Mac Hackin' 2: Snow Leopard Boogaloo

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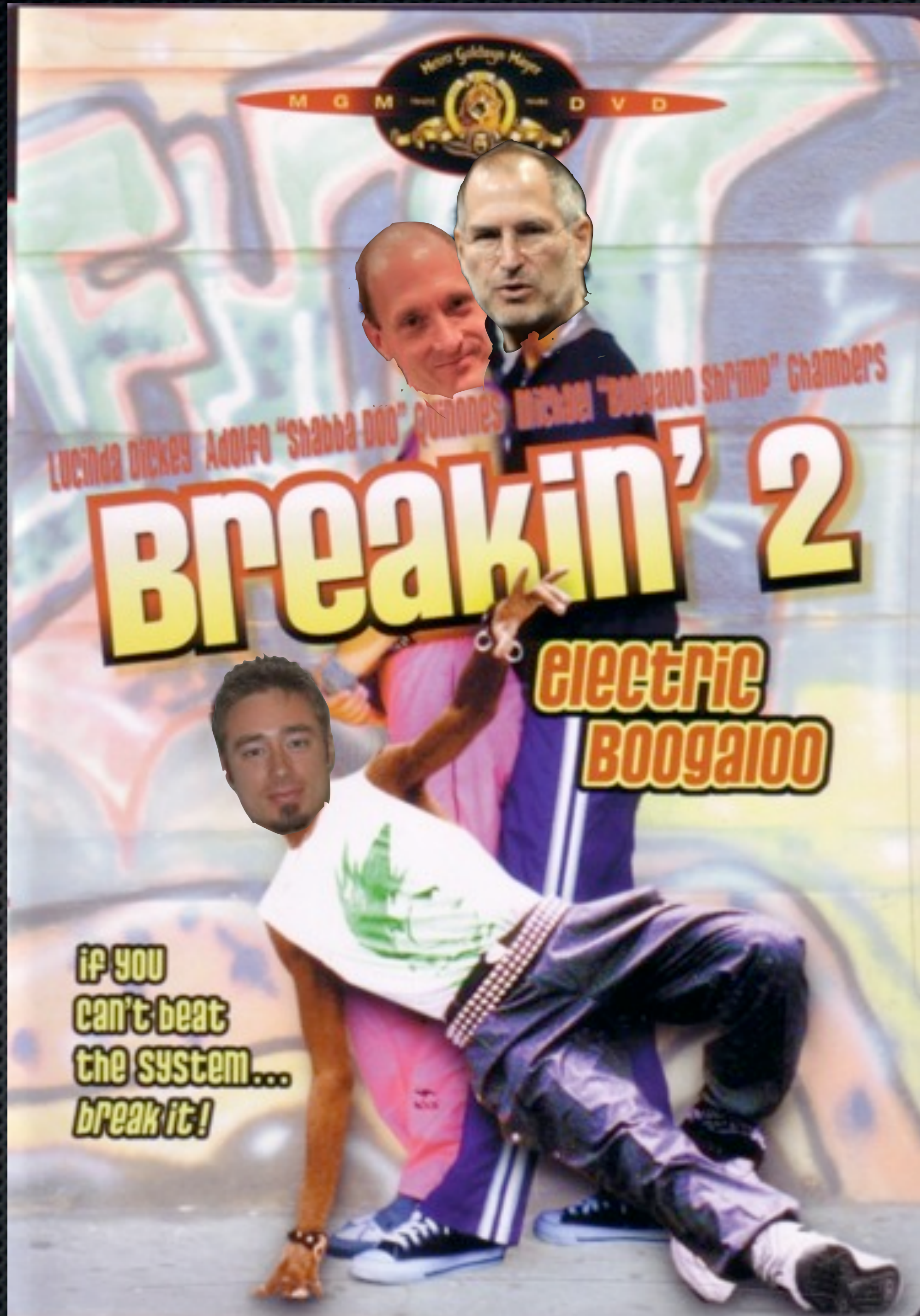
M G M
D V D
Lucinda Dickey Adolfo "Shabba Doo"
Breakin' 2
electric
Boogaloo
if you
can't beat
the system...
break it!

