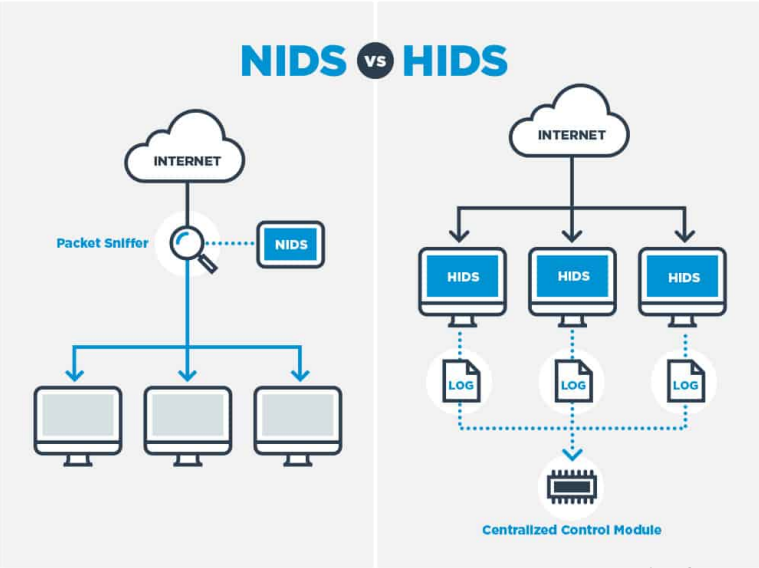
Network Traffic Analysis with Malcolm

Malcolm Development Team • Cybersecurity R&D • Idaho National Lab

Intrusion Detection Systems

- HIDS: Host Intrusion Detection Systems
  - Agents run on individual hosts or devices on a network
- NIDS: Network Intrusion Detection Systems
  - Monitor and analyze network traffic for anomalies: suspicious activity, policy violations, etc.
  - Generally passive/out-of-band; otherwise it's an Intrusion Prevention System
  - Detection methods
    - Signature-based detection (e.g., Suricata)
    - Statistical anomaly-based detection (e.g., Random Cut Forest)
    - Stateful protocol analysis detection (e.g., Zeek)



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IDS: Types of Attacks

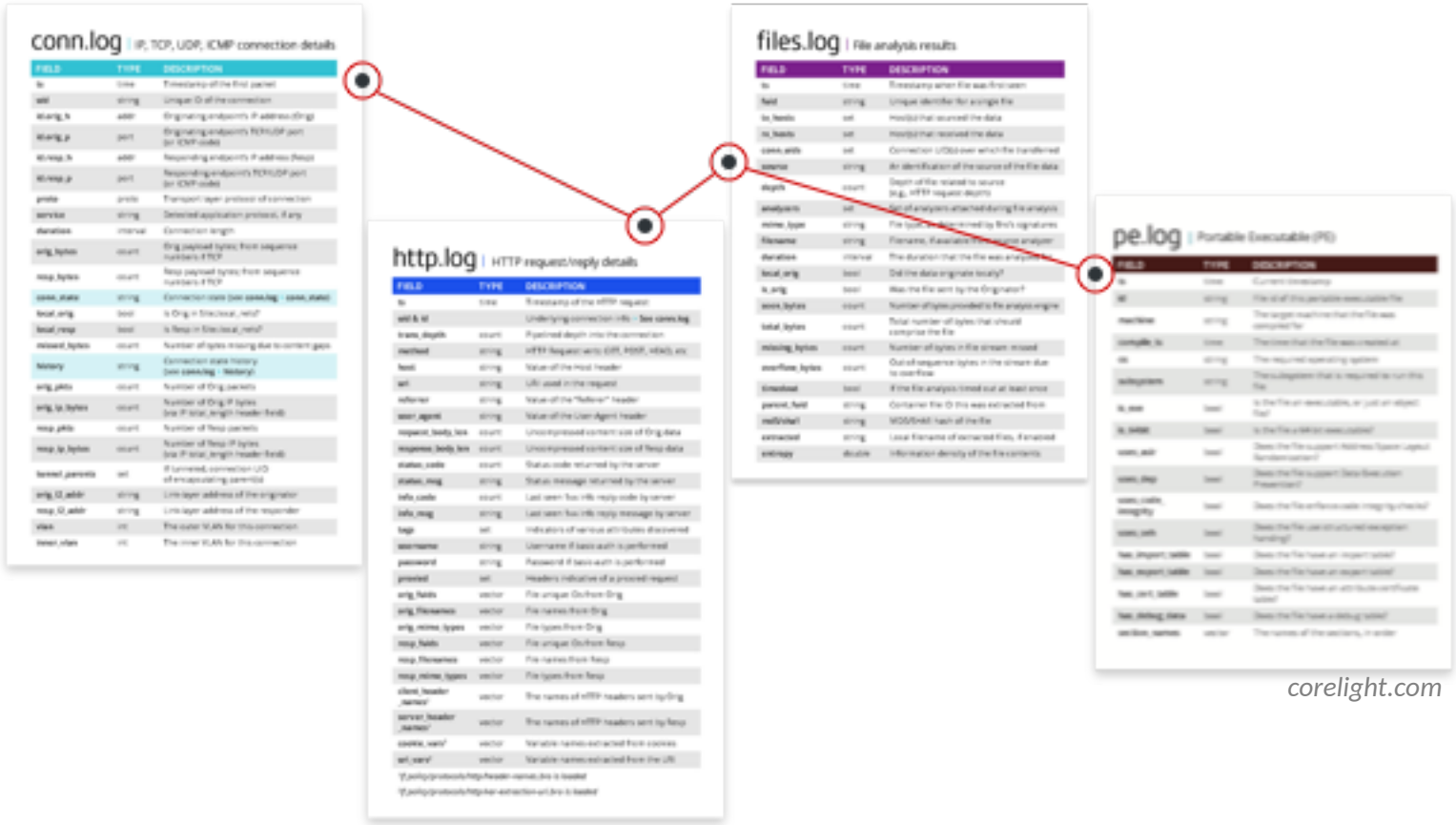
- Scanning Attack
  - Determine network topology
  - IDS highlights connections from one host to many other hosts in the network, or connection attempts to sequential IP addresses and/or ports
- Denial of Service Attack
  - Interrupt service by flooding requests or flaws in protocol implementations
  - IDS identifies large volume of traffic from or to a particular host or invalid connection states (e.g., TCP SYN/ACK with no ACK)
- Penetration Attack
  - Gain access to system resources by exploiting a software or configuration flaw
  - Trickier, but IDS may detect vulnerable software versions or simply alert on unusual operations (e.g., a “write” operation in an already-configured environment with mostly “read” operations)

- Extensible, open-source passive network analysis framework
- More than just an Intrusion Detection System:
  - Packet capture (like TCPDUMP)
  - Traffic inspection (like Wireshark)
  - Intrusion detection (like SNORT)
  - Log recording (like NetFlow and syslog)
  - Scripting framework (like python™)

Strengths	Weaknesses
• Analyzes both link-layer and application-layer behavior • Content extraction • Behavioral analysis • Session correlation • Can add support for uncommon protocols through scripts/plugins	• Session metadata only (not full payload) • Setup and configuration can be complicated • Produces flat textual log files which can be unwieldy for in-depth analysis

Zeek Log Files

- Network Protocols
- Files
- Detection
- Network Observations



corelight.com

Network Protocols

- `conn` – Network session tracking
  - Identified by session 4-tuple (originating IP:port, responding IP:port)
  - One session (line in a log file) for every IP connection
  - Unique identifier (UID) ties lines from other logs to a session
- `http`, `modbus`, `ftp`, `dns`, etc.
  - Protocol-specific log files created as traffic is seen
  - Contain application-layer metadata about network activities

Files

- `files` – File analysis results
  - Each transferred file identified with FUID
  - Associated with connection UID(s) over which file was transferred
  - File name, mime type, file size, etc. provided when available
- `pe` – Analysis of Portable Executable (PE) files
  - Target platform, architecture, OS, etc. for executables transferred across the network
- `x509` – Analysis of X.509 public key certificates

Malcolm Components

https://idaholab.github.io/Malcolm/docs/components.html

Capture & Analysis

- zeek
- Arkime
- SURICATA
- netsniff-ng
- TCPDUMP

File Scanning

- yara
- ClamAV
- CAPA
- VIRUSTOTAL

Forwarding & Enrichment

- fluentbit
- logstash
- beats

Storage

- OpenSearch

Anomaly Detection

- Anomaly Detection Plugin
- Alerting
- Alerting Plugin

Asset Management

- netbox

Visualization

- OpenSearch Dashboards
- Arkime

Payload Analysis

- CyberChef
- Arkime session PCAP export to WIRESHARK

Framework

- docker
- NGINX
- kubernetes

Detection

- `notice` – Zeek concept of “alarms,” notices draw extra attention to an event
  - `Conn::Content_Gap, DNS::External_Name, FTP::Bruteforcing, Heartbleed::SSL_Heartbeat_Attack, HTTP::SQL_Injection_Attacker, Scan::Address_Scan, Scan::Port_Scan, Software::Vulnerable_Version, SSH::Password_Guessing, SSL::Certificate_Expired, Weird::Activity, …`
  - https://docs.zeek.org/en/stable/zeek-noticeindex.html

Detection (cont.)

- `weird` – Unexpected network-level activity
  - > 150 weirdness indicators across many protocols
  - https://docs.zeek.org/en/stable/scripts/base/frameworks/notice/weird.zeek.html#id1
- `signatures` – Signature matches, including hits from enabled carved file scanners like ClamAV, YARA and capa

Network Observations

- Periodic dump of entities seen over the last day
  - `known_certs` – SSL certificates
  - `known_devices` – MAC addresses
  - `known_hosts` – Hosts with TCP handshakes
  - `known_modbus` – Modbus masters and slaves
  - `known_services` – Services (TCP “servers”)
  - `software` – Software being used on the network (e.g., Apache, OpenSSH, etc.)
    - Could be used for identifying vulnerable versions of software or firmware

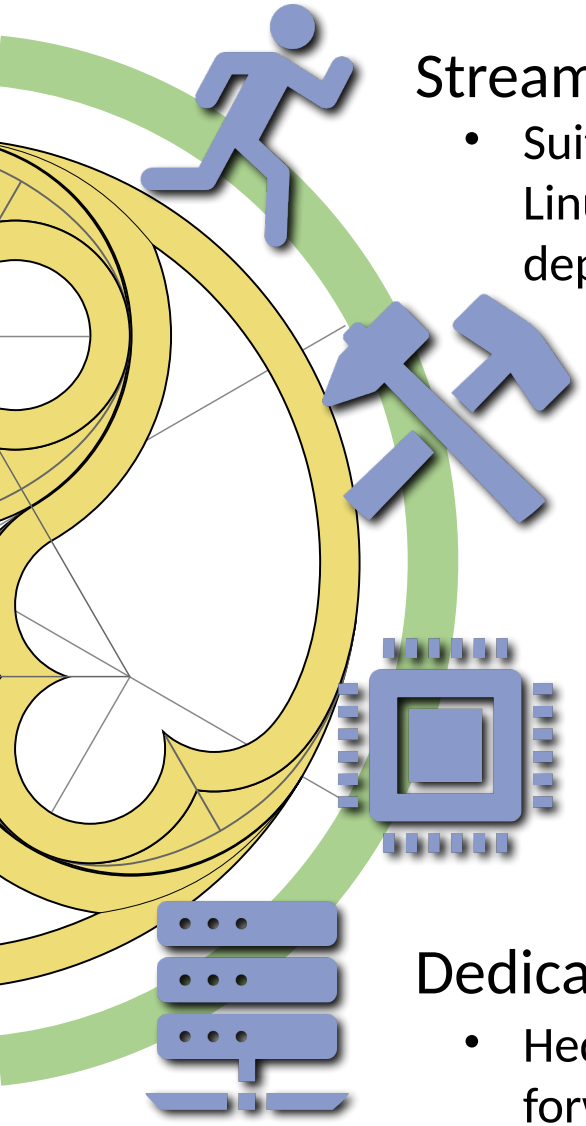
Arkime

Strengths	Weaknesses
• Large scale index packet capture and search tool • Packet analysis engine with support for many common IT protocols • Web interface for browsing, searching, analysis and PCAP carving for exporting • PCAP payloads (not just session header/metadata) are viewable and searchable	• No OT protocol support • Adding new protocol parsers requires C programming

Malcolm

A powerful open-source network traffic analysis tool suite.

https://idaholab.github.io/Malcolm



Streamlined deployment

- Suitable for field use (hunt or incident response) or SOC deployment. Runs in Docker on Linux, macOS and Windows platforms. ISO installer for bare metal installations. Cloud-deployable with Kubernetes. Provides easy-to-use web-based user interfaces.

Industry-standard tools

- Uses Arkime, Zeek, and Suricata for traffic analysis; Logstash for parsing and enrichment; OpenSearch for indexing; and Dashboards and Arkime for visualization. Also leverages OpenSearch Anomaly Detection, NetBox, YARA, capa, ClamAV, CyberChef, and other proven tools for analysis of traffic and artifacts.

Expanding control systems visibility

- Analyzes more protocols used in operational technology (OT) networks than other open-source or paid solutions. Ongoing development is focused on increasing the quantity and quality of industrial control systems (ICS) traffic.

Dedicated sensor appliance

- Hedgehog Linux, a hardened Linux distribution for capturing network traffic and forwarding its metadata to Malcolm.

