing `rwfilter` Calls By Processor

For `rwfilter` calls, one way to spread the processing load is to set up parallel calls, one for each pertinent type of network flow. The operating system on the analysis host may allocate each parallel call to a separate processor, which spreads the overall load. The Linux `wait` command then assures that all of the parallel calls complete before processing proceeds. Another way of spreading the load among processors is to use pipes as described in Section 9.7.

Example 9.1 shows the performance gain from parallel processing by type.

1. The naive `rwfilter` call in Command 1 shows the processing time without parallelism by pulling records of all types that are not ICMP, TCP, or UDP flows in a single call. It retrieves them in a little over 8.5 seconds.

2. Commands 2 through 6 pull the same data as separate parallel calls, one for each pertinent type. This version also drops inapplicable types, specifically `inweb` and `outweb` which are both all TCP data, and thus irrelevant to this analysis. This type dropping and parallelism cuts the response time by roughly 68%, to a little under 3.2 seconds.

9.2.2 Parallelizing `rwfilter` Calls By Flow Time

The SiLK repository is organized by date and hour, as well as by type. Instead of parallelizing by type, you could parallelize by the time of the flow, pulling separate repository files by separate `rwfilter` processes. Example 9.2 does this, showing possible improvement in speed.

1. Command 1 is the same `rwfilter` command used in Example 9.1 to pull the data in a fairly naive fashion. Again, it takes a little over 8.5 seconds to complete.

2. Command 2 uses a Bash `for` loop to iterate through the repository files, processing each one with `rwfilter` in a separate process.

   The list of repository files is generated with the `rwfglob` command. It takes the same selection parameters (in this case, `--start-date` and `--type`) as `rwfilter`, and produces on standard output a list of the repository files that match those parameters. In the body of the loop, `mktemp` provide a unique output file name for each `rwfilter` call, all of which are run concurrently.

   After the `for` loop, the `wait` command pauses until all of the separate `rwfilter` processes complete. Overall, Command 2 takes a little over 5.2 seconds to execute.

3. Finally, Command 3 shows the effect of doing parallel `rwfilter` commands for each of six hours without the overhead of the Bash `for` loop. It executes them in a total of a bit less than 0.2 seconds. Extrapolating this to the full data set, it would take between 2 and 4 seconds to run them all as parallel commands.

```
Show real time, user time, and processor time for each command
<1>$ rwfilter --start=2015/06/01 --end=2015/06/30 --proto=1,6,17 \
   --type=all --fail=oddproto.raw

real    0m8.539s
user    0m7.106s
sys     0m1.424s
<2>$ rwfilter --start=2015/06/01 --end=2015/06/30 --proto=1,6,17 \
   --type=in --fail=oddproto2a.raw &
<3>$ rwfilter --start=2015/06/01 --end=2015/06/30 --proto=1,6,17 \
   --type=out --fail=oddproto2b.raw &
<4>$ rwfilter --start=2015/06/01 --end=2015/06/30 --proto=1,6,17 \
   --type=int2int --fail=oddproto2c.raw &
<5>$ rwfilter --start=2015/06/01 --end=2015/06/30 --proto=1,6,17 \
   --type=ext2ext --fail=oddproto2d.raw &
<6>$ wait

real    0m3.188s
user    0m5.476s
sys     0m0.823s
```

Example 9.1: Using Multiple `rwfilter` Processes to Increase Performance

```
Show real time, user time, and processor time for each command
<1>$ rwfilter --start=2015/06/01 --end=2015/06/30 --proto=1,6,17 \
   --type=all --fail=oddproto.raw

real    0m8.809s
user    0m7.130s
sys     0m1.672s
<2>$ for f in $(rwfglob --start-date=2015/06/01 \
   --end-date=2015/06/30 --type=in,out,int2int,ext2ext \
   --no-summary ) ; do \
     OUTNAME=$(mktemp -u --suffix=".raw" oddprotoXXX); \
     rwfilter $f --proto=1,6,17 --fail=$OUTNAME& \
     done; \
   wait

real    0m5.234s
user    0m7.418s
sys     0m5.640s
<3>$ rwfilter --start=2015/06/16T17 \
   --type=in,out,int2int,ext2ext --proto=1,6,17 \
   --fail=oddprotoLgI.raw& \
rwfilter --start=2015/06/16T18 \
   --type=in,out,int2int,ext2ext --proto=1,6,17 \
   --fail=oddprotoxb0.raw& \
rwfilter --start=2015/06/16T19 \
   --type=in,out,int2int,ext2ext --proto=1,6,17 \
   --fail=oddprotoQ3W.raw& \
rwfilter --start=2015/06/16T20 \
   --type=in,out,int2int,ext2ext --proto=1,6,17 \
   --fail=oddprotowKw.raw& \
rwfilter --start=2015/06/16T21 \
   --type=in,out,int2int,ext2ext --proto=1,6,17 \
   --fail=oddprotoV6x.raw& \
rwfilter --start=2015/06/16T22 \
   --type=in,out,int2int,ext2ext --proto=1,6,17 \
   --fail=oddproto0yx.raw & \
wait

real    0m0.186s
user    0m0.932s
sys     0m0.055s
```

Example 9.2: Using Concurrent `rwfilter` Processes by Hour

9.3 Combining Results From Concurrent `rwfilter` Calls via `rwuniq`, `rwcount`,and `rwstats`

One issue with performing concurrent `rwfilter` commands is drawing the results together after all of the commands are done executing. Due to the way that SiLK stores files, the presence of flows in specific files may not align with the assumptions of an analyst. This causes irregularities in cumulative volumes or in trend lines. Such irregularities are magnified by processing the files separately rather than as a single result.

To minimize this effect, bring the files together for generating results with `rwcount`, `rwuniq`, or `rwstats`, and before any plotting from the data. Options for doing this are shown in Example 9.3. In this example:

1. Command 1 calls `rwfilter` to retrieve records from the repository, `rwsort` to order them, then `rwuniq` to generate a profile (which in this case is sent to `/dev/null`, discarding it automatically). The command runs in a little over 6.1 seconds.
2. Command 2 does the same process as Command 1, but uses the `--presorted` parameter for `rwuniq`, indicating `rwuniq` can be more memory-efficient in its processing. This command runs in about the same time as Command 1.
3. Command 3 skips the call to `rwsort`, letting `rwuniq` handle the ordering of the data. This command runs just slightly slower than Command 1.
4. Command 4 skips the `rwfilter` call, letting `rwuniq` open previously retrieved flow record files and produce a merged result. This command runs much faster, taking a bit over 0.8 seconds to complete.

While a merged input file executes more slowly than letting the profiling tools merge the files, it may be desirable for archival purposes. In this case, consider using `rwsort` because it both merges and orders the flow records. Merging data with `rwsort` is described further in Section 9.5.

```
Show real time, user time, and processor time for each command
<1>$ rwfilter --start=2015/06/01 --end=2015/06/30 --proto=1,6,17 \
   --type=in,out,int2int,ext2ext --fail=stdout \
| rwsort --fields=dip \
| rwuniq --fields=dip --values=bytes,packets \
   --output=/dev/null

real    0m6.166s
user    0m5.503s
sys     0m0.683s
<2>$ rwfilter --start=2015/06/01 --end=2015/06/30 --proto=1,6,17 \
   --type=in,out,int2int,ext2ext --fail=stdout \
| rwsort --fields=dip \
| rwuniq --fields=dip --values=bytes,packets --presorted \
   --output=/dev/null

real    0m6.181s
user    0m5.445s
sys     0m0.738s
<3>$ rwfilter --start=2015/06/01 --end=2015/06/30 --proto=1,6,17 \
   --type=in,out,int2int,ext2ext --fail=stdout \
| rwuniq --fields=dip --values=bytes,packets \
   --output=/dev/null

real    0m6.202s
user    0m5.497s
sys     0m1.595s
<4>$ rwuniq --fields=dip --values=bytes,packets oddproto2a.raw \
   oddproto2b.raw oddproto2c.raw oddproto2d.raw \
   --output=/dev/null

real    0m0.837s
user    0m0.050s
sys     0m0.770s
```

Example 9.3: Response Time for Sorting Records and File Parameters

9.4 Parallelizing via the `rwfilter --threads` Parameter

Besides running concurrent `rwfilter` commands, another option for parallelism is to request each `rwfilter` call to operate using lightweight parallel threads. The `--threads` parameter causes `rwfilter` to spawn the number of parallel threads specified by its argument and allocate to each thread an input file to filter. While the output is not parallelized (as it is with concurrent `rwfilter` commands) the input, parsing, and filtering of records is parallelized.

9.4.1 Improving `rwfilter` Performance with `--threads`

Example 9.4 shows an example of the performance gains that can be achieved by using the `rwfilter --threads` parameter.

1. Command 1 is the same naive `rwfilter` command as in the previous examples, again taking a little over 8.5 seconds to complete.
2. Command 2 shows the same query, this time with `--threads=4`, which decreases the response time to around 3.4 seconds.
3. In Command 3, increasing the argument to `--threads=8` decreases the response time still further, to around 2.5 seconds.
4. In Commands 4 and 5, further increases to `--threads=12` and `--threads=16` decreases the response time by smaller amounts, to around 2.4 and 2.2 seconds, respectively.

9.4.2 Effect of `--threads` On Other `rwfilter` Parameters

The use of `--threads` affects some of the other `rwfilter` parameters. With `--threads`, the `--max-pass` and `--max-fail` limits may be exceeded. This excess on the maximum output also affects the `--print-statistics` and `--print-volume-statistics` parameters if they are used. For many analysts, however, these drawbacks are worth the gain in performance offered by `--threads`.

9.4.3 Limitations On `--threads` Performance Improvements

Unfortunately, the performance gain due to use of threads decreases with the number of concurrent processes (such as when multiple analysts are running `rwfilter` with `--threads`). Figure 9.4.3 shows this decrease.

- For a single process, the performance gain is as described earlier in this section.
- For four concurrent `rwfilter` processes (in this case, four identical processes, representing four users making equivalent `rwfilter` calls), `--threads=1` (the default) takes about 9.6 seconds. Going to `--threads=4` with four processes improves the response time to approximately 4.5 seconds (a gain of 53% vs 60% for the single process). Going to `--threads=8` improves it to approximately 3.9 seconds (a total gain of 59% versus 71% for the single process). Going to 12 and 16 threads in four processes improves it to approximately 3.7 and 3.6 seconds, respectively (total gains of 61% and 62% versus 72% and 74% for the single process).

```
Show real time, user time, and processor time for each command
<1>$ rwfilter --start=2015/06/01 --end=2015/06/30 --type=all \
   --proto=1,6,17 --fail=oddproto.raw

real    0m8.568s
user    0m7.157s
sys     0m1.402s
<2>$ rwfilter --start=2015/06/01 --end=2015/06/30 --type=all \
   --proto=1,6,17 --threads=4 --fail=oddproto2.raw

real    0m4.011s
user    0m9.646s
sys     0m1.583s
<3>$ rwfilter --start=2015/06/01 --end=2015/06/30 --type=all \
   --proto=1,6,17 --threads=8 --fail=oddproto3.raw

real    0m2.845s
user    0m9.818s
sys     0m1.651s
<4>$ rwfilter --start=2015/06/01 --end=2015/06/30 --type=all \
   --proto=1,6,17 --threads=12 --fail=oddproto4.raw

real    0m2.258s
user    0m7.952s
sys     0m1.760s
<5>$ rwfilter --start=2015/06/01 --end=2015/06/30 --type=all \
   --proto=1,6,17 --threads=16 --fail=oddproto5.raw

real    0m2.166s
user    0m8.423s
sys     0m1.809s
```

Example 9.4: Using `rwfilter --threads` to Reduce Response Time

- For ten concurrent processes, `--threads=4` improves the response time by 35%, while going to `--threads=16` only improves it by 46%.

These figures indicate that when multiple users share the same storage and processing resources, the amount of gain due to threads above four may not be of much benefit.

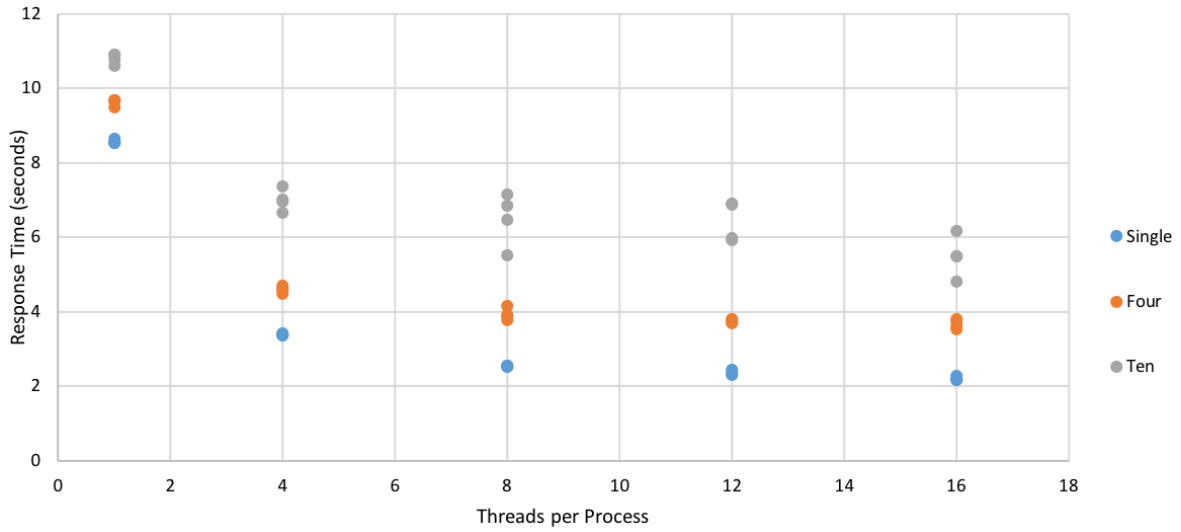

Figure 9.1: Decreasing Response Time by Using `rwfilter --threads` Profiled by Number of Running Processes

9.5 Constructing Efficient Queries

Another approach to improving the performance of SiLK is to design the specific analysis to operate efficiently. This often takes the form of describing key characteristics of the traffic being sought, including:

- the type of traffic wanted (`in`, `out`, `inweb`, `outweb`, `int2int`, `ext2ext`)
- the transport protocols wanted (or not wanted)
- packet sizing (at least bounding the byte count or packet count by maximum or minimum)
- timing for the traffic (either in terms of start time or of duration)
- if TCP, whether this is the initiating side or responding side of the traffic (indicated by initiating TCP flags) and whether they are complete or partial TCP sessions (indicated by terminating TCP flags)
- address ranges of interest (either on the internal or external ends)
- whether the traffic represents a single interaction or multiple interactions
- whether the result desired is a count, a frequency, or some statistical summary
- whether IPv6 data is useful for this analysis

Hint 9.2: Performance for IPv4 Versus IPv6 Addresses

IPv4 data is generally processed more quickly than IPv6 data. If IPv6 addresses are not useful for your analysis but SiLK has been configured for IPv6, you can force SiLK to generate IPv4 data by doing one of the following:

- Use the following Bash command to override SiLK's IPv6 configuration (i.e., the `SILK_IPV6_POLICY` environment variable):

  ```
  export SILK_IPV6_POLICY=ignore
  ```

- Specify the `--ipv6-policy=ignore` parameter to make individual SiLK commands generate IPv4 data instead of IPv6 data.

9.5.1 Pipelining Calls to SiLK commands

The characteristics listed above in Section 9.5 often form the basis of added partitioning parameters on calls to `rwfilter` or added thresholds for `rwuniq` or `rwstats`. When multiple invocations of these tools are needed, they are often pipelined together for efficiency. In practice, `rwfilter` usually has the longest response time. To work around this issue, structure the analysis as a series of calls to `rwuniq` or `rwstats` that explore the same data.

Example 9.5 shows the response time gained by minimizing calls to `rwfilter` and using pipelining between SiLK commands instead of writing data to disk. It's similar conceptually to the `rwfilter` manifold described in Section 4.2.1, which can also improve performance by pipelining successive calls to `rwfilter` instead of writing files to disk at each step.

1. Command 1 shows a series of calls that use `rwfilter` to pull the same data three times. Each `rwfilter` call feeds into a `rwuniq` call to profile the data by source address, by destination address, and by start time. This series of calls takes just over 17 seconds to run.

2. Command 2 shows a series of calls that does the same thing as Command 1, but only calls `rwfilter` once. it stores the result in a file that is then profiled by the three `rwuniq` calls. This series of calls takes just over 6 seconds to run, showing the impact of avoiding repeated `rwfilter` calls.

3. Command 3 shows a pipelined series of calls that does the same thing as Command 1, but passes the data via pipes from a single `rwfilter` call to the three `rwuniq` calls. It links the `rwuniq` calls with `--copy-input=stdout` to pass all of the flows to each `rwuniq` instance. This series of calls takes just over 5.3 seconds to run, reflecting the savings due to pipelining rather than writing and reading a file.

9.5.2 Using Flow Characteristics To Improve `rwfilter` Efficiency

You can take advantage of different flow characteristics to more closely define the scope of `rwfilter` queries, improving their speed and efficiency. To illustrate this process, look at Example 9.6. The goal of the `rwfilter` calls in this example is to identify possible file transfer from the internal network using uncommon protocols.

1. Command 1 displays the naive approach, paralleling the one used in preceding examples: find all uncommon protocol usage with `rwfilter`, then use `rwuniq` to aggregate bytes transferred for each destination IP address. The advantage of this approach is that it is simple to write. Its disadvantage is that it may end up with records retrieved that are not data transfer, and that destination addresses are not necessarily external addresses. This command takes a little over 8.6 seconds.

2. For this data, Command 2 shows that the output contains the header line and entries for nine addresses, three of which were found to be internal addresses.

3. Command 3 displays a revised approach: find all outbound uncommon protocol usage, then aggregate bytes transferred in flows of three packets or more to each external IP address (the destination address for an outgoing flow). This approach has the advantage of still being fairly simple to write with fewer uninteresting records included in results. Its disadvantage is that it may will miss low-and-slow transfers that divide into separate flows, and might include addresses that receive occasional bursts of packets containing protocol signals rather than file transfer. This command took a bit over 3.5 seconds to execute.

4. Command 4 indicates that it identified six external addresses.

5. Command 5 shows another improved approach: find outgoing uncommon protocol traffic with byte counts that indicate more than header information, then aggregate bytes transferred to each external IP address, presenting only aggregates greater than the threshold count of bytes transferred. The advantage to this approach is that it uses a more robust recognition of file transfer that would allow identification of low-and-slow transfers. Its disadvantage is the need to calibrate thresholds properly. This command also took a bit over 3.5 seconds to execute.

