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Forensic Analysis of SOHO Router Binaries

August 2024

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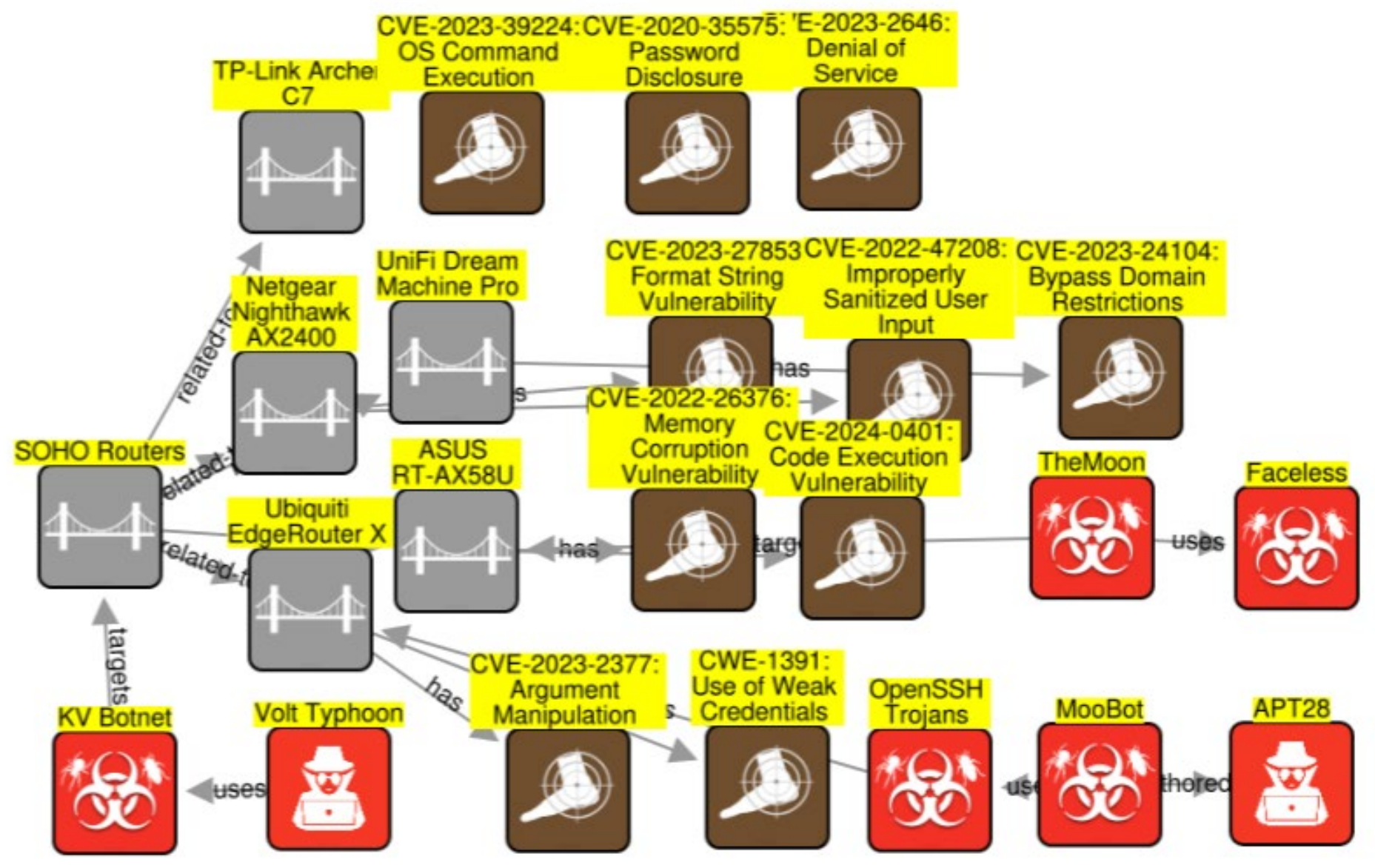
Problem

Small Office/Home Office (SOHO) routers are used by millions of consumers across the United States, and are commensurately vulnerable. **Forensic analysis of SOHO router firmware** helps to understand and mitigate those vulnerabilities.