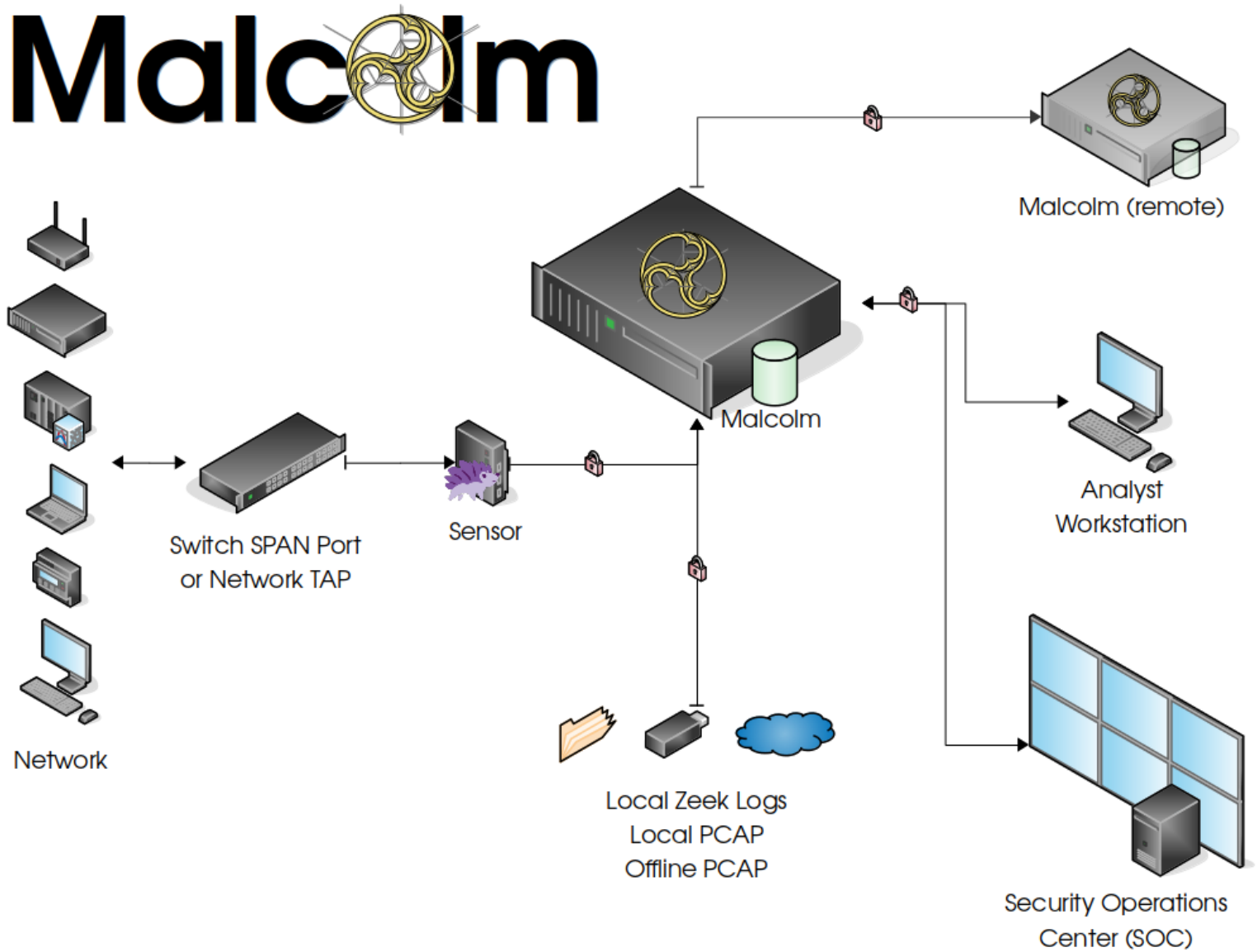
Malcolm Origins and Milestones

- 2018.Q2 – Development begins under USBR/CISA work agreement
- 2018.Q3 to 2019.Q2 – Malcolm field tested at USBR facilities
- 2019.Q2 – Initial public release
- 2019.Q4 – Hedgehog Linux released
- 2021.Q1 – 1k st★rs on GitHub
- 2022.Q3 – First Malcolm-based simulated engagements at INL's ICS Control Environment Lab Resource (CELR)
- 2022.Q3 – Malcolm discussed during session of the U.S. House of Representatives Homeland Security Committee
- 2022.Q4 – NetBox provides asset inventory and interaction analysis
- 2023.Q1 – Kali announces "Purple" distro bundling Malcolm
- 2023.Q2 – Cloud deployable with K8s
- 2024.Q2 – 2k st★rs on GitHub, community discussions board and new training offerings
- 2024.Q3 – First public Malcolm user conference, Mal.Con24

Malcolm What Can It Do For Me?

- Get to know your network: Malcolm **characterizes** traffic by devices and the protocols they use to communicate.
- Understand risks and threats: Malcolm **identifies** active exploits, potential attack vectors, and vulnerable devices and protocols.
- Increase visibility: Malcolm **highlights** inbound, outbound, and internal communications to inform decisions and improve security posture.

Malcolm


Malcolm (remote)
Malcolm
Analyst
Workstation
Switch SPAN Port
or Network TAP
Sensor
Network
Local Zeek Logs
Local PCAP
Offline PCAP
Security Operations
Center (SOC)

Supported Protocols

https://idaholab.github.io/Malcolm/docs/protocols.html

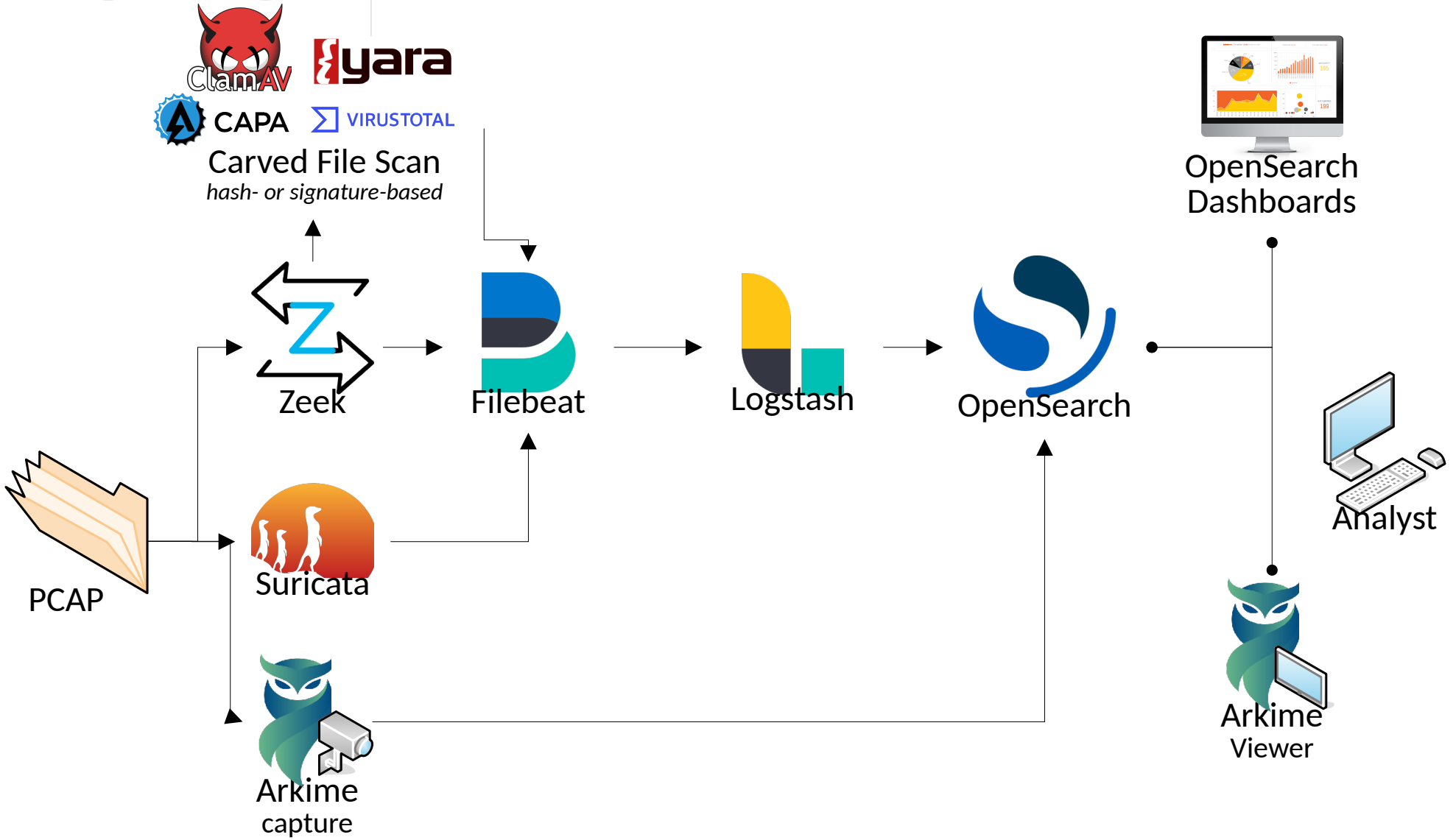
Internet layer
Border Gateway Protocol (BGP)
Building Automation and Control (BACnet)
Bristol Standard Asynchronous Protocol (BSAP)
Distributed Computing Environment / Remote Procedure Calls (DCE/RPC)
Dynamic Host Configuration Protocol (DHCP)
Distributed Network Protocol 3 (DNP3)
Domain Name System (DNS)
EtherCAT
EtherNet/IP / Common Industrial Protocol (CIP)
FTP (File Transfer Protocol)
Genisys
GE Service Request Transport Protocol (SRTP)
Google Quick UDP Internet Connections (gQUIC)
Hypertext Transfer Protocol (HTTP)
IPsec
Internet Relay Chat (IRC)
Lightweight Directory Access Protocol (LDAP)
Kerberos
Modbus
MQ Telemetry Transport (MQTT)
MySQL
NT Lan Manager (NTLM)
Network Time Protocol (NTP)
Oracle
Open Platform Communications Unified Architecture (OPC UA) Binary
Open Shortest Path First (OSPF)
OpenVPN
PostgreSQL
Process Field Net (PROFINET)
Remote Authentication Dial-In User Service (RADIUS)
Remote Desktop Protocol (RDP)
Remote Framebuffer / Virtual Network Computing (RFB/VNC)
S7comm / Connection Oriented Transport Protocol (COTP)
Secure Shell (SSH)
Secure Sockets Layer (SSL) / Transport Layer Security (TLS)
Session Initiation Protocol (SIP)
Server Message Block (SMB) / Common Internet File System (CIFS)
Simple Mail Transfer Protocol (SMTP)
Simple Network Management Protocol (SNMP)
SOCKS
STUN (Session Traversal Utilities for NAT)
Synchrophasor (IEEE C37.118)
Syslog
Tabular Data Stream (TDS)
Telnet / remote shell (rsh) / remote login (rlogin)
TFTP (Trivial File Transfer Protocol)
WireGuard
various tunnel protocols (e.g., GTP, GRE, Teredo, AYIYA, IP-in-IP, etc.)

* *Operational Technology (OT) protocols indicated with* ***bold***

Malcolm

Data Pipeline

https://idaholab.github.io/Malcolm/



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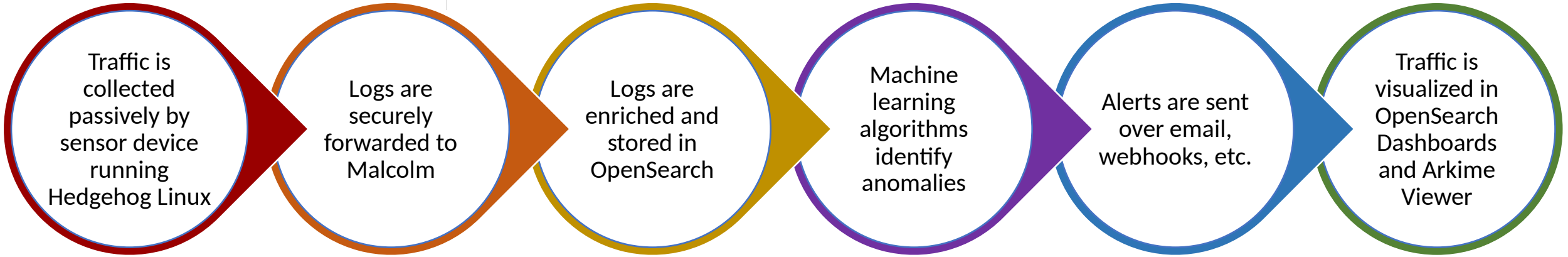


- Zeek, Arkime, and Suricata generate metadata about network communications
- Full PCAP is stored locally on the sensor
- Files transfers are detected, and the files scanned for threats
- PCAP may also be uploaded to or captured by Malcolm without requiring a dedicated sensor

- Communications between the sensor and aggregator are TLS-encrypted
- Sensor data including resource utilization, syslog, audit logs, temperatures, and more may also be forwarded
- Other third-party logs (e.g., Windows even logs, server host logs, etc.) may be shipped using Fluent Bit or Beats

- Lookups are performed for GeoIP, ASN, MAC-to-vendor, community ID, domain name entropy, etc.
- Network events are normalized across protocols and data sources
- Best-guess techniques are applied to identify obscure OT traffic
- Enriched metadata may be forwarded to higher-tiered Malcolm instance

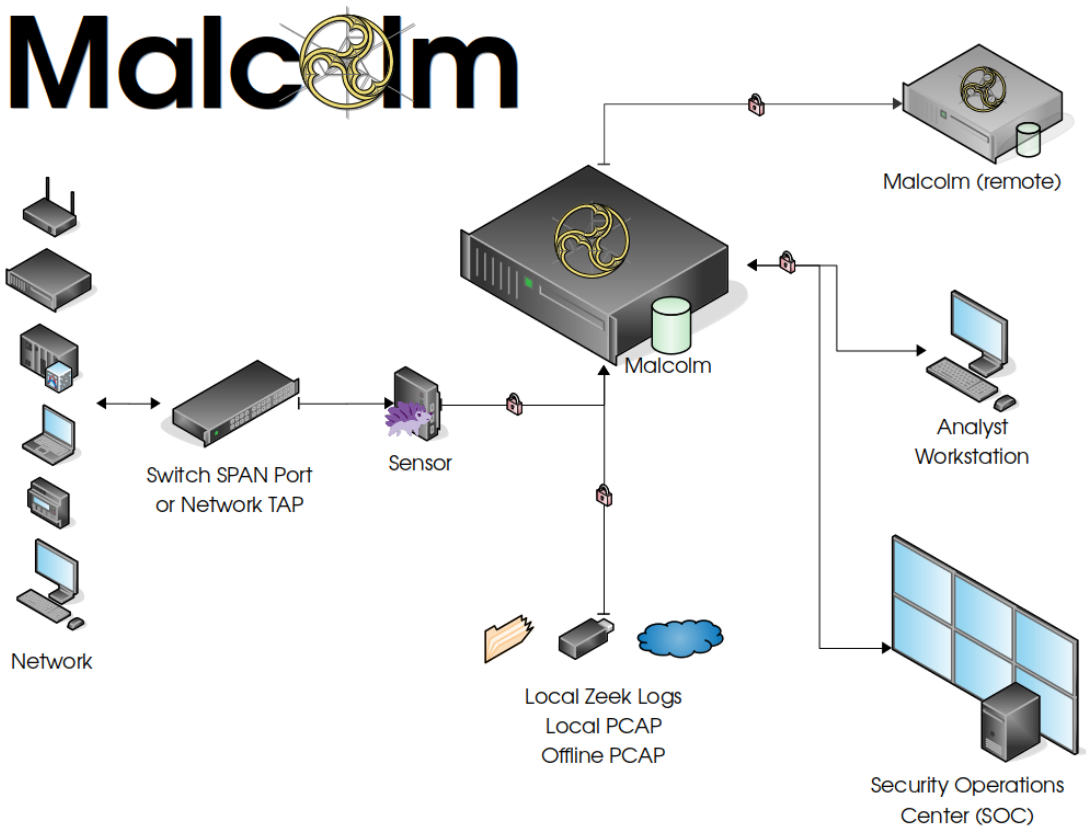
- Default detectors are provided for action and result, flow size, and MIME types of file transfers
- Custom detectors may be created for any aspect of any supported protocol

- Alerts may be triggered by exceeded thresholds, anomalies detected, custom queries, etc.

