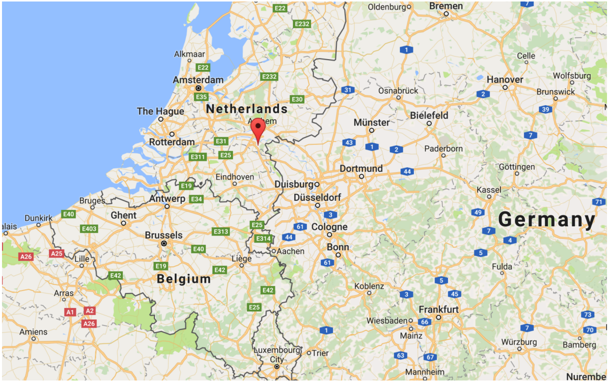
# Detection of browser-based cryptocurrency mining

Veelasha Moonsamy
Radboud University, The Netherlands

25 June 2019
Blockchain and Cryptocurrencies Security School
University of Padova, Italy

# Radboud University, Nijmegen, NL




# DiS research areas

- (Applied) Crypto
  - Symmetric key crypto
  - Identity-based applications
  - Smart cards and RFID security
- Hardware security
  - Side-channel analysis and countermeasures
  - Fault attacks
- System Security
- Efficient implementations of crypto: hardware and software
- Post-quantum crypto
- Lightweight crypto: protocols and implementations
- Privacy engineering (Privacy & Identity lab)
- Read more about DiS members:
  https://www.ru.nl/dis/people/members/

# iHUB – latest development

- https://www.ru.nl/ihub/
- Radboud University's new interdisciplinary research hub on Security, Privacy, and Data Governance
- iHub brings together a diverse range of scholars from across the **humanities**, **social sciences**, **engineering** and **natural sciences**
- Tackle urgent questions raised by the increased digitalization and datafication of science and society
- Join the mailing list to keep up-to-date: https://mailman.science.ru.nl/mailman/listinfo/ihub-followers

# Erasmus+ programme as of January 2019: Nijmegen & Padova

- Allows for students (and staff) to study (and teach) at universities in the EU member states for set periods of time
- Inter-institutional agreement from 2018/19 until 2021/22
- Suitable for both student and staff exchanges
- More about:
  - Bachelor programme: https://www.ru.nl/english/education/bachelors/computing-science/programme-outline/
  - Master programme: https://www.ru.nl/english/education/masters/computing-science/programme-outline/
- All courses are taught in English (both at the Bachelor and Master level)

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1. Summer school on real-world crypto and privacy (June 2020, Croatia)
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2. Interdisciplinary Summerschool on Privacy (September, Nijmegen)
    - 1-6 September 2019
    - https://isp.cs.ru.nl/2019/
    - This year's theme: Dark Patterns

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- Both conferences offer student stipends

# Acknowledgment

- Joint collaboration:

**MineSweeper: An In-depth Look into Drive-by Cryptocurrency Mining and Its Defense**

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- Paper available at: www.veelasha.org
- Link to GitHub repo in the paper

# Cryptocurrency: the rise of decentralized money

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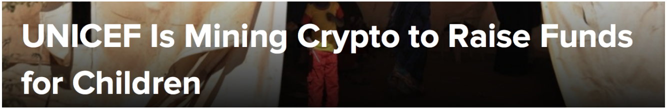
- ... which in turn led to the proliferation of cryptomining services, such as **Coinhive** - introduced in September 2017
- Can be easily integrated into a website to mine on its visitors' devices from within the browser

# From September 2017 onwards ...

It started with:



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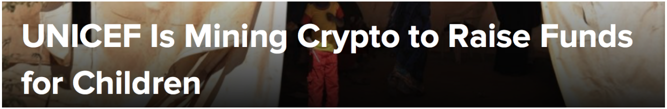


'Our Cryptocurrency Mining Policy: Free Content, No Ads!'