6. Command 6 shows that it found five external addresses. Examination of these addresses found that they were all recipients of tunneled traffic, either VPN or OSPF tunnels.

```
Show real time, user time, and processor time for each command
<1>$ rwfilter --start=2015/06/01 --end=2015/06/30 --proto=1,6,17 \
   --type=out,outweb,int2int,ext2ext --fail=stdout \
| rwuniq --fields=dip,protocol \
   --values=bytes,flows,distinct:sip \
   --output=oddproto-dip.txt ; \
rwfilter --start=2015/06/01 --end=2015/06/30 --proto=1,6,17 \
   --type=out,outweb,int2int,ext2ext --fail=stdout \
| rwuniq --fields=sip,protocol \
   --values=bytes,flows,distinct:dip \
   --output=oddproto-sip.txt ; \
rwfilter --start=2015/06/01 --end=2015/06/30 --proto=1,6,17 \
   --type=out,outweb,int2int,ext2ext --fail=stdout \
| rwuniq --fields=stime,protocol --bin-time=3600 \
   --values=bytes,flows --output=oddproto-stime.txt

real    0m17.005s
user    0m13.658s
sys     0m5.043s
<2>$ rwfilter --start=2015/06/01 --end=2015/06/30 --proto=1,6,17 \
   --type=out,outweb,int2int,ext2ext --fail=oddproto.raw ; \
rwuniq --fields=dip,protocol \
   --values=bytes,flows,distinct:sip oddproto.raw \
   --output=oddproto-dip.txt ; \
rwuniq --fields=sip,protocol \
   --values=bytes,flows,distinct:dip oddproto.raw \
   --output=oddproto-sip.txt ; \
rwuniq --fields=stime,protocol --bin-time=3600 \
   --values=bytes,flows oddproto.raw \
   --output=oddproto-stime.txt

real    0m6.013s
user    0m4.787s
sys     0m1.209s
<3>$ rwfilter --start=2015/06/01 --end=2015/06/30 --proto=1,6,17 \
   --type=out,outweb,int2int,ext2ext --fail=stdout \
| rwuniq --fields=dip,protocol \
   --values=bytes,flows,distinct:sip \
   --output=oddproto-dip.txt --copy-input=stdout \
| rwuniq --fields=sip,protocol \
   --values=bytes,flows,distinct:dip \
   --output=oddproto-sip.txt --copy-input=stdout \
| rwuniq --fields=stime,protocol --bin-time=3600 \
   --values=bytes,flows --output=oddproto-stime.txt

real    0m5.351s
user    0m4.758s
sys     0m1.318s
```

Example 9.5: Avoiding multiple `rwfilter` Commands to Increase Performance

```
Show real time, user time, and processor time for each command
<1>$ rwfilter --start=2015/06/01 --end=2015/06/30 --proto=1,6,17 \
   --type=all --fail=stdout \
| rwuniq --fields=dip --values=bytes \
   --output=dip-bytes.txt

real    0m8.624s
user    0m7.122s
sys     0m1.509s
<2>$ wc -l dip-bytes.txt
10 dip-bytes.txt
<3>$ rwfilter --start=2015/06/01 --end=2015/06/30 --proto=1,6,17 \
   --type=out,ext2ext --fail=stdout \
| rwuniq --fields=dip --values=bytes,packets --packets=3- \
   --output=dip3-bytes.txt

real    0m3.550s
user    0m3.197s
sys     0m1.071s
<4>$ wc -l dip3-bytes.txt
7 dip3-bytes.txt
<5>$ rwfilter --start=2015/06/01 --end=2015/06/30 --proto=1,6,17 \
   --type=out,ext2ext --fail=stdout \
| rwfilter stdin --bytes-per=65- --pass=stdout \
| rwuniq --fields=dip --values=bytes,packets --bytes=2000- \
   --output=dipb-bytes.txt

real    0m3.525s
user    0m3.203s
sys     0m1.719s
<6>$ wc -l dipb-bytes.txt
6 dipb-bytes.txt
```

Example 9.6: Closely Defining Analysis Problem to Increase Performance

9.5.3 Specifying Fewer SiLK Types In `rwfilter` Calls

Part of what lead to the performance improvement in Example 9.6 was a more targeted specification of the SiLK types relevant to the behavior of interest. Rather than going with `--types=all`, which references six types (`in`, `out`, `inweb`, `outweb`, `int2int`, and `ext2ext`), the redefined problem references only two types for outbound non-TCP traffic (`out` and `ext2ext`). This causes `rwfilter` to open fewer parts of the repository and thus execute more quickly.

Example 9.7 isolates the effect of reducing the number of SiLK types in a `rwfilter` call.

1. Command 1 shows the naive query used in previous examples, which takes a little over 8.5 seconds to execute.

2. The `rwfilter` call in Command 2 uses a more restrictive `--type` parameter that only pulls records with four SiLK flow types (`--type=in,out,int2int,ext2ext`). The execution time falls to a little over 6.1 seconds.

9.5.4 Constraining `rwfilter` Output

An additional way to improve the response time for `rwfilter` lies in exploiting the fact that it is more I/O bound than compute bound. One way of doing this (beyond using `--type`, `--start-date`, and `--end-date` to reduce the input being considered) is to use all appropriate partitioning parameters to constrain the output that it generates. This is somewhat counter-intuitive: longer and more complex `rwfilter` commands often run faster than shorter and simpler ones.

Example 9.8 contrasts the naive `rwfilter` command (Command 1) against a more complex `rwfilter` command (Command 2) that uses both a more restrictive `--types` parameter and additional `--packets` and `--bytes` parameters. The response time improves from 8.5 seconds to just over 6 seconds.

9.5.5 Merging the Results of Multiple `rwfilter` Calls

It can be difficult to produce an efficient single `rwfilter` command that pulls all of the data of interest. In some analyses, several calls to `rwfilter` are needed. Examples of when multiple commands are useful include:

- comparing activity during an incident with activity a week earlier and a week later
- comparing activity on an affected network segment against activity on an unaffected one
- identifying progress over time of activity indicative of a particular group of intruders
- identifying the impact of fielding a new defensive measure or modifying a service to improve security

In these cases, you may want to pull data separately for the subsets of traffic desired for comparison or identification. The results can then be merged to form a common pool for statistical summary or trending.

SiLK provides several ways to do this merging. Three tools that are particularly useful are `rwcat`, `rwappend`, and `rwsort`.

```
Show real time, user time, and processor time for each command
<1>$ rwfilter --start=2015/06/01 --end=2015/06/30 --proto=1,6,17 \
   --type=all --fail=oddproto.raw

real    0m8.591s
user    0m7.067s
sys     0m1.516s
<2>$ rwfilter --start=2015/06/01 --end=2015/06/30 --proto=1,6,17 \
   --type=in,out,int2int,ext2ext --fail=oddproto2.raw

real    0m6.130s
user    0m5.435s
sys     0m0.687s
```

Example 9.7: Using Only Needed `rwfilter` Types to Increase Performance

```
Show real time, user time, and processor time for each command
<1>$ rwfilter --start=2015/06/01 --end=2015/06/30 --proto=1,6,17 \
   --type=all --fail=oddproto.raw

real    0m8.623s
user    0m7.103s
sys     0m1.511s
<2>$ rwfilter --start=2015/06/01 --end=2015/06/30 \
   --proto=50,51,83 --type=in,out,int2int,ext2ext \
   --packets=3- --bytes=400- --pass=oddproto2.raw

real    0m6.096s
user    0m5.419s
sys     0m0.671s
```

Example 9.8: Using Additional Parameters with `rwfilter` to Increase Performance

- `rwcat` concatenates the series of flow records in each of its input files into a single series for output, which is most useful for analyses where the order of records in not important.
- `rwappend` inserts the series of flow records in each file (in order) into the end of the output file, which is most useful for analyses where the data is already in the desired order.
- `rwsort` does a merge-sort of the records in all of its input files to produce a single ordered output file, which is most useful when the analyst either cannot depend on the order of the data, or needs to impose a specific order.

These tools have already been introduced and are discussed more thoroughly in Sections 2.2.7 (for `rwsort`) and 6.2.4(for `rwappend` and `rwcat`).

Example 9.9 shows the use of these three commands in merging flow files.

1. Commands 1-5 generate four separate flow files.
2. Command 6 shows how to use `rwcat` to simply concatenate the flow files. This takes approximately 0.01 seconds for these data, but the data will be in no particular order.
3. Command 7 shows the use of `rwappend` to perform a similar amalgamation of the records in the four input files, taking approximately the same time as the `rwcat` command. However, the output file records are in the order of the input files.
4. Command 8 shows the use of `rwsort` to merge the four input files. This takes about the same amount of time as the `rwcat` and `rwappend` commands. However, the records from all files are put in time order by start time on the output.

The distinction between these three commands is based on what can be assumed about the semantics of ordering, rather than which command runs fastest. In particular, if the records need to be in a dependable order, normally an analyst will use `rwsort` to merge them.

```
<1>$ rwfilter --start=2015/06/01 --end=2015/06/30 --proto=1,6,17 \
   --type=in --fail=oddproto2a.raw &
<2>$ rwfilter --start=2015/06/01 --end=2015/06/30 --proto=1,6,17 \
   --type=out --fail=oddproto2b.raw &
<3>$ rwfilter --start=2015/06/01 --end=2015/06/30 --proto=1,6,17 \
   --type=int2int --fail=oddproto2c.raw &
<4>$ rwfilter --start=2015/06/01 --end=2015/06/30 --proto=1,6,17 \
   --type=ext2ext --fail=oddproto2d.raw &
<5>$ wait
<6>$ rwcat oddproto2a.raw oddproto2b.raw oddproto2c.raw \
   oddproto2d.raw --output=oddproto.raw

real    0m0.012s
user    0m0.003s
sys     0m0.002s
<7>$ rwappend --create=oddproto2a.raw oddproto.raw \
   oddproto2a.raw oddproto2b.raw oddproto2c.raw \
   oddproto2d.raw

real    0m0.013s
user    0m0.001s
sys     0m0.005s
<8>$ rwsort --fields=stime oddproto2a.raw oddproto2b.raw \
   oddproto2c.raw oddproto2d.raw --output=oddproto.raw

real    0m0.016s
user    0m0.005s
sys     0m0.004s
```

Example 9.9: Combining Flow Files with `rwcat`, `rwappend`, and `rwsort`

9.6 Using Coarse Parallelism

Flow record files can be quite large. Processing a very large file can be slow, since it will force the processing tools to use paging (moving data in and out of memory to disk) to accommodate. It may be faster to divide these large flow record sizes into manageable pieces, then parallelize the pieces with separate commands. This process is known as *coarse parallelism* since it exploits larger features of the data to work concurrently.

One SiLK tool that aids in doing this is `rwsplit`, which is introduced and discussed thoroughly in Section 6.2.4. Example 9.10 shows an example of using `rwsplit` for coarse parallelism.

1. The `rwfilter` call in Command 1 pulls a large amount of data (all of the TCP, UDP, and ICMP flows in the data set), then uses `rwsort` to aggregate source and destination addresses. It then invokes `rwuniq` to profile possible file transfers. This information can be used to give context to results for less commonly-used protocols. This command takes a bit over 32.7 seconds.

2. Command 2 starts with similar calls to `rwfilter` and `rwsort`. It then calls `rwsplit` to divide the records into several files. Since the `rwuniq` command summarizes by source and destination IP address, this `rwsplit` command divides the records into portions governed by the number of IP addresses. This produces three parts, each of which is then summarized in parallel with the others.

   This command takes a little over 37.5 seconds to execute. This is a bit longer than Command 1, since this data set is too small to require paging of memory even when pulling all of the relevant data. However, this method may result in shorter response times for larger data sets.

3. Command 3 shows the length of the result files, which, accounting for headings one each file, indicates one address is split across two files.

4. By using a Linux text sort, the files can be brought together and the duplication dealt with, as shown in Command 4.

```
Show real time, user time, and processor time for each command
<1>$ rwfilter --start=2015/06/01 --end=2015/06/30 --proto=1,6,17 \
   --type=out,outweb,ext2ext --pass=stdout \
| rwsort --fields=dip,sip \
| rwuniq --fields=dip --values=bytes,packets --bytes=400- \
   --packets=3- --output=comproto.txt

real    0m24.942s
user    0m20.899s
sys     0m9.828s
<2>$ rwfilter --start=2015/06/01 --end=2015/06/30 --proto=1,6,17 \
   --type=out,outweb,ext2ext --pass=stdout \
| rwsort --fields=dip,sip \
| rwsplit --ip-limit=800 --basename='comproto' ; \
rwuniq comproto.00000000.rwf --fields=dip --presort \
   --values=bytes,packets --bytes=400- --packets=3- \
   --output=comproto.00000000.txt& \
rwuniq comproto.00000001.rwf --fields=dip --presort \
   --values=bytes,packets --bytes=400- --packets=3- \
   --output=comproto.00000001.txt& \
rwuniq comproto.00000002.rwf --fields=dip --presort \
   --values=bytes,packets --bytes=400- --packets=3- \
   --output=comproto.00000002.txt& \
wait

real    0m34.255s
user    0m26.841s
sys     0m12.725s
<3>$ wc -l comproto*.txt
   689 comproto.00000000.txt
    58 comproto.00000001.txt
   242 comproto.00000002.txt
   986 comproto.txt
  1975 total
<4>$ sort comproto.00000000.txt comproto.00000001.txt \
   comproto.00000002.txt comproto.txt | uniq | wc -l
989
```

Example 9.10: Coarse Parallelism of `rwuniq` using `rwsplit`

9.7 Using Named Pipes and Process Substitution

When flow files get large, writing and reading them from disk can be quite slow. While temporary files are a useful tool in analysis, they can also greatly slow down the analysis process. To avoid this delay, use process-to-process communication. Linux systems have a variety of options for this:

- *Pipelining processes* (pipes for short, used extensively throughout this handbook), where a generating process sends input to a receiving process progressively, either via standard output and input or via specially-created named pipes (as is used in Section 4.1.2).
- *Process substitution*, where a command string (possibly involving pipes) is used in place of a file or stream.
- *Sockets*, which are used for either process-to-process or host-to-host communication. While they are very powerful tools for harnessing multiple computers in a single analysis, they are complex to set up and won't be further discussed here.

Example 9.11 shows use of pipes and process substitution.

1. Commands 1 through 3 show a naive approach, where all of the possibly-relevant traffic is gathered into a flow record file. The file is refiltered twice to isolate specific cases. Each `rwfilter` call feeds into a `rwuniq` call to generate two profiles: one for transport protocol 50, and the other for transport protocols that are not 50, 1 (ICMP), 6 (TCP) or 17 (UDP). This command takes a little over 17.3 seconds on this data set.
2. Command 4 uses `mkfifo` to create a named pipe.
3. Command 5 pulls records from the repository and filters out records with the ICMP, TCP, and UDP protocols. It then passes the records for transport protocol 50 to the named pipe and the records for other protocols to `rwuniq` to generate a profile.
4. Concurrently, Command 6 pulls the protocol 50 records from the named pipe and generates a similar profile.
5. Command 7 uses `wait` to let Commands 5 and 6 complete. Altogether, this sequence with the named pipes takes a little over 3.5 seconds to complete.
6. Command 8 shows the use of process substitution in place of the named pipe. The first call to `rwfilter` is the same as in Command 5. The second call to `rwfilter` uses process substitution, indicated by the use of `>(`, as the argument to its `--pass` parameter.

   Following the `>(`, Command 8 calls `rwuniq` with input set to the protocol 50 records produced by the `--pass` and output sent to a file—the same profile produced in previous commands, ending with a close parenthesis. The second `rwfilter` call also uses `--fail=stdout` to send non-protocol-50 records to a final `rwuniq` call to generate a similar profile for those records.

   Altogether, this command sequence takes a little over 3.5 seconds to execute. It does not require the `mkfifo` or `wait` commands; concurrency is handled by the process substitution.
7. Command 9 then counts the lines in all of the output text files, reflecting that each `port50` and `not50` profiles from `rwuniq` calls produced the same output.

```
Show real time, user time, and processor time for each command
<1>$ rwfilter --start=2015/06/01 --end=2015/06/30 \
   --type=out,ext2ext --proto=0- --pass=oddproto.raw
<2>$ rwfilter oddproto.raw --proto=50 --pass=stdout \
| rwuniq --fields=dip --values=bytes,packets --packets=3- \
   --output=dip-port50.txt
<3>$ rwfilter oddproto.raw --proto=1,6,17,50 --fail=stdout \
| rwuniq --fields=dip --values=bytes,packets --packets=3- \
   --output=dip-not50.txt

real    0m17.367s
user    0m13.010s
sys     0m2.270s
<4>$ mkfifo /tmp/proto50.fifo
<5>$ rwfilter --start=2015/06/01 --end=2015/06/30 \
   --type=out,ext2ext --proto=1,6,17 --fail=stdout \
| rwfilter stdin --proto=50 --pass=/tmp/proto50.fifo \
   --fail=stdout \
| rwuniq --fields=dip --values=bytes,packets --packets=3- \
   --output=dip3-not50.txt&
<6>$ rwuniq --fields=dip --values=bytes,packets --packets=3- \
   /tmp/proto50.fifo --output=dip3-port50.txt&
<7>$ wait

real    0m3.559s
user    0m3.257s
sys     0m1.025s
<8>$ rwfilter --start=2015/06/01 --end=2015/06/30 \
   --type=out,ext2ext --proto=1,6,17 --fail=stdout \
| rwfilter stdin --proto=50 --pass=>(rwuniq \
   --fields=dip --values=bytes,packets --packets=3- \
   --output=dip4-port50.txt) --fail=stdout \
| rwuniq --fields=dip --values=bytes,packets --packets=3- \
   --output=dip4-not50.txt

real    0m3.583s
user    0m3.197s
sys     0m0.364s
<9>$ wc -l dip*.txt
   5 dip3-not50.txt
   3 dip3-port50.txt
   5 dip4-not50.txt
   3 dip4-port50.txt
   5 dip-not50.txt
   3 dip-port50.txt
  24 total
```

Example 9.11: Pipes and Process Substitution to Improve Response Time

9.8 Specifying Local Temporary Files

Several SiLK commands (in particular, `rwsort`, `rwstats`, and `rwuniq`) have a `--temp-dir` parameter that allows the analyst to specify where temporary files are generated. In general, the default location (`/tmp`, the system temporary partition) works quite well.

Where this partition is too small or otherwise not suitable for a particular analysis, better performance can be obtained by using a local directory on the host where the analysis is being performed than a remote or network-mounted directory. This avoids the overhead of reading and writing to disk over a network.

9.9 Administrative Actions

While this chapter has focused on strategies that analysts can use to decrease the response time for their analyses, the administrators that configure the SiLK installation and repository can also improve the response time of analyses. Strategies that administrators can use include:

- Administrators should not compile their SiLK installation to support IPv6 unless there is IPv6 traffic on their network. Many modern networks, particularly those that handle mobile traffic or embedded devices will have IPv6 traffic present, so this option should be used with care.
- Administrators should remove or comment out sensors that have been dropped, obviated, or otherwise produce no data. Removing them from the `silk.conf` file may improve performance.
- Administrators should remove unused types (especially from the `default-types` definition) in the `silk.conf` file.

