Informing Cyber Threat Intelligence through Dark Web Situational Awareness: The AZSecure Hacker Assets Portal

SAGAR SAMTANI, Department of Operations and Decision Technologies, Indiana University

WEIFENG LI, Department of Management Information Systems, University of Georgia

VICTOR BENJAMIN, Department of Information Systems, Arizona State University

HSINCHUN CHEN, Department of Management Information Systems, University of Arizona

To increase situational awareness, major cybersecurity platforms offer Cyber Threat Intelligence (CTI) about emerging cyber threats, key threat actors, and their modus operandi. However, this intelligence is often reactive, as it analyzes event log files after attacks have already occurred, lacking more active scrutiny of potential threats brewing in cyberspace before an attack has occurred. One intelligence source receiving significant attention is the Dark Web, where significant quantities of malicious hacking tools and other cyber assets are hosted. We present the AZSecure Hacker Assets Portal (HAP). The Dark Web-based HAP collects, analyzes, and reports on the major Dark Web data sources to offer unique perspective of hackers, their cybercriminal assets, and their intentions and motivations, ultimately contributing CTI insights to improve situational awareness. HAP currently supports 200+ users internationally from academic institutions such as UT San Antonio and National Taiwan University, law enforcement entities such as Calgary and Ontario Provincial Police, and industry organizations including General Electric and PayPal.

CCS Concepts: • **Security and privacy** → **Malware and its mitigation**; • **Information systems** → **Data analytics**;

Additional Key Words and Phrases: Situational awareness, dark web, cyber threat intelligence, systems development

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Authors' addresses: S. Samtani, Department of Operations and Decision Technologies, Indiana University, 1275 E. 10th St., Bloomington, Indiana 47405, USA; email: ssamtani@iu.edu; W. Li, Department of Management Information Systems, University of Georgia, 630 S. Lumpkin St., Athens, GA 30602, USA; email: weifeng.li@uga.edu; V. Benjamin, Department of Information Systems, Arizona State University, 300 E. Lemon St., Tempe, AZ 85287, USA; email: victor.benjamin@asu.edu; H. Chen, Department of Management Information Systems, University of Arizona, 1130 E. Helen St., McClelland Hall 430, Tucson, AZ 85721, USA; email: hsinchun.chen@arizona.edu.

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Fig. 1. (a) Healthcare databases for sale on DNM; (b) crypter source code, a key technology for ransomware shared on forums; (c) credit/debit cards and SSNs for sale in a carding shop.

1 INTRODUCTION

Cybersecurity researchers and practitioners have developed numerous security controls to help organizations improve their cybersecurity posture. To help organizations increase situational awareness [10], major industry cybersecurity platforms such as Shadowserver and QRadar offer **Cyber Threat Intelligence (CTI)** about emerging cyber threats and key threat actors [4]. These platforms typically curate intelligence for dissemination to stakeholders via visualizations and/or regular reports. However, this intelligence often lacks the situational awareness of potential threats from cyberspace, as it consists of post-mortem analysis of attacks after they have already occurred [7]. Recognizing this issue, the SANS Institute has urged CTI platforms to leverage “external threat intelligence sources to help alert the organization of threats it was not previously aware of” [4]. One such data source receiving significant attention is the Dark Web. The Dark Web includes hundreds of online markets and social media platforms where millions of hackers globally trade and sell significant quantities malicious hacking tools, content, knowledge, and other cyber assets on hacker forums, **DarkNet Marketplaces (DNMs)**, **Internet-Relay-Chat (IRC)**, and carding shops [3]. The Dark Web also contains information and marketplaces for illicit goods, such as drugs; the system described in this manuscript focuses explicitly on cybersecurity topics. Figure 1 illustrates sample Dark Web content.

The Dark Web’s breadth of malicious cybercriminal knowledge and tools has enabled hackers to execute large-scale cyber-attacks. An example includes the Mirai botnet leaked on forums that infected millions of Internet of Things devices that denied service to major Internet DNS servers [10]. Such cases underscore the Dark Web’s viability for developing awareness of cybercriminal activities and novel CTI [1]. However, anti-crawling measures, multi-lingual content, unstructured data, unfamiliar hacker knowledge, and massive data volume has slowed critically needed CTI research on the Dark Web.

