

# The Art of Pivoting - How You Can Discover More from Adversaries with Existing Information

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🏠 <https://www.ail-project.org>

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- This presentation is part of an open book<sup>1</sup> explores how intelligence and cyber-security analysts can uncover hidden links between threat actor infrastructure and ongoing investigations by pivoting on both classic and unconventional indicators, many of which are often overlooked. The material is grounded in empirical, field-tested strategies used in cyber-security, digital forensics, cyber threat intelligence, and intelligence analysis more broadly.

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<sup>1</sup><https://github.com/adulau/the-art-of-pivoting>

# What is Defender's Pivoting?

- Pivoting<sup>2</sup> is the analytical process of using one known artifact (such as an indicator of compromise (IOC), behavioral fingerprint, or identity trace) to uncover additional, related elements within a threat actor's infrastructure, toolkit, service, or operation. This technique enables analysts **to expand the scope of an investigation**, uncover hidden connections, confirm or attribute activity, and anticipate future adversary behavior.

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<sup>2</sup>The term "pivoting" can cause confusion. In this context, we refer to defender's pivoting using data points, distinct from the threat actor's lateral movement within a compromised infrastructure.

## Six Degrees of Separation and Pivoting

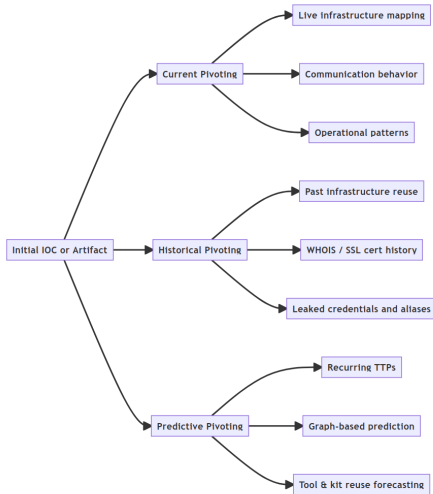
- The concept of *six degrees of separation*<sup>3</sup> suggests that any two individuals are connected through a chain of six or fewer social relationships.
- Similarly, in threat intelligence, pivoting is an analyst's method for uncovering hidden relationships, much like navigating a social graph. Instead of people, we're connecting data points and observables.
- Just as social networks reveal how people are linked, threat intelligence graphs reveal how indicators, infrastructure, and behaviors are interrelated, enabling defenders to map out and understand adversary ecosystems.

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<sup>3</sup>Also referenced in popular culture as the "Six Degrees of Kevin Bacon," or in academic contexts as the "Erdős number," which measures how many co-authorship links separate a researcher from mathematician Paul Erdős.

# Analytical Benefits of Pivoting

- **Current:** Understand how a threat actor interacts, communicates, and operates in real time.
- **Historical:** Reveal past connections between threat actors and specific infrastructure or identities.
- **Predictive:** Anticipate future actions based on recurring patterns, techniques, and operational habits.



# Is Pivoting Evolving?

- We strive to shift pivoting from an art to a science, making it reproducible, practical, and truly actionable for analysts.
- Yet, our perspective is sometimes clouded by **rigid models** or **legacy practices** that may no longer reflect today's threat landscape.
- Should we reconsider our reliance on models like the *Pyramid of Pain*, and critically assess how difficult it really is for adversaries to alter high-value indicators?
- Do threat actors always realize which traces they leave behind<sup>4</sup>, and can they truly gauge the intelligence value of what they expose?

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<sup>4</sup>Remember where the “Anna-Senpai” handle eventually led?

# Re-evaluating Our Indicator Collection and Pivoting Practices

- In the AIL project<sup>5</sup>, we collect a wide range of sources—from social networks and Tor hidden services to forums and specific web infrastructure used by threat actors.
- We've implemented a dynamic correlation engine that allows easy integration of new object types for pivoting and analysis.
- This required a mindset shift: **focusing more on outliers and overlooked data points**, while challenging and discarding some of our older assumptions.