9.10 Summary

This chapter has covered several strategies to improve the response time for SiLK commands. These strategies may also be applied in combination to gain further improvement. Over time, you will learn which approaches are most beneficial to your analyses.

Appendix A

Networking Primer

This appendix reviews basic topics in Transmission Control Protocol/Internet Protocol (TCP/IP). It is not intended as a comprehensive summary of this topic, but it will help to refresh your knowledge and prepare you for using the SiLK tools for analysis.

Upon completion of this appendix, you will be able to

- describe the structure of IP packets and the relationship between the protocols that constitute the IP protocol suite
- explain the mechanics of TCP, such as the TCP state machine and TCP flags

A.1 Understanding TCP/IP Network Traffic

This section provides an overview of the TCP/IP networking suite. TCP/IP is the foundation of internetworking. All packets analyzed by the SiLK system use protocols supported by the TCP/IP suite. These protocols behave in a well-defined manner. One possible sign of a security breach is a deviation from accepted behavior. In this section, you will learn about what is specified as accepted behavior. While there are common deviations from the specified behavior, knowing what is specified forms a basis for further knowledge.

This section is intended as a refresher. The TCP/IP suite is a complex collection of more than 50 protocols and comprises far more information than can be covered in this section. A number of online documents and printed books provide other resources on TCP/IP to further your understanding of the TCP/IP suite.

A.2 TCP/IP Protocol Layers

Figure A.2 shows a basic breakdown of the protocol layers in TCP/IP. The Open Systems Interconnection (OSI) Reference Model, the best known model for layered protocols, consists of seven layers. However, TCP/IP wasn't created with the OSI Reference Model in mind. TCP/IP conforms with the Department of Defense (DoD) ARPANET Reference Model (RFC[25] 871, found at https://tools.ietf.org/html/rfc871), a

[25] A Request for Comments is an official document, issued by the Internet Engineering Task Force. Some RFCs have Standards status; others do not.

four-layer model. Although TCP/IP and the DoD ARPANET Reference Model have a shared history, it is useful and customary to describe TCP/IP's functions in terms of the OSI Reference Model. OSI is the only model in which network professionals sometimes refer to the layers by number, so any reference to Layer 4, or L4, definitely refers to OSI's Transport layer.

Starting with the top row of Figure A.2, a *network application* (such as email, telephony, streaming television, or file transfer) creates a *message* that should be understandable by another instance of the network application on another host. This is known as an *application*-layer message. Sometimes the character set, graphics format, or file format must be described to the destination host—as with Multipurpose Internet Mail Extensions (MIME) in email—so the destination host can present the information to the recipient in an understandable way; this is done by adding metadata to the *presentation*-layer header.

Sometimes users want to be able to resume communications sessions when their connections are lost, such as with online games or database updates; this is accomplished with the *session*-layer checkpointing capabilities. Many communications do not use functions of the presentation and session layers, so their headers are omitted. The *transport*-layer protocols identify with port numbers which process or service in the destination host should handle the incoming data; a protocol like User Datagram Protocol (UDP) does little else, but a more complicated protocol like TCP also performs packet sequencing, duplicate packet detection, and lost packet retransmission.

The *network* layer is where we find Internet Protocol, whose job is to route packets from the network interface of the source host to the network interface of the destination host, across many networks and routers in the internetwork. Those networks are of many types (such as Ethernet, Asynchronous Transfer Mode [ATM], cable modem [DOCSIS®], or digital subscriber line [DSL]), each with its own frame format and rules described by its *data-link*-layer protocol. The data-link protocol imposes a maximum transmission unit (MTU) size on frames and therefore on datagrams and segments as well. The vast majority of enterprise network traffic is transferred over Ethernet at some point, and Ethernet has the lowest MTU (normally 1,500; 1,492 with IEEE® 802.2 LLC) of any modern Data-Link layer protocol. So Ethernet's MTU becomes the effective MTU for the full path.

Finally, the frame's bits are transformed into an energy (electrical, light, or radio wave) signal by the *physical* layer and transmitted across the medium (copper wire, optical fiber, or space). The process of each successively lower layer protocol adding information to the original message is called *encapsulation* because it's like putting envelopes inside other envelopes.

Each layer adds metadata to the packet that it receives from a higher layer by prepending a header like writing on the outside of that layer's envelope. When a signal arrives at the destination host's network interface, the entire process is reversed with *decapsulation*.

OSI Reference Model	DoD (TCP/IP) Arpanet Ref Model
7 Application	Process Level / Applications
6 Presentation	
5 Session	
4 Transport	Host-to-Host
3 Network	Internet
2 Data-Link	Network Interface
1 Physical	

Figure A.1: TCP/IP Protocol Layers

A.3 Structure of the IP Header

IP passes collections of data as datagrams. Two versions of IP are currently used: versions 4 and 6, referred to as IPv4 and IPv6, respectively. IPv4 still constitutes the vast majority of IP traffic in the Internet. IPv6 usage is growing, and both versions are fully supported by the SiLK tools. Figure A.3 shows the breakdown of IPv4 datagrams. Fields that are not recorded by the SiLK data collection tools are grayed out. With IPv6, SiLK records the same information, although the addresses are 128 bits, not 32 bits.

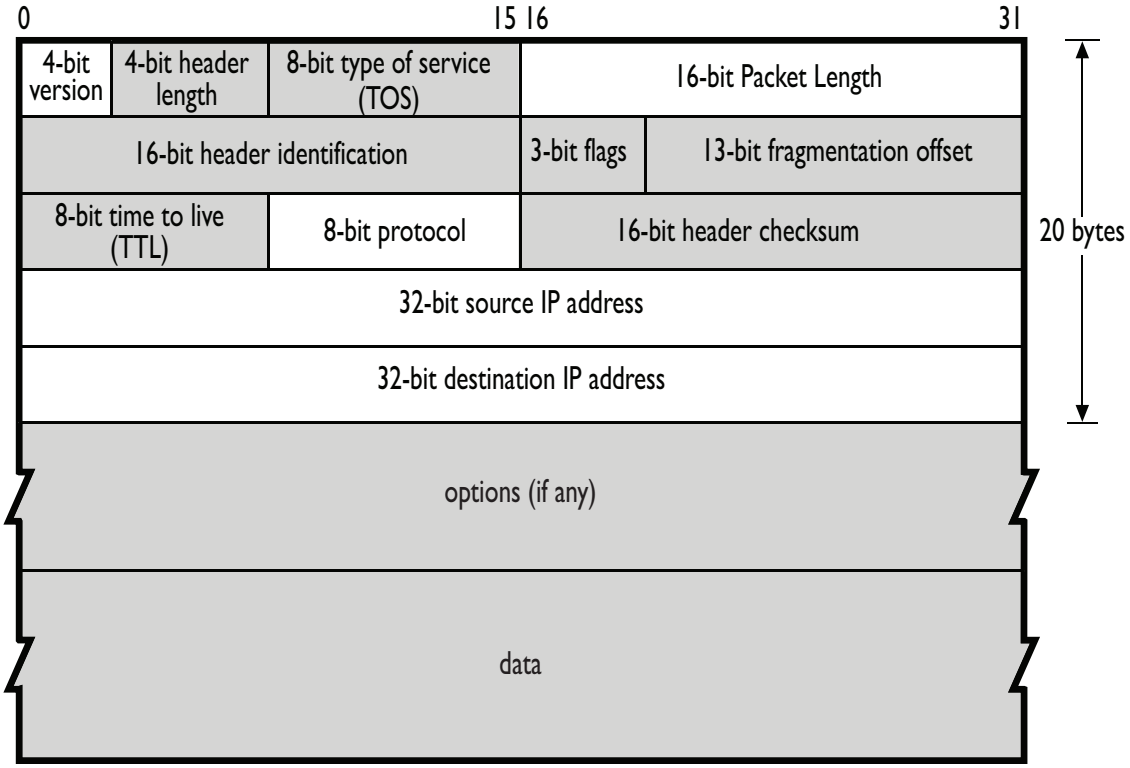

Figure A.2: Structure of the IPv4 Header

A.4 IP Addressing and Routing

IP can be thought of as a very-high-speed postal service. If someone in Pittsburgh sends a letter to someone in New York, the letter passes through a sequence of postal workers. The postal worker who touches the mail may be different every time a letter is sent, and the only important address is the destination. Normally, there is no reason that New York has to respond to Pittsburgh, and if it does (such as for a return receipt), the sequence of postal workers could be completely different.

IP operates in the same fashion: There is a set of routers between any pair of sites, and packets are sent to the routers the same way that the postal system passes letters back and forth. There is no requirement that the set of routers used to pass data to a destination must be the same as the set used for the return trip, and the routes can change at any time.

Most importantly, the only IP address that must be valid in an IP packet is the destination address. IP itself does not require a valid source address, but some other protocols (e.g., TCP) cannot complete without valid source and destination addresses because the source needs to receive the acknowledgment packets to complete a connection. (However, there are numerous examples of intruders using *incomplete* connections for malicious purposes.)

A.4.1 Structure of an IP Address

The Internet has space for approximately four billion unique IPv4 addresses. While an IPv4 address can be represented as a 32-bit integer, it is usually displayed in *dotted decimal* (or *dotted quad*) format as a set of four decimal integers separated by periods (dots); for example, 128.2.118.3, where each integer is a number from 0 to 255, representing the value of one byte (octet).

IP addresses and ranges of addresses can also be referenced using *CIDR blocks*. CIDR is a standard for grouping together addresses for routing purposes. When an entity purchases or leases a range of IP addresses from the relevant authorities, that entity buys/leases a routing block, that is used to direct packets to its network.

CIDR blocks are usually described with CIDR notation, consisting of an address, a slash (`/`), and a prefix length. The prefix length is an integer denoting the number of bits on the left side of the address needed to identify the block. The remaining bits are used to identify hosts within the block. For example, 128.2.0.0/16 would signify that the leftmost 16 bits (2 octets), whose value is 128.2, identify the CIDR block and the remaining bits on the right can have any value denoting a specific host within the block. So all IP addresses from 128.2.0.0 to 128.2.255.255, in which the first 16 bits are unchanged, belong to the same block. Prefix lengths range from 0 (all addresses belong to the same unspecified network; there are 0 network bits specified)[26] to 32 (the whole address is made of unchanging bits, so there is only one address in the block; the address is a single host).

With the introduction of IPv6, all of this is changing. IPv6 addresses are 128 bits in length, for a staggering 3.4×10^{38} (340 undecillion or 340 trillion trillion trillion) possible addresses. IPv6 addresses are represented as groups of eight hexadectets (four hexadecimal digit integers); for example

```
FEDC:BA98:7654:3210:0037:6698:0000:0510
```

Each integer is a number between 0 and FFFF (the hexadecimal equivalent of decimal 65,535). IPv6 addresses

[26] CIDR /0 addresses are used almost exclusively for empty routing tables and are not accepted by the SiLK tools. This effectively means the range for CIDR prefix lengths is 1–32 for IPv4.

are allocated in a fashion such that the high-order and low-order digits are manipulated most often, with long strings of hexadecimal zeroes in the middle. There is a shorthand of `::` that can be used once in each address to represent a series of zero-valued hexadectets. The address `FEDC::3210` is therefore equivalent to `FEDC:0:0:0:0:0:0:3210`.

IPv4-compatible (`::0:0/96`) and IPv4-mapped (`::FFFF:0:0/96`) IPv6 addresses are displayed by the SiLK tools in a mixed IPv6/IPv4 format (complying with the canonical format), with the network prefix displayed in hexadecimal, and the 32-bit field containing the embedded IPv4 address displayed in dotted quad decimal. For example, the IPv6 addresses `::102:304` (IPv4-compatible) and `::FFFF:506:708` (IPv4-mapped) will be displayed as `::1.2.3.4` and `::FFFF:5.6.7.8`, respectively.

The routing methods for IPv6 addresses are beyond the scope of this handbook—see RFC 4291 (https://tools.ietf.org/html/rfc4291) for a description. Blocks of IPv6 addresses are generally denoted with CIDR notation, just as blocks of IPv4 addresses are. CIDR prefix lengths can range from 0 to 128 in IPv6. For example, `::FFFF:0:0/96` indicates that the most significant 96 bits of the address `::FFFF:0:0` constitute the network prefix (or network address), and the remaining 32 bits constitute the host part.

In SiLK, the support for IPv6 is controlled by configuration. Check for IPv6 support by running *any_SiLK_tool* `--version` (e.g., `rwcut --version`). Then examine the output to see if "IPv6 flow record support" is "yes."

A.4.2 Reserved IP Addresses

While IPv4 has approximately four billion addresses available, large segments of IP address space are reserved for the maintenance and upkeep of the Internet. Various authoritative sources provide lists of the segments of IP address space that are reserved. One notable reservation list is maintained by the Internet Assigned Numbers Authority (IANA) at https://www.iana.org/assignments/ipv4-address-space. IANA also keeps a list of IPv6 reservations at https://www.iana.org/assignments/ipv6-address-space.

In addition to this list, the Internet Engineering Task Force (IETF) maintains several RFCs that specify other reserved spaces. Most of these spaces are listed in RFC 6890, "Special-Purpose IP Address Registries" at https://tools.ietf.org/html/rfc6890. Table A.4.2 summarizes major IPv4 reserved spaces. IPv6 reserved spaces are shown in Table A.4.2.

Examples in this handbook use addresses in the private and documentation spaces, or addresses that are obviously fictitious, such as 1.2.3.4. This is done to protect the identities of organizations on whose data we tested our examples. Analysts may observe, in real captured traffic, addresses that are not supposed to appear on the Internet. This may be due to misconfiguration of network infrastructure devices or to falsified (spoofed) addressing.

In general, link-local (169.254.0.0/16 in IPv4, FE80::/10 in IPv6) and loopback (127.0.0.0/8 and ::1) destination IP addresses should not cross any routers. Private IP address space (10.0.0.0/8, 172.16.0.0/12, 192.168.0.0/16, and FC00::/7) should not enter or traverse the Internet, so it should not appear at edge routers. Consequently, the appearance of these addresses at these routers indicates a failure of routing policy. Similarly, traffic should not come into the enterprise network from these addresses; the Internet as a whole should not route that traffic to the enterprise network.

Space	Description	RFC
0.0.0.0/8	This host (0) or specified host on this network (source)	1122
10.0.0.0/8	Private networks	1918
100.64.0.0/10	Carrier-grade Network Address Translation	6598
127.0.0.0/8	Loopback (self-address)	6890
169.254.0.0/16	Link local (autoconfiguration)	6890
172.16.0.0/12	Private networks	1918
192.0.0.0/24	Reserved for IETF protocol assignments	6890
192.0.0.0/29	Dual-Stack Lite	6333
192.0.0.170/31	NAT64/DNS64 Prefix Discovery	7050
192.0.2.0/24	Documentation (example.com or example.net)	5737
192.31.196.0/24	Nameserver for AS112 Redirection Using DNAME	7535
192.52.193.0/24	Automatic Multicast Tunneling	7450
192.88.99.0/24	6to4 relay anycast (border between IPv6 and IPv4)	3068
192.168.0.0/16	Private networks	1918
192.175.48.0/24	Direct Delegation AS112 Service	7534
198.18.0.0/15	Network Interconnect Device Benchmark Testing	2544
198.51.100.0/24	Documentation (example.com or example.net)	5737
203.0.113.0/24	Documentation (example.com or example.net)	5737
224.0.0.0/4	Multicast (destination)	5771
240.0.0.0/4	Future use (except 255.255.255.255)	1112
255.255.255.255	Limited broadcast (destination)	919

Table A.1: IPv4 Reserved Addresses

Space	Description	RFC
::/128	"Unspecified" address (source)	4291
::1/128	Loopback address [similar to 127.0.0.0/8]	4291
::0.0.0.0/96	IPv4-compatible addresses (deprecated by RFC 4291)	1933
::FFFF:0.0.0.0/96	IPv4-mapped addresses	4291
64:FF9B::0.0.0.0/96	IPv4-IPv6 translation with well-known prefix	6052
100::/64	Discard-only address block	6666
2001::/23	IETF protocol assignments	2928
2001::/32	Teredo tunneling	4380
2001:1::1/128	Port Control Protocol Anycast	7723
2001:2::/48	Benchmarking	5180
2001:3::/32	Automatic Multicast Tunneling	7450
2001:4:112::/48	Nameserver for AS112 Redirection Using DNAME	7535
2001:10::/28	Overlay Routable Cryptographic Hash IDentifiers (deprecated)	4843
2001:20::/28	ORCHIDv2	7343
2001:DB8::/32	Documentation addresses [similar to 192.0.2.0/24]	3849
2002::/16	6to4 addresses [related to 192.88.99.0/24]	3056
2620:4F:8000::/48	Direct Delegation AS112 Service	7534
FC00::/7	Unique local addresses [similar to RFC 1918 private addresses] primarily seen as FD00::/8	4193
FE80::/10	Link-local unicast (similar to 169.254.0.0/16)	4291
FEC0::/10	Formerly reserved for site-local unicast addresses (deprecated by RFC 3879)	1884
FF00::/8	Multicast [similar to 224.0.0.0/4]	4291

Table A.2: IPv6 Reserved Addresses

A.5 Major Protocols

A.5.1 Protocol Layers and Encapsulation

In the multi-layered scheme used by TCP/IP, lower layer protocols *encapsulate* higher layer protocols, like envelopes within envelopes. When we open the innermost envelope, we find the message that belongs to the highest layer protocol. Conceptually, the envelopes have metadata written on them. In practice, the metadata are recorded in *headers*. The header for the lowest layer protocol is sent over the network first, followed by the headers for progressively higher layers. Finally, the message from the highest layer protocol is sent after the last header.

TCP/IP was created before the OSI Reference Model. But if we refer to a layer by its number (e.g., Layer 3 or L3), we always mean the specified layer in that model. While the preceding description of encapsulation is generally true, the model actually assigns protocols to layers based on the protocol's functions, not its order of encapsulation. This is most apparent with Internet Control Message Protocol (ICMP), which the model assigns to the Network layer (L3), even though its header and payload are encapsulated by IP, which is also a Network layer protocol. From here on, we will ignore this fine distinction, and we will consider ICMP to be a Transport layer (L4) protocol because it is encapsulated by IP, a Layer 3 protocol.

A.5.2 Transmission Control Protocol (TCP)

TCP, the most commonly encountered transport protocol on the Internet, is a stream-based protocol that reliably transmits data from the source to the destination. To maintain this reliability, TCP is very complex: The protocol is slow and requires a large commitment of resources.

Figure A.5.2 shows a breakdown of the TCP header, which adds 20 additional bytes to the IP header. Consequently, TCP packets will always be at least 40 bytes (60 for IPv6) long. As the shaded portions of Figure A.5.2 show, most of the TCP header information is not retained in SiLK flow records.

TCP is built on top of an unreliable infrastructure provided by IP. IP assumes that packets can be lost without a problem, and that responsibility for managing packet loss is incumbent on services at higher layers. TCP, which provides ordered and reliable streams on top of this unreliable packet-passing model, implements this feature through a complex state machine as shown in Figure A.5.2. The transitions in this state machine are described by labels in a $\frac{stimulus}{action}$ format, where the top value is the stimulating event and the bottom values are actions taken prior to entry into the destination state. Where no action takes place, an "x" is used to indicate explicit inaction.