# From September 2017 onwards ...

And things went downhill very quickly:

CRYPTOVEST NEWS ICOs COINs KNOWLEDGE INDUSTRY

Trending Topics #Bitcoin News #Ethereum News #Bitcoin Cash News #Ripple News

**Cryptocurrency Mining Malware Expected to Explode in 2018**

**Cryptojackers Found on Starbucks WiFi Network, GitHub, Pirate Streaming Sites**

By Catalin Cimpanu December 13, 2017 09:25 AM

Cryptojacking Attacks Explode by 8,500 Percent

Stealthy miners steal resources and increase vulnerability

# Recent update

- 08 March 2019: Coinhive is no longer in operation* [1]

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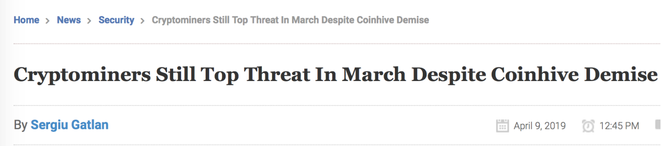
- Community's reaction:

Help Net Security
April 10, 2019

Share this article

**Coinhive stops digging, but cryptomining still dominates**



Home > News > Security > Cryptominers Still Top Threat In March Despite Coinhive Demise

**Cryptominers Still Top Threat In March Despite Coinhive Demise**

By Sergiu Gatlan

April 9, 2019 12:45 PM

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# Drive-by mining aka *Cryptojacking*

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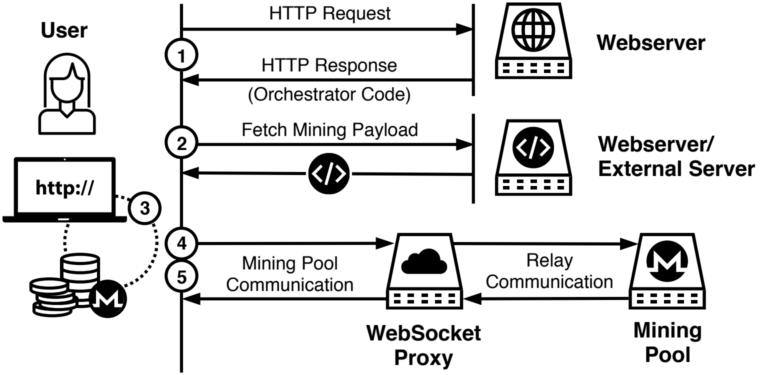
- In this work: we study the prevalence of drive-by mining attacks on Alexa's Top 1 million websites

# Threat Model



# Current detection methods

Two main approaches have been used:

1. Blacklist-based approach
2. High CPU-based approach

# Current detection method: Blacklist-based approach

- Existing defenses:

[2] https://gitlab.com/ZeroDot1/CoinBlockerLists
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- Shortcomings:
  - Not scalable
  - Prone to high false negatives
  - Easily defeated by URL randomization and domain generation algorithms

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- Consequently, many drive-by miners started throttling their CPU usage to around 25%
- Implications:
  - False positives, as there might exist other CPU-intensive use cases (e.g. games)
  - False negatives, as cryptominers have started to throttle their CPU usage to evade detection

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- Discuss why current defenses based on blacklisting and CPU usage are ineffective
- Propose **MineSweeper**, a novel detection approach based on the identification of the cryptographic functions (static analysis) and cache events (during run-time)