- Dozens of custom dashboards are provided for all supported protocols
- PCAP payloads are retrieved from sensor on demand
- Create custom visualizations via drag-and-drop interface
- Malcolm authenticates users from its own list or Active Directory / LDAP

Configuring and Running Malcolm

- Runs natively in Docker, use ISO installer for VM or bare metal install, or cloud deploy with Kubernetes
- Recommended system requirements: 64+GB RAM, 16+ CPU cores, “enough” storage for PCAP and logs
- Documentation and source code on GitHub: https://idaholab.github.io/Malcolm
- Walkthroughs on YouTube “Malcolm Network Traffic Analysis”



Malcolm

Dashboards

Visualize traffic or track down security concerns with dozens of pre-built dashboards, or create your own

Arkime

Delve into session details including full packet payloads

NetBox

Model and document your network infrastructure

CyberChef

Slice and dice data with this web app for encryption, encoding, compression and data analysis

Documentation

Read the Malcolm user guide

Artifact Upload

Upload previously-captured PCAP files or archived Zeek logs for analysis

Local Account Management

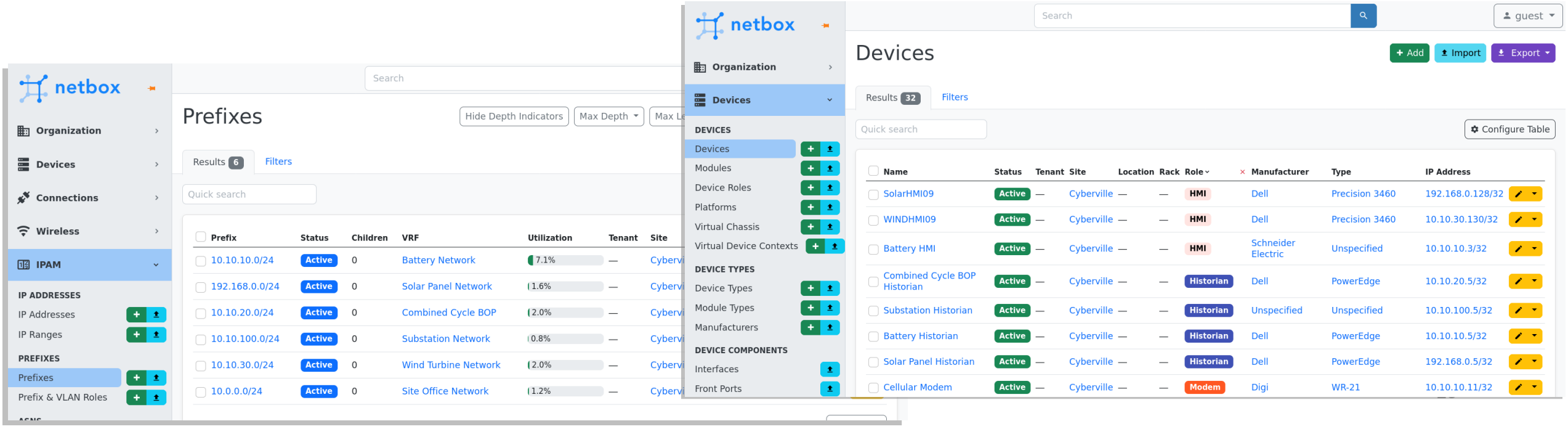
Manage the local user accounts maintained by Malcolm

Extracted Files

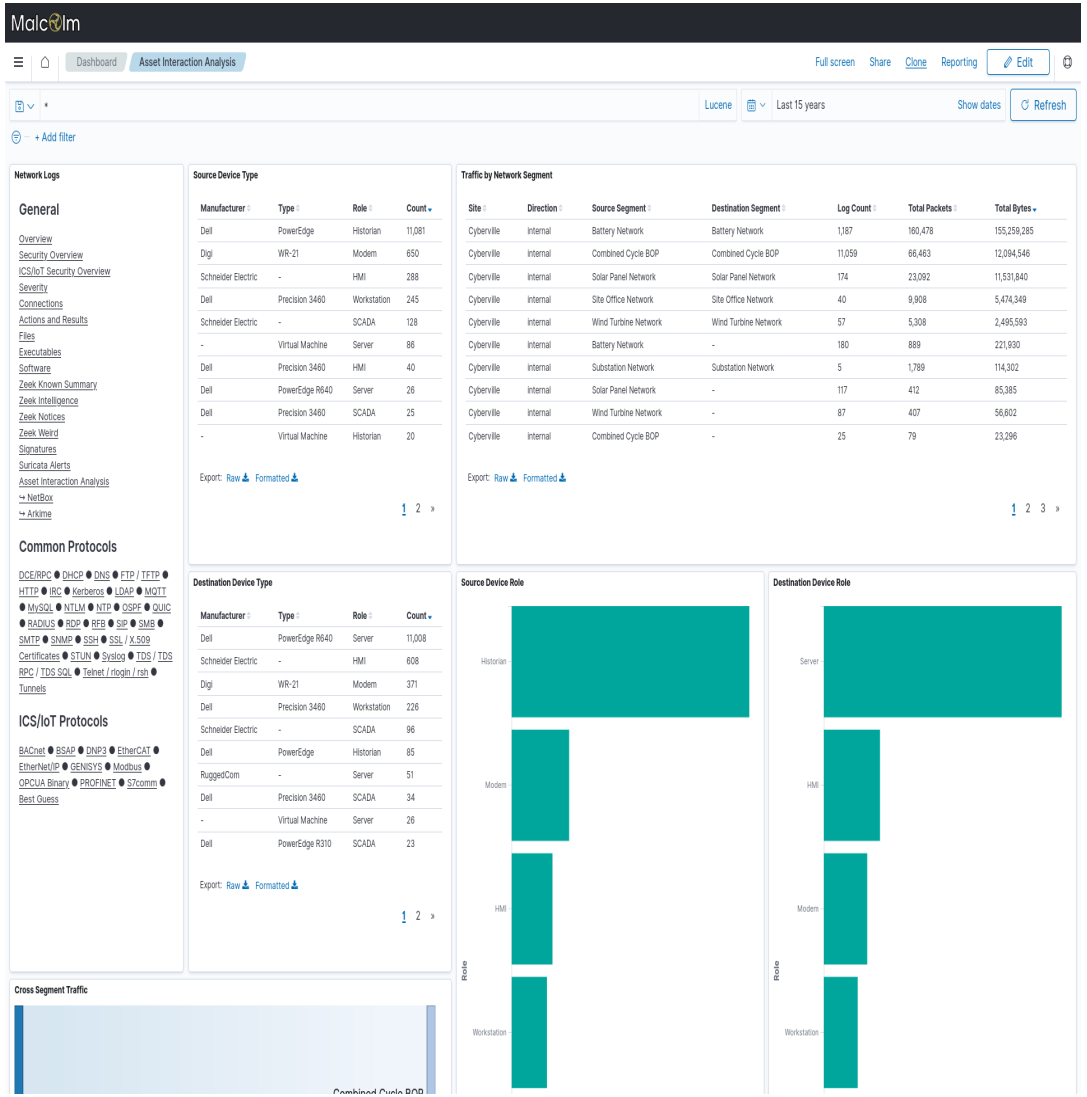
Browse the preserved extracted files carved and scanned by Malcolm

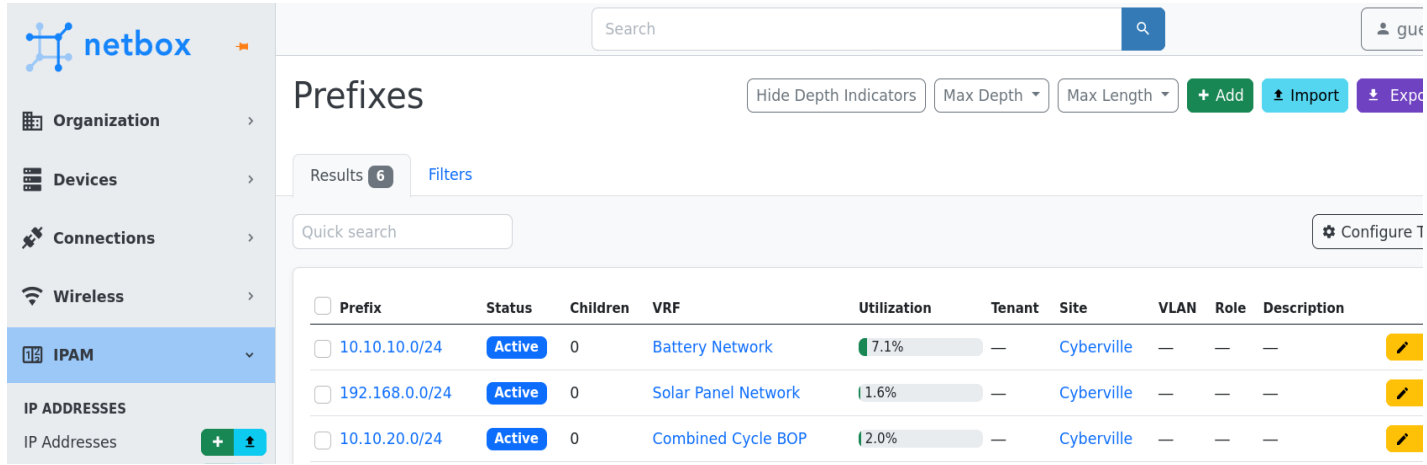
Identifying Network Hosts and Subnets

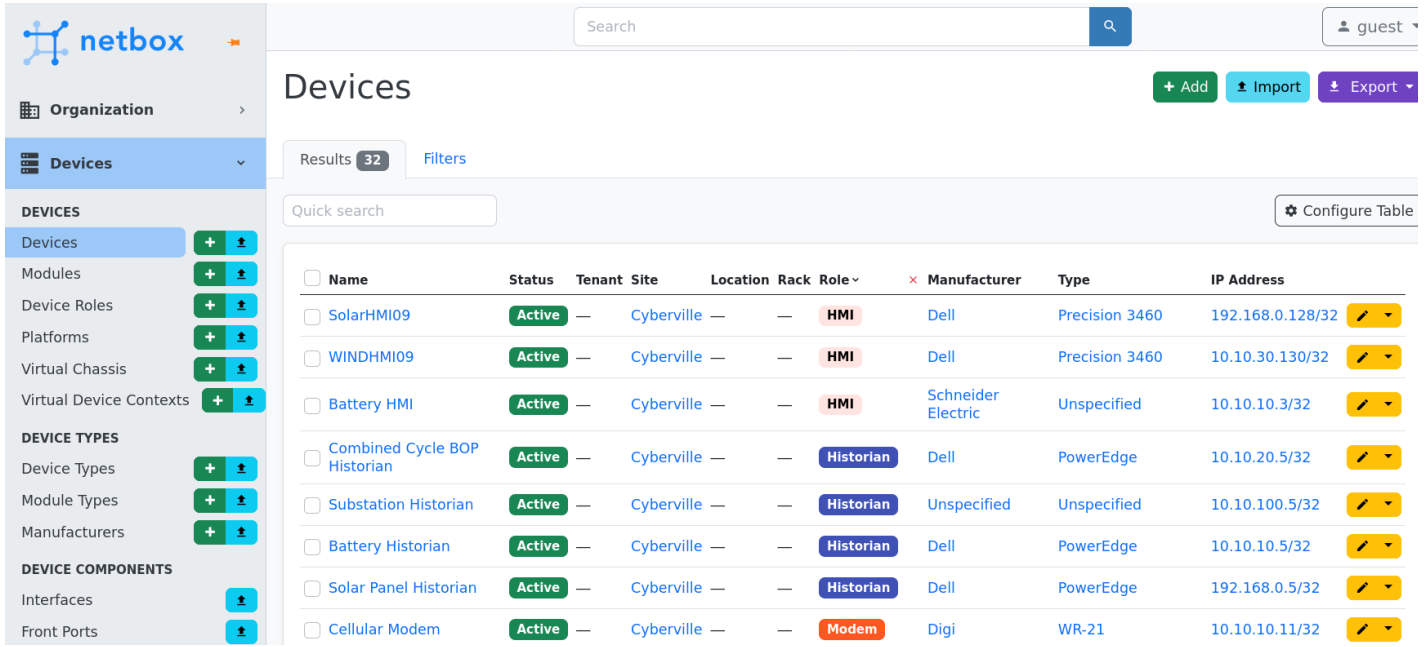
- Assign custom names to network devices and subnets prior to traffic ingest
- Allows identification of cross-segment traffic and network log enrichment
- Define in NetBox



Asset Interaction Analysis

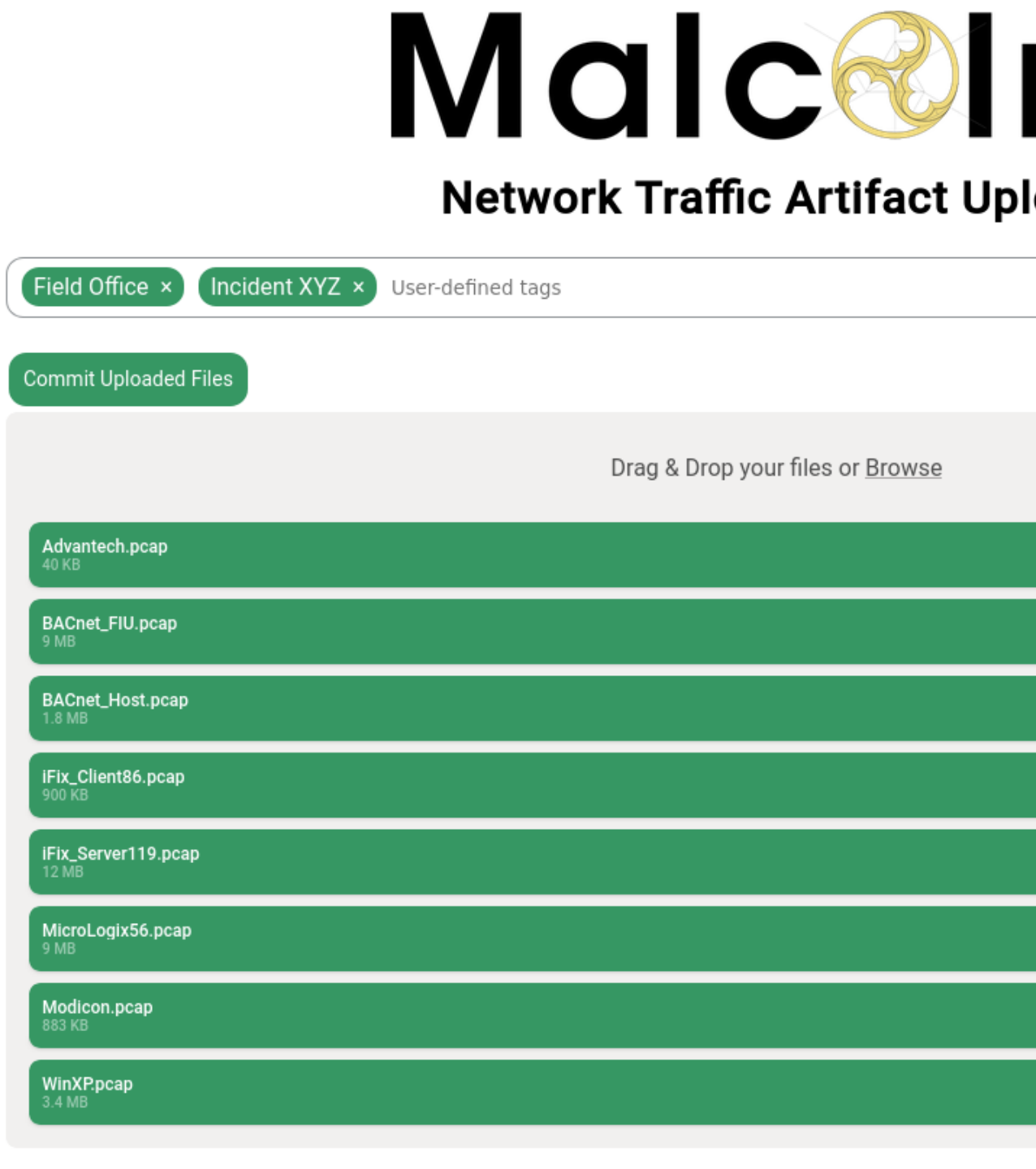






Importing Traffic Captures for Analysis

- Upload PCAP files or archived Zeek logs
  - pcapng not supported yet
- Specify tags for search and filter
- Specify NetBox site



