

Network Black Ops:

Extracting Unexpected Functionality
from Existing Networks

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Introduction (Who am I?)

- Fifth Year Of Public Security Research
 - Subjects: SSH, TCP/IP, DNS
 - Code: Paketto Keiretsu, OzymanDNS
- Several books
 - Hack Proofing your Network
 - Stealing The Network: How To Own The Box
 - Aggressive Network Self-Defense
- Formerly of Cisco and Avaya

What Are We Here To Do Today?

- IP Fragmentation
- Firewall / IPS Fingerprinting
- DNS Poisoning (and other tricks)
- **DNS v. The Sony Rootkit**
- Scanning The Internet
- Visualizing That Scan

Introducing IP Fragmentation

- "Fragmentation...an interesting early architectural error that shows how much experimentation was going on while IP was being designed." -- Paul Vixie
- Fragmentation: If a packet is too large for the underlying link layer, it may be split by any router (unless behavior is explicitly disabled) into multiple fragments
- Why a problem? IP is supposed to be "stateless"
 - Fire a packet and forget about it
 - Receive a packet and be done with it
 - Fragmentation keeps the former but destroys reception
 - Systems need to keep fragments around, wait for future fragments, reassemble...what if fragments overlap?

IP Fragmentation: Some History

- Major mechanism for evading IDS
 - “Insertion, Evasion, and Denial of Service: Eluding Network Intrusion Detection.” – Newsham and Ptacek, 1998
 - Fragrouter, Dug Song, 1999

Remaining Adventures in Reassembly: Adventures In Temporality

- IP has been mostly “picked clean”...is there anything left?
- Timing Attacks
 - Successful against cryptosystems all the time
 - Are there any timers in IP?
- The IP Fragment Reassembly Timer
 - Maximum amount of time a fragment will be held, unassembled, before it “expires” and is flushed
 - **LibNIDS actually noticed that you need to handle this to reassemble correctly!**
 - Differs from OS to OS – yes, it’s a fingerprint
 - Ofir Arkin noted IP fragment scanning, but not fingerprinting
 - Can we evade with this?

It's Skew

- What if the IDS has a different concept of expiration time than the host?
 - If IDS expires first: Just send fragments too slow for the IDS but fast enough for the target
 - **This definitely happens**
 - But what if host expires first?
 - Linux/FreeBSD timer: 30s
 - Snort frag2 timer: 60s
 - Is it possible to still evade an IDS when its timer lasts longer than that of your target's?

Protocol Inversion

- Problem: IDS keeps fragments for too long
- Solution: Make IDS drop fragments
- Strategy: Fragments leave the reassembly queue when either they aren't reassembled...or when they are.
 - Is it possible to give the IDS something to reassemble against – without causing the target host to undergo a similar reassembly?
 - Of course – use a timing attack!

The Temporal IP Attack

- Prepare:
 - Nice request, malicious request, and a shared header between the two
 - *Header*: HTTP 1/1 GET
 - *OKFrag*: index.html
 - *MalFrag*:
msadc/..%255c../..%255c../..%255c../winnt/system32/cmd.exe
?/c+dir+c:%5c
- 1) Send IDS payload
- 2) Wait. Host will drop. IDS won't.
- 3) Send shared header. IDS sees the two fragments it needs to reassemble a packet – and gets a legitimate request. Host dropped the IDS payload, so it just stores the header.
- 4) Send host payload. Host sees the two fragments it needs to reassemble a packet – and gets attacked. IDS dropped the shared header, so it just stores the host payload (and never reassembles it).

Time Anneals All Wounds

- T=0: Send MalPay
 - Host: OKFrag in Reassembly Queue
 - IDS: OKFrag in Reassembly Queue
- T=30: <just wait>
 - Host: Nothing in Reassembly Queue
 - IDS: OKFrag in Reassembly Queue
- T=31: Send Header
 - Host: Header in Reassembly Queue
 - **IDS: Header+OKFrag = OKPacket**
- T=32: Send MalFrag
 - Host: **Header+Malfrag=MalPacket**
 - IDS: Malfrag in Reassembly Queue

Changing Course

- Some IPS's will block this (they handle the IP ID overlap). What now?
 - What are IPS's?
 - Firewalls w/ dynamic rulesets / censoring IDS
 - These dynamic rulesets can trigger on increasingly obscure faults across the entire communication stack
 - What they'll trigger against differs from product to product, version to version
 - Security products in general are under increased scrutiny
 - Combine complex state machines with a need for maximum efficiency
 - Over 20 advisories regarding vulnerabilities in security products
 - *Blocking sends information*
 - Is it possible to use this leaked information to **fingerprint security architectures**?