This handbook does not thoroughly describe the state machine in Figure A.5.2 (see https://tools.ietf.org/html/rfc793 for a complete description), however, flows representing well-behaved TCP sessions will behave in certain ways. For example, a flow for a complete TCP session must have at least four packets: one packet that sets up the connection, one packet that contains the data, one packet that terminates the session, and one packet acknowledging the other side's termination of the session.[27] TCP behavior that deviates from this provides indicators that can be used by an analyst. An intruder may send packets with odd TCP flag combinations as part of a scan (e.g., with all flags set on). Different operating systems handle protocol violations differently, so odd packets can be used to elicit information that identifies the operating system in use or to pass through some systems benignly, while causing mischief in others.

[27] It is technically possible for there to be a valid three-packet complete TCP flow: one SYN packet, one SYN-ACK packet containing the data, and one RST packet terminating the flow. This is a very rare circumstance; most complete TCP flows have more than four packets.

TCP Flags

TCP uses *flags* to transmit state information among participants. A flag has two states: high or low; so a flag represents one bit of information. There are six commonly used flags:

ACK: Short for "acknowledge," ACK flags are sent in almost all TCP packets and used to indicate that previously sent packets have been received.

FIN: Short for "finalize," the FIN flag is used to terminate a session. When a packet with the FIN flag is sent, the target of the FIN flag knows to expect no more input data. When both have sent and acknowledged FIN flags, the TCP connection is closed gracefully.

PSH: Short for "push," the PSH flag is used to inform a TCP receiver that the data sent in the packet should immediately be sent to the target application (i.e., the sender has completed this particular send), approximating a message boundary in the stream.

RST: Short for "reset," the RST flag is sent to indicate that a session is incorrect and should be terminated. When a target receives a RST flag, it terminates immediately. Some implementations terminate sessions using RST instead of the more proper FIN sequence.

SYN: Short for "synchronize," the SYN flag is sent at the beginning of a session to establish initial sequence numbers. Each side sends one SYN packet at the beginning of a session.

URG: Short for "urgent" data, the URG flag is used to indicate that urgent data (such as a signal from the sending application) is in the buffer and should be used first. The URG flag should only be seen in Telnet-like protocols such as Secure Shell (SSH). Tricks with URG flags can be used to fool intrusion detection systems (IDS).

Reviewing the state machine will show that most state transitions are handled through the use of SYN, ACK, FIN, and RST. The PSH and URG flags are less directly relevant. Two other rarely used flags are understood by SiLK: ECE (Explicit Congestion Notification Echo) and CWR (Congestion Window Reduced). Neither is relevant to security analysis at this time, although they can be used with the SiLK tool suite if required. A ninth TCP flag, NS (Nonce Sum), is not recognized or supported by SiLK.

Major TCP Services

Traditional TCP services have well-known ports; for example, 80 is Web, 25 is SMTP, and 53 is DNS. IANA maintains a list of these port numbers at https://www.iana.org/assignments/service-names-port-numbers. This list is useful for legitimate services, but it does not necessarily contain new services or accurate port assignments for rapidly changing services such as those implemented via peer-to-peer networks. Furthermore, there is no guarantee that traffic seen (e.g., on port 80) is actually web traffic or that web traffic cannot be sent on other ports.

A.5.3 UDP and ICMP

After TCP, the most common protocols on the Internet are UDP and ICMP. While IP uses its addressing and routing to deliver packets to the correct interface on the correct host, Transport layer protocols like TCP and UDP use their port numbers to deliver packets inside the host to the correct process or service. Whereas TCP also provides other functions, such as data streams and reliability, UDP provides only delivery. UDP does

not understand that sequential packets might be related (as in streams); UDP leaves that up to higher layer protocols. UDP does not provide reliability functions, like detecting and recovering lost packets, reordering packets, or eliminating duplicate packets. UDP is a fast but unreliable message-passing mechanism used for services where throughput is more critical than accuracy. Examples include audio/video streaming, as well as heavy-use services such as the Domain Name System (DNS).

ICMP, a reporting protocol that works in tandem with IP, sends error messages and status updates, and provides diagnostic capabilities like echo.

UDP and ICMP Packet Structure

Figure A.5.3 shows a breakdown of UDP and ICMP packets, as well as the fields collected by SiLK. UDP can be thought of as TCP without the additional state mechanisms; a UDP packet has both source and destination ports, assigned in the same way TCP assigns them, as well as a payload.

ICMP is a straight message-passing protocol and includes a large amount of information in its first two fields: Type and Code. The Type field is a single byte indicating a general class of message, such as "destination unreachable." The Code field contains a byte indicating greater detail about the type, such as "port unreachable." ICMP messages generally have a limited payload; most messages have a fixed size based on type, with the notable exceptions being echo request (ICMPv4 type 8 or ICMPv6 type 128) and echo reply (ICMPv4 type 0 or ICMPv6 type 129).

Major UDP Services and ICMP Messages

UDP services are covered in the IANA webpage whose URL is listed above. As with TCP, the values given by IANA are slightly behind those currently observed on the Internet. IANA also excludes port utilization (even if common) by malicious software such as worms. Although not official, numerous port databases on the web can provide insight into the current port utilization by services.

ICMPv4 types and codes are listed at https://www.iana.org/assignments/icmp-parameters. ICMPv6 types and codes are listed at https://www.iana.org/assignments/icmpv6-parameters. These lists are definitive and include references to RFCs explaining the types and codes.

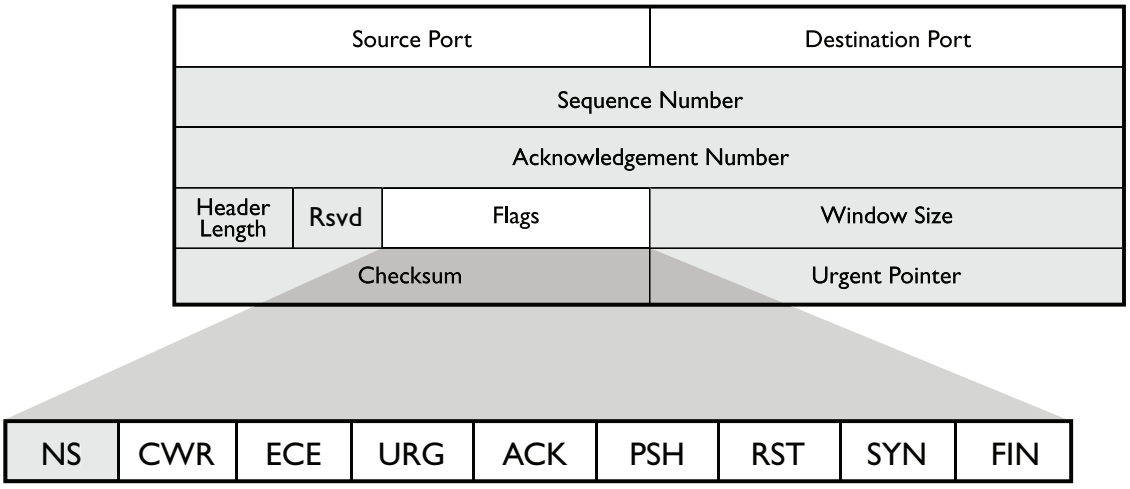

Figure A.3: TCP Header

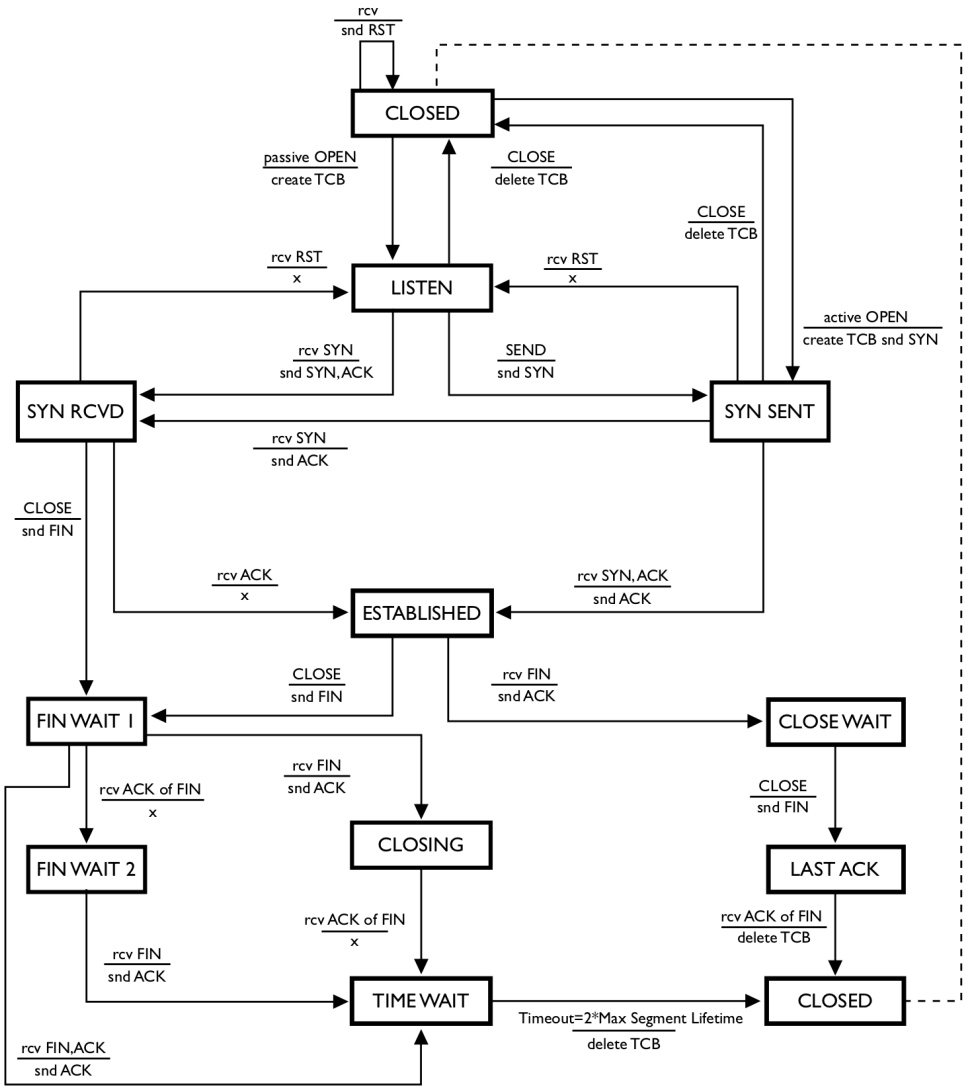

Figure A.4: TCP State Machine

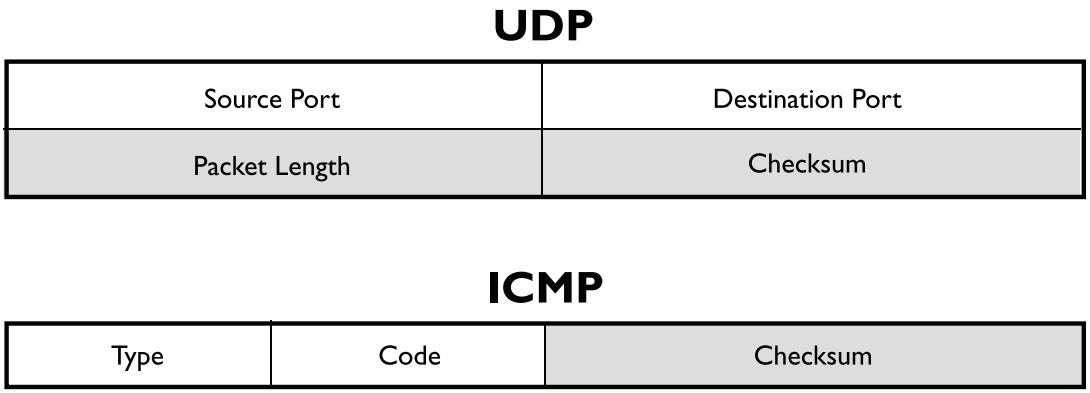

Figure A.5: UDP and ICMP Headers

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Appendix B

Using UNIX to Implement Network Traffic Analysis

This appendix provides a review of basic UNIX operations. SiLK is implemented on UNIX (e.g., Apple® OS X®, FreeBSD®, Solaris®) and UNIX-like operating systems and environments (e.g., Linux®, Cygwin); consequently an analyst must be able to work with UNIX to use the SiLK tools.

B.1 Using the UNIX Command Line

UNIX uses a program known as a shell to obtain commands from a user and either perform the task described by that command or invoke another program that will. Linux usually uses Bash (Bourne-Again SHell) for its shell. When the shell is ready to accept a command from the user, it displays a string of characters known as a prompt to let the user know that he or she can enter a command now. Besides notifying the user that a command can be accepted at this time, the prompt may convey additional information. The choice of information to be conveyed may be made by the user by providing a prompt template to the shell. In this handbook, the prompt will appear as in Example B.1.

The integer between angle brackets will be used to refer to specific commands in examples. Commands can be invoked by typing them directly at the command line. UNIX commands are typically abbreviated English words and accept space-separated parameters. Parameters are just values (like filenames), an option-name/value pair, or just an option name. Option names are double dashes followed by hyphenated words, single dashes followed by single letters, or (rarely) single dashes followed by words (as in the `find` command). Table B.1 lists some of the more common UNIX commands. To see more information on these commands type `man` followed by the command name. Example B.2 and the rest of the examples in this handbook show the use of some of these commands.

```
<1>$
```

Example B.1: A UNIX Command Prompt

Command	Description
`cat`	Copies streams and/or files onto standard output (show file content)
`cd`	Changes [working] directory
`chmod`	Changes file-access permissions. Needed to make script executable
`cp`	Copies a file from one name or directory to another
`cut`	Isolates one or more columns from a file
`date`	Shows the current or calculated day and time
`echo`	Writes arguments to standard output
`exit`	Terminates the current shell or script (log out) with an exit code
`export`	Assigns a value to an environment variable that programs can use
`file`	Identifies the type of content in a file
`grep`	Displays from a file those lines matching a given pattern
`head`	Shows the first few lines of a file's content
`kill`	Terminates a job or process
`less`	Displays a file one full screen at a time
`ls`	Lists files in the current (or specified) directory
	`-l` (for long) parameter to show all directory information
`man`	Shows the online documentation for a command or file
`mkdir`	Makes a directory
`mv`	Renames a file or moves it from one directory to another
`ps`	Displays the current processes
`pwd`	Displays the working directory
`rm`	Removes a file
`sed`	Edits the lines on standard input and writes them to standard output
`sort`	Sorts the contents of a text file into lexicographic order
`tail`	Shows the last few lines of a file
`time`	Shows the execution time of a command
`top`	Shows the running processes with the highest CPU utilization
`uniq`	Reports or omits repeated lines. Optionally counts repetitions
`wc`	Counts the words (or, with `-l` parameter, counts the lines) in a file
`which`	Verifies which copy of a command's executable file is used
`$(...)`	Inserts the output of the contained command into the command line
var=*value*	Assigns a value to a shell variable. For use by the shell only, not programs

Table B.1: Some Common UNIX Commands

```
<1>$ echo Here are some simple commands:
Here are some simple commands:
<2>$ date
Thu Jul  3 15:56:24 EDT 2014
<3>$ date -u
Thu Jul  3 19:56:24 UTC 2014
<4>$ # This is a comment line. It has no effect.
<5>$ #The next command lists my running processes
<6>$ ps -f
UID        PID  PPID  C STIME TTY          TIME CMD
user1     8280  8279  0 14:43 pts/2    00:00:00 -bash
user1    10358 10355  1 15:56 pts/2    00:00:00 ps -f
<7>$ cat animals.txt
Animal  Legs    Color
------  ----    -----
fox     4       red
gorilla 2       silver
spider  8       black
moth    6       white
<8>$ file animals.txt
animals.txt: ASCII text
<9>$ head -n 3 animals.txt
Animal  Legs    Color
------  ----    -----
fox     4       red
<10>$ cut -f 1,3 animals.txt
Animal  Color
------  -----
fox     red
gorilla silver
spider  black
moth    white
```

Example B.2: Using Simple UNIX Commands

B.2 Standard In, Out, and Error

Many UNIX programs, including most of the SiLK tools, have a default for where to obtain input and where to write output. The symbolic filenames `stdin`, `stdout`, and `stderr` are not the names of disk files, but rather they indirectly refer to files. Initially, the shell assigns the keyboard to stdin and assigns the screen to stdout and stderr. Programs that were written to read and write through these symbolic filenames will default to reading from the keyboard and writing to the screen. But the symbolic filenames can be made to refer indirectly to other files, such as disk files, through shell features called *redirection* and *pipes*.

B.2.1 Output Redirection

Some programs, like `cat` and `cut`, have no way for the user to tell the program *directly* which file to use for output. Instead these programs always write their output to stdout. The user must inform *UNIX*, not the program, that stdout should refer to the desired file. The program then only knows its output is going to stdout, and it's up to UNIX to route the output to the desired file. One effect of this is that any error message emitted by the program that refers to its output file can only display "stdout," since the actual output filename is unknown to the program.

The shell makes it easy to tell UNIX that you wish to *redirect* stdout from its default (the screen) to the file that the user specifies. This is done right on the same command line that runs the program, using the greater-than symbol (`>`) and the desired filename (as shown in Command 1 of Example B.3).

SiLK tools that write binary (non-text) data to stdout will emit an error message and terminate if stdout is assigned to a terminal device. Such tools must have their output directed to a disk file or piped to a SiLK tool that reads that type of binary input.

B.2.2 Input Redirection

A very few programs, like `tr`, have no syntax for specifying the input file and rely entirely on UNIX to connect an input file to stdin. The shell provides a method for redirecting input very similar to redirecting output. You specify a less-than symbol (`<`) followed by the input filename as shown in Command 2 of Example B.4.

B.2.3 Pipes

The real power of stdin and stdout becomes apparent with *pipes*. A pipe connects the stdout of the first program to the stdin of a second program. This is specified in the shell using a vertical bar character (`|`), known in UNIX as the pipe symbol.

In Example B.5, the `head` program reads the first four lines from the `animals.txt` file and writes those lines to `stdout` as normal, except that `stdout` does not refer to the screen. The `cut` program has no input filename specified and is programmed to read from `stdin` when no input filename appears on the command line. The pipe connects the stdout of `head` to the stdin of `cut` so that `head`'s output lines become `cut`'s input lines without those lines ever touching a disk file. `cut`'s stdout was not redirected, so its output appears on the screen.

```
<1>$ cut -f 1,3 animals.txt >animalcolors.txt
<2>$ cat animalcolors.txt
Animal  Color
------  -----
fox     red
gorilla silver
spider  black
moth    white
<3>$ rm animalcolors.txt
<4>$ ls animalcolors.txt
ls: animalcolors.txt: No such file or directory
```

Example B.3: Output Redirection

```
<1>$ #Translate hyphens to slashes
<2>$ tr - / <animals.txt
Animal  Legs    Color
//////  ////    /////
fox     4       red
gorilla 2       silver
spider  8       black
moth    6       white
```

Example B.4: Input Redirection

```
<1>$ head -n 4 animals.txt | cut -f 1,3
Animal  Color
------  -----
fox     red
gorilla silver
```

Example B.5: Using a Pipe

B.2.4 Here-Documents

Sometimes we have a small set of data that is manually edited and perhaps doesn't change from one run of a script to the next. If so, instead of creating a separate data file for the input, we can put the input data right into the script file. This is called a *here-document*, because the data are right here in the script file, immediately following the command that reads them.