TP-Link Archer C7
CVE-2023-39224: OS Command Execution
CVE-2020-35575: Password Disclosure
E-2023-2646: Denial of Service
Netgear Nighthawk AX2400
UniFi Dream Machine Pro
CVE-2023-27853: Format String Vulnerability
CVE-2022-47208: Improperly Sanitized User Input
CVE-2023-24104: Bypass Domain Restrictions
SOHO Routers
ASUS RT-AX58U
CVE-2022-26376: Memory Corruption Vulnerability
CVE-2024-0401: Code Execution Vulnerability
TheMoon
Faceless
Ubiquiti EdgeRouter X
related-to
has
targets
uses
CVE-2023-2377: Argument Manipulation
CWE-1391: Use of Weak Credentials
OpenSSH Trojans
KV Botnet
Volt Typhoon
MooBot
APT28

Figure 1: A visual representation of recent SOHO router vulnerabilities using Structured Threat Intelligence Graph (STIG). [1]

Introduction

Analysis starts with extraction of publicly-available firmware for SOHO routers in a multitude of formats, such as .bin, .img, and .w.

- Tools like Binwalk are used to decompress firmware from ASUS, Netgear, Ubiquiti, and TP-Link routers **into a complete squashfs Linux filesystem** [2].
- Analysis focused especially on analyzing BusyBox executables, a software suite that provides several Unix utilities in a single file [3]

Impact

The BusyBox version inside each router filesystem **rarely changed,** even across **months or years of firmware updates.** This demonstrates the importance of **constant firmware scrutiny**, by both venders and consumers, to protect against security vulnerabilities.

Analysis

BinWalk

- Firmware analysis tool for analyzing, reverse engineering, and extracting firmware images
- Used to **extract firmware images** for Ubiquiti, TP-Link, Netgear routers
- A different tool, called UnBlob, was used to extract ASUS routers. [4]
- Binwalk was also used to **build entropy graphs, extract Linux kernel images, and identify CPU architectures.**