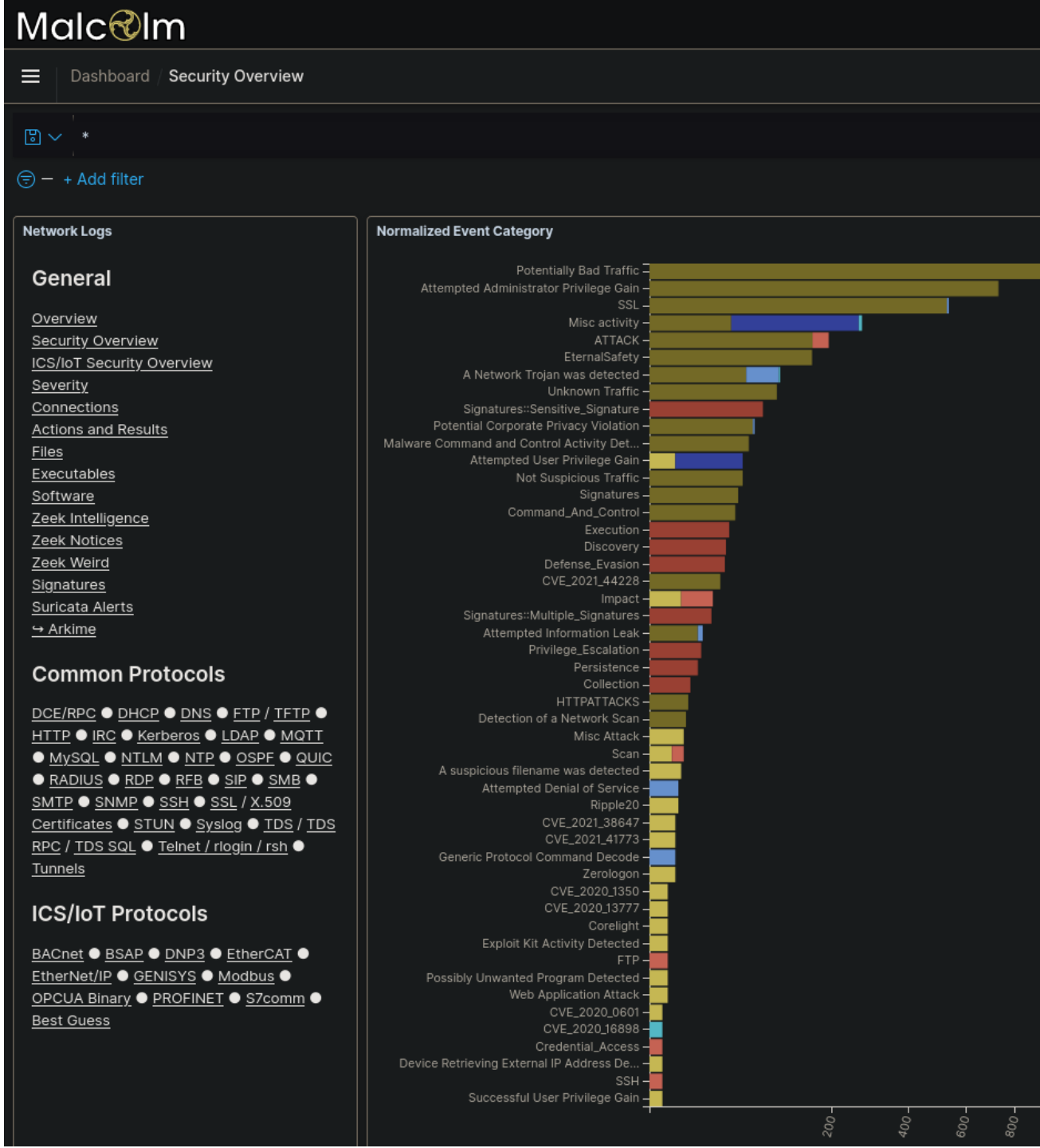
Data Tagging and Enrichment

- Logstash enriches Zeek and Suricata log metadata
  - MAC addresses to hardware vendor
  - GeoIP and ASN lookups
  - Internal/external traffic based on IP ranges
  - Reverse DNS lookups
  - DNS query and hostname entropy analysis
  - Connection fingerprinting (JA4+ for TLS and more, HASSH for SSH, Community ID for flows)

- `tags` field
  - Populated for Arkime sessions, Zeek logs and Arkime alerts with tags provided on upload and words extracted from PCAP filenames
  - `ics`, `ics_best_guess`, `cross_segment`, `etc.`

OpenSearch Dashboards

- Front end for Zeek logs and Suricata alerts
- Prebuilt visualizations for all supported protocols
- WYSIWYG editors to create custom visualizations and dashboards
- Drill down from high-level trends to specific items of interest

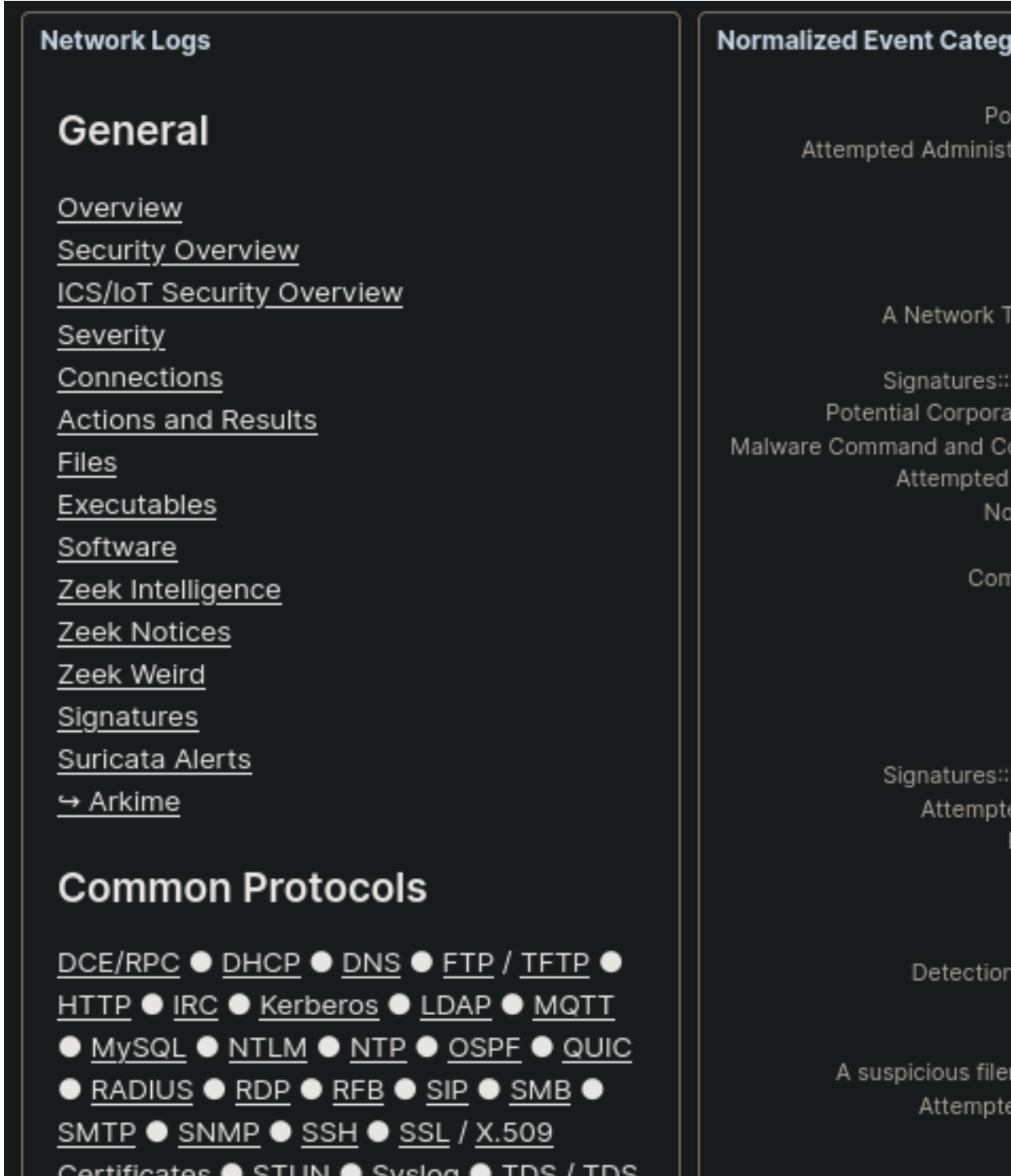


Dashboards Filters and Search

- Time filter: define search time frame
- Query bar: write queries in Lucene syntax or DQL (Dashboards Query Language)
- Filter bar: define filters using a UI
  - Pin filters as you move across dashboards
- Save queries and filters for reuse

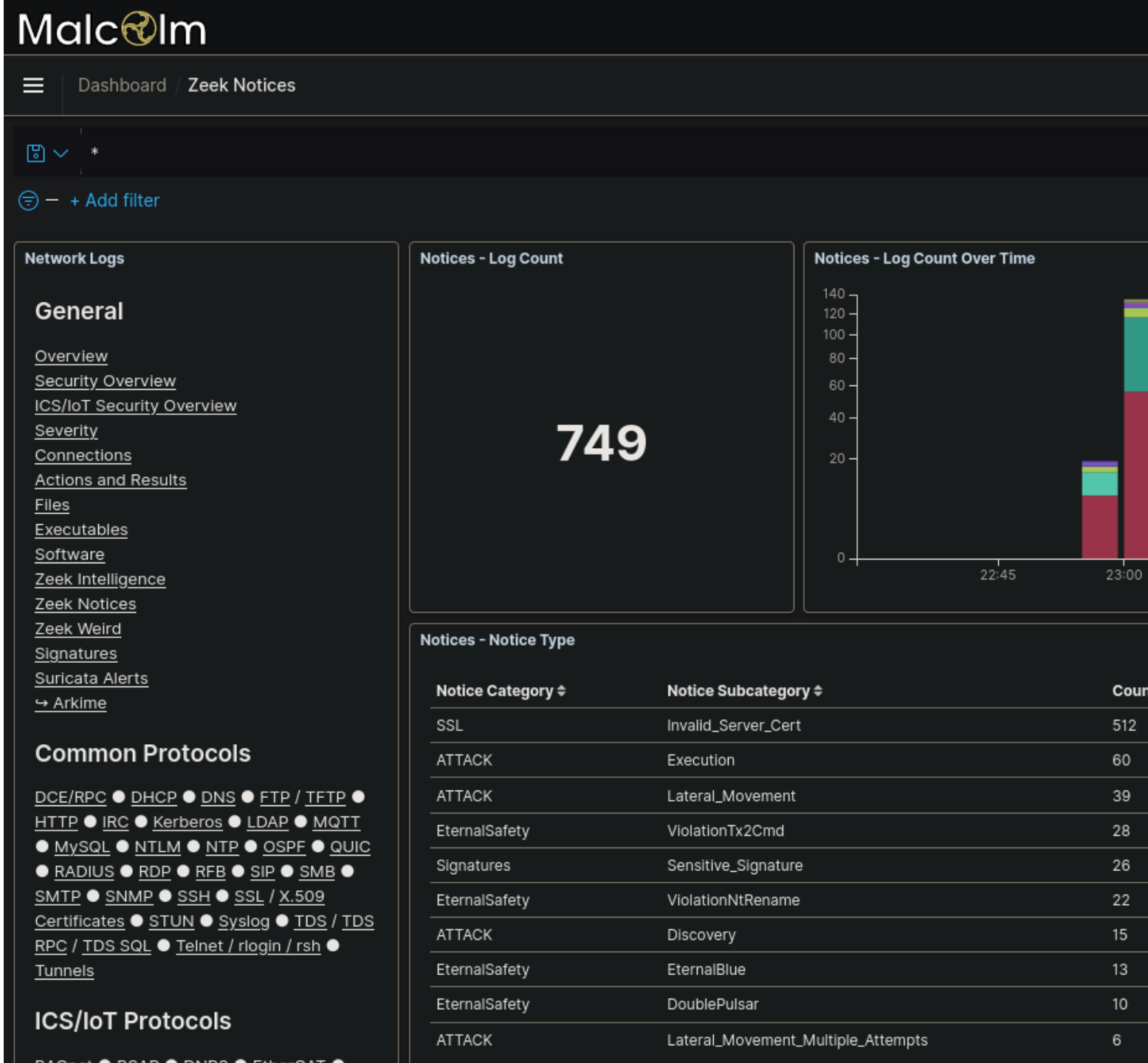
Overview Dashboards

- High-level view of trends, sessions and events
- Populated from logs across all protocols
- Good jumping-off place for investigation



