
# Forensic Carving of Network Packets and Associated Data Structures

*By*

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# Forensic Carving of Network Packets and Associated Data Structures

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# Outline



# Networks and Forensics

## Forensic Value of Network Information:

- Devices are (invariably) connected to network(s)
- Users, applications, and operating systems interconnect (both explicitly and in the background)
- Network activity is *invaluable* forensic information:
  - Commonly visited web sites
  - Network attachment point(s)
  - File transfer
  - etc.

# Networks and Forensics

## Our Approach:

- Not looking at network traffic on the wire
- Not looking at logs (IDS/Firewall/Anomaly detector, etc)
- Instead – a storage-centric view

## Post-facto residual network data

Are *low-level binary* network data structures persisted to non-volatile storage?

# Networks and Forensics

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- Not looking at network traffic on the wire
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- Instead – a storage-centric view

## Post-facto residual network data

Are *low-level binary* network data structures persisted to non-volatile storage?

# Network Carving

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## e.g.:

```
struct ip {
  u_int   ip_v:4,                  /* version */
          ip_hl:4;                 /* header length */
  u_char  ip_tos;                  /* type of service */
  u_short ip_len;                  /* total length */
  u_short ip_id;                   /* identification */
  u_short ip_off;                  /* fragment offset field */
  u_char  ip_ttl;                  /* time to live */
  u_char  ip_p;                    /* protocol */
  u_short ip_sum;                  /* checksum */
  struct  in_addr ip_src,ip_dst;   /* source and dest address */
}
```

# Network Carving

## In this work, we ask:

Are *low-level binary* network data structures persisted to non-volatile storage?