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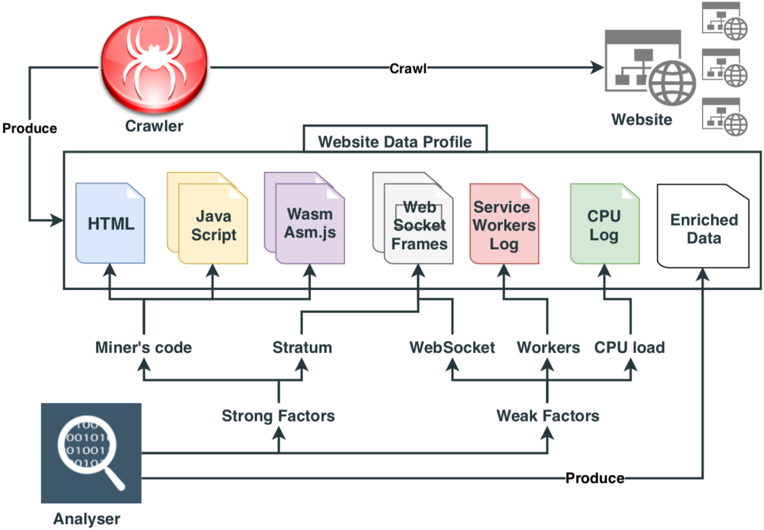
  6. What are the common characteristics across different drive-by mining services that can be used for their detection?

# Large-scale Analysis: experiment set-up



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- Crawled 991,513 websites; 4.6 TB raw data and 550 MB data profiles

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  - Keywords: `CoinHive.Anonymous` or `coinhive.min.js`

# Preliminary results: Cryptomining code (2/2)

- Identification of mining payload
  - Dump the Wasm (WebAssembly) payload
  - `-dump-wasm- module` flag in Chrome dumps the loaded Wasm modules
  - Keyword-based search: `cryptonight_hash` and `CryptonightWasmWrapper`

# Effectiveness of fingerprint-based detection

| Mining Service | Number of Websites | Percentage |
|---|---|---|
| Coinhive | 514 | 59.35% |
| CoinImp | 94 | 10.85% |
| Mineralt | 90 | 10.39% |
| JSECoin | 50 | 5.77% |
| CryptoLoot | 39 | 4.50% |
| CryptoNoter | 31 | 3.58% |
| Coinhave | 14 | 1.62% |
| Minr | 13 | 1.50% |
| Webmine | 8 | 0.92% |
| DeepMiner | 5 | 0.58% |
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- Issues with keyword-based fingerprinting: code obfuscation and manual effort of updating signatures

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- Use of WebSockets to allow full-duplex, asynchronous communication between code running on a webpage and servers
- Search in WebSocket frames for keywords related to Stratum protocol

| **Command** | **Keywords** |
|---|---|
| Authentication | type:auth \| command:connect \| identifier:handshake \| command:info |
| Authentication accepted | type:authed \| command:work |
| Fetch job | identifier:job \| type:job \| command:work \| command:get_job \| command:set_job |
| Submit solved hash | type:submit \| command:share |
| Solution accepted | command:accepted |
| Set CPU limits | command:set_cpu_load |

# Preliminary results: Mining pool communication (2/2)

- 59,319 (5.39%) websites use WebSockets
- 1,008 websites use Stratum protocol for communication
- 2,377 websites encode the data (Hex code or salted Base64)
  - more on this later

# Summary of key findings

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- All the websites (100.00%) use Wasm for the cryptomining payload and open a WebSocket
- At least 197 (11.36%) websites throttle their CPU usage to less than 50%, while for only 12 (0.69%) mining websites we observed a CPU load of less than 25%.

# In-depth analysis: evasion techniques

- We identified three evasion techniques, which are widely used by the drive-by mining services in our dataset
    1. Code obfuscation
    2. Obfuscated Stratum communication
    3. Anti-debugging tricks

# In-depth analysis: code obfuscation

- ***Packed code***: The compressed and encoded orchestrator script is decoded using a chain of decoding functions at run time.
- ***PCharCode***: The orchestrator script is converted to charCode and embedded in the webpage. At run time, it is converted back to a string and executed using JavaScript's `eval()` function.
- ***Name obfuscation***: Variable names and functions names are replaced with random strings.
- ***Dead code injection***: Random blocks of code, which are never executed, are added to the script to make reverse engineering more difficult.
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  All of the above mainly applied to orchestrator code; the only obfuscation on mining payload is *name obfuscation*