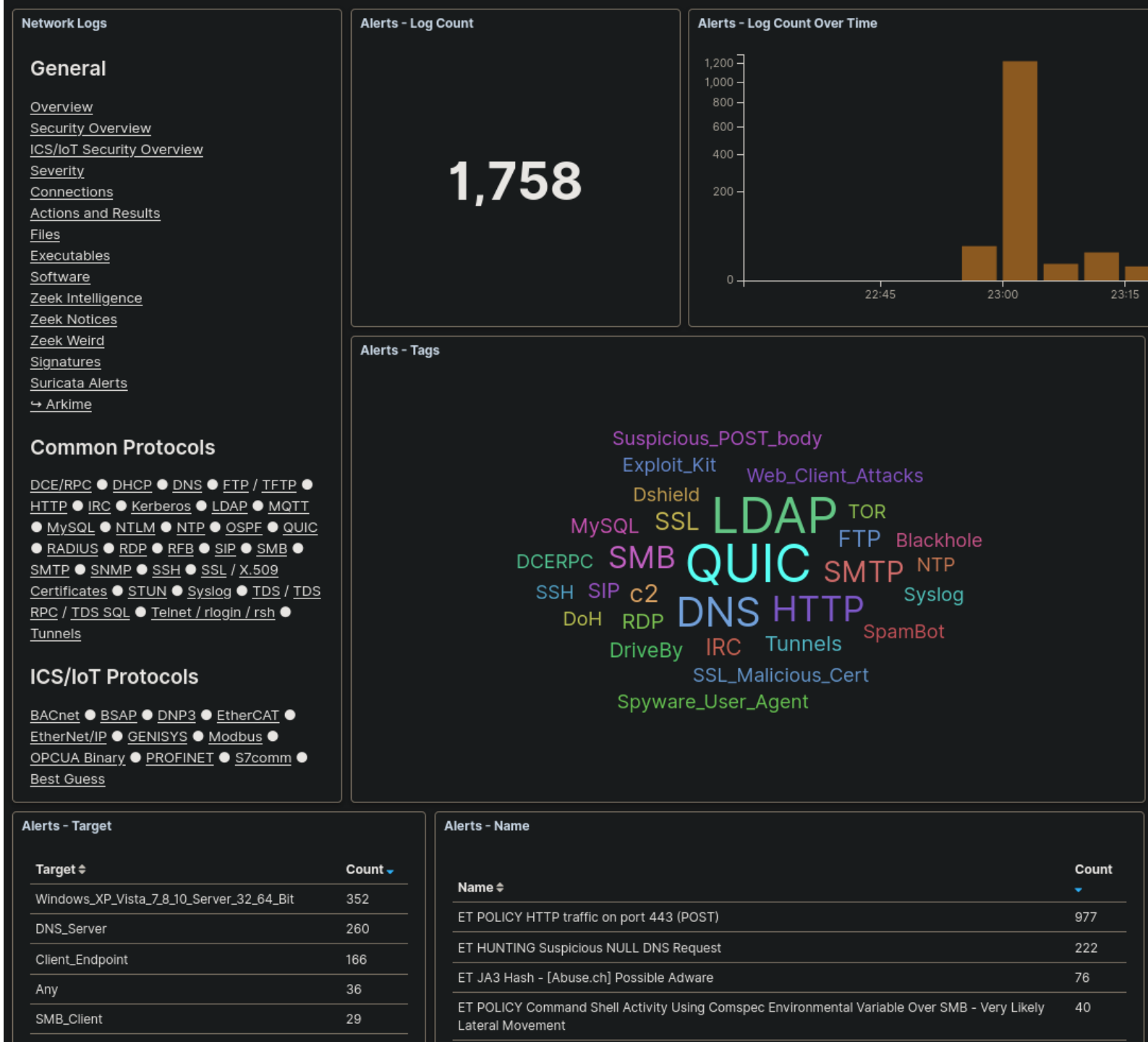
Zeek Notices

- Zeek notices are things that are odd or potentially bad
- In addition to Zeek's defaults, Malcolm raises notices for recent critical vulnerabilities and attack techniques

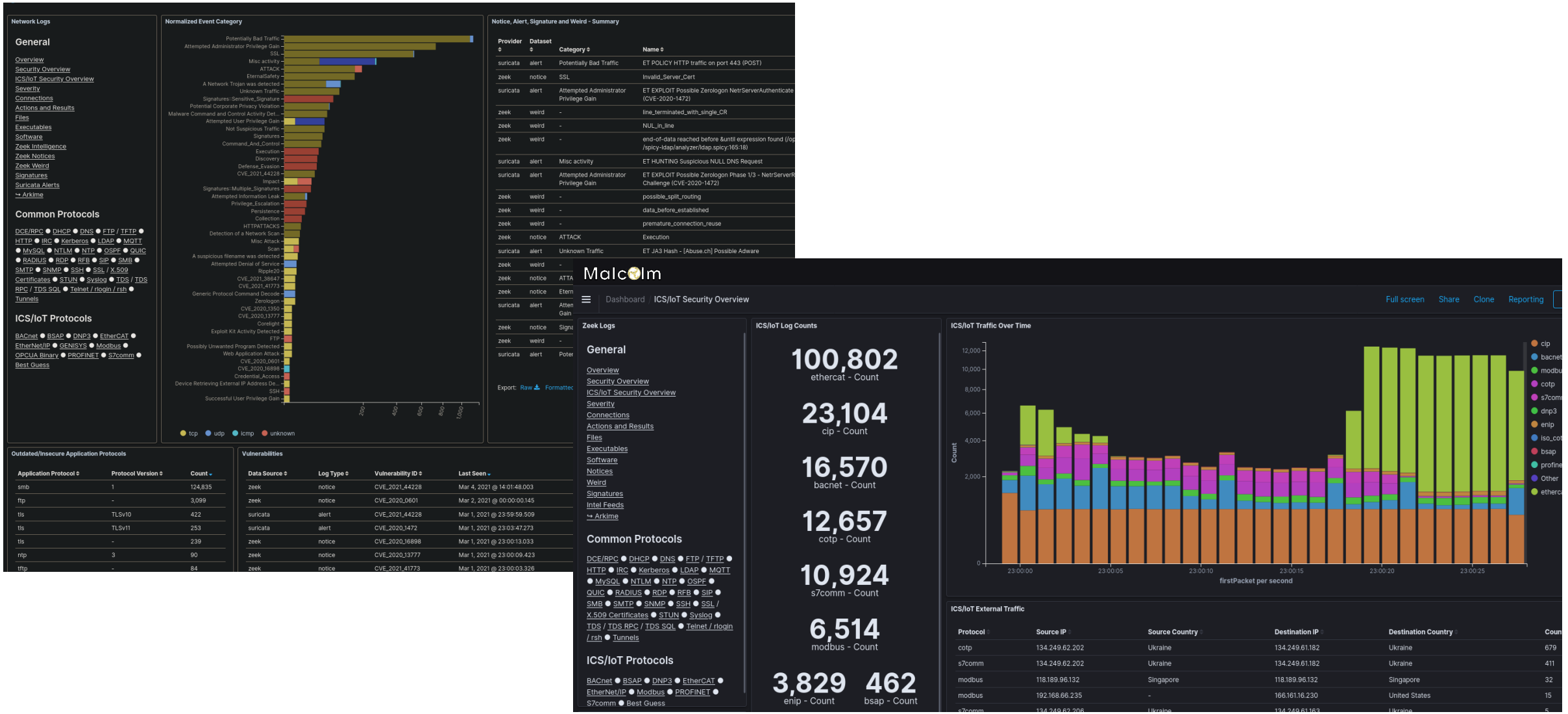


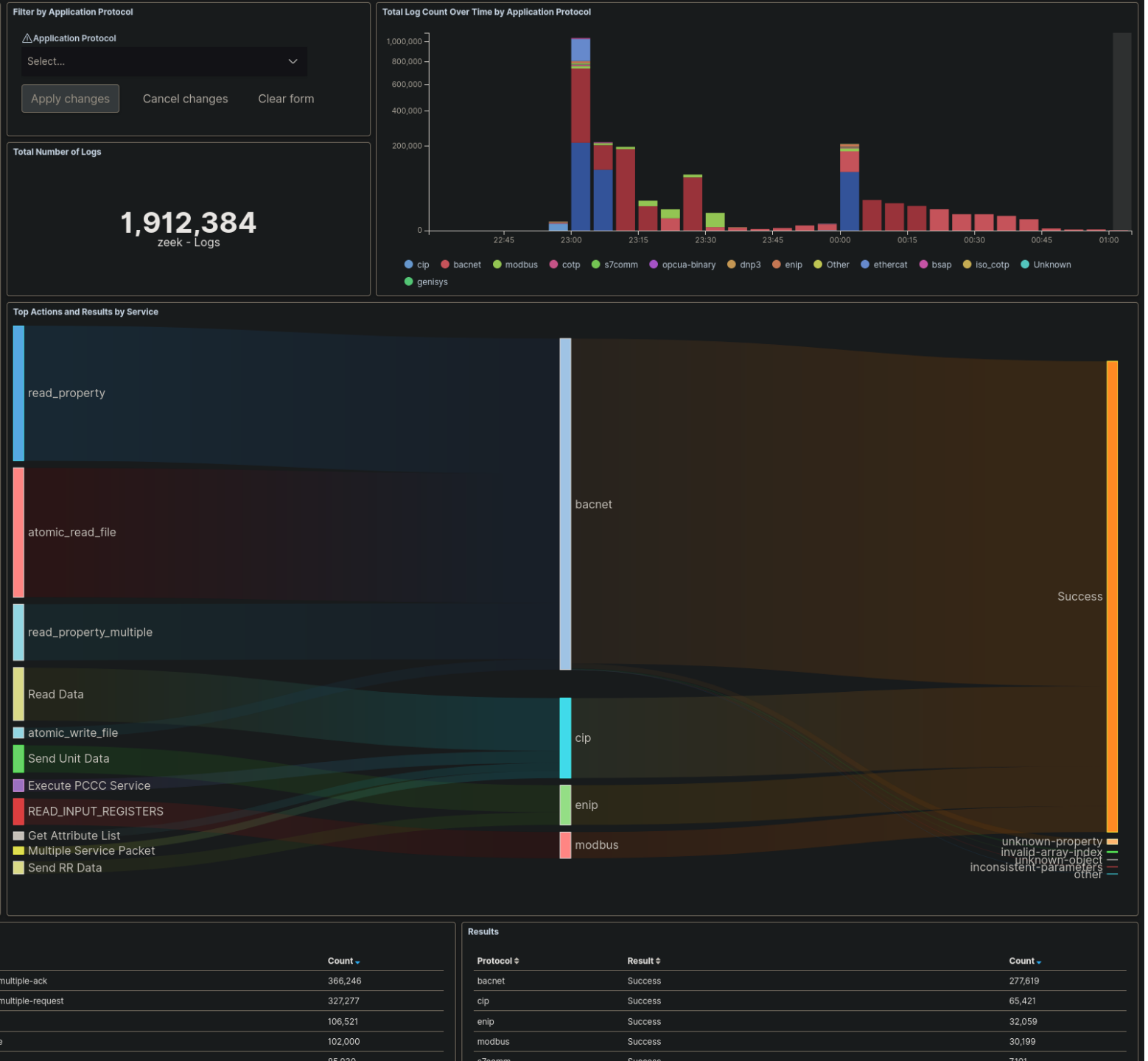
Suricata Alerts

- Protocol-aware Suricata signatures generate alerts for suspect traffic
- Use the default Emerging Threats Open ruleset or custom signatures from other sources



Security & ICS/IoT Security Overviews



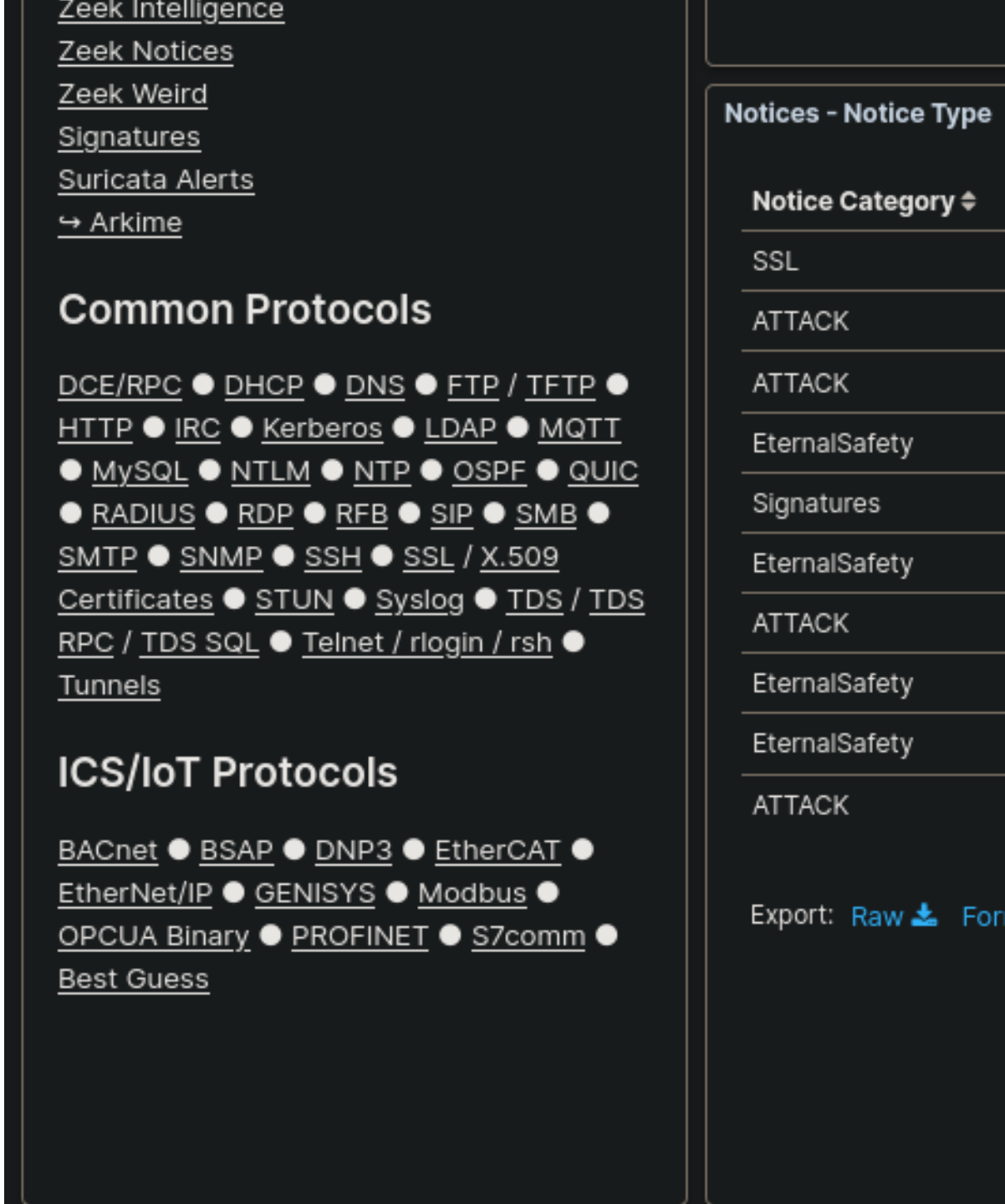


Actions and Results

- Malcolm normalizes “action” (e.g., write, read, create file, logon, logoff, etc.) and “result” (e.g., success, failure, access denied, not found) across protocols