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<sup>5</sup><https://ail-project.org/>

# Looking at Broken Indicators—and Still Using Them

- MurmurHash3 is still widely used for favicon correlation. It enables quick discovery of Tor hidden services exposed on the clear web through simple hash-based pivoting.
- If MurmurHash3 is known to be flawed, why do we still use it? Because despite its weaknesses<sup>6</sup>, it remains effective—and threat actors rarely think to modify their favicons.
- An interesting angle: some actors may attempt to create hash collisions. Correlating on **colliding** favicons can itself become a pivoting technique. So why stop calculating them?

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<sup>6</sup>The same question can be asked about other algorithms used in threat intelligence processing.



# Favicons as Differentiators and Composite Correlation Points

The screenshot shows the FOFA search interface. The search bar contains the hash "icon\_hash='198658945'". The results list shows 40 results, with 27 unique IP addresses. The first result is for "godnotaba.space". The details for this result are as follows:

Header	Products
godnotaba - moxeroper respectu a TOR 172.67.160.22 United States of America / California / San Fra... ASN: 13335 Organization: CLOUDFLARENET godnotaba.space 2025-04-01 cloudflare	HTTP/1.1 200 OK Connection: close Transfer-Encoding: chunked Alt-Svc: h3="443"; ma=86400 Cache-Control: no-cache Cache-Control: max-age=0, no-cache, s-maxage=10 Cl-Cache-Status: DYNAMIC Cl-Ray: 828e8f80b2b012 PDX Content-Type: text/html; charset=UTF-8 Frame-Trust: 0; 800 1000; 0.0 0.0 0.0 0.0

The screenshot shows a graph visualization interface. The top section displays a table with the following data:

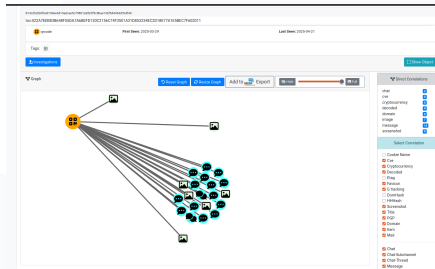
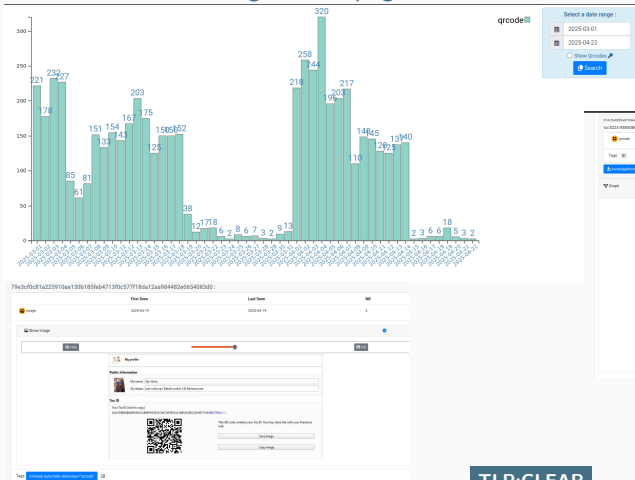
Object type	First seen	Last seen
Favicon	20241107	20250422

Below the table, there is a "Trage" section and a "Investigations" button. The graph section shows a network of nodes and edges. The nodes are labeled with letters and numbers, and the edges represent correlations between them. The graph is titled "Graph" and includes buttons for "Reset Graph", "Resize Graph", and "Add to HSP".

Even seemingly innocuous favicons can act as unique fingerprints—useful for correlating threat infrastructure across campaigns or layers (e.g., Tor vs. clear web).

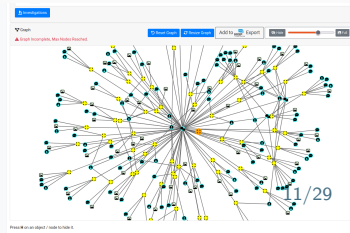
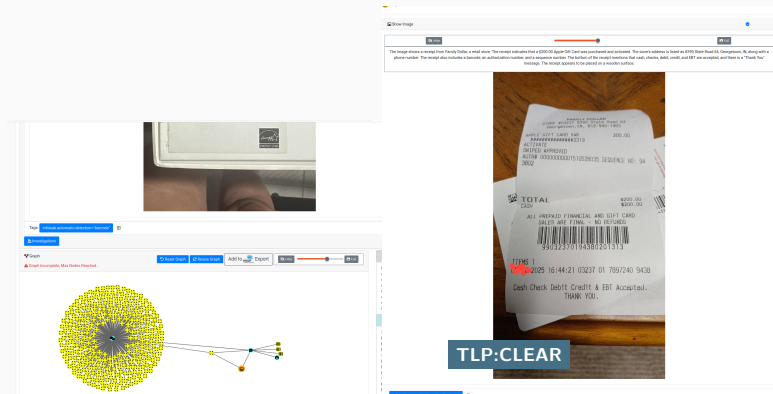
## Uncommon Indicator Extraction: QR Codes