Hopcount Desync (SLIDE FROM 2003 – FW fingerprinting is not new)

```
■ root@arachnadox:~# scanrand -blk -e
  local.doxpara.com:80,21,443,465,139,8000,31337
■   UP:      64.81.64.164:80      [11]    0.477s
■  DOWN:    64.81.64.164:21      [12]    0.478s
■   UP:      64.81.64.164:443    [11]    0.478s
■  DOWN:    64.81.64.164:465    [12]    0.478s
■  DOWN:    64.81.64.164:139    [22]    0.488s
```

What's going on:

The host is genuinely 11 or 12 hops away. All of the up ports reflect that, but only a few of the downed ports. The rest are showing double the remote distance. This is due to the a PIX firewall interspersed between myself and the target. It's (too) quickly reflecting the SYN I sent to it right back to me as a RST|ACK, without resetting values like the TTL. Thus, the same source value decrements twice across the network – $22 = 11 * 2$ – and we can detect the filter.

Firewall/IPS Fingerprinting: Other products

- Tipping Point: Does not allow out-of-order TCP segments – everything must arrive on the edge of a window
- Checkpoint: Does not allow (by default) DNS packets that declare EDNS0 (DNSSec!) support
- L3/L4 Mechanisms
 - Invalid Checksums (at IP, TCP, UDP, ICMP)
 - Invalid Options (at IP and TCP, and actually UDP too)
 - Out of order fragments/segments (at IP and TCP)
 - Invalid ICMP type, code
- Application Layer Mechanisms
 - Invalid HTTP request types, or TRACE/WebDAV
 - SQL Injection in TCP payloads (WITHOUT the necessary line terminator)
 - Invalid DNS
- Using Schiffman's "Firewalk" methodology, each query leaks the location of the blockage – and I can always walk to the host before the FW

Blocking Must Never Extend To This Level

- “After sufficient amounts of invalid traffic, we just ban you from our network. Fingerprint THIS!”
 - I’ve heard this a lot lately. Some of you know why.
 - *Many* automatic shunning systems deployed
 - *Not a good idea.*
 - To understand why automatic shunning is bad – just dig.

It Might Be Bad To Shun These Guys.

- ; <<>> DiG 9.3.0rc2 <<>>
- . 511355 IN NS F.ROOT-SERVERS.NET.
- . 511355 IN NS G.ROOT-SERVERS.NET.
- . 511355 IN NS H.ROOT-SERVERS.NET.
- . 511355 IN NS I.ROOT-SERVERS.NET.

- ;; ADDITIONAL SECTION:
- A.ROOT-SERVERS.NET. 172766 IN A 198.41.0.4
- B.ROOT-SERVERS.NET. 604777 IN A 192.228.79.201
- C.ROOT-SERVERS.NET. 604782 IN A 192.33.4.12
- D.ROOT-SERVERS.NET. 604786 IN A 128.8.10.90
- E.ROOT-SERVERS.NET. 604791 IN A 192.203.230.10
- F.ROOT-SERVERS.NET. 604797 IN A 192.5.5.241
- J.ROOT-SERVERS.NET. 172766 IN A 192.58.128.30

Something More Elegant

- Spoofing malicious traffic from the root servers – ugly, yes, kills a net connection, sure, but:
 - Too large scale
 - Been whispered about for years
- But there are other name servers...
 - I've been investigating DNS poisoning
 - Is it possible, given networks that implement automatic network shunning, to poison name server caches and thus selectively hijack network traffic?