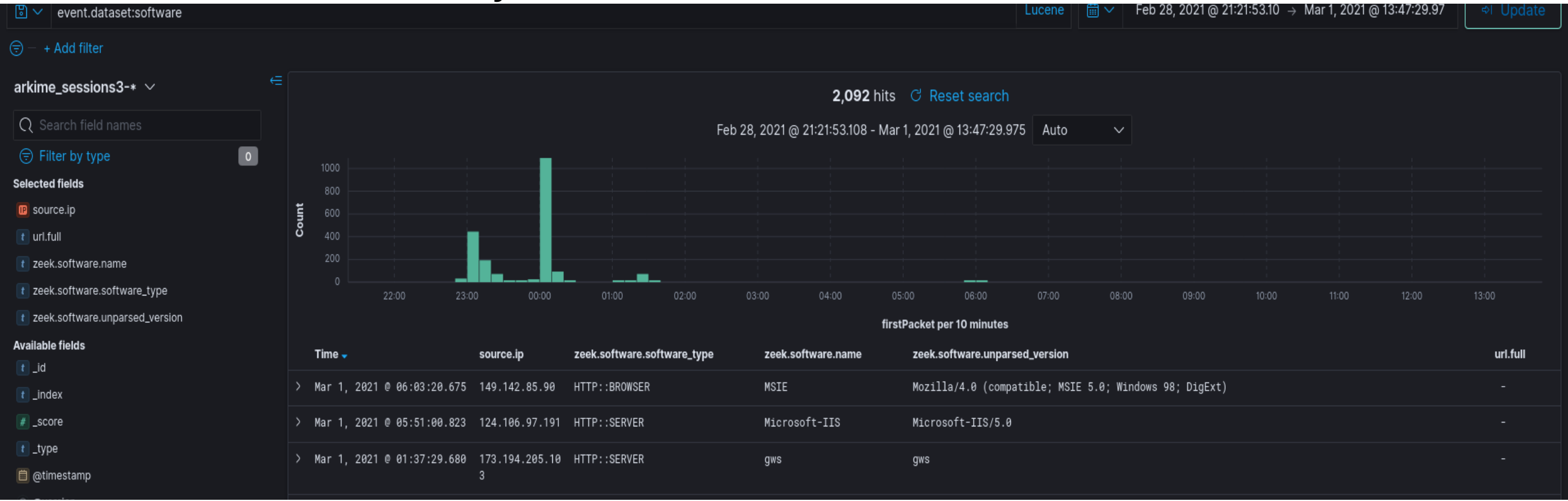
Protocol Dashboards

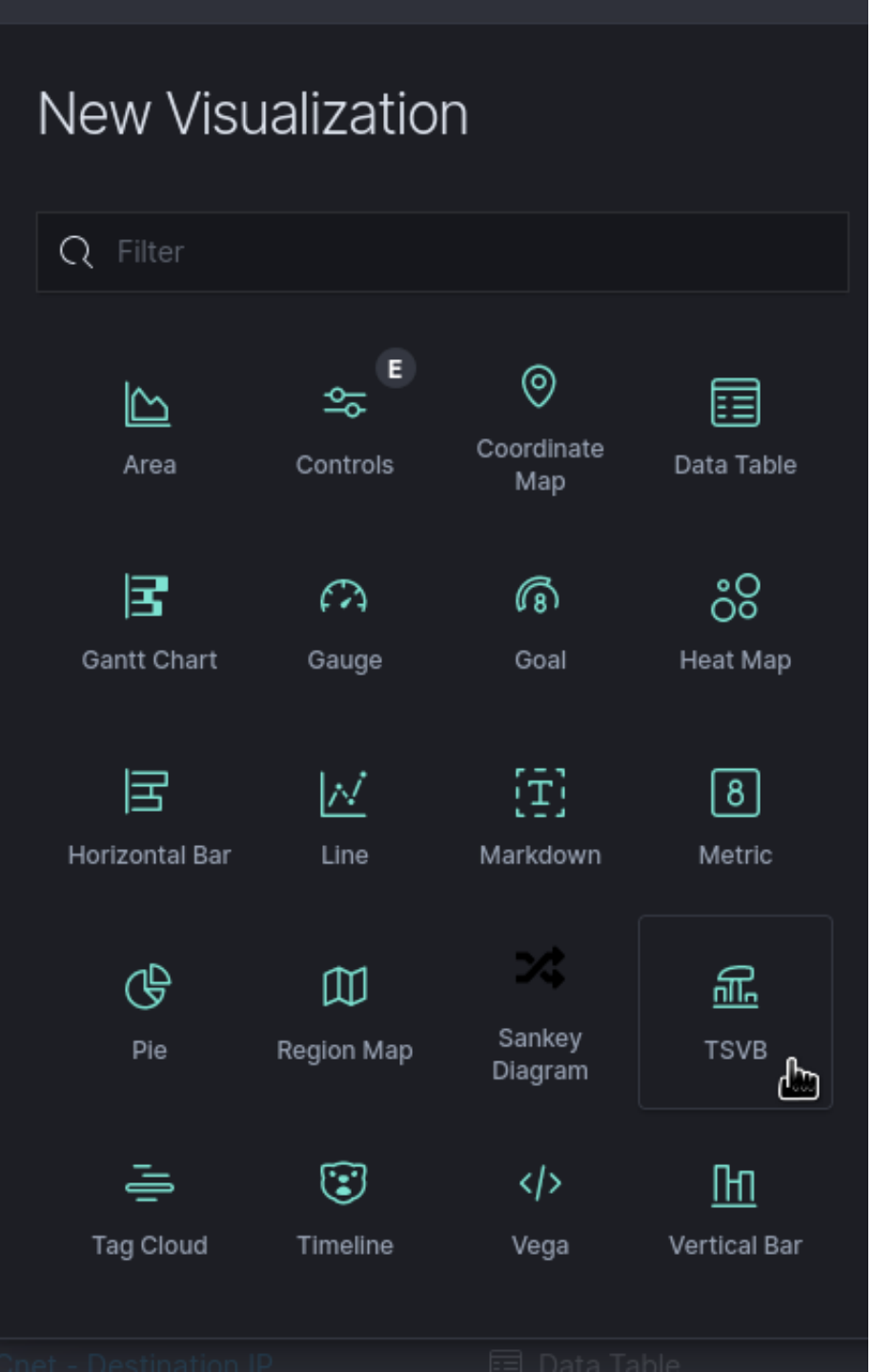
- Highlight application-specific fields of interest
- Grouped by common IT protocols and ICS/IoT protocols
- ICS protocols
  - BACnet
  - BSAP
  - DNP3
  - EtherCAT
  - EtherNet/IP
  - GENISYS
  - GE SRTP
  - Modbus
  - OPCUA Binary
  - PROFINET
  - S7comm
  - Synchrophasor (IEEE-C37.118)



Discover

- Field-level details of logs matching filter criteria
- Create and view saved searches and column configurations
- View other events just before and after an event





Custom Visualizations

- Create new visualizations from scratch or based on existing charts or dashboards

Search Syntax Comparison

	Arkime	Dashboards (Lucene)	Dashboards (DQL)
Field exists	`event.dataset == EXISTS!`	`_exists_:event.dataset`	`event.dataset:*`
Field does not exist	`event.dataset != EXISTS!`	`NOT _exists_:event.dataset`	`NOT event.dataset:*`
Field matches a value	`port.dst == 22`	`destination.port:22`	`destination.port:22`
Field does not match a value	`port.dst != 22`	`NOT destination.port:22`	`NOT destination.port:22`
Field matches at least one of a list of values	`tags == [external_source, external_destination]`	`tags:(external_source OR external_destination)`	`tags:(external_source or external_destination)`
Field range (inclusive)	`http.statuscode >= 200 && http.statuscode <= 300`	`http.statuscode:[200 TO 300]`	`http.statuscode >= 200 and http.statuscode <= 300`

Search Syntax Comparison (cont.)

	Arkime	Dashboards (Lucene)	Dashboards (DQL)
Field range (exclusive)	`http.statuscode > 200 && http.statuscode < 300`	`http.statuscode:{200 TO 300}`	`http.statuscode > 200 and http.statuscode < 300`
Field range (mixed exclusivity)	`http.statuscode >= 200 && http.statuscode < 300`	`http.statuscode:[200 TO 300}`	`http.statuscode >= 200 and http.statuscode < 300`
Match all search terms (AND)	`(tags == [external_source, external_destination]) && (http.statuscode == 401)`	`tags:(external_source OR external_destination) AND http.statuscode:401`	`tags:(external_source or external_destination) and http.statuscode:401`
Match any search terms (OR)	`(zeek_ftp.password == EXISTS!) || (zeek_http.password == EXISTS!) || (zeek.user == "anonymous")`	`_exists_:zeek_ftp.password OR _exists_:zeek_http.password OR zeek.user:"anonymous"`	`zeek_ftp.password:* or zeek_http.password:* or zeek.user:"anonymous"`

Search Syntax Comparison (cont.)

	Arkime	Dashboards (Lucene)	Dashboards (DQL)
Global string search (anywhere in the document)	all Arkime search expressions are field-based	`microsoft`	`microsoft`
Wildcards	`host.dns == "*micro?oft*"` (`?` for single character, `*` for any characters)	`dns.host:*micro?oft*` (`?` for single character, `*` for any characters)	`dns.host:*micro*ft*` (`*` for any characters)
Regex	`host.http == /.*www\.f.*k\.com.*/`	`zeek_http.host: /.*www\.f.*k\.com.*/`	Dashboards Query Language does not currently support regex
IPv4 values	`ip == 0.0.0.0/0`	`source.ip:"0.0.0.0/0" OR destination.ip:"0.0.0.0/0"`	`source.ip:"0.0.0.0/0" OR destination.ip:"0.0.0.0/0"`
IPv6 values	`(ip.src == EXISTS! || ip.dst == EXISTS!) && (ip != 0.0.0.0/0)`	`(_exists_:source.ip AND NOT source.ip:"0.0.0.0/0") OR (_exists_:destination.ip AND NOT destination.ip:"0.0.0.0/0")`	`(source.ip:* and not source.ip:"0.0.0.0/0") or (destination.ip:* and not destination.ip:"0.0.0.0/0")`

Search Syntax Comparison (cont.)

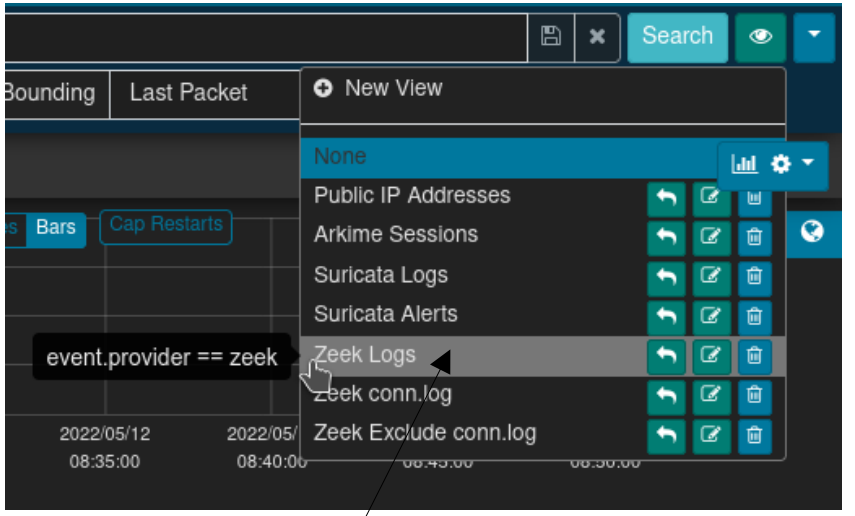
	Arkime	Dashboards (Lucene)	Dashboards (DQL)
GeoIP information available	`country == EXISTS!`	`_exists_:destination.geo OR _exists_:source.geo`	`destination.geo:* or source.geo:*`
Log type	`event.dataset == notice`	`event.dataset:notice`	`event.dataset:notice`
IP CIDR Subnets	`ip.src == 172.16.0.0/12`	`source.ip:"172.16.0.0/12"`	`source.ip:"172.16.0.0/12"`
Search time frame	Use Arkime time bounding controls under the search bar	Use Dashboards time range controls in the upper right-hand corner	Use Dashboards time range controls in the upper right-hand corner
GeoIP information available	`country == EXISTS!`	`_exists_:destination.geo OR _exists_:source.geo`	`destination.geo:* or source.geo:*`

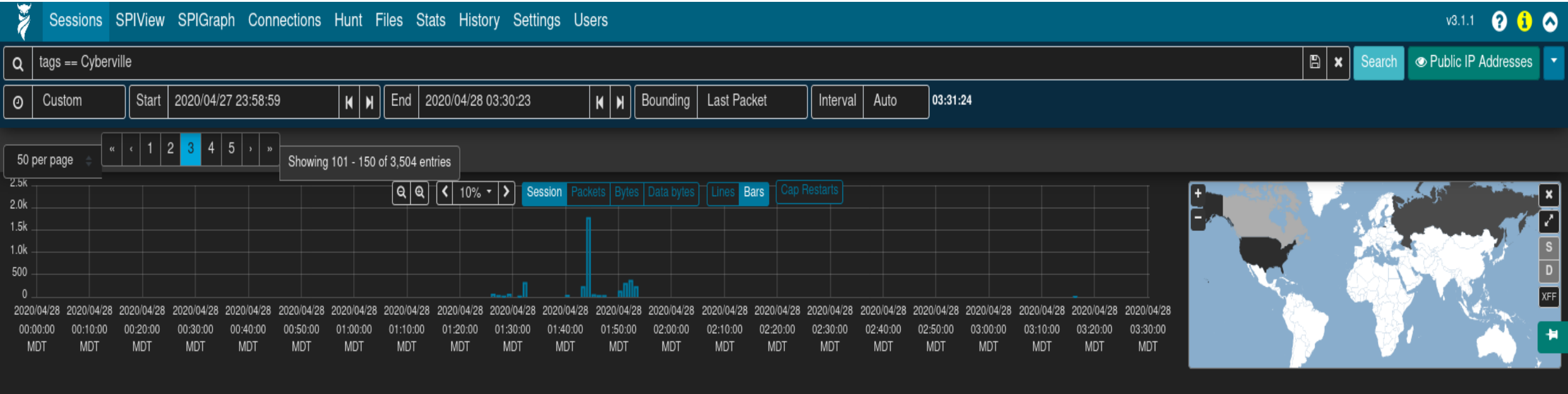
Arkime

- Front end for enriched Zeek logs, Suricata alerts **and** Arkime sessions
  - Malcolm's custom Arkime data source adds full support for Zeek and Suricata logs to Arkime, including ICS protocols
- Filter by data source (Zeek, Suricata or Arkime); or, view together
- "Wireshark at scale": full PCAP availability for
  - viewing packet payload
  - exporting filtered and joined PCAP sessions
  - running deep-packet searches

Arkime Filters and Search

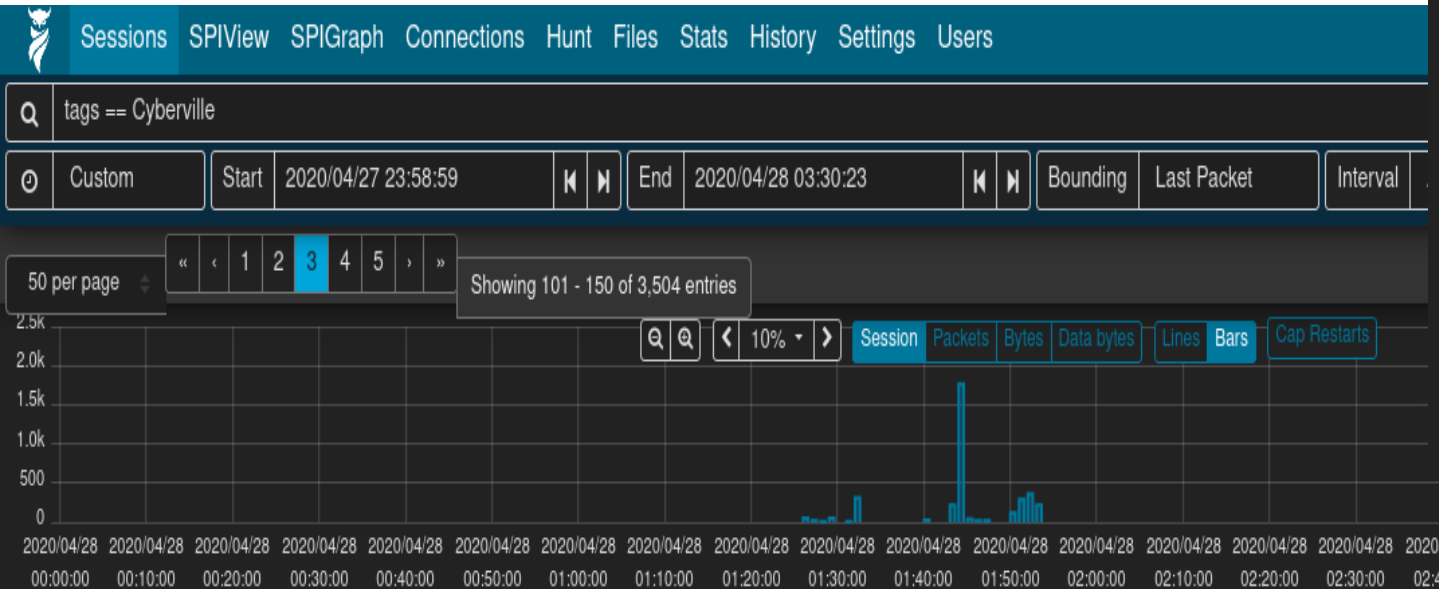
- Time filter: define search time frame
- Map filter: restrict results to geolocation
- Query bar: write queries in Arkime syntax
- Views: overlay previously-specified filters on current search