About Us

- We hack Macs
    - Every year at PWN2OWN (Dino: 2007, Charlie: 2008-2010)
    - We've probably hacked yours also (look for an extra thread in launchd)
    - Wrote the book on it

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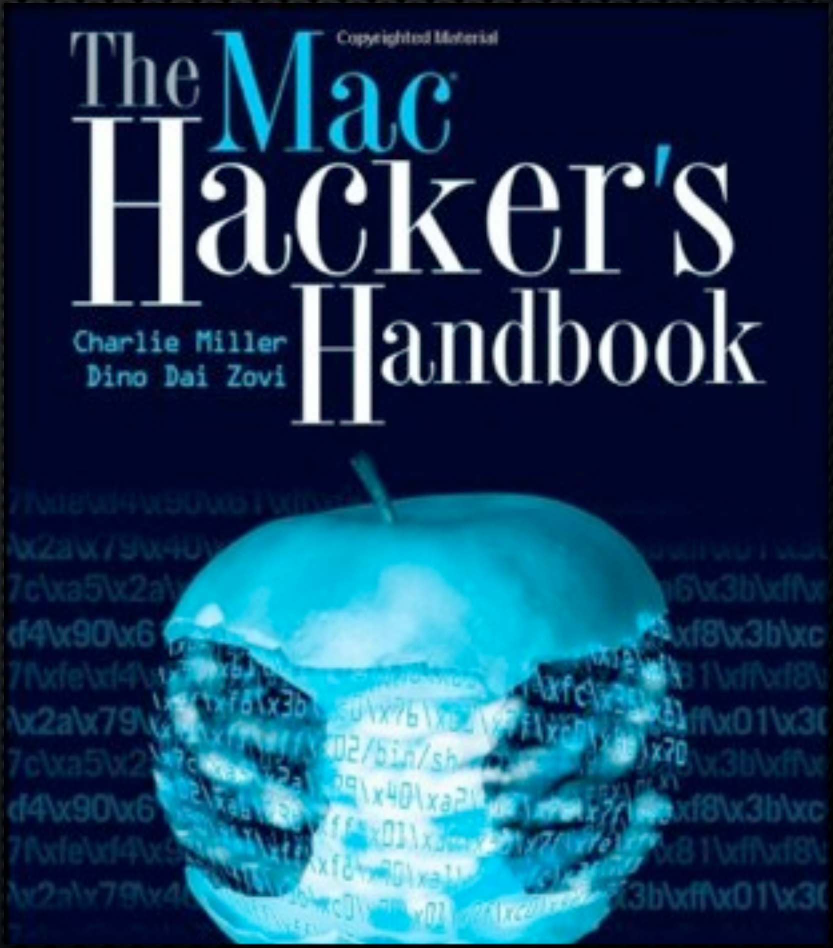

About this talk

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- This talk will discuss just how much real protection these improvements provide and how they make exploitation impossible

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64-Bit

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64-bit in Mac OS X 10.6

- Snow Leopard's increased use of 64-bit was touted as one of its key features
  - Primarily for making more memory available to applications
  - But Apple even touts 64-bit applications as a security feature
  - It offers some security benefits, but not as much as you would hope