- QR codes are increasingly seen across social networks, Tor hidden services, and even in ransomware negotiation pages.



# Uncommon Indicator Extraction from Images: Barcodes

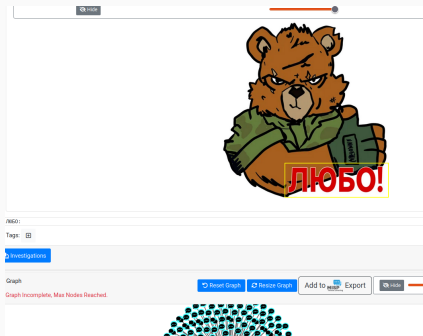
- Following a request from law enforcement, we implemented barcode extraction (Code 128, Code 39, Code 93, etc.).
- Barcodes turned out to be **valuable correlation points**, not only in large data leaks, but also in social media interactions involving threat actors.



TLP:CLEAR

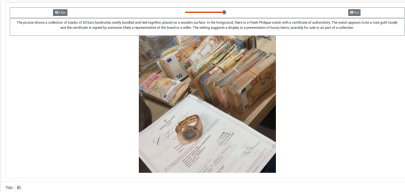
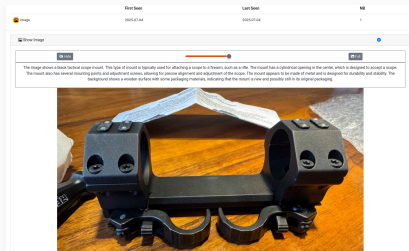
# Semantic and Textual Information in Images

- Images often contain **valuable textual data**, such as device numbers, identifiers, and embedded messages, that can be extracted for analysis.
- CRNN-based OCR models perform well and are highly efficient on modern hardware, making large-scale image parsing feasible.



# Automatic Description and Analysis of Images

- **Vision-language models and multimodal AI** can automatically generate descriptions of images. In AIL, this capability is implemented as a **local-only vision analysis** for all collected images (e.g., from social networks, screenshots).
- Extracted descriptions enable investigators to **correlate on terms, keywords, or objects** identified in the images, creating new pivoting opportunities.
- **Investigator benefit:** sensitive or harmful images do not need to be viewed directly, since analysis and correlation can be performed on the extracted textual descriptions.



- Has everything already been explored in HTML document classification, hashing, or structural similarity detection?
- Following a discussion with CERT-PL, we discovered that a **simple strategy yields excellent results**<sup>7</sup> and led to the development of the dom-hash algorithm.


```
def _compute_dom_hash(html_content):  
    soup = BeautifulSoup(html_content, "lxml")  
    to_hash = "|".join(t.name for t in soup.findAll()).encode()  
    return sha256(to_hash).hexdigest()[:32]
```


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<sup>7</sup>Tested against LookyLoo dataset <https://lookyloo.circl.lu>


# Fast Clustering of Tor Hidden Services using dom-hash


41214c7f28ba66a97eee68c16a299f2f


Object type	First seen	Last seen	Nb seen
 dom-hash	20230404	20240509	122


Tags: 