## e.g.:

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struct ip {
  u_int   ip_v:4,                  /* version */
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  u_short ip_len;                  /* total length */
  u_short ip_id;                   /*
  u_short ip_off;                  /*
  u_char  ip_ttl;                  /*
  u_char  ip_p;                    /* protocol */
  u_short ip_sum;                  /* checksum */
  struct  in_addr ip_src,ip_dst;   /* source and dest address */
}
```

Surprisingly, yes!

# Outline



# Prior Work

## Network Carving Prior Work:

- Network data in ASCII form, e.g. web cache, cookies, etc.
- Fully-qualified Domain Names, e.g. `www.cnn.com`
- E-Mail Domain Names, e.g. `rob@nps.edu`
- "Dotted Quads," e.g. `157.166.224.26`

## Volatility [Walters]

- Volatility memory analysis framework "`connscan2`" closest in spirit to our effort
- Carves memory dumps and intact Windows hibernation files for Windows TCP connection structures

# NPS Research

## Our Contributions

- Using ground-truth corpus, develop methodology for carving binary network data:
  - Windows `_TCPT_OBJECT`
  - IP Packets
  - Ethernet Frames
  - Socket Structures
- Opportunistic hibernation decompression, including fragments
- Filtering and Validation techniques
- Working implementation in the `bulk_extractor` (`http://afflib.org/`) tool
- Evaluation on ground-truth and large (1800 drive) corpus

# Outline



# Ground Truth

## Ground-Truth Corpus:

- In order to find binary network carving structure signatures, we carefully create a ground-truth corpus
- Experimented with: Windows, OSX, Linux
- Wipe drive with DBAN to ensure no residual data
- From a virgin OS install, we establish several HTTP and SCP connections to *known* destination IPs
- Image the host's disk after each connection

# Finding Signatures

## Finding Signatures:

- A binary IPv4 address is simply an unsigned 32-bit integer
- To find network addresses, we find discriminatory surrounding context
- Determine if there exist common predecessor/successor patterns surrounding instances of the known IP

# Frequency Analysis

## Finding Signatures

- Tempting to use intuitive heuristics:
  - “a four byte IP address is preceded by a variable fragment field and a protocol field equal to six.”
- But heuristics brittle, difficult to define, and inaccurate

## Instead:

- Search for IP address
- Collect (within 20 Bytes offset) preceding and surrounding *N*-grams
- Where a “gram” is simply a byte