Technically, That is True

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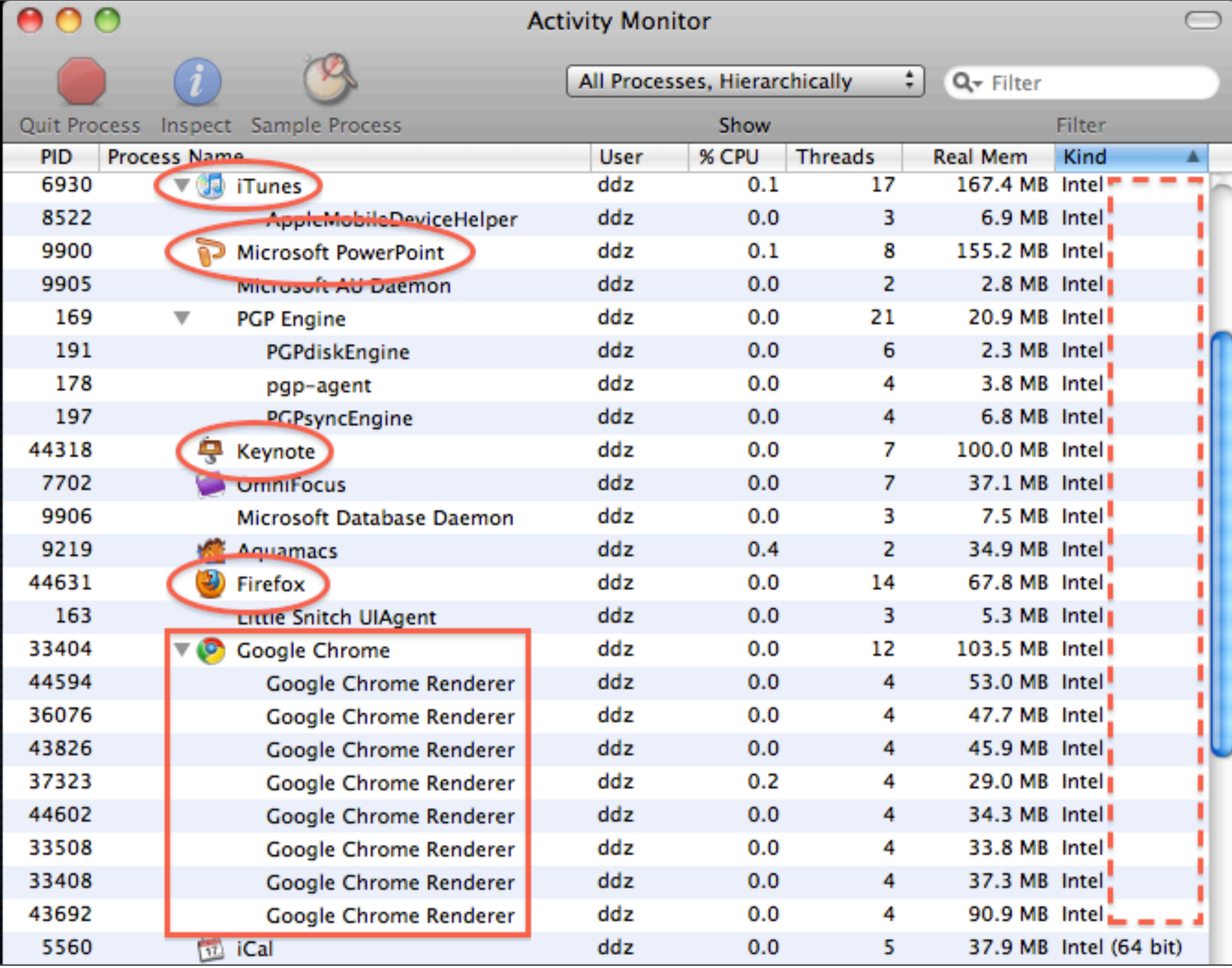
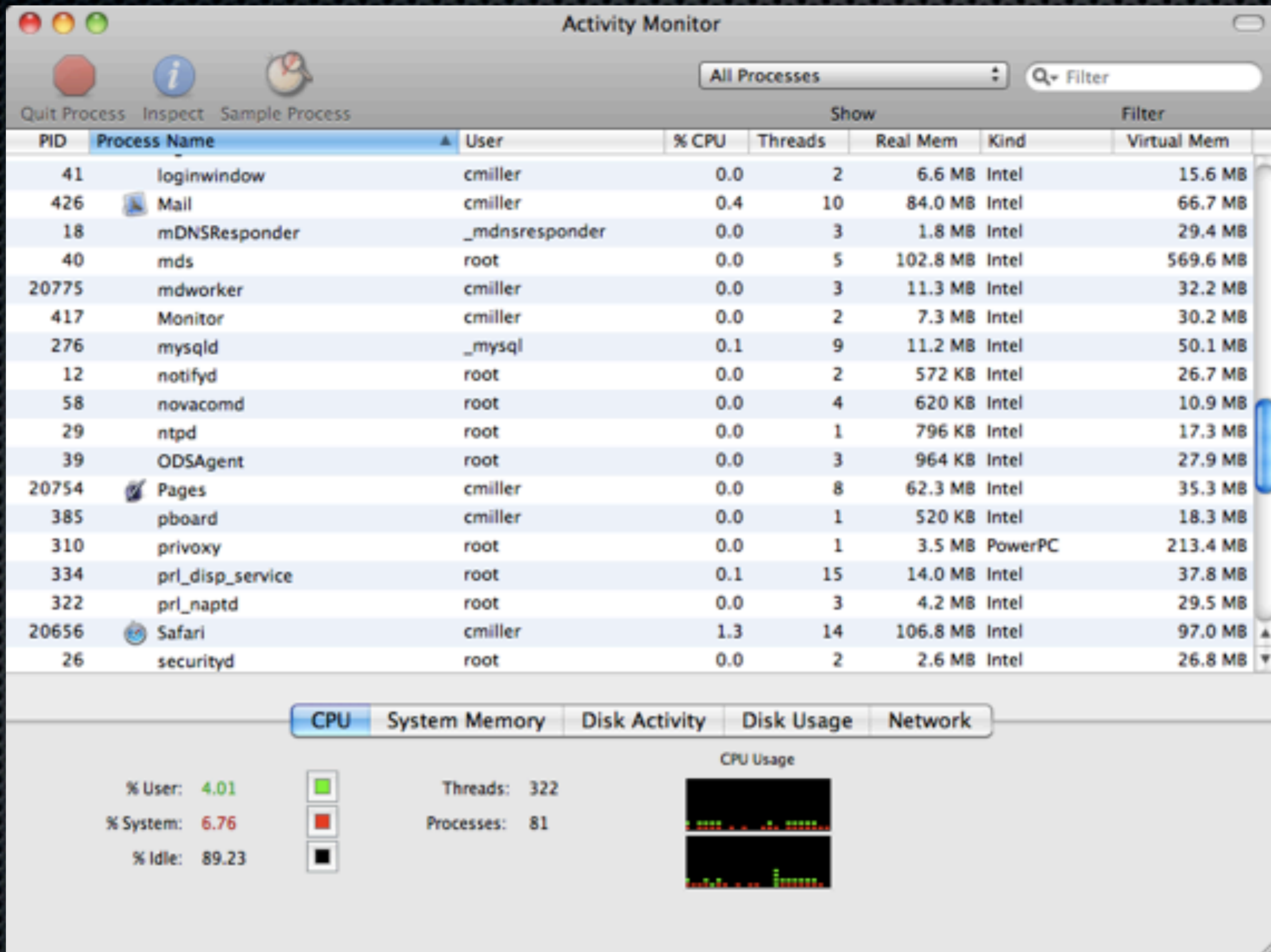
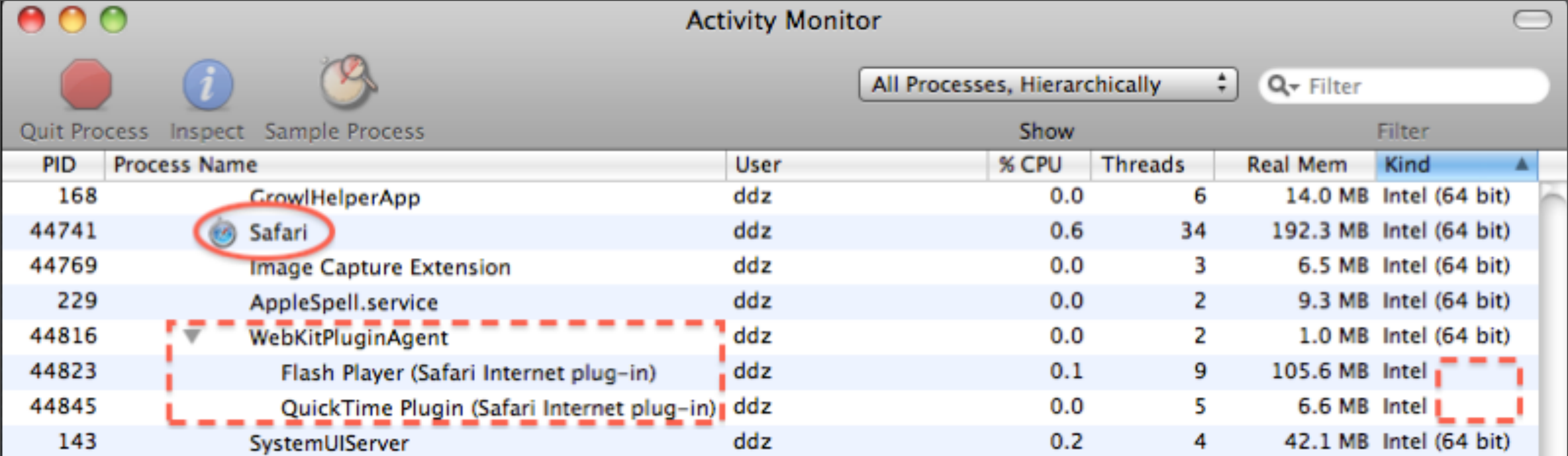
- Function arguments are no longer stored on the stack
- Hardware-supported non-executable heap memory
- Heap block header metadata checksums (also in 32-bit procs)