Example B.6 illustrates the use of a here-document to supply several filenames to a SiLK program called `rwsort`. The `rwsort` program has an option called `--xargs` telling it to get a list of input files from `stdin`. The here-document supplies data to `stdin` and is specified with double less-than symbols (`«`), followed by a string that defines the marker that will indicate the end of the here-document data. The lines of the script file that follow the command are input data lines until a line with the marker string is reached.

B.2.5 Named Pipes

Using the pipe symbol, a script creates an *unnamed* pipe. Only one unnamed pipe can exist for output from a program, and only one can exist for input to a program. For there to be more than one, you need some way to distinguish one from another. The solution is *named* pipes.

Unlike unnamed pipes, which are created in the same command line that uses them, named pipes must be created prior to the command line that employs them. As named pipes are also known as *FIFOs* (for First In First Out), the command to create one is `mkfifo` (make FIFO). Once the FIFO is created, it can be opened by one process for reading and by another process (or multiple processes) for writing.

Scripts that use named pipes often employ another useful feature of the shell: running programs in the background. In Bash, this is specified by appending an ampersand (`&`) to the command line. When a program runs in the background, the shell will not wait for its completion before giving you a command prompt. This allows you to issue another command to run concurrently with the background program. You can force a script to wait for the completion of background programs before proceeding by using the `wait` command.

SiLK applications can communicate via named pipes. In Example B.7, we create a named pipe (in Command 1) that one call to `rwfilter` (in Command 2) uses to filter data concurrently with another call to `rwfilter` (in Command 3). Results of these calls are shown in Commands 5 and 6. Using named pipes, sophisticated SiLK operations can be built in parallel. A backslash (\) at the very end of a line indicates that the command is continued on the following physical line.

```
<1>$ rwsort --xargs --fields=sTime --output-path=week.rw <<END-OF-LIST
sunday.rw
monday.rw
tuesday.rw
wednesday.rw
thursday.rw
friday.rw
saturday.rw
END-OF-LIST
<2>$ rwfileinfo --fields=count-records *day.rw week.rw
```

Example B.6: Using a Here-Document

```
<1>$ mkfifo /tmp/namedpipe1
<2>$ rwfilter --start-date=2014/03/21T17 --end-date=2014/03/21T18 \
              --type=all --protocol=6 \
              --fail=/tmp/namedpipe1 --pass=stdout \
      | rwuniq --fields=protocol --output-path=tcp.out &
<3>$ rwfilter /tmp/namedpipe1 --protocol=17 --pass=stdout \
      | rwuniq --fields=protocol --output-path=udp.out &
<4>$ wait
<5>$ cat tcp.out
pro|   Records|
  6|  34866860|
<6>$ cat udp.out
pro|   Records|
 17|  17427015|
<7>$ rm /tmp/namedpipe1 tcp.out udp.out
```

Example B.7: Using a Named Pipe

B.3 Script Control Structures

Some advanced examples in this handbook will use control structures available from Bash. The syntax

`for` *name* `in` *word-list-expression*`; do ... done`

indicates a loop where each of the space-separated values returned by *word-list-expression* is given in turn to the variable indicated by *name* (and referenced in commands as `$`*name*), and the commands between `do` and `done` are executed with that value. The syntax

`while` *expression*`; do ... done`

indicates a loop where the commands between `do` and `done` are executed as long as *expression* evaluates to true.

Appendix C

SiLK Commands

This appendix lists the SiLK commands that are used in this guide and describes their most commonly-used options. Section C.31 surveys features, including parameters, that are common across several tools.

C.1 Getting Help with SiLK Tools

All SiLK tools include a help screen that provides a summary of command information. To view the help screen, specify the `--help` parameter with the command.

```
$ command --help
```

SiLK is distributed with UNIX manual pages that explain all the parameters and functionality of each tool in the suite.

```
$ man command
```

All SiLK tools also have a `--version` parameter that identifies the version installed. Since the suite is still being extended and evolved, this version information may be quite important.

```
$ command --version
```

C.2 `rwsiteinfo` Command Summary

rwsiteinfo

Description	Displays SiLK configuration file information for a site, its sensors, and the traffic they collect.
Call	`rwsiteinfo --fields=`*parameters* `--sensor=`*sensors*
Parameters	**`--fields`** Displays information about the parameters specified in a comma-separated list (required). See Table C.2 for a list of commonly-used parameters. Specify `:list` after a parameter to display output in a comma-separated list instead of columns. **`--sensor`** Displays information about the specified sensor or sensors **`--type`** Displays information about the SiLK types specified in a comma- separated list **`--column-separator`** Uses the specified character as a column separator (default is `|`) **`--no-titles`** Do not print column headers. **`--list-delimiter`** Uses the specified character as a list delimiter (default is `,`) For additional parameters, see Table C.31.1 and Table C.31.1.

Parameter	Description
sensor	Name of sensor
describe-sensor	Description of sensor from configuration file
type	Type of SiLK network data (see Section 1.2.6 for more information)
repo-start-date	Time and date of first data file written to SiLK repository
repo-send-date	Time and date of last data file written to SiLK repository
repo-file-count	Number of files written to SiLK repository

Table C.1: Parameters for `rwsiteinfo --fields`

C.3 `rwfilter` Command Summary

rwfilter

Description	Searches for, retrieves, and partitions SiLK flow records
Call	`rwfilter {`*`selection	input`*`} `*`partition output`*` [`*`other`*`]`
Parameters	Specify either *selection* or *input* parameters. ***selection*** parameters (described in Table C.3) tell `rwfilter` to pull data from SiLK repository files by supplying desired attributes of the records stored in the repository. ***input*** parameters specify a SiLK data source other than the repository and can include *filenames* (e.g., `infile.rw`) or *pipe names* (e.g., `stdin` or `/tmp/my.fifo`) to specify locations from which to read records. As many filenames as desired may be given, with both files and pipes used in the same command. The `--xargs` parameter specifies a file containing filenames from which to read flow records. ***partition*** parameters define tests that divide the input records into two groups: (1) "pass" records, which satisfy all the tests and (2) "fail" records, which fail to satisfy at least one of the tests. Each call to `rwfilter` must have at least one partitioning parameter unless the only output parameter is `--all-destination`, which does not require the difference between passing and failing to be defined. Commonly used partitioning parameters are listed in Tables C.3–C.3.) ***output*** specify which statistics or sets of records should be returned from the call. There are five output parameters, as described in Table C.3. Each call to `rwfilter` must have at least one of these parameters. For additional parameters, see Table C.31.1 and Table C.31.1.

`rwfilter` Selection Parameters

rwfilter Partitioning Parameters

Figure C.3 shows several groups of partitioning parameters. This section focuses on the parameters that partition records based on fields in the flow records. Section 5.1.3 discusses IP sets and how to filter with those sets. Section 6.2.7 describes prefix maps and country codes. Section 6.2.1 discusses tuple files and the parameters that use them. Lastly, Section 8.1.2 describes the use of PySiLK plug-ins. Figure C.3 also illustrates the relative efficiency of the types of partitioning parameters. Choices higher in the illustration may be more efficient than choices lower down. So analysts should prefer IPsets to tuple files when either would work, and they should prefer `--saddress` or `--scidr` to IPsets when those would all work.

Parameter	Example	Description
`--data-rootdir`	/datavol/repos	Location of SiLK repository
`--sensors`*	1–5	Sensor(s) used to collect data
`--class`*	all	Category of sensors
`--type`*	inweb,in,outweb,out	Category of flows within class
`--flowtypes`*	c1/in,c2/all	Class/type pairs
`--start-date`	2014/6/13	First day or hour of data to examine
`--end-date`	2014/3/20T23	Final day or hour of data to examine

*These selection keywords may be used as partitioning options if an input file or pipe is named.

Table C.2: `rwfilter` Selection Parameters

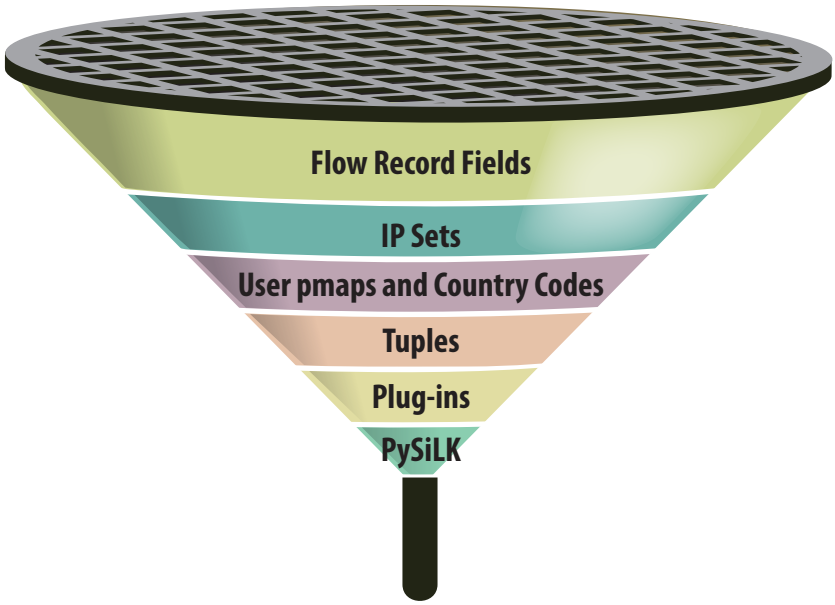

Figure C.1: `rwfilter` Partitioning Parameters

Parameter	Example	Partition Based on
`--packets`	1–3	Packet count in flow
`--bytes`	400–2400	Byte count in flow
`--bytes-per-packet`	1000–1400	Average bytes/packet in flow
`--duration`	1200–	Duration of flow in seconds
`--ip-version`	6	IP version of the flow record

Table C.3: Single-Integer- or Range-Partitioning Parameters

Parameter	Example	Partition Based on
`--protocol`	0,2–5,7–16,18–	Protocol number (1=ICMP, 6=TCP, 17=UDP)
`--sport`	0–1023	Source port
`--dport`	25	Destination port
`--aport`	80,8080	Any port. Like `--sport`, but for either source or destination
`--application`	2427,2944	Application-layer protocol (see https://tools.netsa.cert.org/yaf/applabel.html#LABELS)
`--icmp-type`	0–41,253,254	Type of ICMP message
`--icmp-code`	0,16	Subtype of ICMP message

Table C.4: Multiple-Integer- or Range-Partitioning Parameters

Parameter	Example	Partition Based on
`--saddress`	198.51.100.1,254	Single address, CIDR block, or wildcard for source
`--daddress`	198.51.100.0/24	Like `--saddress`, but for destination
`--any-address`	2001:DB8::x	Like `--saddress`, but for either source or destination
`--next-hop-id`	10.2–5.x.x	Like `--saddress`, but for next hop address
`--scidr`	198.51.100.1,203.0.113.64/29	Multiple addresses and CIDR blocks for source address
`--dcidr`	FC00::/7,2001:DB8::/32	Like `--scidr`, but for destination
`--any-cidr`	203.0.113.199,192.0.2.44	Like `--scidr`, but for either source or destination
`--nhcidr`	203.0.113.8/30,192.0.2.6	Like `--scidr`, but for next hop address
`--sipset`	tornodes.set	Source address existing in IPset file
`--dipset`	websvrs.set	Destination address existing in IPset file
`--anyset`	dnssvrs.set	Either source or destination address in IPset file
`--nhipset`	lgvolume.set	Next hop address in IPset file
`--not-`*param*	Any address parameter can be inverted using the `--not-` prefix	

Table C.5: Address-Partitioning Parameters

Parameter	Example	Partition Based on
`--flags-all`	SF/SF,SR/SR	Accumulated TCP flags
`--flags-initial`	S/SA	TCP flags in the first packet of flow
`--flags-session`	/FR	Flags in the packets after the first
`--attributes`	T/T,C/C	Termination attributes or packet size uniformity

Table C.6: High/Mask Partitioning Parameters

Parameter	Example	Partition Based on
`--stime`	2014/4/7–2014/4/8T12	Flow's start time
`--etime`	2014/4/7T8:30–2014/4/8T8:59	Flow's end time
`--active-time`	2014/4/7T11:33:30–	Overlap of active range and period between flow's start and end times

Table C.7: Time-Partitioning Parameters

Parameter	Example	Partition Based on
`--pmap-src-`*mapname*	Zer0n3t,YOLOBotnet	Source mapping to a specified label
`--pmap-dst-`*mapname*	DMZ,bizpartner	Destination mapping to a specified label
`--pmap-any-`*mapname*	mynetdvcs	Source or destination mapping to a specified label (see Section 6.2.7 on page 132)
`--scc`	ru,cn,br,ko	Source address's country code
`--dcc`	ca,us,mx	Destination address's country code
`--any-cc`	a1,a2,o1,--	Source or destination address's country code
`--stype`	1	category index of source address
`--dtype`	2	category index of destination address

Table C.8: Prefix-Map-Partitioning Parameters

Parameter	Example	Partition Based on
`--tuple-file`	torguard.tuple	Match to any specified combination of field values (see Section 6.2.1 on page 115)
`--python-expr`	`'rec.sport==rec.dport'`	Truth of expression (see Section 8.2 on page 173)
`--python-file`	complexrules.py	Truth of value returned by the program in the Python file (see Section 8.2 on page 173)
`--plugin`	flowrate.so	Custom partitioning with a C language program (see Section 8.1 on page 172)

Table C.9: Miscellaneous Partitioning Parameters

Note on specifying partitioning parameters: Partitioning parameters specify a collection of flow record criteria, such as the protocols 6 and 17 or the specific IP address 198.51.100.71. As a result, almost all partitioning parameters describe some group of values. These ranges are generally expressed in the following ways:

Value range: Value ranges are used when all values in a closed interval are desired. A value range is two numbers separated by a hyphen, such as `--packets=1-4`, which indicates that flow records with a packet count from one through four (inclusive) belong to the *pass* set of records. Some partitioning parameters (such as `--duration`) only make sense with a value range (searching for flows with a duration exact to the millisecond would be fruitless); An omitted value on the end of the range (e.g., `--bytes=2048-`) specifies that any value greater than or equal to the low value of the range passes. Omitting the value at the start of a range is not permitted. The options in Table C.3 should be specified with a single value range, except `--ip-version` which accepts a single integer.

Value alternatives: Fields that have a finite set of values (such as ports or protocol) can be expressed using a comma-separated list. In this format a field is expressed as a set of numbers separated by commas. When only one value is acceptable, it is presented without a comma. Examples include `--protocol=3` and `--protocol=3,9,12`. Value ranges can be used as elements of value alternative lists. For example, `--protocol=0,2-5,7-16,18-` says that all flow records that are not for ICMP (1), TCP (6), or UDP (17) traffic are desired. The options in Table C.3 are specified with value alternatives.

IP addresses: IP address specifications are expressed in three ways: a single address; a CIDR block (a network address, a slash (`/`), and a prefix length); and a SiLK address wildcard. The `--saddress`, `--daddress`, `--any-address`, and `--next-hop-id` options, and the `--not-` forms of those options accept a single specification that may be any of three forms. The `--scidr`, `--dcidr`, `--any-cidr`, and `--nhcidr` options, and the `--not-` forms of those options accept a comma-separated list of specifications that may be addresses or CIDR blocks but not wildcards. SiLK address wildcards are address specifications with a syntax unique to the SiLK tool suite. Like CIDR blocks, a wildcard specifies multiple IP addresses. But while CIDR blocks only specify a continuous range of IP addresses, a wildcard can even specify discontiguous addresses. For example, the wildcard `1-13.1.1.1,254` would select the addresses 1.1.1.1, 2.1.1.1, and so on until 13.1.1.1, as well as 1.1.1.254, 2.1.1.254, and so on until 13.1.1.254. For convenience, the letter `x` can be used to indicate all values in a section (equivalent to `0-255` in IPv4 addresses, `0-FFFF` in IPv6 addresses). CIDR notation may also be used, so `1.1.0.0/16` is equivalent to `1.1.x.x` and `1.1.0-255.0-255`. Any address range that can be expressed with CIDR notation also can be expressed with a wildcard. Since CIDR notation is more widely understood, it probably should be preferred for those cases. As explained in Section A.4.1, IPv6 addresses use a double-colon syntax as a shorthand for any sequence of zero values in the address and use a CIDR prefix length. The options in Table C.3, except the set-related options, are specified with IP addresses. The set-related options specify a filename.

TCP flags: The `--flags-all`, `--flags-initial`, and `--flags-session` options to `rwfilter` use a compact, yet powerful, way of specifying filter predicates based on the presence of TCP flags. The argument to this parameter has two sets of TCP flags separated by a forward slash (`/`). To the left of the slash is the *high* set; it lists the flags that must be set for the flow record to pass the filter. The flag set to the right of the slash contains the *mask*; this set lists the flags whose status is of interest, and the set must be non-empty. Flags listed in the mask set but not in the high set must be off to pass. The flags listed in the high set must be present in the mask set. (For example, `--flags-initial=S/SA` specifies a filter for flow records that initiate a TCP session; the S flag is high [on] and the A flag is low [off].) The options in Table C.3, except `--attributes`, are specified with TCP flags; `--attributes` also specifies flags in a high/mask format, but the flags aren't TCP flags.

Attributes: The `--attributes` parameter takes any combination of the letters `S`, `T`, and `C`, expressed in high/mask notation just as for TCP flags. `S` indicates that all packets in the flow have the same length (never present for single-packet flows). `T` indicates the collector terminated the flow collection due to active timeout. `C` indicates the collector produced the flow record to continue flow collection that was terminated due to active timeout. Only the `--attributes` parameter uses attributes for values.

Time ranges: Time ranges are two times, potentially precise to the millisecond, separated by a hyphen; in SiLK, these times can be expressed in their full *YYYY/MM/DD*`T`*hh*:*mm*:*ss.mmm* form (e.g., `2005/02/11T03:18:00.005-2005/02/11T05:00:00.243`). The times in a range may be abbreviated by omitting a time (but not date) component and all the succeeding components. If all the time components are omitted, the `T` (or colon) that separates the time from the date may also be omitted. Abbreviated times (times without all the components down to the millisecond) are treated as though the last component supplied includes the entire period specified by that component, not just an instant (i.e., if the last component is the day, it represents a whole day; if it's the hour, it represents the whole hour.) So `2014/1/31` represents one whole day. `2014/1/31-2014/2/1` represents two days. `2014/1/31T14:50-2014/1/31T14:51` represents two whole minutes. `2014/1/31T12-` represents all time from 2014/1/31 noon forward. The options in Table C.3 are specified with time ranges.