 Investigations


 Graph

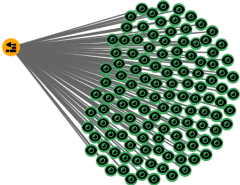
 Reset Graph

 Resize Graph


Add to  Export

 Hide

 Full



TLP: CLEAR

 Direct

Correlations

domain 122

item 919

Select Correlation

☐ Cookie Name

☒ Cve

☒ Cryptocurrency

☒ Decoded

☐ Etag

☒ Favicon

☒ G tracking

☐ DomHash

☐ HHHash

☒ Screenshot

☒ Title

☒ PGP

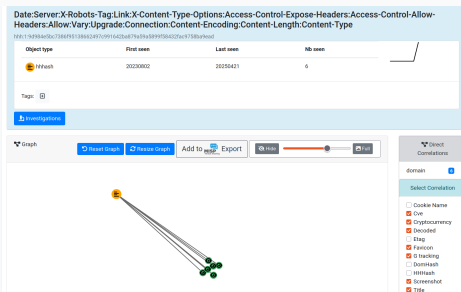
☒ Domain

☐ Item

☒ Mail

# What Simple Correlations Are Often Missed? — HTTP Headers

HTTP (version 1) response headers can act as subtle fingerprints (HHHash)<sup>8</sup> for linking threat infrastructure.



20250421 HHHashes Name:

Show 10 of 21 entries

Search:

	First Seen	Last Seen	Total	Last days
Server Date:Content-Type:Transfer-Encoding:Connection:Set-Cookie:X-Cache-Status:Content-Encoding	20240422	20250421	2827	
Server Date:Content-Type:Content-Length:Connection:Set-Cookie:last-modified:etag:X-Cache-Status:Accept-Ranges	20250201	20250421	781	
Date:Server:Upgrade:Connection:Last-Modified:ETag:Accept-Ranges:Vary:Content-Encoding:Content-Length:Content-Type	20230405	20250421	76	
Date:Server:Upgrade:Connection:Last-Modified:ETag:Accept-Ranges:Content-Length:Content-Type	20230405	20250421	69	
Date:Server:Upgrade:Connection:Last-Modified:ETag:Accept-Ranges:Content-Length:Vary:Content-Type	20230405	20250421	33	
Date:Server:Upgrade:Connection:Last-Modified:ETag:Accept-Ranges:Vary:Content-Encoding:Transfer-Encoding:Content-Type	20230405	20250421	32	
Date:Server:Link:Upgrade:Connection:Vary:Content-Encoding:Content-Length:Content-Type	20230405	20250421	27	
Date:Server:Access-Control-Allow-Origin:Access-Control-Allow-Credentials:X-Content-Type-Options:X-Robots-Tag:Expires:Cache-Control:Upgrade:Connection:Vary:Content-Encoding:Content-Length:Content-Type	20230405	20250421	8	
Date:Server:X-Robots-Tag:Link:X-Content-Type-Options:Access-Control-Expose-Headers:Access-Control-Allow-Headers:Allow:Vary:Upgrade:Connection:Content-Encoding:Content-Length:Content-Type	20230802	20250421	6	
Date:Server:Expires:Cache-Control:Link:Upgrade:Connection:Vary:Content-Encoding:Content-Length:Content-Type	20230412	20250421	5	

Showing 1 to 10 of 21 entries

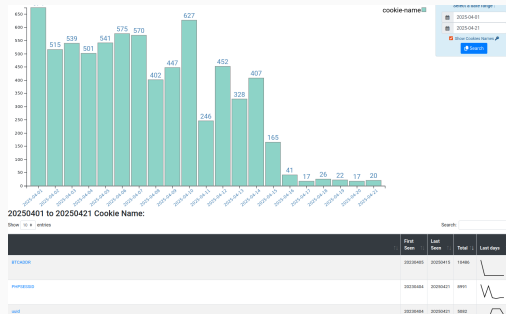
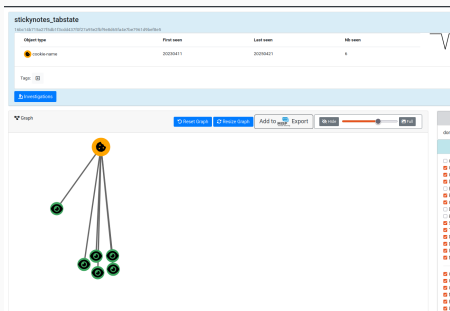
Previous 1 2 3 Next

<sup>8</sup>[https://www.foo.be/2023/07/HTTP-Headers-Hashing\\_HHHash](https://www.foo.be/2023/07/HTTP-Headers-Hashing_HHHash)