PID	Process Name	User	% CPU	Threads	Real Mem	Kind
6930	iTunes	ddz	0.1	17	167.4 MB	Intel
8522	AppleMobileDeviceHelper	ddz	0.0	3	6.9 MB	Intel
9900	Microsoft PowerPoint	ddz	0.1	8	155.2 MB	Intel
9905	Microsoft AU Daemon	ddz	0.0	2	2.8 MB	Intel
169	PGP Engine	ddz	0.0	21	20.9 MB	Intel
191	PGPdiskEngine	ddz	0.0	6	2.3 MB	Intel
178	pgp-agent	ddz	0.0	4	3.8 MB	Intel
197	PGPsyncEngine	ddz	0.0	4	6.8 MB	Intel
44318	Keynote	ddz	0.0	7	100.0 MB	Intel
7702	OmniFocus	ddz	0.0	7	37.1 MB	Intel
9906	Microsoft Database Daemon	ddz	0.0	3	7.5 MB	Intel
9219	Aquamacs	ddz	0.4	2	34.9 MB	Intel
44631	Firefox	ddz	0.0	14	67.8 MB	Intel
163	Little Snitch UIAgent	ddz	0.0	3	5.3 MB	Intel
33404	Google Chrome	ddz	0.0	12	103.5 MB	Intel
44594	Google Chrome Renderer	ddz	0.0	4	53.0 MB	Intel
36076	Google Chrome Renderer	ddz	0.0	4	47.7 MB	Intel
43826	Google Chrome Renderer	ddz	0.0	4	45.9 MB	Intel
37323	Google Chrome Renderer	ddz	0.2	4	29.0 MB	Intel
44602	Google Chrome Renderer	ddz	0.0	4	34.3 MB	Intel
33508	Google Chrome Renderer	ddz	0.0	4	33.8 MB	Intel
33408	Google Chrome Renderer	ddz	0.0	4	37.3 MB	Intel
43692	Google Chrome Renderer	ddz	0.0	4	90.9 MB	Intel
5560	iCal	ddz	0.0	5	37.9 MB	Intel (64 bit)