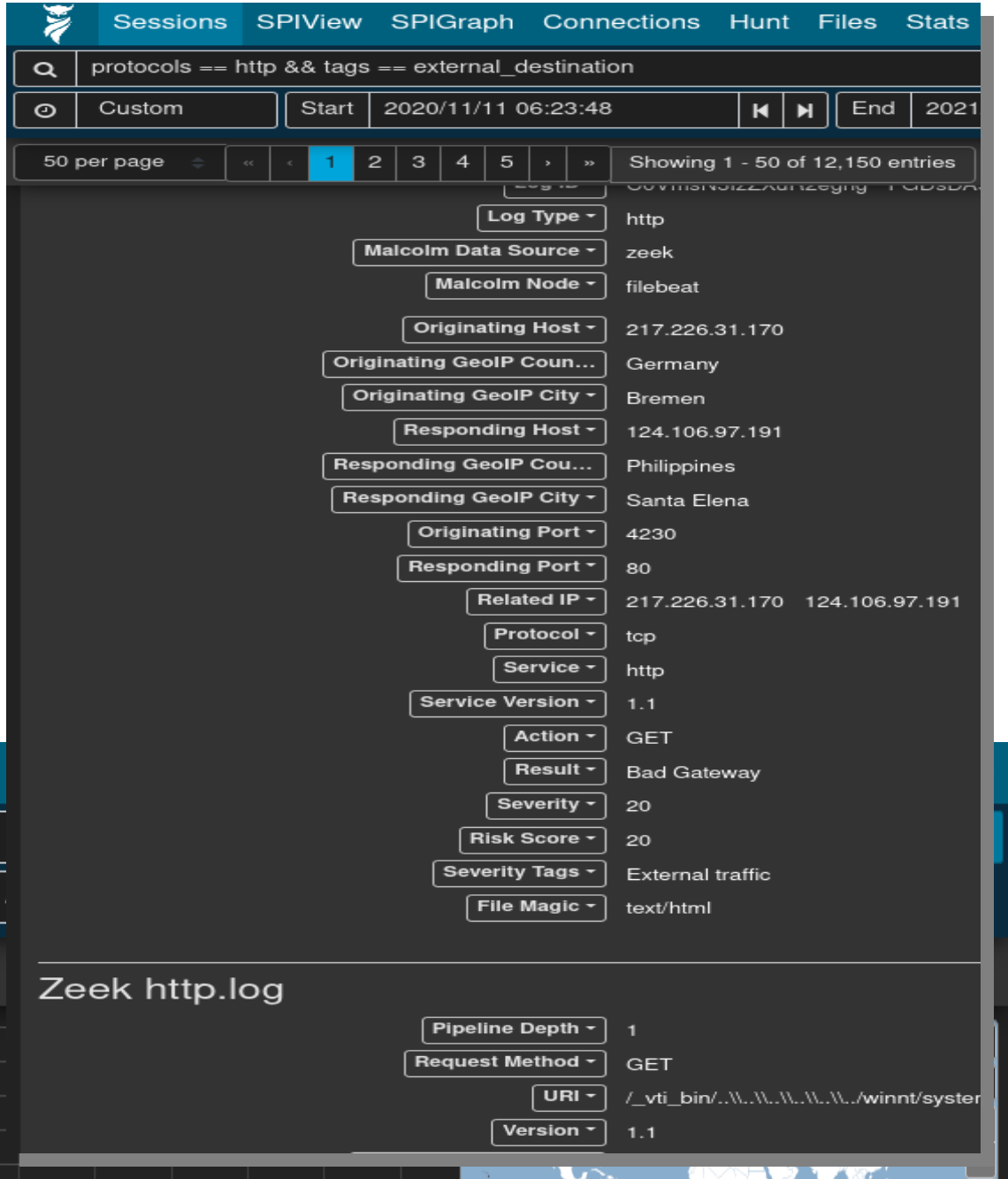




Sessions

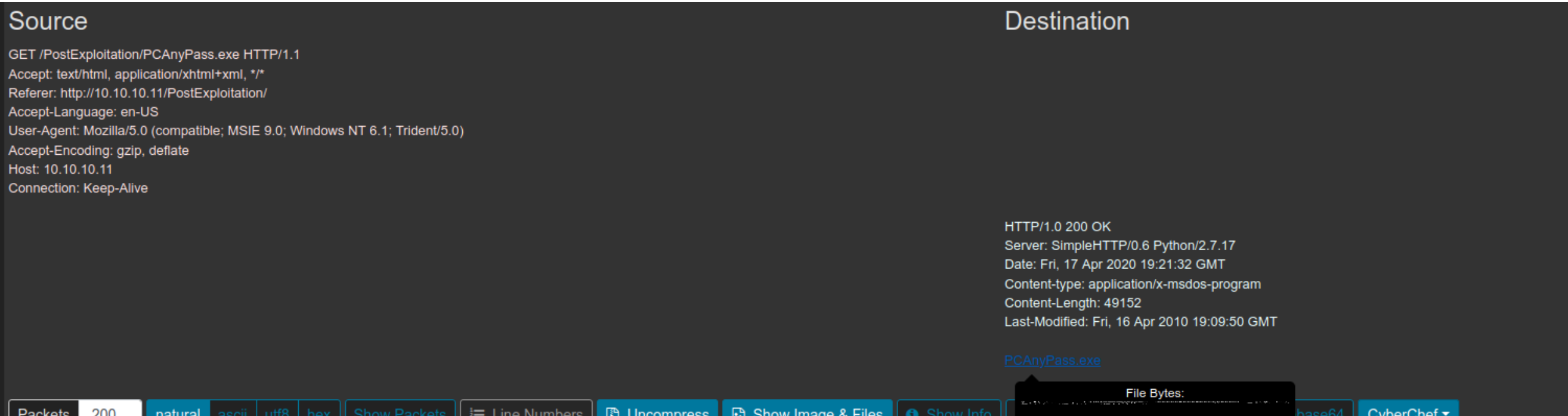
- Field-level details of sessions/logs matching filters
- Similar to Dashboards' Discover





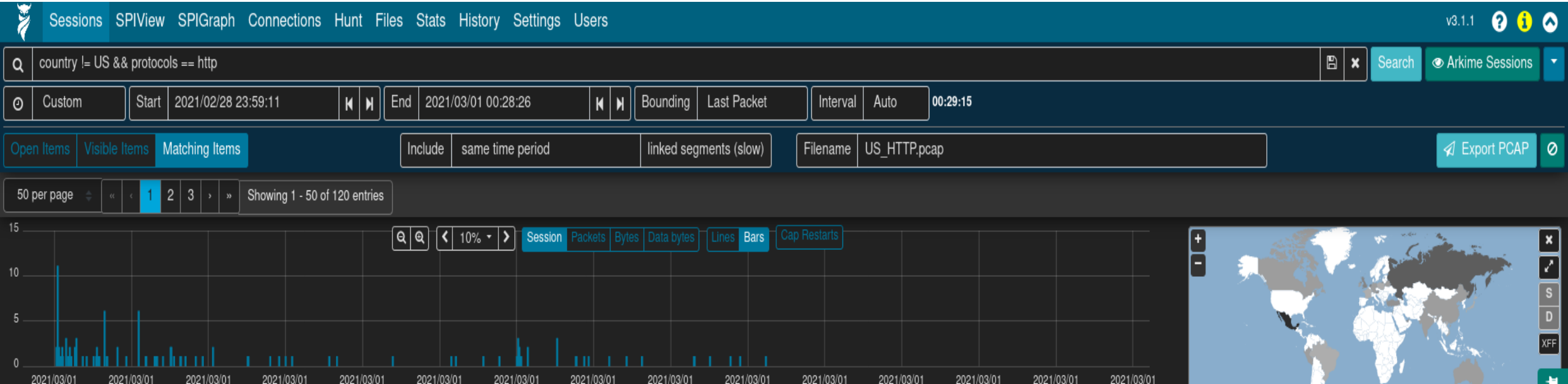
Packet Payloads

- Displayed for Arkime sessions with full PCAP (i.e., not Zeek logs)
- File carving on the fly
- Download session PCAP
- Examine payload with CyberChef



Export PCAP

- Creates a new PCAP file from filtered sessions
- Include open, visible or all matching sessions
- Apply “Arkime Sessions” view to sessions first
- Narrow as much as possible prior to exporting (huge PCAP files are a pain)

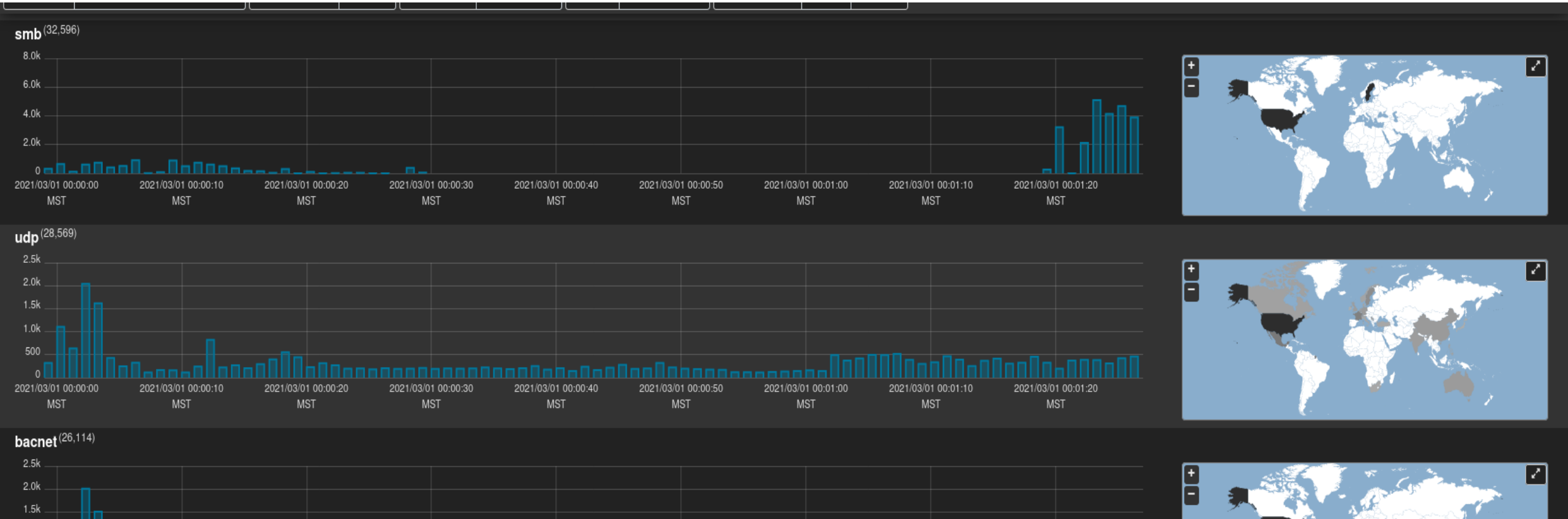


SPIView

- Explore “top *n*” and field cardinality for all fields of both Arkime sessions and Zeek logs
- Apply filters or pivot to Sessions or SPIGraph view for field values of interest
- Limit search to ≤ 1 week before using (it runs many queries)

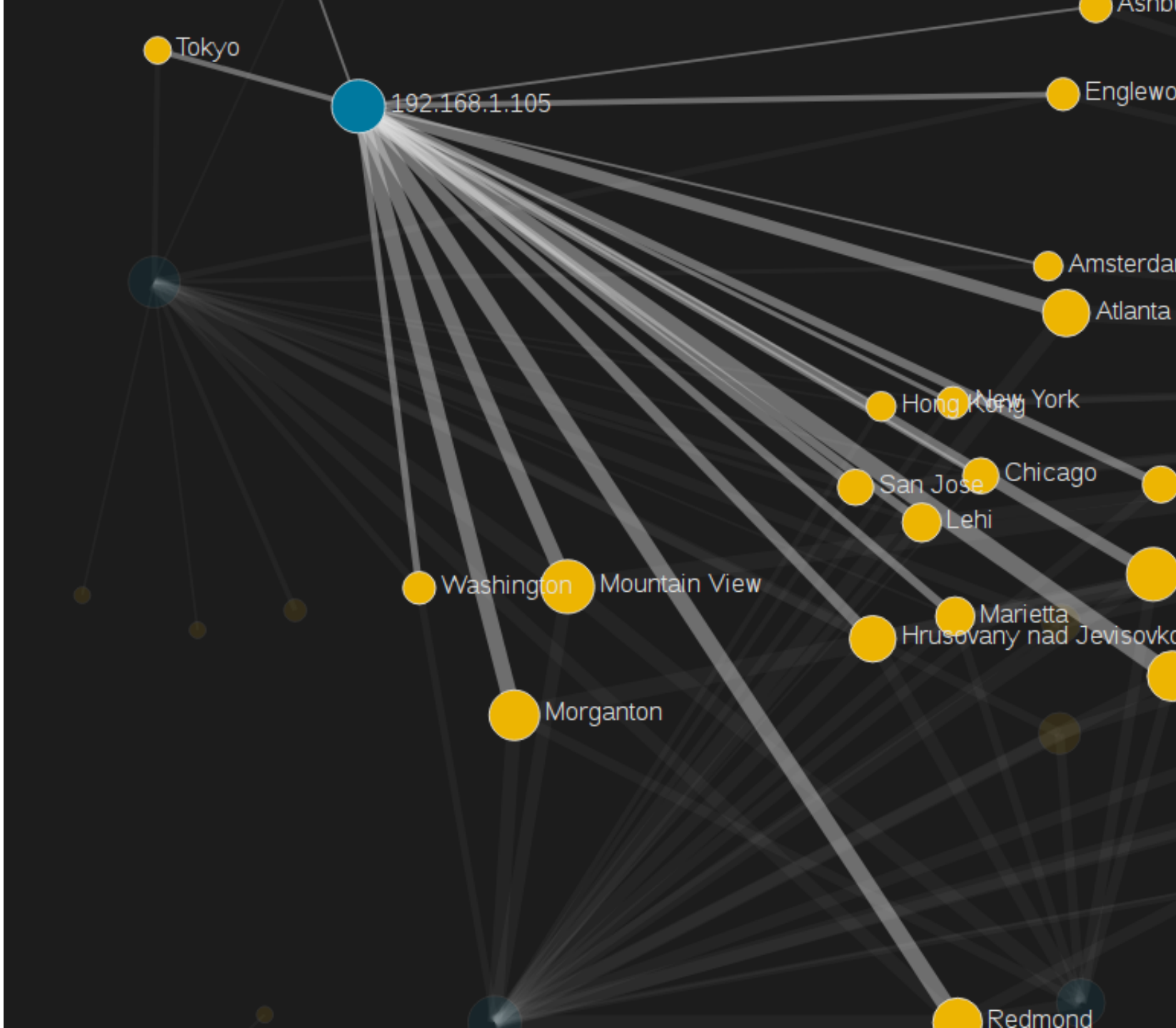
SPIGraph

- View “top *n*” field values chronologically and geographically
- Identify trends and patterns in network traffic