# Frequency Analysis

## IPv4 2-Gram Analysis

| **Predecessor Freq** | | **Successor Freq** | |
|---|---|---|---|
| Count | 2-gram | Count | 2-gram |
| 434 | 0x4000 | 428 | 0x0016 |
| 421 | 0x0800 | 426 | 0x0447 |
| 368 | 0xF202 | 412 | 0x0A79 |
| 368 | 0x4006 | 374 | 0xAC14 |
| 368 | 0x4508 | 374 | 0x694A |
| 368 | 0x0017 | 41 | 0x0000 |
| 66 | 0x4500 | 12 | 0x2000 |
| ... | ... | ... | ... |

# Frequency Analysis

## IPv4 2-Gram Analysis

| Predecessor Freq | | Successor Freq | |
|---|---|---|---|
| Count | 2-gram | Count | 2-gram |
| 434 | 0x4000 | | |
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| 368 | 0xF202 | | |
| 368 | 0x4006 | | |
| 368 | 0x4508 | | |
| 368 | 0x0017 | | |
| 66 | 0x4500 | | |
| ... | ... | ... | ... |

### Decoding:

- `0x4000`: IP Flags=Don't Fragment
- To our surprise, discovered Ethernet frame data!
- `0x0800`: Ethernet "type"=IP
- ...

# Frequency Analysis

## IPv4 2-Gram Analysis

| Predecessor Freq | | S |
|---|---|---|
| Count | 2-gram | C |
| 434 | 0x4000 | |
| 421 | 0x0800 | |
| 368 | 0xF202 | |
| 368 | 0x4006 | |
| 368 | 0x4508 | |
| 368 | 0x0017 | |
| 66 | 0x4500 | |
| ... | ... | |

### Decoding:

- Manual inspection on *N*-Gram frequency leads to robust signatures
- `0x4508/0x4500`: IPv4, w/ & w/o ToS
- `0x4006`: IP TTL=64, Proto=TCP
- While TTL=64 is common here, doesn't generalize
- ...

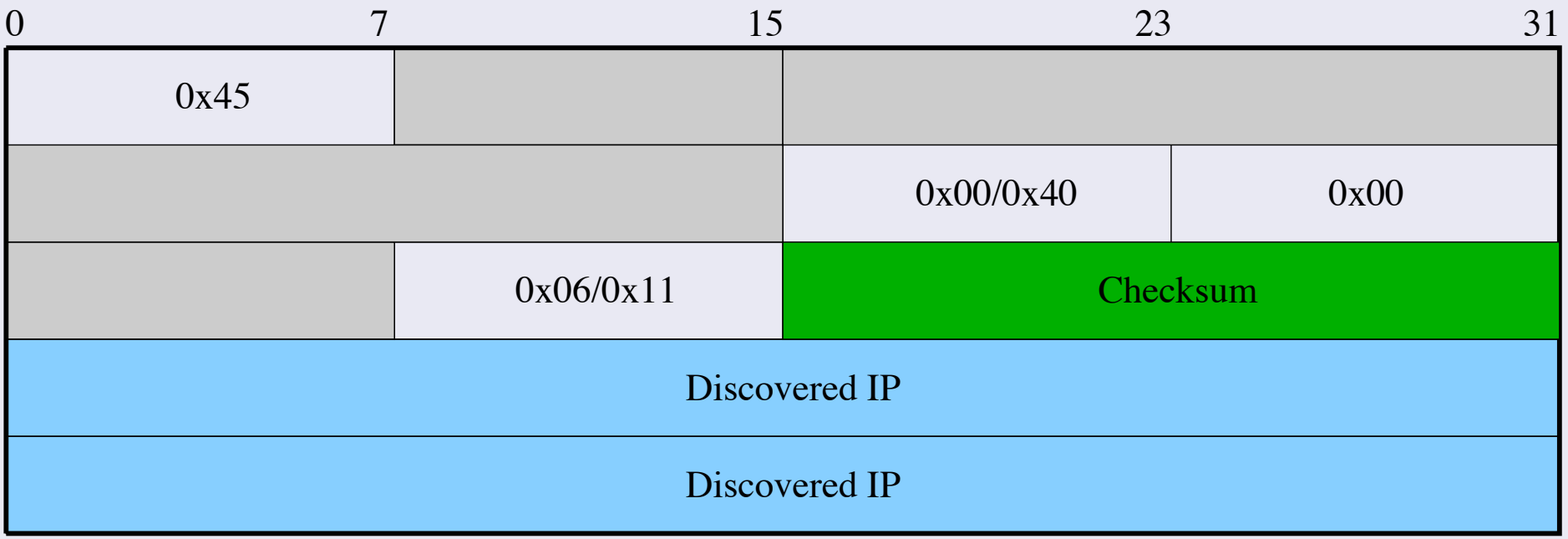
# Carving Signatures

Signatures: Manual Inspection + *N*-Gram Analysis

**Key**

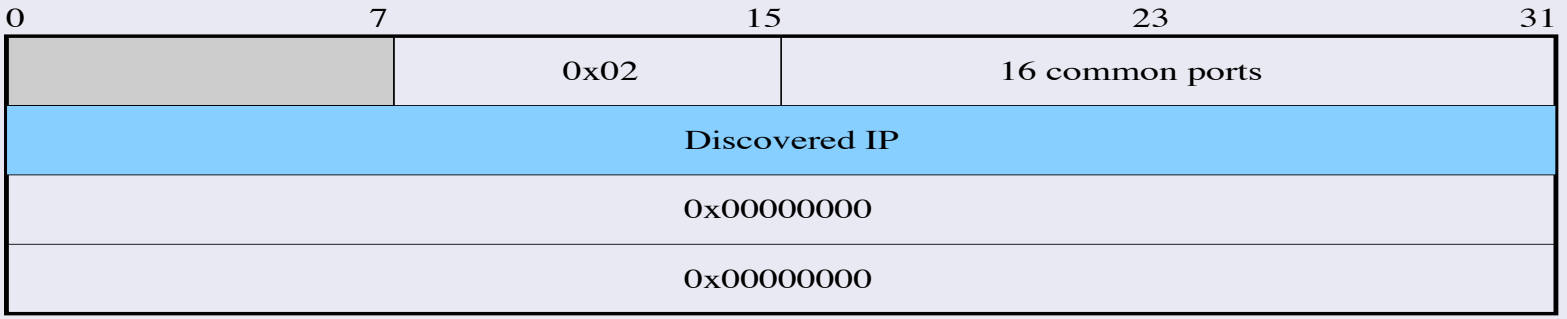
= Required
= Carved
= Wildcard
= Validation

## IP Carving

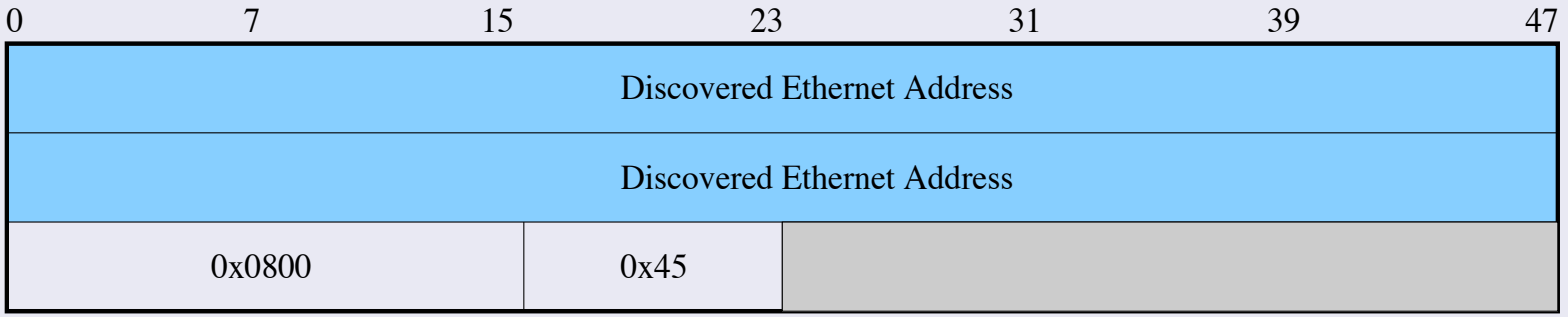


# Carving Signatures

## Socket Carving




## Ethernet Carving




- Note: False positives possible, particularly with long strings of zeros; see paper for theoretical false positive analysis

# Hibernation Decompression

## Why Focus on Hibernation

- Network data structures in system memory
- Persist to hibernation
- Windows overwrites beginning of hibernation files when resuming
- Prevents existing systems from analyzing hibernation
- We find an 8-byte XPress compression signature within compressed memory page header

# Hibernation Decompression

## Opportunistically decompress XPress pages

| Address | Count | Decompressed Count |
|---|---|---|
| 172.20.105.74 | 25 | 600 |
| 172.20.104.199 | 41 | 434 |
| 18.26.0.230 | 43 | 162 |
| 172.20.20.11 | 0 | 4 |
| ... | ... | ... |

- Improves recall by an order of magnitude on our test image!