This article presents a novel Dark Web-based CTI system, the **AZSecure Hacker Assets Portal (HAP)**. Developed by the AI Lab at the University of Arizona and funded by NSF’s **Scholarship-for-Service (SFS)** and Secure and Trustworthy Cyberspace programs, HAP’s design was guided by feedback from CTI sharing organizations such as **Policing in Cyberspace (POLCYB)** and **National Cyber Forensics Training Alliance (NCFTA)**

Table 1. Overview and CTI Value of Dark Web Data Sources

Platform	Data Sources	Description	Example Platforms	CTI Value
Hacker Forums	Leaked forums	Forums that have been leaked to the general public	Antichat, Blackhackerz, Blackhat World	-Discussions mentioning past and future attacks -Advertisements for hacking services (e.g., DDoS for hire)
	Seized forums	Forums that have been shut down and seized by law enforcement	Darkode, shadowcrew, cardersmarket	-Free hacking tutorials and exploits (e.g., SQLi, BlackPOS)
	Active forums	Active, accessible forums that have not been seized or are offline	OpenSC, Ashiyane, reverse4you, exelab	-Identify key threat actors -Discover emerging hacking/threats
Carding/Fullz Shops	Carding/Fullz shops	Shops selling stolen credit/debit cards and sensitive information (e.g., Social Security Numbers, drivers licenses, insurance cards)	cardersshop, BESTVALID, rescatorccfullz, fullzshop	-Identify breached individuals and organizations -Discover trends of afflicted financial service industries
Internet-Relay-Chat	Active IRC Channels	Clear-text, instant messaging, communication that is not stored	Anonops, whyweprotest, anonet, opddosisis	-Preferred method of communication for hacktivist groups (e.g., Anonymous) -Since chats are not logged, hackers more freely share hacking knowledge and targets
DarkNet Markets	Grams	Search engine for identifying DNMs	—	-Identify markets to collect to generate CTI
	Active market website	Active marketplaces that have not been seized	Minerva, therealdeal, dream market	-Identify new, emerging exploits (0-days, ransomware) -Discover breached content (e.g., logins) -Early indicator for breached companies -Identify key sellers/buyers

to provide real-time CTI data, capabilities, and situational awareness to cybersecurity researchers and educators, government agencies, and industry professionals. It contains data similar to what can be found in Figure 1, including datapoints featured in published academic studies [3]. Specifically, HAP:

- Collects a comprehensive set of Dark Web platforms.
- Synergistically incorporates state-of-the-art CTI, data mining, and text mining methodologies to organize Dark Web contents into the HAP interface to facilitate content browsing, searching, and downloading.
- Offers dynamic visualizations for scholars to systematically gain situational awareness through exploring the vast Dark Web and formulate novel scholarly research inquiries related to emerging threat detection, key hacker identification, data fusion, and others.

2 DARK WEB CONTENT AND DARK WEB-BASED CTI PLATFORMS

Each Dark Web platform offers distinct CTI value. We provide a summary data sources, descriptions, example platforms, and CTI value for each platform in Table 1.

Table 2. Selected Industry and Academic Dark Web-based CTI Platforms

Sector	Platform	Dark Web Data Source				Analytics*	Operational Intel*
		Forum	DNM	C. Shop	IRC		
Industry	Verint	✓	✓	NL	NL	Network/text	Portal, API
	Skybox Security	✓	✓	NL	NL	NL	Portal, Feeds
	LookingGlass	✓	NL	NL	Yes	ML	Portal, API
	Recorded Future	✓	✓	✓	NL	ML, NLP	Portal, Feeds
	Blueliv	NL	✓	NL	NL	NL	Portal
	Digital Shadows	✓	✓	NL	NL	Basic search	Portal, API
	Flashpoint	✓	NL	✓	NL	Search, SME	API
	Surfwatch Labs	✓	✓	No	No	SME, search	Portal
	ZeroFox	NL	✓	No	No	Search	Portal, API
	CYR3CON	✓	✓	NL	NL	Rule-based	Blogs, feeds
	DarkOwl	✓	✓	✓	✓	NL	Portal, feeds
	Experian	NL	✓	✓	NL	Search	Portal
Academic	AZSecure DIBBs	✓	✓	✓	✓	None	Newsletters
	Intl. CyberCrime Research	✓	✓	No	No	NL	Newsletters
	IARPA CAUSE	✓	✓	✓	✓	ML	Newsletters
	Cambridge Cybercrime Centre	✓	No	No	No	None	Newsletters
	IMPACT	No	✓	No	No	NL	Papers/data
	MEMEX	✓	✓	NL	✓	NL	Papers/data

* Note: NL = Not Listed; ML=Machine Learning; API=Application Programming Interface; SME=Subject Matter Expert; NLP=Natural Language Processing.