Country codes: The `--scc`, `--dcc`, and `--any-cc` parameters take a comma-separated list of two-letter country codes, as specified by IANA.[28] There are also four special codes: `--` for unknown, `a1` for anonymous proxy, `a2` for satellite provider, and `o1` for other. The options in Table C.3 are specified with country codes. These options require a country-code mapping file to be built and installed.

Address types: The `--stype` and `--dtype` parameters accept a single index. Records pass if their source or destination addresses produce a matching index when looked up in address-types mapping file. These parameters require the mapping file to be built and installed.

`rwfilter` Output Parameters

[28] https://www.iana.org/domains/root/db/

Miscellaneous `rwfilter` Parameters

Additional `rwfilter` parameters that are commonly useful in analysis or maintaining the repository are listed below. These depend on the implementation and are described in Table C.3.

The `--threads` parameter takes an integer scalar N to specify using N threads to read input files and filter records. The default value is one or the value of the `SILK_RWFILTER_THREADS` environment variable if that is set. Using multiple threads is preferable for queries that look at many files but return few records. Current experience is that performance peaks at about two to three threads per CPU (core) on the host running `rwfilter`, but this result is variable with the type of query and the number of records returned from each file. There is no advantage in having more threads than input files. There may also be a point of diminishing returns, which seems to be around 20 threads.

To improve query efficiency when few records are needed, the `--max-pass-records` parameter allows the analyst to specify the maximum number of records to return via the path specified by the `--pass` parameter.

Parameter	Example	Description
`--pass-destination`	stdout	Send SiLK flow records matching all partitioning parameters to pipe or file
`--fail-destination`	faildata.rw	Like `--pass`, but for records failing to match
`--all-destination`	allrecs.rw	Like `--pass`, but for all records
`--print-statistics`	—	Print (default to stderr) count of records passing and failing
`--print-volume-statistics`	out-vol.txt	Print counts of flows/bytes/packets read, passing, and failing to named file or stderr

Table C.10: `rwfilter` Output Parameters

Parameter	Description
`--print-missing-files`	Print names of missing repository files to stderr. Doubles as a selection parameter.
`--threads`	Specify number of process threads to be used in filtering
`--max-pass-records`	Specifies the maximum number of records to return as matching partitioning parameters
`--max-fail-records`	Specifies the maximum number of records to return as *not* matching partitioning parameters
`--dry-run`	Performs a sanity check on parameters. Does not retrieve records. Prints a list of the names of files that would be accessed.
For additional parameters, see Table C.31.1 and Table C.31.1 .	

Table C.11: Miscellaneous `rwfilter` Parameters

C.4 rwstats Command Summary

rwstats

Description	Summarizes SiLK flow records by one of a limited number of key-and-value pairs and displays the results as a top-*N* or bottom-*N* list
Call	`rwstats flowrecs.rw --fields=protocol --values=Records --top --count=20`
Parameters	Choose one or none: **`--top`** Prints the top *N* keys and their values (default) **`--bottom`** Prints the bottom *N* keys and their values **`--overall-stats`** Prints minima, maxima, quartiles, and interval-count statistics for bytes, packets, and bytes per packet across all flows **`--detail-proto-stats`** Prints overall statistics for each specified protocol. Protocols are specified as integers or ranges separated by commas. Choose one for `--top` or `--bottom`: **`--count`** Displays the specified number of key-and-value pairs **`--percentage`** Displays key-and-value pairs where the value is greater than (`--top`) or less than (`--bottom`) this percentage of the total value **`--threshold`** Displays key-and-value pairs where the the specified constant is greater than or less than a threshold value. Options for `--top` or `--bottom`: **`--fields`** Uses the indicated fields as the key (see Table C.6) – required **`--values`** Calculates values for the specified fields (default: Records) **`--presorted-input`** Assumes input is already sorted by key **`--no-percents`** Does not display percent-of-total or cumulative-percentage **`--bin-time`** Adjusts `sTime` and `eTime` to multiple of the argument in seconds **`--temp-directory`** Specifies the location for temporary data when memory is exceeded For additional parameters, see Table C.31.1 and Table C.31.1.

C.5 `rwcount` Command Summary

rwcount

Description	Calculates volumes over time periods of equal duration
Call	`rwcount flowrecs.rw --bin-size=3600`
Parameters	**`--bin-size`** Specifies the number of seconds per bin (default 30) **`--load-scheme`** Specifies how the flow volume is allocated to bins (see Table C.5 for details) **`--skip-zeroes`** Does not print empty bins **`--start-time`** Specifies the initial time of the first bin **`--end-time`** Specifies a time in the last bin, extended to make a whole bin **`--bin-slots`** Displays timestamps as internal bin indices For additional parameters, see Table C.31.1 and Table C.31.1.

Value	Parameter Name	Volume Allocation	Guidelines for Use
0	bin-uniform	Allocates equal parts of volume to every bin in timespan	Computes the average load per bin, smoothing out peaks and valleys.
1	start-spike	Stores entire volume in the first millisecond of flow (i.e., the flow's stime bin)	Emphasizes the onset of periodic behavior. Puts all packets and bytes into one bin even if the flow spans multiple bins.
2	end-spike	Stores entire volume in the last millisecond of the flow (i.e., the flow's etime bin)	Emphasizes flow termination. Puts all packets and bytes into one bin even if the flow spans multiple bins.
3	middle-spike	Stores entire volume in the middle millisecond of the flow	Emphasizes payload transfer. Puts all packets and bytes into one bin even if the flow spans multiple bins.
4	time-proportional	Proportionally allocates the flow's bytes, packets, and record count (1 for one flow) to all bins in the flow according to how much time the flow spent in each bin's timespan	**Default load scheme; recommended for most analyses.** Gives the average load per time period. Smooths out peaks and valleys over time.
5	max-volume	Assigns entire flow volume to each bin	Overestimates load; computes worst-case scenario for service loading.
6	min-volume	Assigns one flow to each bin	Underestimates load; computes best case scenario for service loading.

- For `--load-scheme` values `0` through `4`, the flow record count adds up to 1. The byte and packet counts add up to the counts in the flow record.
- For `--load-scheme` values `5` and `6`, the flow record count does not add up to 1. The byte and packet counts do not add up to the counts in the flow record.

Table C.12: Time distribution options for `rwcount --load-scheme`

C.6 `rwcut` Command Summary

rwcut

Description	Reads SiLK flow data and displays it as text
Call	`rwcut flowrecs.rw --fields=1-5,sTime`
Parameters	Choose one or none: **`--fields`** Specifies which fields to display (default is 1–12) **`--all-fields`** Displays all fields Options: **`--start-rec-num`** Specifies record offset of first record from start of file **`--end-rec-num`** Specifies record offset of last record from start of file **`--tail-recs`** Specifies record offset of first record from end of file (cannot combine with `--start-rec-num` or `--end-rec-num`) **`--num-recs`** Specifies maximum number of output records For additional parameters, see Table C.31.1 and Table C.31.1.

Field Number	Field Name	Description
1	sIP	Source IP address for flow
2	dIP	Destination IP address for flow
3	sPort	Source port for flow (or 0)
4	dPort	Destination port for flow (or 0)
5	protocol	Transport-layer protocol number for flow
6	packets, pkts	Number of packets in flow
7	bytes	Number of bytes in flow (starting with IP header)
8	flags	Cumulative TCP flag fields of flow (or blank)
9	sTime	Start date and time of flow
10	duration	Duration of flow
11	eTime	End date and time of flow
12	sensor	Sensor that collected the flow
13	in	Ingress interface or VLAN on sensor (usually zero)
14	out	Egress interface or VLAN on sensor (usually zero)
15	nhIP	Next-hop IP address (usually zero)
16	sType	Type of source IP address (pmap required)
17	dType	Type of destination IP address (pmap required)
18	scc	Source country code (pmap required)
19	dcc	Destination country code (pmap required)
20	class	Class of sensor that collected flow
21	type	Type of flow for this sensor class
—	iType	ICMP type for ICMP and ICMPv6 flows (SiLK V3.8.1+)
—	iCode	ICMP code for ICMP and ICMPv6 flows (SiLK V3.8.1+)
25	icmpTypeCode	Both ICMP type and code values (before SiLK V3.8.1)
26	initialFlags	TCP flags in initial packet
27	sessionFlags	TCP flags in remaining packets
28	attributes	Termination conditions
29	application	Standard port for application that produced the flow

Table C.13: Arguments for the `--fields` Parameter

C.7 `rwsort` Command Summary

rwsort

Description	Sorts SiLK flow records using key field(s)
Call	`rwsort unsorted1.rw unsorted2.rw --fields=1,3 --output-path=sorted.rw`
Parameters	**`--fields`** Specifies key fields for sorting (required) **`--presorted-input`** Specifies only merging of already sorted input files **`--reverse`** Specifies sort in descending order **`--temp-directory`** Specifies location of high-speed storage for temp files **`--sort-buffer-size`** Specifies the in-memory sort buffer (2 GB default) For additional parameters, see Table C.31.1 and Table C.31.1.

C.8 rwuniq Command Summary

rwuniq

Description	Counts records per combination of multiple-field keys
Call	`rwuniq filterfile.rw --fields=1-5,sensor --values=Records`
Parameters	**`--fields`** Specifies fields to use as key (required) **`--values`** Specifies summary counts (default: Records) **`--bin-time`** Establishes bin size for time-oriented bins **`--presorted-input`** Reduces memory requirements for presorted records **`--sort-output`** Sorts results by key, as specified in the `--fields` parameter For options to filter output rows, see Table C.8. For additional parameters, see Table C.31.1 and Table C.31.1.

Parameter	Description
`--bytes`	Only output rows whose byte counts are in the specified range
`--packets`	Only output rows total packet counts are in the specified range
`--flows`	Only output rows whose flow (record) counts are in the specified range
`--sip-distinct`	Only output rows whose counts of distinct (unique) source IP addresses are in the specified range
`--dip-distinct`	Only output rows whose counts of distinct (unique) destination IP addresses are in the specified range

Table C.14: Output-Filtering Options for `rwuniq`

C.9 `rwnetmask` Command Summary

rwnetmask

Description	Zeroes all bits past the specified prefix length on the specified address in SiLK flow records
Call	`rwnetmask flows.rw --4sip-prefix-length=24 --output-path=sip-24.rw`
Parameters	Choose one or more: **`--4sip-prefix-length`** Gives number of high bits of source IPv4 address to keep **`--4dip-prefix-length`** Gives number of high bits of destination IPv4 to keep **`--4nhip-prefix-length`** Gives number of high bits of next-hop IPv4 to keep **`--6sip-prefix-length`** Gives number of high bits of source IPv6 to keep **`--6dip-prefix-length`** Gives number of high bits of destination IPv6 to keep **`--6nhip-prefix-length`** Gives number of high bits of next-hop IPv6 to keep For additional parameters, see Table C.31.1 and Table C.31.1.

C.10 `rwcat` Command Summary

rwcat

Description	Concatenates SiLK flow record files and copies to a new file
Call	`rwcat someflows.rw moreflows.rw --output-path=allflows.rw`
Parameters	`--ipv4-output` Converts IPv6 records to IPv4 records following the `asv4` policy; ignores other IPv6 records `--byte-order` Writes the output in this byte order. Possible choices are `native` (the default), `little`, and `big` For additional parameters, see Table C.31.1 and Table C.31.1.

C.11 rwappend Command Summary

rwappend

Description	Appends the flow records from the successive files to the first file
Call	`rwappend allflows.rw laterflows.rw`
Parameters	`--create` Creates the output file if it does not already exist. Determines the format and version of the output file from the flow record file optionally named in this parameter `--print-statistics` Prints to standard error the count of records that are read from each input file and written to the output file For additional parameters, see Table C.31.1 and Table C.31.1.

C.12 `rwsplit` Command Summary

rwsplit

Description	Divides the flow records into successive files
Call	`rwsplit allflows.rw --flow-limit=1000 --basename=sample`
Parameters	Choose one: **`--ip-limit`** Specifies the IP address count at which to begin a new sample file **`--flow-limit`** Specifies the flow count at which to begin a new sample file **`--packet-limit`** Specifies the packet count at which to begin a new sample file **`--byte-limit`** Specifies the byte count at which to begin a new sample file Options: **`--basename`** Specifies the base name for output sample files (required) **`--sample-ratio`** Specifies the denominator for the ratio of records read to number written in a sample file (e.g., 100 means to write 1 out of 100 records) **`--seed`** Seeds the random number generator with this value **`--file-ratio`** Specifies the denominator for the ratio of sample filenames generated to the total number written (e.g., 10 means 1 of every 10 files will be saved) **`--max-outputs`** Specifies the maximum number of files to write to disk For additional parameters, see Table C.31.1 and Table C.31.1.

C.13 rwtuc Command Summary

rwtuc

Description	Generates SiLK flow records from textual input similar to `rwcut` output
Call	`rwtuc flows.rw.txt --output-path=flows.rw`
Parameters	**`--fields`** Specifies the fields to parse from the input. Values may be • a field number: 1–15, 20–21, 26–29 • a field name equivalent to one of the field numbers above (see Table C.6 on page 257) • the keyword **`ignore`** for an input column not to be included in the output records. The parameter is unnecessary if the input file has appropriate column headings. **`--bad-input-lines`** Specifies the file or stream to write each bad input line to (filename and line number prepended) **`--verbose`** Prints an error message for each bad input line to standard error **`--stop-on-error`** Prints an error message for a bad input line to standard error and exits **`--`*`fixed-value-parameter`*** Uses the value as a fixed value for this field in all records. See Table C.13 for the parameter name for each field. For additional parameters, see Table C.31.1 and Table C.31.1.

Field	Parameter Name	Field	Parameter Name
sIP	--saddress	in	--input-index
dIP	--daddress	out	--output-index
sPort	--sport	nhIP	--next-hop-ip
dPort	--dport	class	--class
protocol	--protocol	type	--type
packets	--packets	iType	--icmp-type
bytes	--bytes	iCode	--icmp-code
flags	--flags-all	initialFlags	--flags-initial
sTime	--stime	sessionFlags	--flags-session
duration	--duration	attributes	--attributes
eTime	--etime	application	--application
sensor	--sensor		

Table C.15: Fixed-Value Parameters for `rwtuc`

C.14 rwset Command Summary

rwset

Description	Generates IP-set files from flows
Call	`rwset flows.rw --sip-file=flows_sip.set`
Parameters	Choose one or more: **`--sip-file`** Specifies an IP-set file to generate with source IP addresses from the flows records **`--dip-file`** Specifies an IP-set file to generate with destination IP addresses from the flows records **`--nhip-file`** Specifies an IP-set file to generate with next-hop IP addresses from the flows records **`--any-file`** Specifies an IP-set file to generate with both source and destination IP addresses from the flows records Options: **`--record-version`** Specifies the version of records to write to a file. Allowed arguments are 0, 2, 3, and 4; record version affects size and backwards compatibility. It can also be set by the `SILK_IPSET_RECORD_VERSION` environment variable. **`--invocation-strip`** Does not copy command lines from the input files to the output files For additional parameters, see Table C.31.1 and Table C.31.1.

C.15 `rwsetcat` Command Summary

rwsetcat

Description	Lists contents of IP-set files as text on standard output
Call	`rwsetcat low_sip.set >low_sip.set.txt`
Parameters	**`--network-structure`** Prints the network structure of the set. Syntax: [`v6:`|`v4:`][*list-lengths*[`S`][`/`[*summary-lengths*]]] A length may be expressed as an integer prefix length (often preferred) or a letter: `T` for total address space (/0), `A` for /8, `B` for /16, `C` for /24, `X` for /27, and `H` for Host (/32 for IPv4, /128 for IPv6); with `S` for default summaries. **`--cidr-blocks`** Groups IP addresses that fill a CIDR block **`--ip-ranges`** Groups consecutive addresses; provides the most compact display **`--count-ips`** Prints the number of IP addresses. Disables default printing of addresses **`--print-statistics`** Prints set statistics (min-/max-IP address, etc.). Also disables default printing of addresses **`--print-ips`** Prints IP addresses when count or statistics parameter is given For additional parameters, see Table C.31.1 and Table C.31.1.

C.16 `rwsettool` Command Summary

rwsettool

Description	Manipulates IP-set files to produce new IP-set files
Call	`rwsettool --intersect src1.set src2.set --output-path=both.set`
Parameters	Choose one: **`--union`** Creates set containing IP addresses in any input file **`--intersect`** Creates set containing IP addresses in all input files **`--difference`** Creates set containing IP addresses from first file not in any of the remaining files **`--mask`** Creates set containing one IP address from each block of the specified bitmask length when any of the input IPsets have an IP address in that block **`--fill-blocks`** Creates an IPset containing a completely full block with the specified prefix length when any of the input IPsets have an IP address in that block **`--sample`** Creates an IPset containing a random sample of IP addresses from all input IPsets. Requires either the `--size` or `--ratio` option Options: **`--size`** Specifies the sample size (number of IP addresses sampled from each input IPset). Requires the `--sample` parameter **`--ratio`** Specifies the probability (as a floating point value between 0.0 and 1.0) that an IP address will be sampled. Requires the `--sample` parameter **`--seed`** Specifies the random number seed integer for the `--sample` parameter and is used only with that parameter **`--note-strip`** Does not copy notes from the input files to the output file **`--invocation-strip`** Does not copy command history from the input files to the output file **`--record-version`** Specifies the IP-set record version to write. v2 only supports IPv4; v3 requires SiLK 3; v4 is more compact and requires SiLK 3.7 or later; 0 uses v2 for IPv4 sets, and v3 otherwise. For additional parameters, see Table C.31.1 and Table C.31.1.

C.17 `rwsetbuild` Command Summary

rwsetbuild

Description	Create a binary IPset file from a list of IP addresses
Call	`rwsetbuild myset.set.txt myset.set`
Parameters	`--ip-ranges=DELIM` Range of IP addresses, where DELIM is the delimiter. `--invocation-strip` Do not include the command line in the file For additional parameters, see Table C.31.1 and Table C.31.1.

C.18 rwbag Command Summary

rwbag

Description Generates bags from flow records

Call

```
rwbag flow.rw --sip-bytes=x.bag --sip-flows=y.bag
```

Parameters `--key-count` Writes bag of *count* by unique *key* value. May be specified multiple times. Allowed values for *key* and *count* are

Key		Count	
sip	Source IP address	flows	Count flow records
dip	Destination IP address	packets	Sum packets in records
nhip	Next-hop IP address	bytes	Sum bytes in records
input	Router input port		
output	Router output port		
sport	Source port		
dport	Destination port		
proto	Protocol		
sensor	Sensor ID		

For additional parameters, see Table C.31.1 and Table C.31.1.