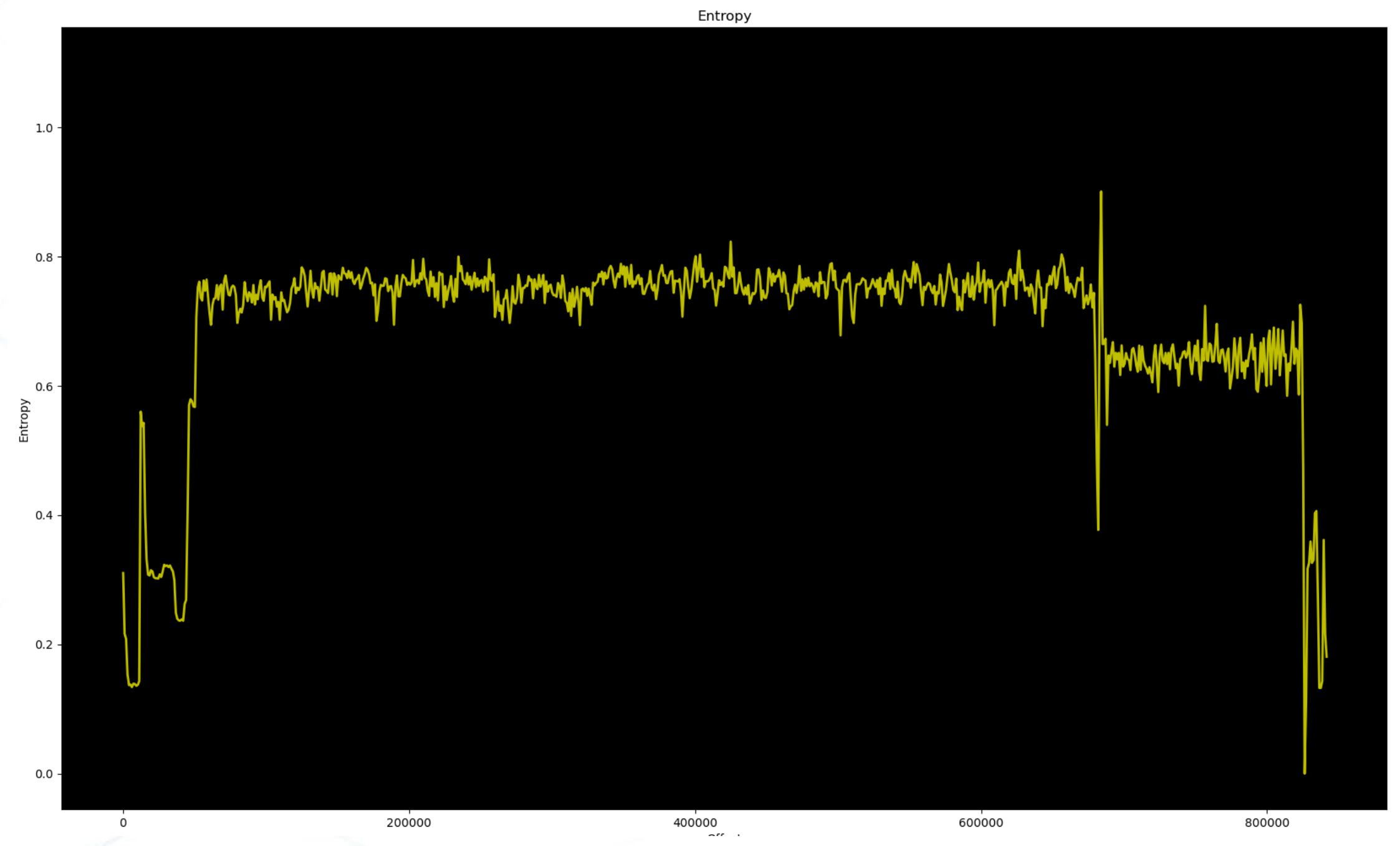
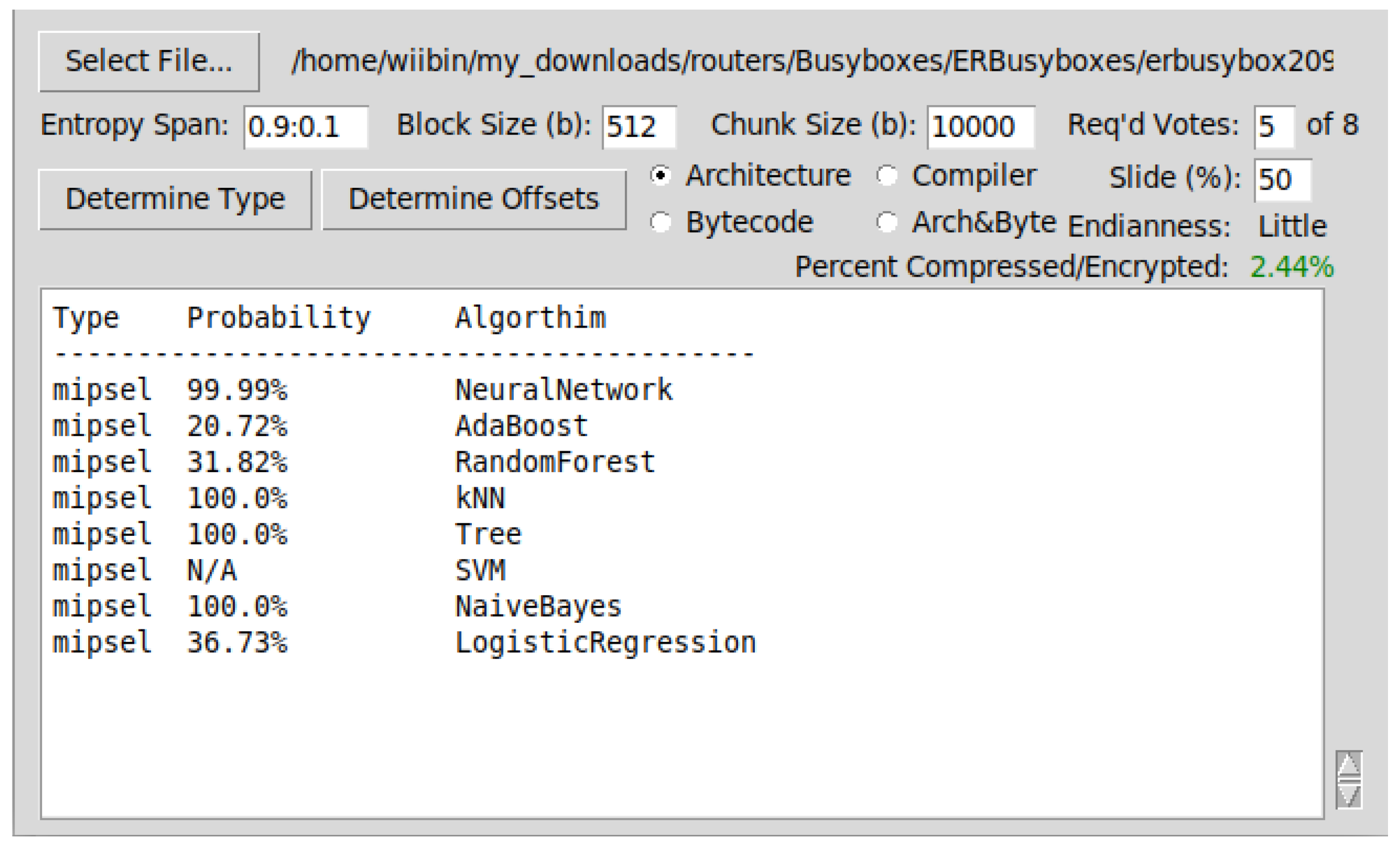