## Another Simple Correlation? — Cookie Names

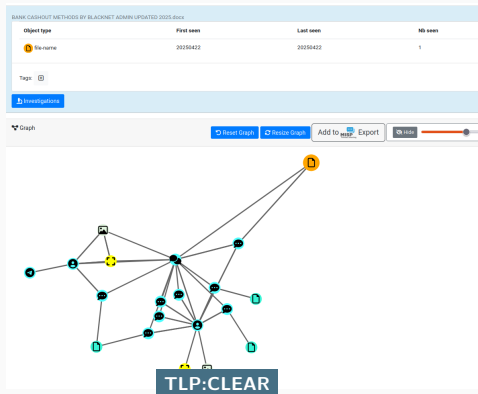
- Custom or reused cookie names<sup>9</sup> can serve as low-noise indicators for linking **attacker-controlled web infrastructure**.



<sup>9</sup>The value of the cookie are also interesting but correlation cannot be used as it without further processing

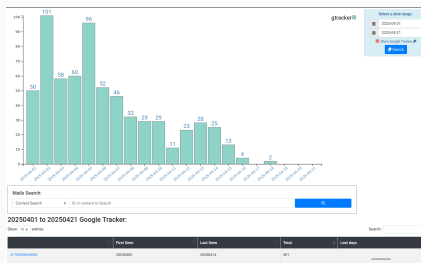
# An Even Simpler Correlation Indicator? — Filenames

- In threat intelligence, filenames are often dismissed as unreliable or noisy indicators that may lead to false conclusions.
- However, in some cases, especially on social networks or in leak dumps, filenames can carry meaningful context that reveals key aspects of a threat actor's activity.



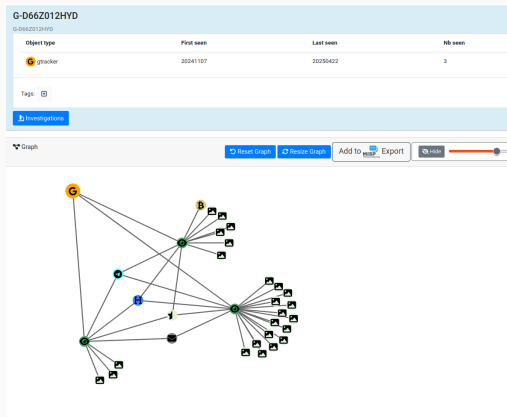
# Indicators That Threat Actors Should Avoid—But Still Use

- It is **commonly assumed** that threat actors avoid including labels or metadata that could link their infrastructure or even their operational teams.
- However, our regular crawling of Tor hidden services revealed that Google Analytics tracking codes<sup>10</sup> were reused across multiple sites, uncovering unexpected and meaningful correlations.



<sup>10</sup>Based on monthly crawling of Tor hidden services, which explains the distribution shown in the graph.

# Even "Weak" Indicators Like Google Analytics Can Be Powerful in Composite Correlation



## Why it matters:

- Google Analytics tracking IDs are often reused across phishing domains, malicious sites, or cloned templates.
- While GA IDs alone may not prove attribution, when combined with other indicators (e.g., favicon hash, dom-hash, or TLS cert), they help cluster infrastructure belonging to the same threat actor or Tor operator.
- Many actors underestimate the traceability of third-party embedded analytics even Ransomware groups.

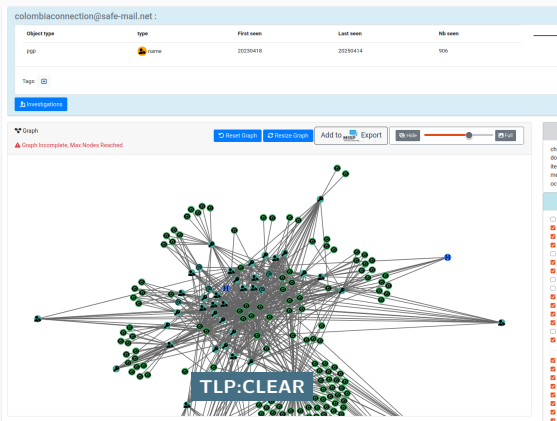
# Unexpected Correlation from Cryptographic Materials

- Threat actors often simplify their operations by generating Tor onion services with custom "vanity" addresses—based on recognizable prefixes derived from cryptographic key fingerprints.
- While the exact logic behind the generation is not always disclosed, building a tree or graph structure of these vanity addresses can **reveal shared patterns** and uncover related services.