The Name Game

- The general theme: Block communication between two name servers
 - Bad: Targeted Denial of Service – Customers from a particular network are unable to contact a particular bank/merchant/email provider
 - Worse: Targeted DNS Poisoning – Being unable to communicate, a window is left open for an extended period of time for a flood of fake replies to eventually hit on the correct answer
 - It's a race, and the other guy now has a broken leg
 - Welcome to Worst Case Scenario Engineering
- Can either block server at client net, or client at server net

Double Sided

- Spoof malicious traffic from the client network to the server network
 - Client will have outstanding requests to the server – if they're using a fixed DNS port*, only 32K requests on average to find their TXID's
 - How do we make them look up a given network on demand?
 - Recursion – Just ask them to look up www.merchant.com
 - PTR NS Forwarding – Claim that, to look up your IP, it's necessary to ask the nameserver at www.merchant.com. Then use your IP to go to their web server

Double Density

- Spoof malicious traffic from the server network to the client network
 - Client can make requests, but server responses are blocked
 - But wait? Aren't *our own* forged responses blocked too?
 - Funny thing about DNS...about 15% of servers reply from a different IP address than you talked to in the first place!
 - With a lack of interface affinity in servers, comes an ignorance of incoming IP address on clients
 - This is BTW why UDP NAT2NAT works
 - So while the *legitimate* server responds in vain, *our attacks can come in from anywhere*
- **Moral of the story: Automated network shunning is a very bad idea. Do not give the world access to your firewall tables.**

Poppa's Got A New Pair Of Shoes

- Prolexic – who I worked with on the Opte internet mapping project – has given me a very high bandwidth connection to work with
 - They're a third-party spam filter for IP – your data is BGP'd to them, they forward you a filtered stream.
 - I actually can't generate packets faster than this network can route ☹
- Been actively probing the Internet DNS Infrastructure
 - Partnering with Mike Schiffman of Cisco Critical Infrastructure Assurance Group and Sebastian Kraemer at the University of Potsdam (and maybe you – send me a proposal?)
 - Extremely large scale scans – every IP, every name server, everywhere

Always Bet On Black

- 100% legitimate packets – this isn't a global pen test, this is an investigation in to the largest cooperative caching architecture on the Internet – one that is getting poisoned again
- Asking: How is this architecture laid out? How prevalent is DNSSEC support? Where do we need to invest resources in protection? And what is going on with DNS poisoning?
 - We can't manage what we can't measure. This is an attempt to measure.
- Not the first to do a large scale network scan

DON'T TRY THIS AT HOME

- “Where’d my colo go?” 😊
 - You **will** get complaints
 - You **will** get calls from scary sounding places
 - As well you should. This is behavior that normally precedes an attack.
 - So why am I doing it? **Because the attackers should not have better intel than we do.**

Open And Honest

■ Reverse DNS

- deluvian root # nslookup 209.200.133.226
Non-authoritative answer:
226.133.200.209.in-addr.arpa name = infrastructure-audit-1.see-port-80.doxpara.com.

■ Web info

- Technical details
- Explanation of motivation
- Links to papers, news articles
- My phone #

ARIN Updated

- NetRange: 209.200.133.224 - 209.200.133.255 CIDR: 209.200.133.224/27 NetName: DANKAMINSKY-SECURITY-RESEARCH NetHandle: NET-209-200-133-224-1 Parent: NET-209-200-128-0-1 NetType: Reassigned Comment: This is a security research project, please send all Comment: abuse and alert requests to dan@doxpara.com. RegDate: 2005-07-08 Updated: 2005-07-08

And even with...

- Still, large scale analysis does not go unnoticed, uninvestigated, and uncomplained about
 - After further explanation, almost all administrators have been courteous
 - “Thank you for the information. See you in Vegas.”

Some Early Results

- Priority 1: Google was taken out by an exploit that hit MSDNS systems forwarding to BIND4/8. Find all of these.
- To begin with – need to identify all name servers on the Internet
 - Requirement: Legitimate lookup that worked on every normal name server, but would not be of a type to require recursion
 - Disabling the recursion desired bit doesn't always work, apparently
 - Lookup: 1.0.0.127.in-addr.arpa PTR
 - Expected reply: localhost.
 - Actual replies: Rather more complicated.
 - Could also have sent traffic on TCP/53 but not all servers accept
- Now can set about finding which ones are related to which other ones