Figure 2: The entropy graph of the Unifi UDM Pro v1.9.2 BusyBox executable.

WiiBin

- After firmware images have been decompressed into a filesystem, WiiBin processes the binaries inside to find their **endianness, architecture, the percent compressed/encrypted, and compiler data**. [5]
- WiiBin can be scripted to analyze multiple files at once
- Found **near-exact data** for Busyboxes from **different versions of the same firmware**



/home/wiibin/my_downloads/routers/Busyboxes/ERBusyboxes/erbusybox209

Entropy Span: 0.9:0.1 Block Size (b): 512 Chunk Size (b): 10000 Req'd Votes: 5 of 8

● Architecture ○ Compiler Slide (%): 50

○ Bytecode ○ Arch&Byte Endianness: Little

Percent Compressed/Encrypted: 2.44%

```
Type    Probability     Algorthim
-----------------------------------------
mipsel  99.99%          NeuralNetwork
mipsel  20.72%          AdaBoost
mipsel  31.82%          RandomForest
mipsel  100.0%          kNN
mipsel  100.0%          Tree
mipsel  N/A             SVM
mipsel  100.0%          NaiveBayes
mipsel  36.73%          LogisticRegression
```

Figure 3: Determining the architecture of a Ubiquiti EdgeRouter X In WiiBin using eight different machine learning algorithms.

@DisCo

- @DisCo is a machine learning tool used **to determine function similarity in disassembled binaries.** [6]
- Analyzed similarities and determined versions of extracted BusyBox files from each router; 4-6 versions of each router were used
- Surprisingly, there was **very little overlap** between files that did not derive from the same router.
- Venders from all five routers utilized the **same version** of the BusyBox software across **different firmware updates**
- These files all contained the **same open-source software**, so such distinct differences between venders was unexpected.