# Validation

## To Mitigate False Positives:

- *Checksum:* Self-validate using IP checksum. Not always feasible due to checksum offloading. 82% of IPs in ground-truth have valid checksums.
- *Filtering:* Eliminate bogus IP addresses not appearing in the BGP routing table, e.g. `127.0.0.0/8` and `240.0.0.0/4`.
- *Frequency:* Compute histograms of discovered IPs to determine *most likely* addresses.
- *Correlation:* We examine if discovered binary IPs correspond to e.g. ASCII addresses

# Outline



# Comparisons to State-of-the-Art

## Given our carving signatures and methodology:

- Compare to Volatility
- Analyze $\sim$ 1,800 images in Real Data Corpus

# Comparisons to State-of-the-Art

## Comparison to Volatility

- Fresh Windows XP install
- Large transfer, then hibernation
- We find the true source and destination IPs with high confidence as most frequent
- Volatility `connscan2` finds nothing

- NIST CFReDS memory images, labeled with ground-truth
- We discover IP of connection to `w3.org`
- Volatility `connscan2` finds nothing

# Against Real Data Corpus

## Real Data Corpus

- RDC: 1,817 images (including cameras, computers, mp3 players, etc)
- Discover IP addresses on 40% of images
- Note, binary carving permits checksum validation == high-confidence IPs!

## How many addresses are "real?"

- We don't have ground-truth
- Perform ASCII-based IP carving, correlate
- Good correlation between carving modalities for $\sim$ 20% of the images
- On 66 drives, we find validated IPs *not* found in ASCII form
- See paper for full analysis

# RDC IP addresses

## In RDC, where are IP addresses found?

- 10% in `hiberfil.sys`
- 2% in `WIN386.SWP`
- 58% in unallocated regions of disk!
- Suggests that valuable information in ephemeral stores needs to be carved by examining physical disk

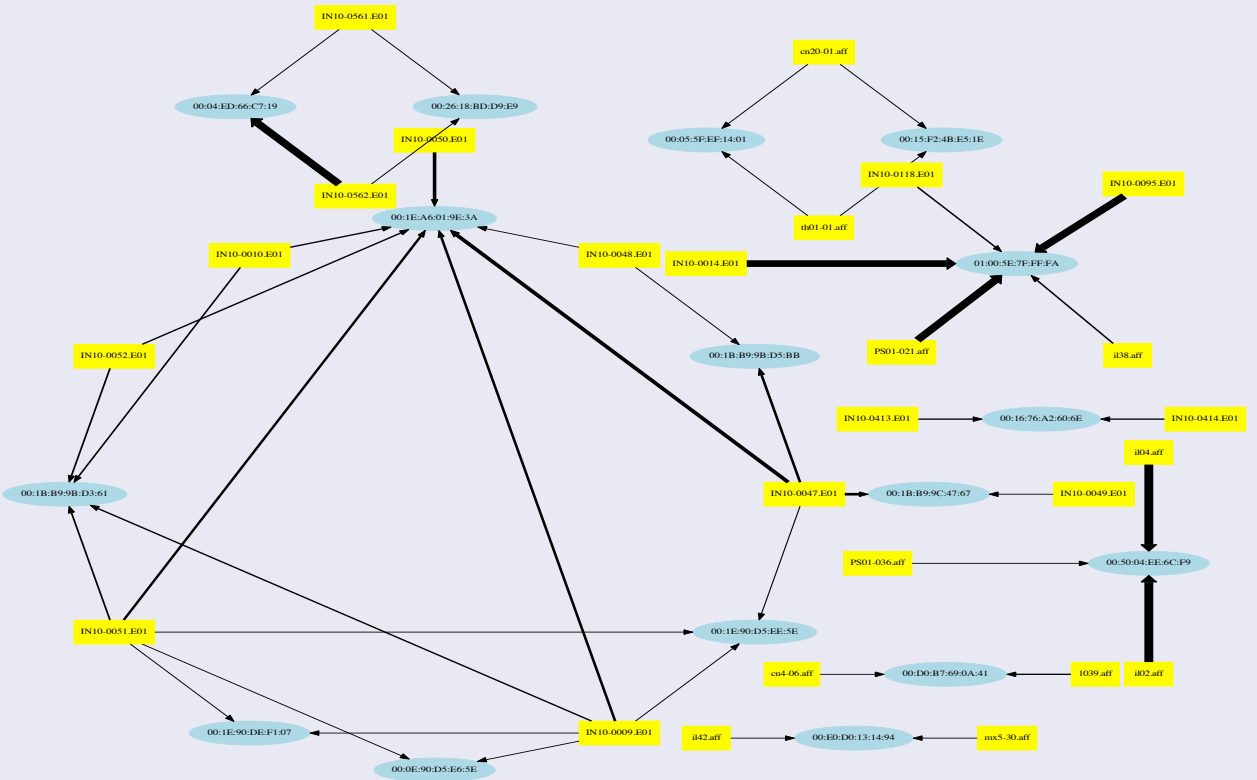
## Geolocation

- Lots of private (RFC1918) addresses
- Limited success; see paper

# Cross-Drive MAC Analysis

## Cross-Drive MAC Analysis

- Many RDC images bought in batches
- We find 16 Ethernet common between images!
- Graph shows 8 distinct clusters:



# Outline



# Future Work

## Future Work:

- Examine other network structs: IPv6, 802.11, 802.15, 802.16, etc.
- Examine available application layer information
- Currently applying techniques to mobile smartphone images

# Summary

- Demonstrated forensic value of *binary* network structures via controlled and real-world experiments
- Demonstrated importance of physical device scanning, including opportunistic hibernation decompression

## Thanks!

Questions?