Finding Interrelationships

- Recursion Desired: Able to control whether a server looks values up for you, or if it just tells you what it already knows
- Three mechanisms for determining interrelationships:
 - Simple Injection: Inject a value into one server using a recursive unique request. Then non-recursively query other servers for that name
 - Accurate, but slow (N^2)
 - TTL Offset Measurement: Recursively request a unique value from each server, and analyze the Time To Live on the response data.
 - Response may be “fresh” – have original TTL, “3600 seconds”
 - Response may be “stale” – have offset TTL, “3540 seconds”
 - See who we were scanning 60 seconds ago to see which lookup caused this cache entry to already exist
 - Server/Recurser Correlation: Recursively request a unique value in a domain you control, then see who comes to that domain to service that request
 - Ask Alice to look up Alice.Doxpara.Com. If Bob comes looking for Alice, Alice and Bob appear to be linked.

What was found?

- 2.5M *verified* name servers
 - Up to nine million possible, but 2.5M have been / remain responsive
 - All 2.5M have been run through Roy Arend's FPDNS
 - NOTE: FPDNS gives more data than CH TXT (explicit version requesting), and...er...doesn't set off nearly as many alarms.
- At least 230K forwarding to Bind8, as specifically forbidden as per ISC BIND documentation – almost 10% of the sampled DNS!
- At least 13K Windows name servers still forwarding to Bind8!
 - At least 53K "OTHER"
 - BIND8->BIND8 forwardings must be further analyzed, to determine multihomed vs. a true forwarding relationship
 - This can be found by – can data enter one cache, without entering the other? If so, one is higher in a hierarchy than another
 - Is BIND9->BIND8 forwarding problematic? 18.7K instances.

Anything else?

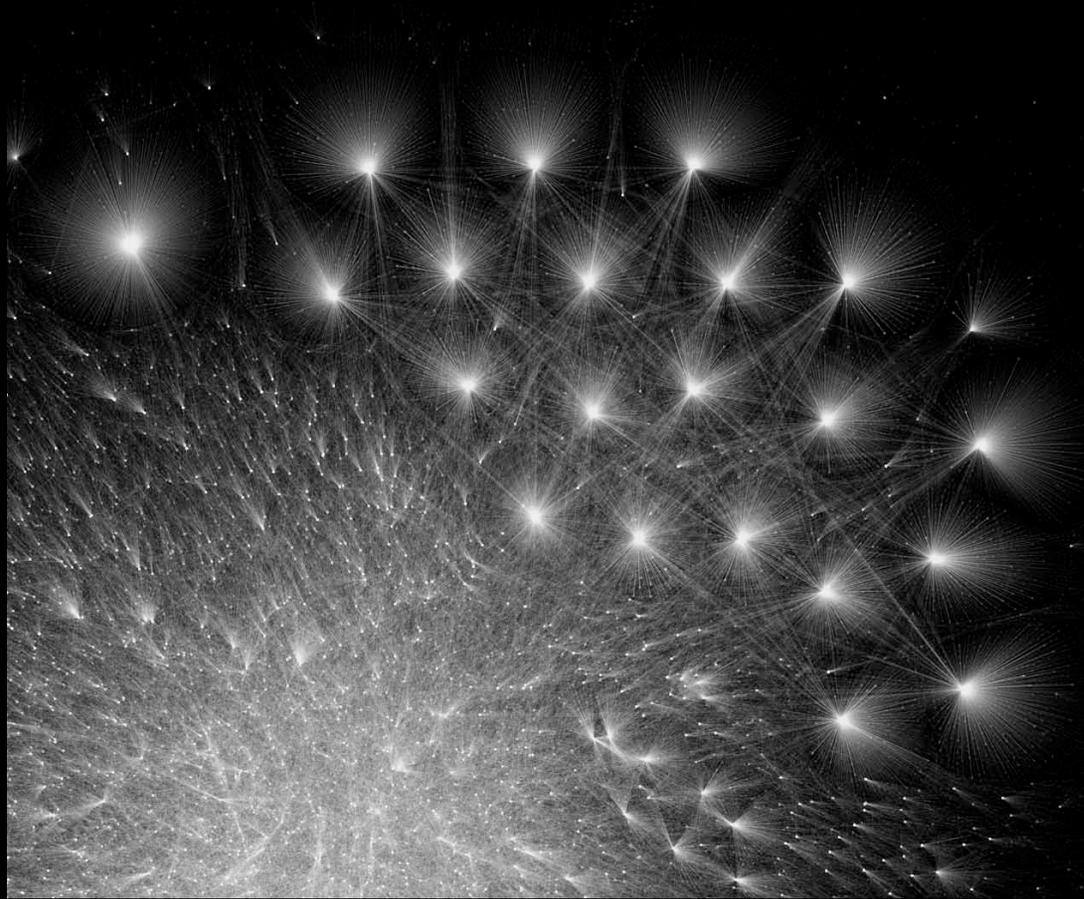
- Many, many hosts out there do reverse lookups, not expecting the target they're investigating to be aware of this
 - 38K name servers doing lookups
 - Some who are invisible to direct querying
 - Exponential curve of requests – most only have 1, maximum has 14,221
 - Cable modem DNS
 - Warning: Possible to backwards map from scanned IP to elicited PTR request by shuffling scan orders and looking for correlation between a particular IP being contacted and the PTR request returning!