C.19 `rwbagbuild` Command Summary

rwbagbuild

Description	Creates a binary bag from non-flow data (expressed as text)
Call	`rwbagbuild --bag-input=ip-byte.bag.txt --key-type=sIPv4 --counter-type=sum-bytes --output-path=ip-byte.bag`
Parameters	Choose one: **`--set-input`** Creates a bag from the specified IPset, which may be `stdin` or a hyphen (`-`) **`--bag-input`** Creates a bag from a delimiter-separated text file, which can be `stdin` or a hyphen (`-`) Options: **`--delimiter`** Specifies the delimiter separating the key and value for the `--bag-input` parameter. Cannot be the pound sign (`#`) or the line-break character (new line) **`--default-count`** Specifies the integer count for each key in the new bag, overriding any values present in the input **`--key-type`** Sets the key type to this value. Allowable options are shown in Table C.19. **`--counter-type`** Sets the counter type to this value. Allowable options are shown in Table C.19. For additional parameters, see Table C.31.1 and Table C.31.1.

Type	Description, allowed values
sIPv4	Source IP addresses, IPv4 only, dotted quad, CIDR, wildcard, or integer
dIPv4	Destination IP address, IPv4 only, dotted quad, CIDR, wildcard, or integer
sPort	Source port, integer 0–65,535
dPort	Destination port, integer 0–65,535
protocol	IP protocol, integer 0–255
packets	Packet count, integer
bytes	Byte count, integer
flags	Bit string of TCP cumulative TCP flags (CEUAPRSF), integer 0–255
sTime	Starting time of the flow, integer seconds from UNIX epoch
duration	Duration of the flow, integer seconds
eTime	Ending time of the flow, integer seconds from UNIX epoch
sensor	Sensor ID, integer
input	SNMP index of input interface, integer
output	SNMP index of output interface, integer
nhIPv4	Next-hop IP address, IPv4 only, dotted quad, CIDR, wildcard, or integer
initialFlags	TCP flags in first packet in the flow, integer 0–255
sessionFlags	Cumulative TCP flags excluding the first packet, integer 0–255
attributes	Flags for termination conditions and packet size uniformity, integer
application	Guess as to the content of the flow, as set by the flow generator, integer 0–65,535
class	Class of the sensor, integer
type	Type of the flow, integer
icmpTypeCode	An encoded version of the ICMP type and code, where the type is in the upper byte and the code is in the lower byte
sIPv6	Source IP address, IPv6, canonical form or integer
dIPv6	Destination IP address, IPv6, canonical form or integer
nhIPv6	Next-hop IP address, IPv6, canonical form or integer
records	Count of flows, integer
sum-packets	Sum of packet counts, integer
sum-bytes	Sum of byte counts, integer
sum-duration	Sum of duration values, integer seconds
any-IPv4	Source, destination, or next-hop IPv4 address, dotted quad or integer
any-IPv6	Source, destination or next-hop IPv6 address, canonical form or integer
any-port	Source or destination port, integer 0–65,535
any-snmp	Input or output SNMP index of interface, integer
any-time	Start or end time value, integer seconds since UNIX epoch
custom	An integer

Table C.16: rwbagbuild Key or Value Options

C.20 `rwbagcat` Command Summary

rwbagcat

Description	Displays or summarizes bag contents
Call	`rwbagcat x.bag --output-path=x.bag.txt`
Parameters	Choose one or none: **`--network-structure`** Prints the sum of counters for each specified CIDR block in the comma-separated list of CIDR block sizes and/or letters **`--bin-ips`** Inverts the bag and counts keys by distinct volume values. Allowed arguments are `linear` (count keys with each volume [the default]), `binary` (count keys with volumes that fall in ranges based on powers of 2), and `decimal` (count keys that fall in ranges determined by a decimal logarithmic scale). Options: **`--mincounter`** Displays only entries with counts of at least the value given as the argument **`--maxcounter`** Displays only entries with counts no larger than the value given as the argument **`--minkey`** Displays only entries with keys of at least the value given as the argument **`--maxkey`** Displays only entries with keys no larger than the value given as the argument **`--key-format`** Specifies the formatting of keys for display. Allowed arguments are `canonical` (display keys as IP addresses in canonical format), `zero-padded` (display keys as IP addresses with zeroes added to fully fill width of column), `decimal` (display keys as decimal integer values), `hexadecimal` (display keys as hexadecimal integer values), and `force-ipv6` (display all keys as IP addresses in the canonical form for IPv6 with no IPv4 notation). **`--mask-set`** Outputs records whose keys appear in the argument set-file **`--zero-counts`** Prints keys with a counter of zero (requires `--mask-set` or both `--minkey` and `--maxkey`) **`--print-statistics`** Prints statistics about the bag to given file or standard output For additional parameters, see Table C.31.1 and Table C.31.1.

C.21 rwbagtool Command Summary

rwbagtool

Description	Manipulates bags and generates cover sets
Call	`rwbagtool --add x.bag y.bag --output-path=z.bag`
Parameters	Choose one (or none with one input bag): **`--add`** Adds bags together (union) **`--subtract`** Subtracts from the first bag all the other bags (difference) **`--minimize`** Writes to the output the minimum counter for each key across all input bags **`--maximize`** Writes to the output the maximum counter for each key across all input bags **`--divide`** Divides the first bag by the second bag **`--scalar-multiply`** Multiplies each counter in the bag by the specified value. Accepts a single bag file as input. **`--compare`** Compares key/value pairs in exactly two bag files using the operation (OP) specified by the argument. Keeps only those keys in the first bag that also appear in the second bag and whose counter satisfies the OP relation with those in the second bag. The counter for each key that remains is set to 1. Allowed OPs are `lt` (less than), `le` (less than or equal to), `eq` (equal to), `ge` (greater than or equal to), `gt` (greater than). Choose zero or more masking/limiting parameters to restrict the results of the above operation or the sole input bag: **`--intersect`** Intersects the specified set with keys in the bag **`--complement-intersect`** Masks keys in the bag using IP addresses *not* in given IP-set file **`--minkey`** Cuts bag to entries with key of at least the value given as an argument **`--maxkey`** Cuts bag to entries with key of at most the value given as an argument **`--mincounter`** Outputs records whose counter is at least the value given as an argument, an integer **`--maxcounter`** Outputs records whose counter is not more than the value given as an argument, an integer Options: **`--coverset`** Generates an IPset for bag keys instead of creating a bag **`--invert`** Counts keys for each unique counter value **`--note-strip`** Does not copy notes from the input files to the output file **`--output-path`** Specifies where resulting bag or set should be stored For additional parameters, see Table C.31.1 and Table C.31.1.

C.22 `rwaggbag` Command Summary

rwaggbag

Description	Generates aggregate bags from flow records
Call	`rwaggbag --keys=sport,dport --counters=records,sum-bytes --output-path=ports.aggbag flow.rw`
Parameters	***`--keys`*** Writes an aggregate bag of *keys* value(s). Comma-separated keys are sorted in the order in which they are specified. Allowable *keys* values are listed in Table C.22. **`--counters`** Counts the values of the specified comma-separated field(s). Allowable *counters* values are listed below. **Counter** — **Value** `records` — Count of flows `sum-packets` — Sum of packet counts `sum-bytes` — Sum of byte counts `sum-duration` — Sum of duration values in seconds **`--output-path=`*`path`*** Writes the binary aggregate bag to *path*, where *path* is a filename, a named pipe, `stdout` (standard output), or `stderr` (standard error). `rwaggbag` requires at least one field to be listed for `--keys` and `--counters`. For additional parameters, see Table C.31.1.

Key	Description
sIPv4	Source IP addresses, IPv4
sIPv6	Source IP addresses, IPv6
dIPv4	Destination IP address, IPv4
dIPv6	Destination IP address, IPv6
sPort	Source port
dPort	Destination port
protocol	IP protocol
packets	Packet count
bytes	Byte count
flags	Bit string of TCP cumulative TCP flags (CEUAPRSF)
sTime	Starting time of the flow
duration	Duration of the flow
eTime	Ending time of the flow
sensor	Sensor ID
input	router SNMP index of input interface
output	router SNMP index of output interface
nhIPv4	Next-hop IP address, IPv4
nhIPv6	Next-hop IP address, IPv6
initialFlags	TCP flags in first packet in the flow
sessionFlags	Cumulative TCP flags excluding the first packet
attributes	Flags for termination conditions and packet size uniformity
application	Guess as to the content of the flow, as set by the flow generator

Table C.17: rwaggbag Keys

C.23 `rwaggbagbuild` Command Summary

rwaggbagbuild

Description	Creates a binary aggregate bag from non-flow data (expressed as text)
Call	`rwaggbagbuild --fields=sIPv4,records,sum-packets,sum-bytes --output-path=sip-traffic.aggbag sip-traffic.aggbag.txt`
Parameters	`--fields` Sets the keys and counters for the aggregate bag to the specified values. Allowable options are shown in Table C.23. At least one key and one counter must be specified. `--column-separator` Specifies the delimiter separating the `--fields` parameter values (default is `|`). Cannot be the pound sign (`#`) or the line-break character (new line). `--constant-field=`*`field=value`* For each entry read from the input file(s), insert a field named *field* and set its value to *value*. *value* is a textual representation of the field's value as described in the description of the `--fields` parameter above. When *field* is a counter field and the same key appears multiple times in the input, *value* is added to the counter multiple times. If a field named *field* appears in an input file, its value from that file is ignored. Specify `--constant-field` multiple times to insert multiple fields. `--no-titles` Parses the first line of the input as field values. Normally, `rwaggbagbuild` examines the first line to determine if the line contains the names (titles) of fields and skips the line if it does. `rwaggbagbuild` exits with an error when `--no-titles` is given but `--fields` is not. `--output-path=`*`path`* Writes the binary aggregate bag to *path*, where *path* is a filename, a named pipe, `stdout` (standard output), or `stderr` (standard error). For additional parameters, see Table C.31.1.

Type	Description, allowed values
sIPv4	Source IP addresses, IPv4 only, dotted quad, CIDR, wildcard, or integer
dIPv4	Destination IP address, IPv4 only, dotted quad, CIDR, wildcard, or integer
sPort	Source port, integer 0–65,535
dPort	Destination port, integer 0–65,535
protocol	IP protocol, integer 0–255
packets	Packet count, integer
bytes	Byte count, integer
flags	Bit string of TCP cumulative TCP flags (CEUAPRSF), integer 0–255
sTime	Starting time of the flow, integer seconds from UNIX epoch
duration	Duration of the flow, integer seconds
eTime	Ending time of the flow, integer seconds from UNIX epoch
sensor	Sensor ID, integer
input	SNMP index of input interface, integer
output	SNMP index of output interface, integer
nhIPv4	Next-hop IP address, IPv4 only, dotted quad, CIDR, wildcard, or integer
initialFlags	TCP flags in first packet in the flow, integer 0–255
sessionFlags	Cumulative TCP flags excluding the first packet, integer 0–255
attributes	Flags for termination conditions and packet size uniformity; S, F, T, C.
application	Guess as to the content of the flow, as set by the flow generator, integer 0–65,535
class	Class of the sensor, integer
type	Type of the flow, integer
icmpTypeCode	An encoded version of the ICMP type and code, where the type is in the upper byte and the code is in the lower byte
sIPv6	Source IP address, IPv6, canonical form or integer
dIPv6	Destination IP address, IPv6, canonical form or integer
nhIPv6	Next-hop IP address, IPv6, canonical form or integer
records	Count of flows for key, integer
sum-packets	Sum of packet counts for key, integer
sum-bytes	Sum of byte counts for key, integer
sum-duration	Sum of duration values for key, integer seconds
any-IPv4	Source, destination, or next-hop IPv4 address, dotted quad or integer
any-IPv6	Source, destination or next-hop IPv6 address, canonical form or integer
any-port	Source or destination port, integer 0–65,535
any-snmp	Input or output SNMP index of interface, integer
any-time	Start or end time value, integer seconds since UNIX epoch
custom-counter	Customized counter, integer
custom-key	Customized key
ignore	Skips this field

Table C.18: rwaggbagbuild Key and Value Options

C.24 `rwaggbagcat` Command Summary

rwaggbagcat

Description	Displays or summarizes aggregate bag contents
Call	`rwaggbagcat x.aggbag --output-path=x.aggbag.txt`
Parameters	**`--output-path=`*`path`* Writes the text output to *path*, where *path* is a filename, a named pipe, `stdout` (standard output), or `stderr` (standard error). **`--timestamp-format`** The format, timezone, and/or modifier to use when printing timestamps. **`--ip-format`** Specify how IP addresses are printed. **`--integer-sensors`** Print the integer ID of the sensor rather than its name. **`--integer-tcp-flags`** Print the TCP flag fields (`flags`, `initialFlags`, `sessionFlags`) as an integer value. (Typically, the characters `F`, `S`, `R`, `P`, `A`, `U`, `E`, `C` are used to represent the TCP flags.) **`--no-titles`** Turns off column titles. **`--no-columns`** Disables fixed-width columnar output. **`--column-separator`** Specifies the delimiter separating the `--fields` parameter values (default is `|`). . **`--no-final-delimiter`** Do not print the column separator after the final column. **`--delimited or --delimited=`*`C`*** For additional parameters, see Table C.31.1.

C.25 rwaggbagtool Command Summary

rwaggbagtool

Description	Manipulates aggregate bags and extracts bags and cover sets
Call	`rwaggbagtool --add x.aggbag y.aggbag --output-path=z.aggbag`
Parameters	Choose one (or none with one input bag): **`--add`** Sums each of the counters for each key for all the aggregate bag input files. All of the aggregate bag files must have the same set of key fields and counter fields. **`--subtract`** Subtracts from the first aggregate bag all the other aggregate bags. If a key does not appear in the first aggregate bag file, `rwaggbagtool` assumes it has a value of 0. If any counter subtraction results in a negative number, the key will not appear in the resulting aggregate bag file. **`--output-path=`*`path`*** Writes the binary output to *path*, where *path* is a filename, a named pipe, `stdout` (standard output), or `stderr` (standard error). Filtering parameters: **`--min-field=`*`field=value`*** Thresholds aggregate bag to entries where the *field* is less than the *value* given as an argument **`--max-field`** Thresholds aggregate bag to entries where the *field* is greater than the *value* given as an argument **`--set-intersect=`*`field=IPset`*** Intersects the specified *IPset* with *fields* in the aggregate bag **`--set-complement=`*`field=IPset`*** Removes all *fields* in the aggregate bag whose values are in the specified *IPset*. Field manipulation: **`--insert-field=`*`field=value`*** For each entry in an aggregate bag, insert a field named *field* and set its value to *value* if the input file does not contain the named field. *value* is a textual representation of the field's value as described in the `--fields` switch of `rwaggbagbuild`. This switch may be repeated in order to insert multiple fields. **`--remove-fields=`*`field_list`*** Remove the fields specified in *field_list* from each of the aggregate bag input files, where *field_list* is a comma-separated list of field names. Field names that are not in the input aggregate bag are ignored. **`--select-fields=`*`field_list`*** For each aggregate bag input file, removes all fields that are NOT included in *field_list*. Extraction: **`--to-ipset=`*`field`*** Extract an IPset file from an aggregate bag by treating the values in the field named *field* as IP addresses, inserting the IP addresses into the IPset, and writing the IPset to the standard output or the destination specified by `--output-path`. **`--to-bag=`*`bag_key,bag_counter`*** Extract a bag file from an aggregate bag. Use the *bag_key* field as the key for the bag, and the *bag_counter* field as the counter for the bag. Write the bag to the standard output or the destination specified by `--output-path`. For additional parameters, see Table C.31.1.

C.26 `rwfileinfo` Command Summary

rwfileinfo

Description Displays summary information about one or more SiLK files

Call `rwfileinfo allflows.rw --fields=count-records,command-lines`

Parameters **`--fields`** Selects which summary information to display via number or name (by default, all the available fields). Possible values include

#	Field	Description
1	`format`	Binary file format indicator
2	`version`	Version of file header
3	`byte-order`	Byte order of words written to disk
4	`compression`	Type of space compression used
5	`header-length`	Number of bytes in file header
6	`record-length`	Number of bytes in fixed-length records
7	`count-records`	Number of records in the file unless record-length=1
8	`file-size`	Total number of bytes in the file on disk
9	`command-lines`	List of stored commands that generated this file
10	`record-version`	Version of records in file
11	`silk-version`	Software version of SiLK tool that produced this file
12	`packed-file-info`	Information from packing process
13	`probe-name`	Probe info for files created by flowcap
14	`annotations`	List of notes
15	`prefix-map`	Prefix map name and header version
16	`ipset`	IP-set format information
17	`bag`	Bag key and count information

`--summary` Prints a summary of total files, file sizes, and records

For additional parameters, see Table C.31.1 and Table C.31.1.

C.27 rwpmapbuild Command Summary

rwpmapbuild

Description	Creates a prefix map from a text file
Call	`rwpmapbuild --input-file=sample.pmap.txt --output-file=sample.pmap`
Parameters	**`--input-file`** Specifies the text file that contains the mapping between addresses and prefixes. When omitted, read from `stdin` **`--mode`** Specifies the type of input as if a `mode` statement appeared in the input. Valid values are `ipv4`, `ipv6`, and `proto-port`. **`--output-file`** Specifies the filename for the binary prefix map file **`--ignore-errors`** Writes the output file despite any errors in the input For additional parameters, see Table C.31.1 and Table C.31.1.

C.28 `rwpmaplookup` Command Summary

rwpmaplookup

Description	Shows label associated with an addresses' prefix map, address type, or country code
Call	`rwpmaplookup --map-file=spyware.map address-list.txt`
Parameters	Choose one: `--map-file` Specifies the pmap that contains the prefix map to query `--address-types` Finds IP addresses in the address-types mapping file specified in the argument or in the default file when no argument is provided `--country-codes` Finds IP addresses in the country-code mapping file specified in the argument or in the default file when no argument is provided Options: `--fields` Specifies the fields to print. Allowed values are: `key` (key used to query), `value` (label from prefix map), `input` (the text read from the input file [excluding comments] or IP address in canonical form from set input file), `block` (CIDR block containing the key), `start-block` (low address in CIDR block containing the key), and `end-block` (high address in CIDR block containing the key.) Default is `key,value`. `--no-files` Does not read from files and instead treat the command line arguments as the IP addresses or protocol/port pairs to find `--no-errors` Does not report errors parsing the input `--ipset-files` Treats the command-line arguments as names of binary IP-set files to read For additional parameters, see Table C.31.1 and Table C.31.1.