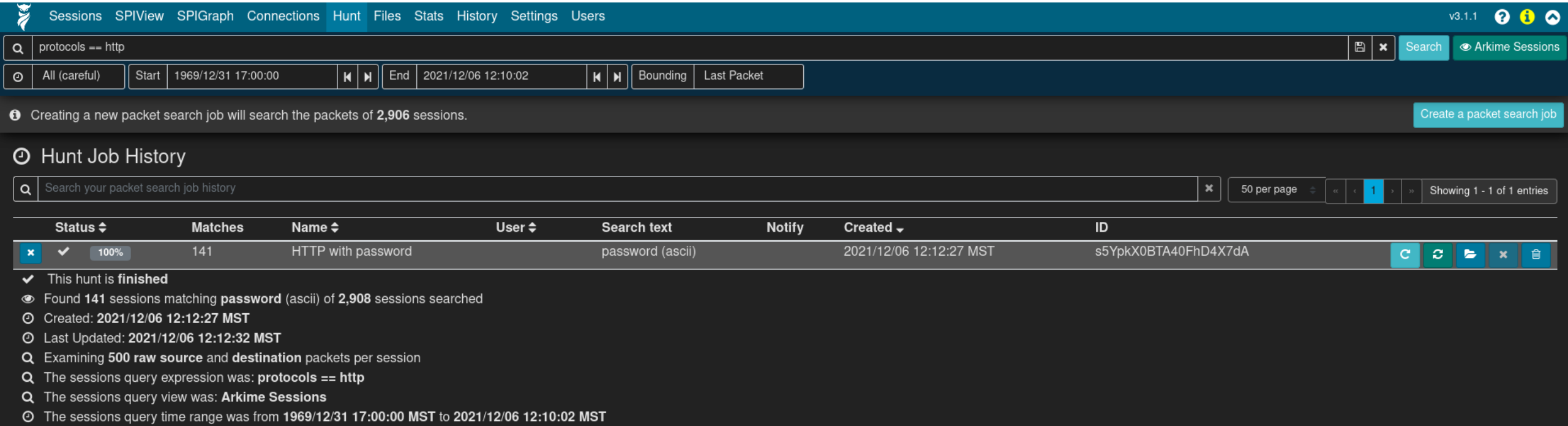
Connections

- Visualize logical relationship between hosts
- Use any combination of fields for source and destination nodes
- Compare current vs. previous (baseline) traffic



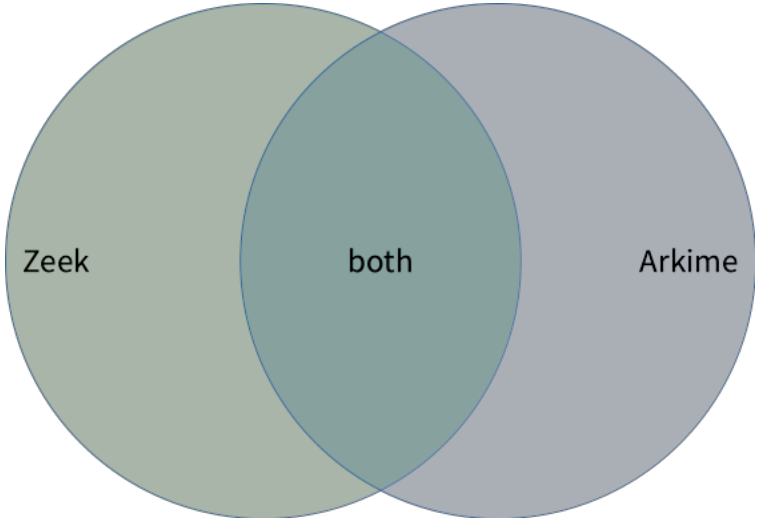
Packet Search (“Hunt”)

- Deep-packet search (“PCAP grep”) of session payloads
- Search for ASCII, hex codes or regular expression matches
- Apply “Arkime Sessions” view to sessions first



Data Source Correlation

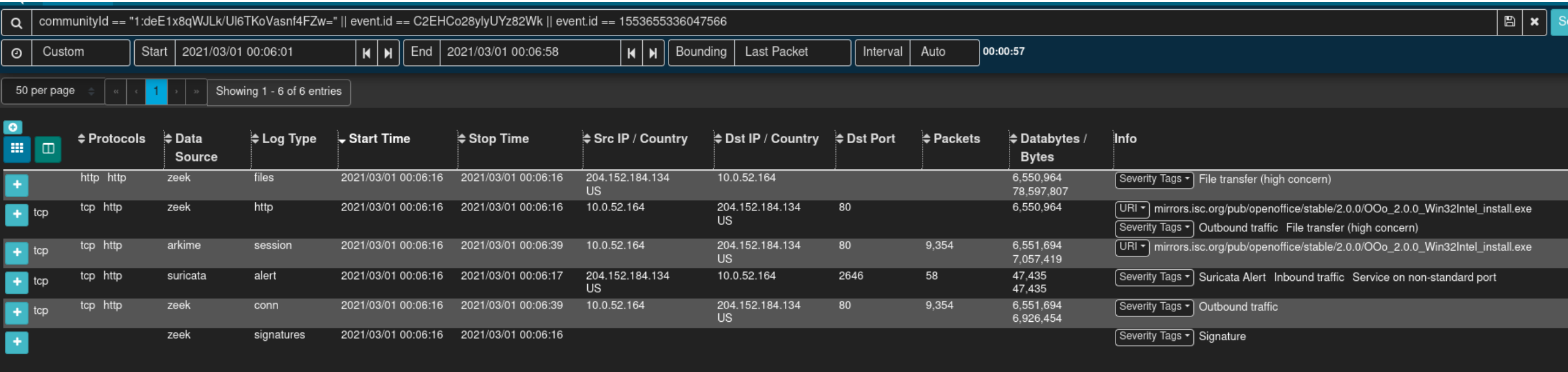
- Search syntax is different between Arkime and Dashboards (and in some cases, so are field names)
  - See search syntax comparison table, Malcolm and Arkime docs
- Despite considerable overlap, there are differences in protocol parser support among Zeek, Suricata and Arkime
  - Learning the strengths of each will help you more effectively find the good stuff



Correlate Zeek or Suricata Logs and Packet Payloads

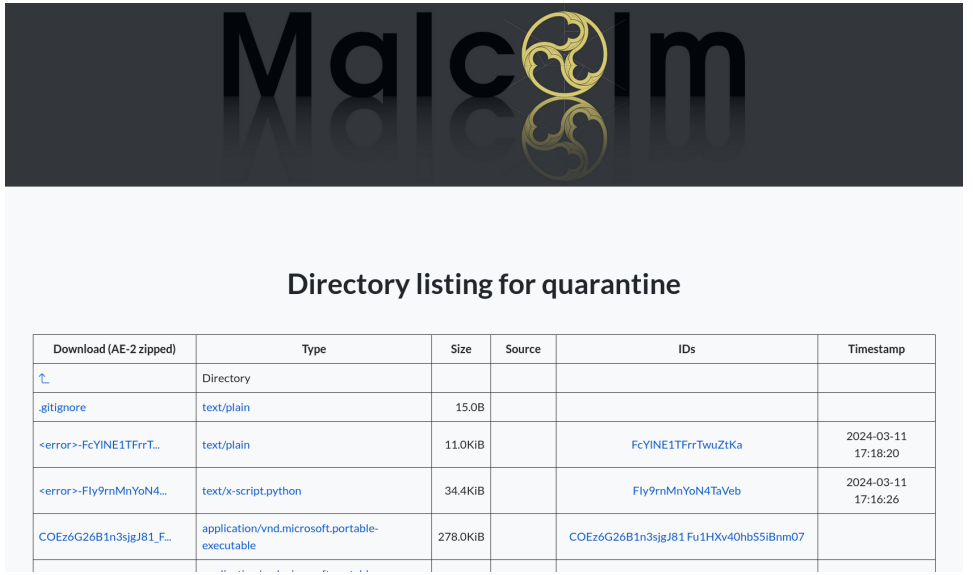
- Correlate Zeek or Suricata logs and Arkime sessions using common fields
- `communityId` fingerprints flows to bridge data sources
- `rootId/event.id` filters logs for the same session
- Filter community ID OR'ed with `event.id` to see all Arkime sessions and Zeek or Suricata logs for the same traffic

```
communityId == "1:r7tGG//fXP1P0+BXH3zXETCtEFI=" || event.id == "CQcoro2z6adgtGlk42"
```



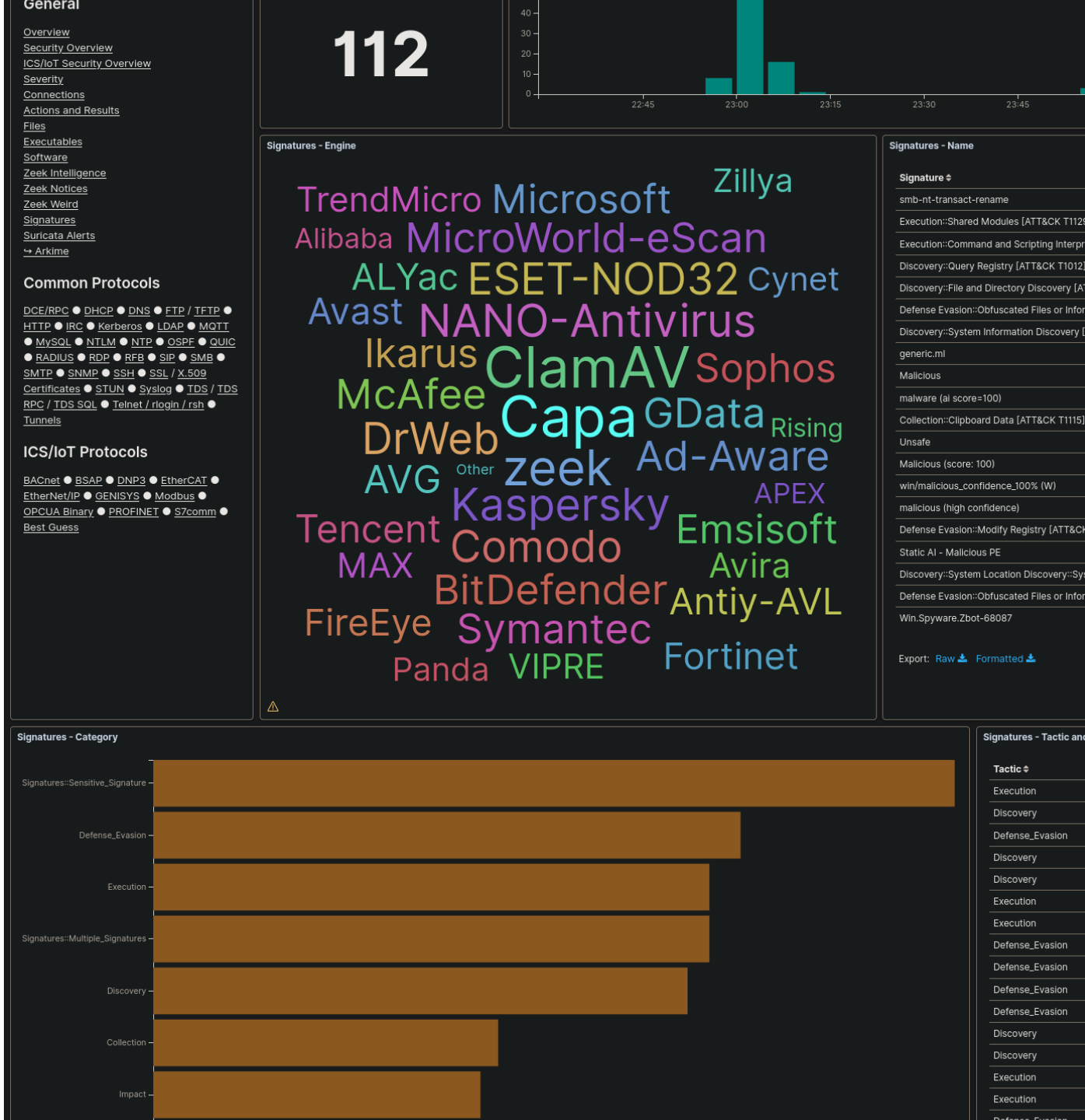
File Analysis

- Zeek can “carve” file transfers from common protocols
- Malcolm can examine carved files and flag hits
  - ClamAV – open source antivirus engine
  - YARA – pattern matching swiss army knife
  - Capa – portable executable capabilities analyzer
  - VirusTotal – online database of file hashes
    - requires API token and internet connection
- Triggering files can be saved to `zeek-logs/extract_files` under Malcolm directory for further analysis and downloaded via web UI
  - Be careful! Carved files may contain live malware!



Signatures

- Signatures dashboard in Dashboards shows scanned file hits
- `event.id` field contains `zeek.fuid` and `zeek.uid`: use it to pivot from the *Signatures – Logs* table to other dashboards with pertinent session details



Search Tips

- Always check your search time frame
- “Zoom in” (apply filters) for a particular field value, pivot to another field then “zoom out” (remove filters)
- Most UI controls can work with any data field (3000+)
- Filter on `event.dataset` (e.g., `conn` to see conn.log)
- Filter on protocol regardless of data source (e.g., `protocol:http` in Dashboards and `protocols == http` in Arkime)
- Use tags

Towards the Future

- Expand training via prepackaged modules, videos, and hands-on exercises
- Vulnerability/IOC sharing and identification (CSAF) and exploitation visibility (KEV)
- Improve access control and single sign-on (SSO) support
- Support generic (Sigma) rules and analytics

- Improve cloud deployment
- Evaluate/integrate NLP/LLM plugins in development at PNNL and explore other ML/AI integrations
- Integration of Assemblyline malware analysis platform
- Improve integration of third-party and host logs
- Increase OT/ICS protocol support
  - IEC 104, HART-IP, ANSI C12.22, Omron FINS and more

Malcolm

Thank you!

Visit Malcolm on GitHub to read the docs, make suggestions, report issues and st★r to show your support!