So What's New

- Scans have been repeated, analysis is under way
 - Over 50GB of compressed traffic
 - Writing a custom anonymizer for research consumption
- Original Thought: Most interrelationships are shallow – maybe one hop deep. Reality more complicated.
 - Majority of hosts resolve for themselves
 - About 40K *connected* graphs, most 2 deep (ask Alice, get request from Bob).
 - Then...there's this other guy.

I LIKE BIG GRAPHS AND I CANNOT LIE

- 220K node
- 330K edge
- 22 deep?
- One case:
Ask one
host, 1200
different IP's
forward the
request???



But Just In Case You Think Pretty
Pictures Are Meaningless...



The Need for Accurate Maps: Measuring The Sony Rootkit

- Sony did a bad thing – placed malicious code on 2.1M CDs
 - Some people think the malice is contained to the cloaking code.
 - Malice Through Overstayed Welcome: If you are my friend, but you refuse to leave my home, you very quickly become not my friend. If you do this to all your friends, quickly you have no friends.
 - Sony's DRM was designed to achieve bare minimum, *if any*, consent – and then to avoid any situation where that consent could be effectively revoked
 - **If your reaction to “If people knew we were here, they'd try to get rid of us” is to try to make people not know you're there, you are a criminal and you apparently know it**
 - Repeatedly releasing broken uninstallers – one of which actually just updated your code to the latest version – doesn't help

No Data!

- But how widespread was the problem?
 - Security professionals: We have different responses to something on 100 hosts, vs, +10K vs. +1M
 - Could have been a mountain out of a molehill – what if we found a rootkit and nobody was silly enough to install it?
 - Where's our normal data?
 - Sony: Likely advised not to release accurate figures
 - Microsoft: Likely in some sort of Blu-Ray deathmatch
 - AV Vendors: Sony approached them days after the story broke. They've released no figures since.
 - Bruce Schneier: What do we do when the makers of malware are colluding with the very people we pay to protect us from malware?
 - Stay Tuned.
 - Rather than waiting...

Data: Any Port In A Sony Storm

- All discs with the XCP-Aurora rootkit *also* had code that connected to a Sony owned site, `connected.sonymusic.com`
 - This is not an IP address that the Internet can route. To retrieve traffic from this address, a DNS lookup from a local name server is required
 - When a server looks content up, it caches the response in case the results would be useful to anyone
 - They're useful to me
 - Non-recursive queries allow a client to non-destructively query caches – *I'd only get responses if someone had recently caused that server to look up a name*
 - Paper: "DNS Cache Snooping" by Luis Grangeia

Original Results

- *556K hosts w/ Sony linked names*
 - 165 countries
 - Very odd – discs only sold in the US
 - Theory: CD Piracy – just because Sony didn't sell it, doesn't mean it wasn't sold. We got here because of CD Piracy, remember? RIAA confiscated 6M pirate CDs in the US in 2003 – and they didn't get them all.
 - .mil / .gov penetration detected
 - Not just American
 - Mappage
 - Partiview – software for Astrophysicists...and white hats ☺
 - Used libipgeo and IP2Location to place IP's on shiny OpenGL globe

Signal To Noise Ratio[0]