C.29 rwmatch Command Summary

rwmatch

Description	Matches IPv4 flow records that have stimulus-response relationships (IPv6 support introduced in Version 3.9.0)
Call	`rwmatch --relate=1,2 --relate=2,1 query.rw response.rw matched.rw`
Parameters	Choose one or none: **`--absolute-delta`** Includes potentially matching flows that start less than the interval specified by `--time-delta` after the end of the initial flow of the current match (default) **`--relative-delta`** Continues matching with flows that start within the interval specified by `--time-delta` from the greatest end time seen for previous members of the current match **`--infinite-delta`** After forming the initial pair of the match, continues matching on relate fields alone, ignoring time Options: **`--relate`** Specifies the numeric field IDs (1–8; see Figure C.6 on page 257) that identify stimulus and response (required; may be specified multiple times) Starting with Version 3.9.0 values may be 1–8, 12–14, 20–21, 26–29, iType, and iCode; values may be specified by name or numeric ID. **`--time-delta`** Specifies the number of seconds by which a time window is extended beyond a record's end time. The default value is zero. **`--symmetric-delta`** Also makes an initial match for a query that starts between a response's start time and its end time extended by `--time-delta` **`--unmatched`** Includes unmatched records from the query file and/or the response file in the output. Allowed arguments (case-insensitive) are one of these: `q` (query file), `r` (response file), `b` (both) For additional parameters, see Table C.31.1 and Table C.31.1.

C.30 `rwgroup` Command Summary

rwgroup

Description	Flags flow records that have common attributes
Call	`rwgroup --id-fields=sIP --delta-field=sTime --delta-value=3600 --output-path=grouped.rw`
Parameters	Choose one or both: **`--id-fields`** Specifies the fields that need to be identical **`--delta-field`** Specifies the field that needs to be close. Requires the `--delta-value` parameter Options: **`--delta-value`** Specifies closeness for the `--delta-field` parameter **`--objective`** Specifies that the `--delta-value` argument applies relative to the first record, rather than the most recent **`--rec-threshold`** Specifies the minimum number of records in a group **`--summarize`** Produces a single record as output for each group, rather than all flow records For additional parameters, see Table C.31.1 and Table C.31.1.

C.31 Features Common to Several Commands

Many of the SiLK tools share features such as using common parameters, providing help, handling the two versions of IP addresses, and controlling the overwriting of existing output files.

C.31.1 Parameters Common to Several Commands

Many options apply to several of the SiLK tools, as shown in Table C.31.1.

Table C.31.1 lists the same options as in Table C.31.1 and provides descriptions of the options. Three of the options described accept a small number of fixed values; acceptable values for `--ip-format` are listed and described in Table C.31.1, values for `--timestamp-format` are described in Table C.31.1, and values for `--ipv6-policy` are described in Table C.31.1 on page 289.

Parameter	rwfilter	rwstats	rwcount	rwcut	rwsort	rwuniq
--help	✓	✓	✓	✓	✓	✓
--legacy-help		✓				
--version	✓	✓	✓	✓	✓	✓
--site-config-file	✓	✓	✓	✓	✓	✓
filenames	✓	✓	✓	✓	✓	✓
--xargs	✓	✓	✓	✓	✓	✓
--print-filenames	✓	✓	✓	✓	✓	✓
--copy-input		✓	✓	✓		✓
--pmap-file	✓	✓		✓	✓	✓
--plugin	✓	✓		✓	✓	✓
--python-file	✓	✓		✓	✓	✓
--output-path		✓	✓	✓	✓	✓
--no-titles		✓	✓	✓		✓
--no-columns		✓	✓	✓		✓
--column-separator		✓	✓	✓		✓
--no-final-delimiter		✓	✓	✓		✓
--delimited		✓	✓	✓		✓
--ipv6-policy		✓		✓		✓
--ip-format		✓		✓		✓
--timestamp-format		✓	✓	✓		✓
--integer-sensors		✓		✓		✓
--integer-tcp-flags		✓		✓		✓
--pager		✓	✓	✓		✓
--note-add	✓				✓	
--note-file-add	✓				✓	
--dry-run	✓			✓		

Table C.19: Common Parameters in Essential SiLK Tools

Parameter	Description
`--help`	Prints usage description and exits
`--legacy-help`	Prints help for legacy switches
`--version`	Prints this program's version and installation parameters
`--site-config-file`	Specifies the name of the SiLK configuration file to use instead of the file in the root directory of the repository
filenames	Specifies one or multiple filenames as non-option arguments
`--xargs`	Specifies the name of a file (or `stdin` if omitted) from which to read input filenames
`--print-filenames`	Displays input filenames on `stderr` as each file is opened
`--copy-input`	Specifies the file or pipe to receive a copy of the input records
`--pmap-file`	Specifies a prefix-map filename and a map name as *mapname*`:`*path* to create a many-to-one mapping of field values to labels. For `rwfilter`, this creates new partitioning options: `--pmap-src-`*mapname*, `--pmap-dst-`*mapname*, and `--pmap-any-`*mapname*. For other tools, it creates new fields `src-`*mapname* and `dst-`*mapname* (see Section 6.2.7)
`--plugin`	For `rwfilter`, creates new switches and partitioning options with a plug-in program written in the C language. For other tools, creates new fields
`--python-file`	For `rwfilter`, creates new switches and partitioning options with a plug-in program written in Python. For other tools, creates new fields
`--output-path`	Specifies the output file's path
`--no-titles`	Doesn't print column headings
`--no-columns`	Doesn't align neat columns. Deletes leading spaces from each column
`--column-separator`	Specifies the character displayed after each column value
`--no-final-delimiter`	Doesn't display a column separator after the last column
`--delimited`	Combines `--no-columns`, `--no-final-delimiter`, and, if a character is specified, `--column-separator`
`--ipv6-policy`	Determines how IPv4 and IPv6 flows are handled when SiLK has been installed with IPv6 support (see Table C.31.1)
`--ip-format`	Chooses the format of IP addresses in output (see Table C.31.1)
`--timestamp-format`	Chooses the format and/or timezone of timestamps in output (see Table C.31.1)
`--integer-sensors`	Displays sensors as integers, not names
`--integer-tcp-flags`	Displays TCP flags as integers, not strings
`--pager`	Specifies the program used to display output one screen at a time
`--note-add`	Adds a note, specified in this option, to the output file's header
`--note-file-add`	Adds a note from the contents of the specified file to the output file's header
`--dry-run`	Checks parameters for legality without actually processing data

Table C.20: Parameters Common to Several Commands

Value	Description
`canonical`	Displays IPv4 addresses as dotted decimal quad and most IPv6 addresses as colon-separated hexadectets. IPv4-compatible and IPv4-mapped IPv6 addresses will be displayed in a combination of hexadecimal and decimal. For both IPv4 and IPv6, leading zeroes will be suppressed in octets and hexadectets. Double-colon compaction of IPv6 addresses will be performed.
`zero-padded`	Octets are zero-padded to three digits, and hexadectets are zero-padded to four digits. Double-colon compaction is not performed, which simplifies sorting addresses as text.
`decimal`	Displays an IP address as a single, large decimal integer.
`hexadecimal`	Displays an IP address as a single, large hexadecimal integer.
`force-ipv6`	Display all addresses as IPv6 addresses, using only hexadecimal. IPv4 addresses are mapped to the ::FFFF:0:0/96 IPv4-mapped netblock.

Table C.21: `--ip-format` Values

Value	Description
`default`	Formats timestamps as *YYYY/MM/DD*`T`*hh:mm:ss.sss* (`rwcut` and `rwcount` may display milliseconds; `rwuniq` and `rwstats` never do)
`iso`	Formats timestamps as *YYYY-MM-DD hh:mm:ss.sss*
`m/d/y`	Formats timestamps as *MM/DD/YYYY hh:mm:ss.sss*
`epoch`	Formats timestamps as the number of seconds since 1970/01/01 00:00:00 UTC (UNIX epoch) *ssssssssss.sss*
`no-msec`	Truncates milliseconds (*.sss*) from `sTime`, `eTime`, and `dur` fields – `rwcut` only
`utc`	Specifies timezone to use Coordinated Universal Time (UTC)
`local`	Specifies timezone to use the `TZ` environment variable or the system timezone

Table C.22: `--timestamp-format` *format*, *modifier*, and *timezone* Values

Appendix D

Additional Information on SiLK

Network Traffic Analysis with SiLK has been designed to provide an overview of data analysis with SiLK on an enterprise network. This overview has included the definition of network flow data, the collection of that data on the enterprise network, and the analysis of that data using the SiLK tool suite. The last chapter provided a discussion on how to extend the SiLK tool suite to support additional analyses.

This handbook provides a large group of analyses in the examples, but these examples are only a small part of the set of analyses that SiLK can support. The SiLK community continues to develop new analytical approaches and provide new insights into how analysis should be done. The authors wish the readers of this handbook good fortune in participation as part of this community.

D.1 SiLK Support and Documentation

The SiLK tool suite is available in open-source form at https://tools.netsa.cert.org/silk.

Before asking others to help with SiLK questions, it is wise to look first for answers in these resources:

***SiLK_tool* `--help`:** All SiLK tools (e.g., `rwfilter` or `rwcut`) support the `--help` option to display terse information about the syntax and usage of the tool.

`man` pages: All SiLK tools have online documentation known as manual pages, or `man` pages, that describe the tool more thoroughly than the `--help` text. The description is not a tutorial, however. `man` pages can be accessed with the `man` command on a system that has SiLK installed or via web links listed on the SiLK Documentation webpage at https://tools.netsa.cert.org/silk/docs.html#manuals.

***The SiLK Reference Guide*:** This guide contains the entire collection of `man` pages for all the SiLK tools in one document. It is provided at https://tools.netsa.cert.org/silk/reference-guide.html in HTML format and at https://tools.netsa.cert.org/silk/reference-guide.pdf in Adobe® Portable Document Format (PDF) .

SiLK Tool Suite Quick Reference booklet: This very compact booklet (located at https://tools.netsa.cert.org/silk/silk-quickref.pdf) describes the dozen most used SiLK commands in a small ($5.5'' \times 8.5''$) format. It also includes tables of flow record fields and transport layer protocols.

SiLK FAQ: This webpage answers frequently asked questions about the SiLK analysis tool suite. Find it at https://tools.netsa.cert.org/silk/faq.html.

D.2 FloCon Conference and Social Media

The CERT Division of the SEI supports FloCon®, an annual international conference devoted to large-scale data analysis for improving the security of networked systems—including flow analysis. More information on FloCon is provided at https://resources.sei.cmu.edu/news-events/events/flocon.

Since the FloCon conference covers a range of network security topics, including network flow analysis, the conference organizers encourage ongoing discussions. In support of this, the following social networking opportunities are offered:

@FloCon_News Twitter account: The FloCon conference organizers post notices related to FloCon here. View (and follow!) the FloCon tweets at https://twitter.com/FloCon_News.

"FloCon Conference" LinkedIn member: The FloCon Conference member page (https://www.linkedin.com/in/flocon) displays postings from the conference organizers, as well as from participants.

"FloCon" LinkedIn group: You can request membership to this private LinkedIn group at https://www.linkedin.com/groups?gid=3636774. Here, members discuss matters related to the FloCon conference and network flow analysis.

D.3 Email Addresses and Mailing Lists

The primary SiLK email addresses and lists are described below:

netsa-tools-discuss@cert.org: This distribution list is for discussion of tools produced by the CERT/CC for network situational awareness, as well as for discussion of flow usage and analytics in general. The discussion might be about interesting usage of the tools or proposals to enhance them. You can subscribe to this list at https://lists.sei.cmu.edu.

netsa-help@cert.org: This email address is for bug reports and general inquiries related to SiLK, especially support with deployment and features of the tools. It provides relatively quick response from CERT/CC users and maintainers of the SiLK tool suite. While a specific response time cannot be guaranteed, this address has proved to be a valuable asset for bugs and usage issues.

netsa-contact@cert.org: This email address provides an avenue for recipients of CERT Situational Awareness Group technical reports to reach the reports' authors. The focus is on analytical techniques. Public reports are provided at https://www.cert.org/netsa/publications.

flocontact@cert.org: General email address for inquiries about FloCon.

flocommunity@cert.org: This distribution list addresses a community of analysts built on the core of the FloCon conference. The list is not focused exclusively on FloCon itself, although it will include announcements of FloCon events.

Appendix E

Further Reading and Resources

This chapter gives helpful background information for many of the topics discussed in this guide. It is intended to be a starting point for further learning!

E.1 Network Flow and Related Topics

Much has been written on NetFlow, SiLK, and related analysis. Here we provide a non-comprehensive list of examples you may wish to consider. Several related topics will enhance your ability to to use SiLK effectively.

E.1.1 Technical Papers

Rick Hofstede, et al. *Flow Monitoring Explained: From Packet Capture to Data Analysis With NetFlow and IPFIX*, IEEE Communications Surveys and Tutorials (Volume 16, Issue 4, Fourth quarter 2014) https://ieeexplore.ieee.org/document/6814316/?arnumber=6814316&tag=1

T. Taylor, S. Brooks, J. McHugh. "NetBytes Viewer: An Entity-Based NetFlow Visualization Utility for Identifying Intrusive Behavior." In: Goodall J.R., Conti G., Ma KL. (eds) *VizSEC 2007. Mathematics and Visualization.* Springer, Berlin, Heidelberg. https://link.springer.com/chapter/10.1007/978-3-540-78243-8_7#citeas

T. Taylor, D. Paterson, J. Glanfield, C. Gates, S. Brooks and J. McHugh, "FloVis: Flow Visualization System," *2009 Cybersecurity Applications and Technology Conference for Homeland Security*, Washington, DC, 2009, pp. 186-198. doi: 10.1109/CATCH.2009.18 http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4804443&isnumber=4804414

Jeff Janies, Red Jack. *Protographs: Graph-Based Approach to NetFlow Analysis.* FloCon 2011 https://resources.sei.cmu.edu/asset_files/Presentation/2011_017_101_50576.pdf

M. Thomas, L. Metcalf, J. Spring, P. Krystosek and K. Prevost, "SiLK: A Tool Suite for Unsampled Network Flow Analysis at Scale," *2014 IEEE International Congress on Big Data*, Anchorage, AK, 2014, pp. 184-191. doi: 10.1109/BigData.Congress.2014.34 http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6906777&isnumber=6906742

V. Marinov, J. Schoenwaelder. "Design of an IP Flow Record Query Language." In: D. Hausheer, J. Schoenwaelder (eds) *Resilient Networks and Services.* AIMS 2008. Lecture Notes in Computer Science, vol 5127. Springer, Berlin, Heidelberg, 2008

M. M. Najafabadi, T. M. Khoshgoftaar, C. Calvert and C. Kemp,"Detection of SSH Brute Force Attacks Using Aggregated Netflow Data," *2015 IEEE 14th International Conference on Machine Learning and Applications (ICMLA)*, Miami, FL, 2015, pp. 283-288. doi: 10.1109/ICMLA.2015.20 http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7424322&isnumber=7424247

Udaya Wijesinghe, Udaya Tupakula, Vijay Varadharajan. "An Enhanced Model for Network Flow Based Botnet Detection." *Proceedings of the 38th Australasian Computer Science Conference (ACSC 2015)*, Sydney, Australia, 27 - 30 January 2015 http://crpit.com/confpapers/CRPITV159Wijesinghe.pdf

E.1.2 Books on Network Flow and Network Security

Michael W. Lucas. *Network Flow Analysis.* no starch press. June 2010, ISBN-13: 978-1-59327-203-6 https://nostarch.com/networkflow

Omar Santos, *Network Security with NetFlow and IPFIX.* 2016 Cisco Systems, Inc, Cisco Press, Indianapolis, IN http://www.ciscopress.com/store/network-security-with-netflow-and-ipfix-big-data-analytics-9781587144387

E.2 Bash Scripting Resources

Throughout this book, we use bash scripts to organize and execute collections of SiLK commands. There are many books, online classes, and web tutorials on Bash and its uses. Here are some that may be helpful.

E.2.1 Online Tutorial

Online Shell Scripting Tutorial: https://www.shellscript.sh

E.2.2 Books on Bash Scripting

Many books have been written on Bash and shell scripting in general. See the following publishers for their current list of titles relating to Bash.

Google search for Bash scripting books: https://www.google.com/search?q=list+of+books+on+Bash+scripting

O'Reilly
https://www.oreilly.com
https://ssearch.oreilly.com/?q=bash

No Starch Press, Inc.
https://nostarch.com
https://nostarch.com/search/node/bash%20scripting

John Wiley and Sons/WROX
http://www.wrox.com/WileyCDA/Section/id-WROX_SEARCH_RESULT.html?query=bash

Addison Wesley
https://openlibrary.org/search?q=bash+scripting&mode=everything

Linux Training Academy
https://www.linuxtrainingacademy.com/books

E.3 Visualization

The following tools are useful for visually displaying SiLK data.

E.3.1 Rayon

Rayon is a Python library and set of tools for generating basic, two-dimensional statistical visualizations. Rayon can be used to automate reporting; provide data visualization in command-line, GUI or web applications; or do ad-hoc exploratory data analysis.

https://tools.netsa.cert.org/rayon/index.html

E.3.2 FloViz

FloViz is a comprehensive and extensible set of visualization tools. It is integrated with the SiLK tool suite via a relational database that stores data such as sets and multisets (bags) that are derived from NetFlow and similar sources.

https://web.cs.dal.ca/~sbrooks/projects/NetworkVis/index.html

E.3.3 Graphviz - Graph Visualization Software

Network flow records can be visualized as directed graphs. Graphviz can be used to produce such visualizations.

https://www.graphviz.org

E.3.4 The Spinning Cube of Potential Doom

First implemented as a demonstration, it is an interesting display of network traffic at the Supercomputing conference in 2004. It has since taken on a life of its own.

http://www.nersc.gov/news-publications/nersc-news/nersc-center-news/1998/cube-of-doom

Stephen Lau. "The Spinning Cube of Potential Doom." *Commun. ACM 47, 6* (June 2004), 25-26. https://dx.doi.org/10.1145/990680.990699

E.4 Networking Standards

Service Name and Transport Protocol Port Number Registry
https://www.iana.org/assignments/service-names-port-numbers

RFC 871, A Perspective on the ARPANET Reference Model.
https://tools.ietf.org/html/rfc871

ETF RFC 3954, Cisco Systems NetFlow Services Export Version 9, 2004
https://www.ietf.org/rfc/rfc3954.txt

RFC 4291, IP Version 6 Addressing Architecture
https://tools.ietf.org/html/rfc4291

RFC 6890, Special-Purpose IP Address Registries
https://tools.ietf.org/html/rfc6890.

IPFIX standards:

RFC3917: Requirements for IP Flow Information Export (IPFIX)

RFC3955: Candidate Protocols for IP Flow Information Export (IPFIX)

RFC5101: Specification of the IP Flow Information Export (IPFIX) Protocol for the Exchange of IP Traffic Flow Information (IPFIX)

RFC5102: Information Model for IP Flow Information Export

RFC5103: Bidirectional Flow Export Using IP Flow Information Export

RFC5153: IPFIX Implementation Guidelines

RFC5470: Architecture for IP Flow Information Export

RFC5471: Guidelines for IP Flow Information Export (IPFIX) Testing

RFC5472: IP Flow Information Export (IPFIX) Applicability

RFC5473: Reducing Redundancy in IP Flow Information Export (IPFIX) and Packet Sampling (PSAMP) Reports

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Carnegie Mellon University
Software Engineering Institute

Network Traffic Analysis with SiLK

Analyst's Handbook for SiLK Version 3.15.0 and Later

June 2019