The screenshot shows the 'Vanity Explorer' web application. On the left, there's a sidebar with a blue plus icon and a search input containing '365c'. Below the search input, it says 'Vanity Length: 4'. The main area has a 'Show 10 entries' dropdown and a 'Search:' input. A table with two columns, 'Length+1 Vanities' and 'NB Domains', displays one entry: '365cp' with a value of '10'. Below the table, it says 'Showing 1 to 1 of 1 entries' and has 'Previous', '1', and 'Next' navigation links. At the bottom, there's a 'Hide' button, a progress bar, and a 'Full' button. A dark bar at the very bottom shows '365c' and a blue box with the number '10'.

# Pivoting on Encrypted Messages and Metadata

- Sometimes, **collecting encrypted messages or public keys** can reveal unexpected links, especially when metadata is extracted from PGP blocks.
- Elements such as key IDs, user IDs, creation dates, or repeated usage of the same key across services can all serve as valuable pivot points.



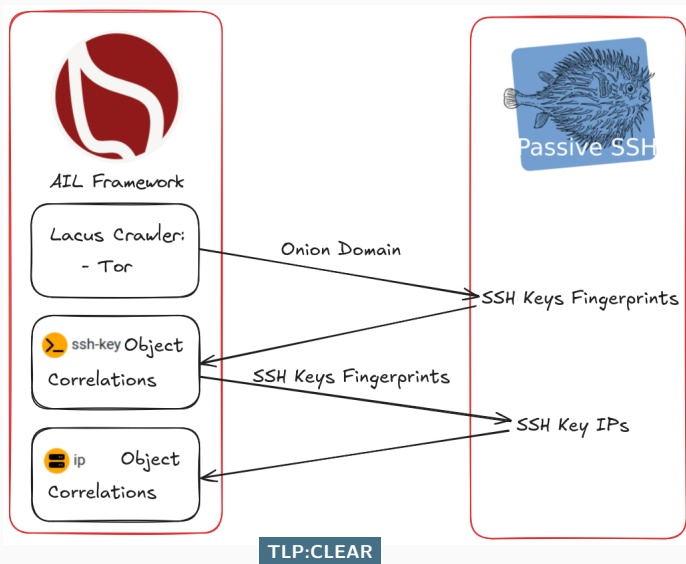
- Open-source **passive-ssh** scanner & database<sup>11</sup>
- Captures: public keys, banners, **hassh** fingerprints
- Maintains full host-SSH history (who → where, when)
- Lean ReST API – lookup by key / hassh / banner
- Deanomize onions



<sup>11</sup><https://github.com/D4-project/passive-ssh>


<sup>12</sup><https://github.com/D4-project/passive-ssh>

# AIL - Passive SSH





# AIL - SSH Correlation - Shared fingerprints

all project

[Home](#) [Submit](#) [Tags](#) [Leaks Hunter](#) [Crawlers](#) [Objects](#) [Search](#) [Settings](#) [Log Out](#)

Toggle Sidebar

Investigations

Investigations

Add Investigation

Explorers

Chats Explorer

Objects

Chat

CVE

Cookie Name

Etag

HHHash

Dom-Hash

Favicon

GTracking

File Name

Image

OCR

Barcode

eb:1e:a2:c4:27:67:3e:9f:d8:83:69:34:4f:04:a7:19

eb:1e:a2:c4:27:67:3e:9f:d8:83:69:34:4f:04:a7:19

Object type	Key type	First seen	Last seen
ssh-key	ecdsa-sha2-nistp256	20250618	20250622

Tags:

Investigations

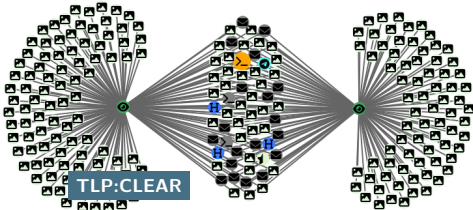
Graph

Reset Graph

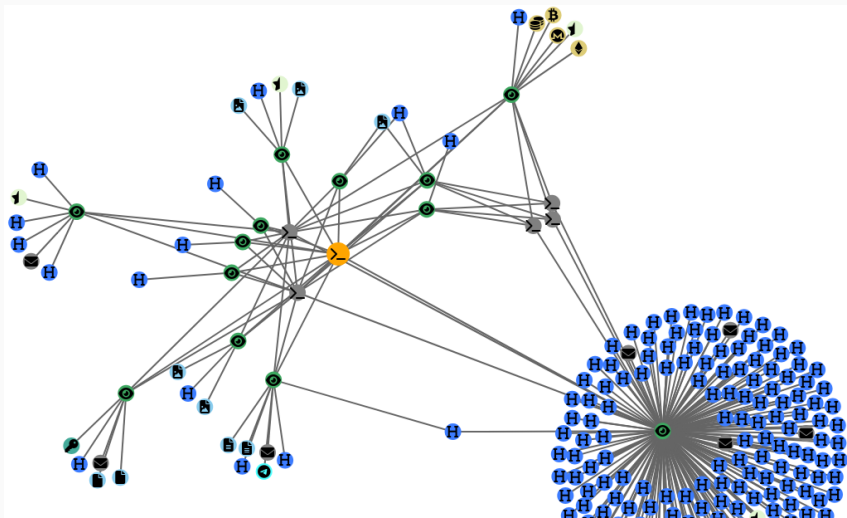
Resize Graph

Add to MISP Export

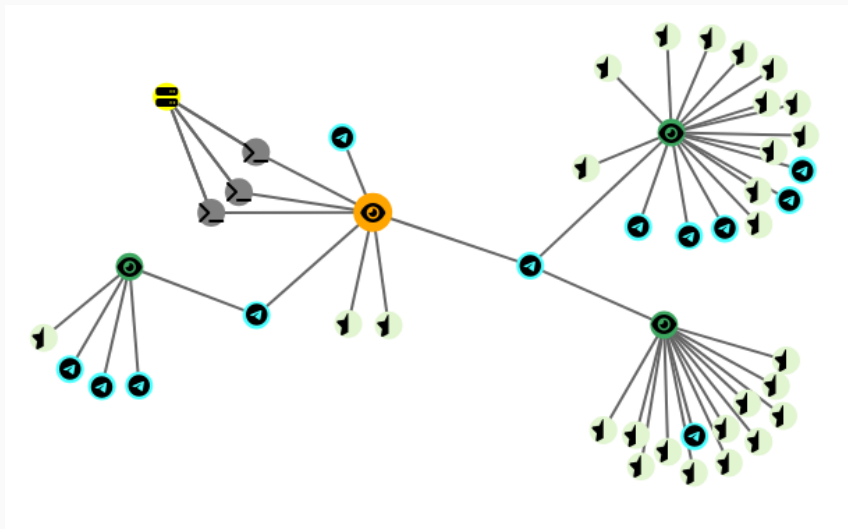
Hide



# AIL - SSH Correlation - Shared fingerprints



# AIL - Deanomized Onions through shared fingerprints



- Pivoting is evolving from a manual, intuition-driven process into a reproducible, data-driven discipline—supported by open-source platforms like MISP and AIL.
- Uncommon indicators matter just as much as traditional ones, they often reveal what others overlook.
- Imperfect doesn't mean useless. Even outdated or colliding indicators can still provide valuable correlations.
- **Creativity is essential**, experimenting with new correlation methods leads to deeper insights and better threat discovery.

# Thank you for your attention

- AIL project<sup>13</sup> : <https://github.com/ail-project/ail-framework>
- For questions, contact: [info@circl.lu](mailto:info@circl.lu)
- For LEO/LEA access, contact: [info@misp-lea.org](mailto:info@misp-lea.org)

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<sup>13</sup>All techniques and indicators mentioned in these slides are implemented in the AIL project, using an instance backed by a 4+ year dataset collected from Tor hidden services and various social networks.