■ Already Filtered Noise

- RD-ignorance: Some number of servers will do recursive lookups anyway, even if you ask them not to – and if they're forwarding to anyone, they'll pollute these upstream caches
 - Handled by looking up a “control” name – any host that is able to return a control name has been polluted
 - Knocks out 350K hosts – actually +900K hosts that returned links
- Also filtered out any server that returned incorrect records for any name, and any entry with a fixed TTL divisible by 100 (often signs of fresh data instead of cached)

Signal To Noise Ratio[1]

■ Problems

- updates.xcp-aurora.com
 - Very popular name
 - Supposedly connected to directly by rootkit
 - 75% agreement between servers that connect to updates and connect to connected.sonymusic.com
 - *Not actually linked to by Sony rootkit*
 - High correlation between those who thought they might be infected and those who investigated removal?
 - Not just a geek story?!?

Signal To Noise Ratio[2]

- xcpupdates.sonybmg.com: 302 redirect on connected.sonymusic.com for XCP infected discs
 - Thank you J. Alex Halderman for actually going to Sony and seeing what happens if you go to the connected.sonymusic.com address
 - Thank you DMCA for making me afraid to do this myself.
 - Limitations
 - May not have been in place when story broke
 - Actually hosts a banner ad informing people they've got a problem (**this is good, responsible behavior, and deserves to be specifically identified as such**)
 - Covers discs that may have run the uninstaller by now
 - Problems
 - Does uninstaller prevent immediate reinstallation?
 - Presumably does not apply to discs that never shipped w/ the potentially risky code, as the banner ad is pretty clear that There Be Dragons
 - Site useful for measuring deployment rates

Xcpimages data

- 350K+ positive hits
 - Again, after control nodes are filtered out
- 70K+ in Europe
- 135 countries
- Still finding .gov/.mil
- Conclusion: **Best available data suggests this remains a large scale problem**
 - Sony continues to be invited to provide better data

Hello Attorneys General

- 12588 'FLORIDA'
- 9719 'CALIFORNIA'
- 7962 'MASSACHUSETTS'
- 6310 'NEW JERSEY'
- 5018 'TEXAS'
- 4228 'PENNSYLVANIA'
- 3713 'TENNESSEE'
- 3362 'VIRGINIA'
- 3047 'NEW YORK'
- ...2017 'ILLINOIS'

Projects

- Estimate backend clients per name server by measuring traffic at central authoritative DNS aggregation points
- Better scheduling – determine “least impact” on topology so we can scan faster
- Try to recover some of the filtered nodes by managing the connected graphs

Understanding The Flood

- We could import the received data into LGL (Large Graph Library)
 - Get huge graphs like Opte or Cheswick/Lumeta
 - Static, very resource intensive to compile, can't be really monitored in real time
 - *Our data is streaming in but we're only viewing a static summary of it?*

Xovi: Streaming Graph Visualizer

- Input: Text description of each edge
 - Alice Bob
 - 10.0.1.11 10.0.5.100
 - “www.cnn.com” “/foo”
- Process: Lay nodes out according to Fruchterman-Reingold algorithm
 - Code from Doug Gregor, Boost Graph Library
 - Algorithm very interesting – handles anything, new nodes in the middle of layout, disconnected graphs, etc.
 - Height: Optional, but it’s (out_degree – in_degree)
- Output: Dump to OpenGL
 - SDL implementation – portable to whatever
 - BSD licensed
- So lets see it!

Xovi Tips and Tricks

- Pipe stuff in via SSH

- `ssh user@host "tcpdump -ln not port 22" | ./xovi -`

- Can't SSH into your server? Pipe sflowtool's CSV mode into Xovi

- Web hits: Graph resources to referrers

- `Cat http.log | cut -d`

- `ssh cat http.log | cut -d" " -f 7,11 | xovi.exe -`

TODO

- 0) **DIRECTED GRAPHS SHOULD APPEAR DIRECTED** 😊
- 1) Multi-Sets – I should be able to compare different sets against each other
 - Port 80 vs. Not Port 80
- 2) More Visual Differentiators
 - Color, Shape, Motion, Vibration
- 3) Active Highlighting
 - Highlight an area with your mouse to get details – not just “there is structure” but “what is this structure”
 - Hello splunk
- 4) A slightly more complex grammar for input, or allow TCP input
 - Print timestamps on graph
 - Add labels to graph
- 5) Dynamic configuration of system
 - Sliders for expiration, etc.
- 6) History receding into Z? A Cheswick Stack

Done (?)