Hackers use forums and/or IRC to discuss TTPs, share exploits, and advertise services or products to other hackers [3]. Hackers can contact promoters or navigate to DNMs or shops to purchase goods. Live platforms contain anti-crawling measures that block web crawlers. The overhead required to comprehensively collect active platforms often limits collection to small subsets of Dark Web data or only one platform Dark Web platform type [3]. However, numerous industry and academic hacker community-based CTI platforms have emerged. Table 2 summarizes platforms based on their data, analytics, and operational intel as listed on each organization's websites.

Most entities only gather selected platforms. This prevents a holistic view of hacker activities. Further, the volume, multi-lingual, and jargon-laden nature of Dark Web text require novel procedures tuned to these unique characteristics to maximize CTI precision. Some systems are not CTI focused (e.g., MEMEX), do not provide analytics (e.g., DIBBs), or lack scalable operational intelligence capabilities (e.g., CAUSE). These limitations motivate a novel CTI system with (1) a comprehensive set of hacker community platforms and (2) carefully designed analytics for system organization and situational awareness research opportunities.

3 AZSECURE HACKER ASSETS PORTAL SYSTEM OVERVIEW

HAP (Figure 2) collects, analyzes, and reports on the four major Dark Web data sources to offer unique perspective of hackers, their cybercriminal assets, and their intentions and motivations, ultimately contributing deep, relevant, and new CTI insights and research opportunities for academia, industry, and governments.

Fig. 2. AZSecure HAP System Design.

Table 3. AZSecure Dark Web Data Collection Strategies

Anti-crawling Mechanism	Description	Countermeasure
AJAX	Webpage content is transmitted through AJAX so that HTML does not contain sensitive information	Discover and exploit the link requesting data in the AJAX code
CAPTCHA	Decide whether the request came from a human or bot	Solve CAPTCHA manually, then load the generated session cookie afterwards
DDoS Prevention	Server detects IP request patterns block suspicious IPs	1. Fine-tune crawling rates and request with random patterns to emulate human behavior 2. Constantly alter source IP addresses
IP Range Block	Blacklists IP ranges to block requests	Reroute requests through private proxy servers
Session Timer	Automatic user log outs	Edit expiration date of the website cookie
User-agent Check	The server verifies requests come from a legit browser, rather than a crawler	Wrap requests with headers containing user-agent information
User Authentication	Requires login with credentials	1. Log into platform manually for the first time and load generated session cookie afterwards 2. Fill out the login form automatically

3.1 Dark Web Identification and Collection

We collected active platforms based on SFS, POLCYB, and NCFTA feedback for maximum CTI value. We developed novel counter anti-crawling measures (Table 3) to bypass all current known Dark Web collection barriers. It is possible that in the future, new anti-crawling measures can be developed and employed by Dark Web communities that would require further efforts to be circumvented. This is typical of the arms race between cybersecurity professionals and cybercriminals. Overall, these collection strategies enable automated and comprehensive data collection.

Custom parsers augmented with each anti-crawling mechanism countermeasure extracted CTI-relevant attributes such as screennames, post/listing content, and timestamps. These procedures yielded 10,975,390 records

Table 4. Summary of AZSecure HAP Data Collection

Platform	Number Collected	Number of Records	Languages	Contents
Hacker Forums	34 forums	3,643,216	English, Russian, Arabic, Chinese	Advertisements of credentials (bank accounts, PayPal, health), ransomware, mobile malware, phishing, botnets, tutorials
DarkNet Marketplaces	9 markets	80,075	English, Russian, Dutch	Listings of credentials (bank accounts, PayPal, health), exploits (SQLi, 0-days), tutorials, malware
Carding/Fullz Shops	26 Shops	6,471,839	English	SSNs, debit/credit cards
IRC Channels	21 Channels	767,630	English	Hacktivism, DDoS, and general hacking discussions
Total:	90 Platforms	~10,975,390	English, Russian, Arabic, Dutch, Chinese	—

spanning 2002–2020. Table 4 summarizes the number of platforms collected, the number of extracted data records, language coverage, and available contents.

3.2 HAP System Analytics

HAP synergistically combines CTI analysis, text mining, and data mining to organize and present Dark Web data for users to search, sort, browse, and download assets. Major exploit categories highlighted by the platform were identified using topic extraction on hacker platform content. VirusTotal, a popular Google-based static malware analyzer reports each malware’s operations (e.g., worm, keylogger, Trojan, etc.). Figure 3 illustrates how a retailer can search for **point-of-sale (POS)** malware. POS malware gained popularity after Target’s breach. By searching for “POS,” they can pinpoint BlackPOS (the malware used against Target), identify when, where, and who posted it, and learn malware implementation details.