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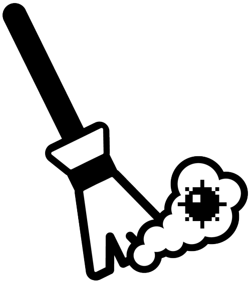
- Identified the Stratum protocol in plaintext for 1,008 websites
- Manually analyzed the WebSocket communication for the remaining 727 websites and found the following:
  - 174 websites obfuscate by encoding the request, either as Hex code, or with salted Base64 encoding before transmitting it through the WebSocket
  - We could not identify any pool communication for remaining 553 websites, either due to other encodings, or due to slow server connections

# In-depth analysis: Anti-debugging tricks

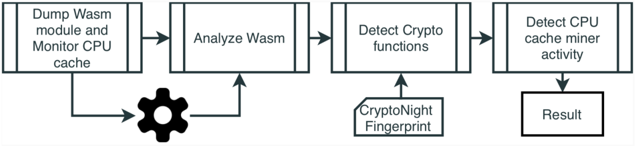
- 139 websites used anti-debugging tricks
- Checked code periodically to see whether the user is analyzing the code served by the webpage using developer tools
- If the developer tools are open in the browser, it stops executing any further code

# MineSweeper



# MineSweeper

- MineSweeper employs multiples stages in order to detect a webminer:



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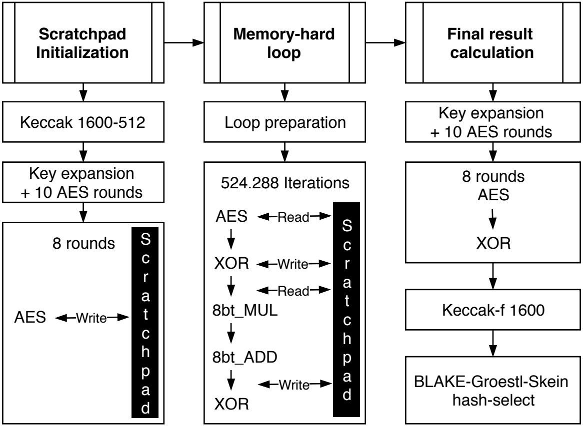
- We exploit two fundamental characteristics:
  - It makes use of several cryptographic primitives, such as: Keccak 1600-516, Keccak-f 1600, AES, BLAKE-256, Groestl-256, and Skein-256
  - A memory hard algorithm
    - High-performances on ordinary CPUs
    - Inefficient on today's special purpose devices (ASICs)
    - Internal memory-hard loop: alternate reads and writes to the Last Level Cache (LLC)

# CryptoNight algorithm (2/2)




- CryptoNight allocates a scratchpad of 2MB in memory
- On modern processors ends up in the LLC

# Wasm analysis

- Linear assembly bytecode translation using the WebAssembly Binary Toolkit (WABT) debugger
- Functions identification - to create an internal representation of the code for each function
- Cryptographic operation count - track the control flow and crypto operands
- Static call graph construction, including identification of loops

# CryptoNight detection

- MineSweeper is given as input a CryptoNight fingerprint
- We created a fingerprint for each of CryptoNight's cryptographic primitives based on operands counts and flow structure

# CryptoNight detection - an example

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- In this case, the similarity score is 3 and difference score is 2
- All three types of instructions are present in `foo()`; `foo()` contains extra XOR and an extra shift instruction

# Evaluation of cryptofunction detection

- Identified 40 unique samples among the 748 collected Wasm samples
- Applied the cryptofunction detection routine of MineSweeper on them

| Detected Primitives | Number of Wasm Samples | Number of Cryptominers | Missing Primitives |
|---|---|---|---|
| 5 | 30 | 30 | - |
| 4 | 3 | 3 | AES |
| 3 | - | - | - |
| 2 | 3 | 3 | Skein, Keccak, AES |
| 1 | - | - | - |
| 0 | 4 | 0 | All |

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# CPU cache events monitoring

- What if an attack would sacrifice part of the profits for obfuscated Wasm?
- Solution: CPU cache events monitoring
- MineSweeper monitors the L1 and L3 for load and store events caused by the CryptoNight algorithm
- Also detects a fundamental characteristic of the CryptoNight algorithm: the memory-hard loop!