- That's all folks 😊
- Any questions?
- Email is dan@doxpara.com – I'm very interested in collaborating / sharing data
 - Need written promise of confidentiality of data before I can transmit

Rapid Infrastructure Mapping HOWTO [0]

- 1) Collect a list of subnets that have at least one host with one service. This will be the destination canary.
- 2) Setting a “max_ttl” value to your average distance to a host, transmit canary connection attempts w/ Scanrand from 1 to max_ttl.
 - Run the scan such that the *last* byte of the IP address is maintained
 - This minimizes bandwidth load per subnet
 - Scanrand places the original TTL in the ipid – can be recovered
 - `scanrand2 -b2m -f hostlist+:53 -l1-$MAX_TTL -t0 -H -M1 -T infra_map > results.sql; cat results.sql | mysql dns`
 - 2mbit, select port 53 for each IP, scan up to maximum TTL, disable timeouts, output SQL to table name “infra_map”. Then cat the file into mysql.

Rapid Infrastructure Mapping HOWTO[1]

- 3) After importing the data into MySQL, reorder it back into normal-seeming traceroutes as such:

```
select trace_hop,trace_mid,trace_dst from newscan  
group by trace_dst,trace_mid order by  
trace_dst,trace_hop
```

```
-----  
1      209.200.133.225 12.10.41.178  
2      67.17.168.1    12.10.41.178  
3      67.17.68.33     12.10.41.178  
4      208.50.13.254   12.10.41.178  
5      12.123.9.86     12.10.41.178  
6      12.122.10.53    12.10.41.178  
7      12.122.9.129   12.10.41.178  
8      12.122.10.2    12.10.41.178  
9      12.123.4.153   12.10.41.178  
10     12.125.165.250  12.10.41.178
```

Rapid Infrastructure Mapping HOWTO[2]

- 4) For each line in the mass traceroute, if the destination of the previous line is the same as this one, and if the hop number for the last line is one less than the previous line, then there can be assumed a link between the last midpoint and the present midpoint.
 - 1 a bar
 - 2 b bar
 - 3 c bar
 - 5 d bar
 - 1 a car
 - Links can be assumed between a and b, and b and c.
 - **There is probably a SQL mechanism to automate this – “if hop > 1 and hop-1 exists, column one is hop-1.trace_mid and column two is hop.trace_mid”**

Rapid Infrastructure Mapping HOWTO[3]

■ OPTIONAL:

- 1) **Find Faraway Hosts:** For each IP where a hop was found at max_ttl, scan that IP up to a new max_ttl
- 2) **Manage The Non-Flat Network:** Scanrand allows scans to come from different points in the network, but arrive at the same collector. Use this to collect routes invisible from your own position.
- 3) **Mind The Gap:** Schedule “gap filling” scans for packets dropped during an initial run
- 4) **Choose Your Path:** Attempt to source route packets, though so many networks block them
- 5) **Map Latency:** Apparently, latency maps are useful. I get full latency information statelessly (timestamp in cookie)
- 5) **Pretty Pictures:** Throw it into an OpenGL grapher

Rapid Infrastructure Mapping: IPv6?

- I need a high speed node w/ IPv6 access
 - I don't think Hurricane Electric wants to tunnel what I've got in mind... ☺
- Traceroute, DNS most obvious legitimate mechanisms for discovering populated space
- Some IP options – source routing, potentially spoofs from multicast may help
 - Routing Headers back to self allows for bidirectional traceroute – able to detect and analyze asymmetric routes!

Why use graphs?

- There's more than just pretty pictures
- Ultimately, services that do not adapt to broken networks are isolated onto *very broken networks*
- Traditional adaptation mechanisms completely fail, since we're only sending a few packets to every host
 - What we need are canaries – they are sent, a few a second, to each hop we're scanning through. When the canaries die, we know we've overloaded that network.
 - Graphs work **perfectly for this**
 - For every destination, we know which routers will get a traffic spike from us communicating with it
 - For every router we are canary-monitoring, we know which destinations we are now closer to
 - **We would thus be able to model outbound transmissions as a high pressure water system, against which taps may be made**