3.3 Core Functionalities and Visualization and Reporting

HAP also provides a set of interactive CTI dashboards by aggregating (e.g., post date, hacker screenname, asset category, etc.). This allows users to discover asset trends, pinpoint key hackers, and identify assets. Figure 4 illustrates how a user can filter on a time point for system-based exploits to identify key hackers and assets posted at that time. Users can further filter on hacker names to identify a hacker’s assets and posting trends. Besides the hacker forum exploit dashboards, the HAP also includes dashboards for DarkNet Marketplaces.

4 AZSECURE HAP’S PRACTICAL CYBERSECURITY IMPLICATIONS FOR SITUATIONAL AWARENESS

The scale, breadth, and depth of HAP data enables numerous novel CTI analytics. Table 5 summarizes five promising CTI opportunity areas provided by HAP. Each inquiry’s possible approaches are carefully selected based on each platform’s characteristics, past literature, and the method’s strengths as it pertains to their respective research direction.

Given the broad nature of the discipline, CTI is often segmented into strategic, operational, and tactical levels of focus. Each level has specified job roles and responsibilities as it pertains to the overall CTI lifecycle. Each component of the HAP holds value to selected stakeholders from both research and practice perspectives. Table 6 provides a brief summary of the different intelligence levels, example stakeholders, the relevant HAP component(s) that can offer value to those stakeholders, and selected security implications. The following sub-sections provide a further discussion of each level.

Fig. 3. HAP provides (a) a navigation for browsing. Users can (b) search and (c) sort assets based on name, type, author, and others. They can also download assets directly. Clicking on an asset provides (d) additional metadata and (e) the Dark Web posting that accompanied the asset. Users can also get a full VirusTotal malware summary (f). Full technical details and additional analysis are available at [3].

4.1 Strategic Intelligence

Strategic CTI focuses on allocating resources towards the cybersecurity concerns facing an organization. Chief Information Security Officer's and other management must effectively communicate the security needs of their organization using reports that feature critical information and visualizations to executive management and other stakeholders regarding attainment of investments in cybersecurity defense. The visualizations can also play an important role in presenting striking visualizations to guide security investments.

Fig. 4. The CTI Dashboards in the HAP allow users to (a) identify trends of specific asset types, (b) key hackers, and (c) assets at specific time points. Users can further (d) select hackers of interest and identify (e) assets and (f) asset trends.

Table 5. Summary of Selected CTI Research Inquiries Possible with HAP Data

CTI Area	CTI Research Inquiry	Dataset(s)	Possible Approach(es)
Threat Detection	Detecting emerging exploits	Forums, IRC, DNMs	Bayesian Forecasting
	Source code evolution	Forums	Syntax trees
	Hacker language evolution	Forums, IRC, DNMs	Diachronic linguistics
Key Hacker Identification	Identifying key hackers	Forums, IRC	Network analysis
	Key seller identification	DNMs, Carding shops	Econometrics
	Hacker longevity/persistence	IRC, Forums	Survival analysis
Multi-lingual analysis	DNM sentiment analysis	Forums, DNMs	Deep Transfer Learning, Adversarial Learning
	Machine translation	Forums, DNMs, IRC	
Global hacker surveillance	Cross-platform data fusion	Forums, IRC, DNMs	Multi-source analysis
	Fusion with log files	Forum exploit data, network logs	Deep Structured Semantic Models
Cybersecurity visualization	Code evolution	Source code in forums	Network/tree visualizations
	Spatial carding crime analysis	Shops	Geo-spatial dashboards

Table 6. Summary of Selected Security Implications for AZSecure HAP for Varying Levels of Cyber Threat Intelligence

Intelligence Level	Selected Stakeholders	Relevant HAP Component(s)	Security Implications
Strategic	Security managers	Dashboards	Guiding security investments
		Visualization	
Operational	IR Team	Reporting	Threat reporting
		Summary statistics	Threat discovery & assessment,
Tactical	Malware Analysts	Malware analysis, summary statistics	Monitoring, escalating, & detecting IOC

4.2 Operational Intelligence

Operational CTI is focused on threat discovery, assessment, remediation, and reporting incidents to strategic and tactical levels of CTI. A key issue curtailing effective situational awareness is information overload. HAP's visualization, reporting and summary statistics can offer intuitive approach to bypassing large tables of data. Summary statistics provide analysts the ability to dynamically create a representation of threats without any prior knowledge and help prioritize top threats and facilitate subsequent remediation activities. Further helping facilitate summary statistics, this visualization can offer significant value in categorizing and clustering threats and target platforms.