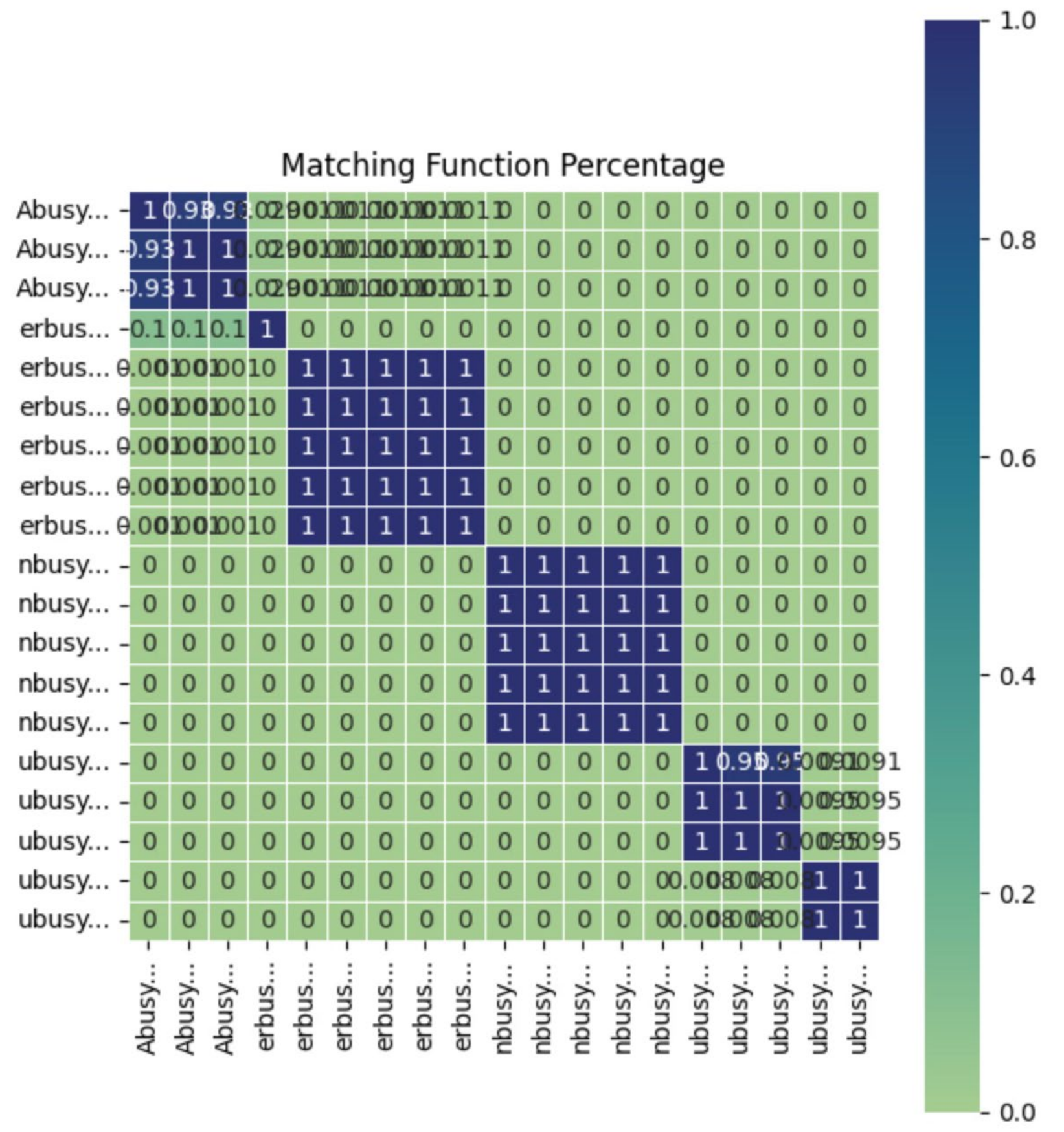


Figure 4: A @DisCo similarity heat map comparing all 19 router Busybox files against each other. Most Busyboxes from related versions are exact matches, with no similarities to other routers.

References:

[1] idaholab, “STIG,” *GitHub*, Aug. 27, 2019. https://github.com/idaholab/STIG (accessed Jul. 22, 2024).

[2]ReFirmLabs, “binwalk,” *GitHub*, Jan. 04, 2021. https://github.com/ReFirmLabs/binwalk (accessed Jul. 22, 2024).

[3] E. Andersen, “BusyBox: The Swiss Army Knife of Embedded Linux,” *busybox.net*. https://busybox.net/about.html (accessed Jul. 22, 2024).

[4] ONEKEY, “unblob,” *GitHub*, Jul. 22, 2024. https://github.com/onekey-sec/unblob (accessed Jul. 22, 2024).

[5] idaholab, “WiiBin,” *GitHub*, Jun. 21, 2024. https://github.com/idaholab/WiiBin (accessed Jul. 22, 2024).

[6] idaholab, “atDisco,” *GitHub*, Nov. 28, 2023. https://github.com/idaholab/atDisco (accessed Jul. 22, 2024).

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