# Evaluation of blacklisting approaches

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# Evaluation of blacklisting approaches

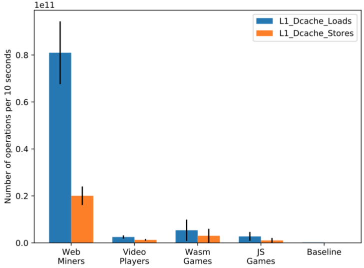
- For comparison, we evaluate MineSweeper against Dr. Mine
- Dr. Mine uses CoinBlockerLists as the basis to detect mining websites
- Visited the 1,735 websites that were mining during our first crawl for the large-scale analysis with both tools
- Dr. Mine could only find 272 websites, while MineSweeper found 785 websites that were still actively mining cryptocurrency

# Evaluation of CPU cache events monitoring (1/2)

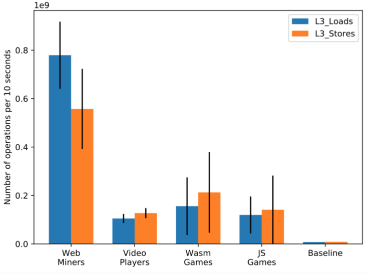
- We visited 7 pages for the following categories of web applications:
  - Web miners
  - Videoplayers
  - Wasm-based games
  - JavaScript (JS) games

# Evaluation of CPU cache events monitoring (2/2)

Our tests confirm us the effectiveness of this detection method on CryptoNight-based algorithms




Performance counter measurements for the L1 cache for different types of web applications (logscale)




Performance counter measurements for the L3 cache for different types of web applications (logscale)

# Conclusion

| | |
|---|---|
| Crawling period | March 12, 2018 – March 19, 2018 |
| # of crawled websites | 991,513 |
| # of drive-by mining websites | 1,735 (0.18%) |
| # of drive-by mining services | 28 |
| # of drive-by mining campaigns | 20 |
| # of websites in biggest campaign | 139 |
| Estimated overall profit | US$ 188,878.84 |
| Most profitable/biggest campaign | US$ 31,060.80 |
| Most profitable website | US$ 17,166.97 |

- Drive-by mining is real and can be very profitable for high traffic websites
- Current defenses are not sufficient to stop malicious mining
- To severely impact their profitability, we need to aim at the core properties of the miners code: **cryptographic functions** and **memory behaviors**

# Post-Minesweeper related work[5]

[5] This is not an exhaustive list

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- *Inadvertently Making Cyber Criminals Rich: A Comprehensive Study of Cryptojacking Campaigns at Internet Scale*, https://www.usenix.org/conference/usenixsecurity19/presentation/bijmans
  - This work builds upon Minesweeper
  - Performs two large studies into the world of cryptojacking, focused on organized cryptomining and the spread of cryptojacking on the Internet.

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- *Dissecting Android Cryptocurrency Miners*, https://arxiv.org/abs/1905.02602
  - Analyzed the Android miners and identified how they work
  - What are the most popular libraries and APIs used to facilitate the development of the mining script
  - What static features are typical for this class of applications

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# Future directions

LATEST OBSESSIONS FEATURED **QUARTZ** EMAILS EDITIONS BECOME A MEMBER

A NEW GENERATION

**The secret lives of students who mine cryptocurrency in their dorm rooms**

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- Network-based cryptomining detection (e.g. with university or company network)
- Detecting "pop-under" windows used for concealing illegitimate mining

Thank you for your attention!

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