4.3 Tactical Intelligence

Tactical intelligence focuses on monitoring, escalating, and detecting **Indicators of Compromises (IoCs)**, executing remediation exercises (e.g., patching vulnerable systems). These indicators are subsequently fed into selected security systems and reporting formats by SOC analysts, malware analysts, and individuals in similar roles. Common challenges that these job functions face include threat identification and prioritization. HAP's malware analysis and summary statistics can offer value to help address these issues. Both provide valuable tactical leads for CTI professionals. An example for the generated intelligence would be the integration of new rules into **Security Information and Event Management (SIEM)** systems. Using the intelligence provided by the malware analysis and summary statistics, the SIEM can quarantine or alert tactical intelligence security analysis if the IoCs appear within devices on their network.

5 CONCLUSIONS AND FUTURE DIRECTIONS

Interested readers can contact the lead author for access to the portal. Given the sensitive nature of Dark Web data, registrants will be asked to identify themselves and summarize their intended HAP use. HAP currently supports 200+ users internationally from academic institutions such as UT San Antonio and National Taiwan University, law enforcement entities such as Calgary and Ontario Provincial Police, and industry including General Electric and PayPal. Advanced HAP functions will be developed to help organizations identify relevant Dark Web data for their vulnerabilities and enable efficient Dark Web data dissemination. Both additions will help HAP serve as a model for the next generation of CTI platforms.

REFERENCES

- [1] Sadia Afroz, Vaibhav Garg, Damon McCoy, and Rachel Greenstadt. 2013. Honor among thieves: A common's analysis of cybercrime economies. In *Proceedings of the eCrime Researchers Summit*. 1–11.
- [2] Mohammed Almukaynizi, Eric Nunes, Krishna Dharaiya, Manoj Senguttuvan, Jana Shakarian, and Paulo Shakarian. 2017. Proactive identification of exploits in the wild through vulnerability mentions online. In *Proceedings of the 2017 International Conference on Cyber Conflict (CyCon U.S. '17)*, 82–88.
- [3] Victor Benjamin, Joseph S. Valacich, and Hsinchun Chen. 2019. DICE-E: A framework for conducting darknet identification, collection, evaluation, with ethics. *MIS Quart.* 43, 1 (2019), 1–22.
- [4] Matt Bromiley. 2016. Threat Intelligence: What it is, and how to use it effectively. Retrieved June 5, 2017 from <https://www.sans.org/reading-room/whitepapers/analyst/threat-intelligence-is-effectively-37282>.
- [5] David Décary-Héту and Dominique Laferrière. 2015. Discrediting vendors in online criminal markets. In *Disrupting Criminal Networks: Network Analysis in Crime Prevention*. 1–27.
- [6] Ernst & Young Global Limited. 2014. Cyber threat intelligence—How to get ahead of cybercrime. Retrieved from [http://www.ey.com/Publication/vwLUAssets/EY-cyber-threat-intelligence-how-to-get-ahead-of-cybercrime/\\$FILE/EY-cyber-threat-intelligence-how-to-get-ahead-of-cybercrime.pdf](http://www.ey.com/Publication/vwLUAssets/EY-cyber-threat-intelligence-how-to-get-ahead-of-cybercrime/$FILE/EY-cyber-threat-intelligence-how-to-get-ahead-of-cybercrime.pdf).
- [7] Sanjay Goel. 2011. Cyberwarfare. *Commun. ACM* 54, 8 (Aug. 2011), 132.
- [8] Luke Graham. 2017. Cybercrime costs the global economy \$450 billion: CEO. Retrieved June 5, 2017 from <https://www.cnn.com/2017/02/07/cybercrime-costs-the-global-economy-450-billion-ceo.html>.
- [9] Tracy Kitten. 2014. Target Malware: Exploring the Origins. Retrieved June 5, 2017 from <http://www.bankinfosecurity.com/interviews/intelcrawler-i-2161>.

- [10] Jan Kohlrausch and Eugene A. Brin. 2020. ARIMA supplemented security metrics for quality assurance and situational awareness. *Digit. Threats: Res. Pract.* 1, 1, Article 6 (Mar. 2020), 1–21. DOI: <https://doi-org.proxy-remote.galib.uga.edu/10.1145/3376926>

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