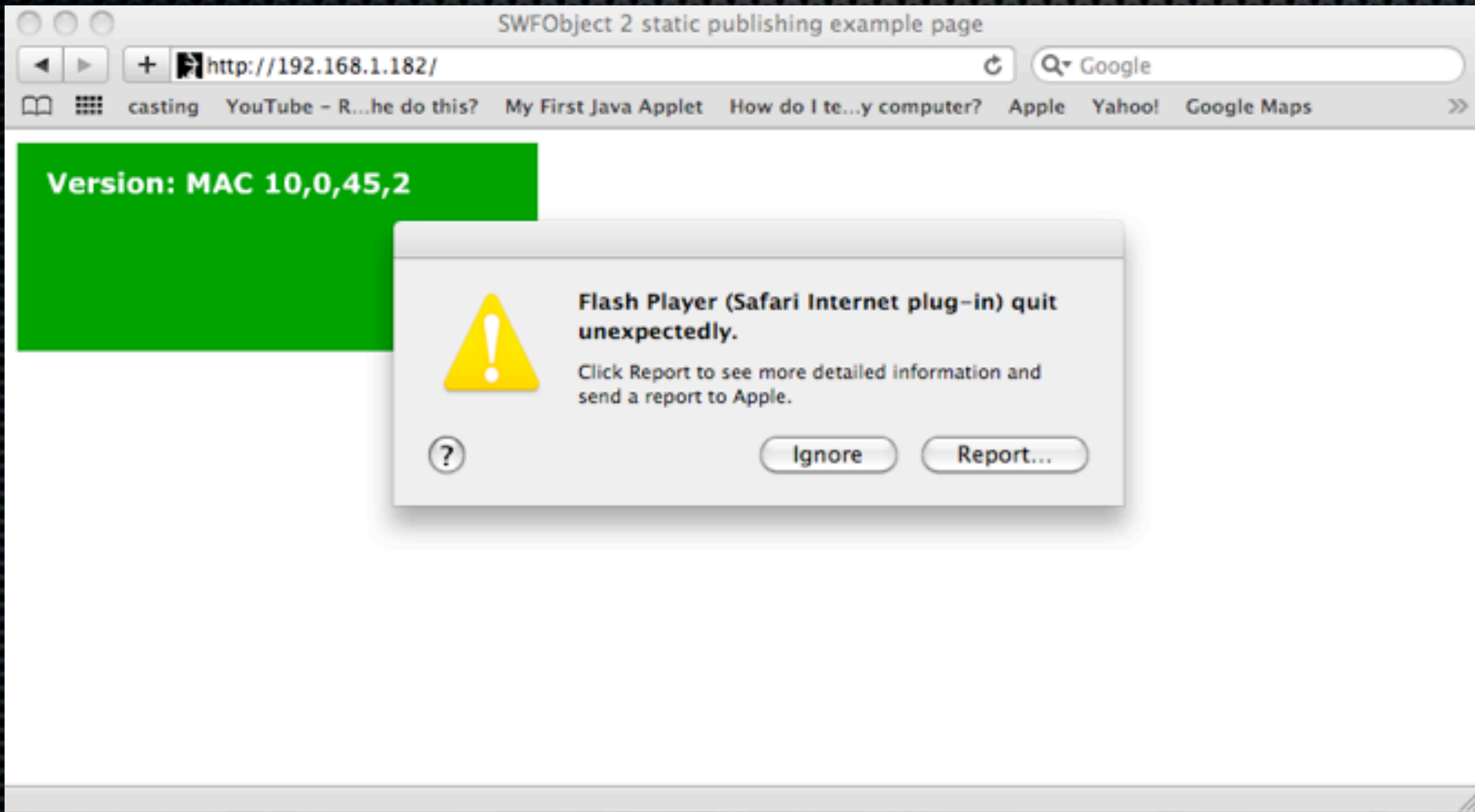
Older macs - all 32 bit





- The Safari browser itself is 64-bit
- Safari runs 32-bit plugins out-of-process
  - Flash Player is 32-bit
  - QuickTime Plugin is 32-bit
  - Some plugins are 64-bit and run in-process (Java)
- WebKitPluginAgent (64-bit) and WebKitPluginHost (32-bit) communicate over Mach IPC
- Avoids requiring a 32-bit Safari to watch YouTube

“Crash resiliency”

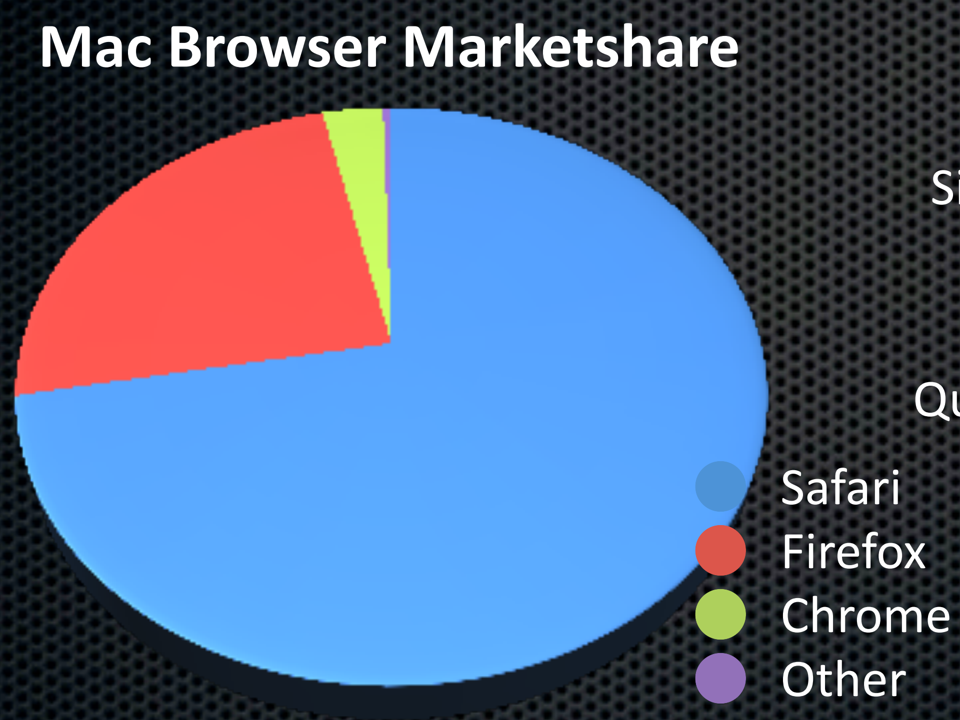


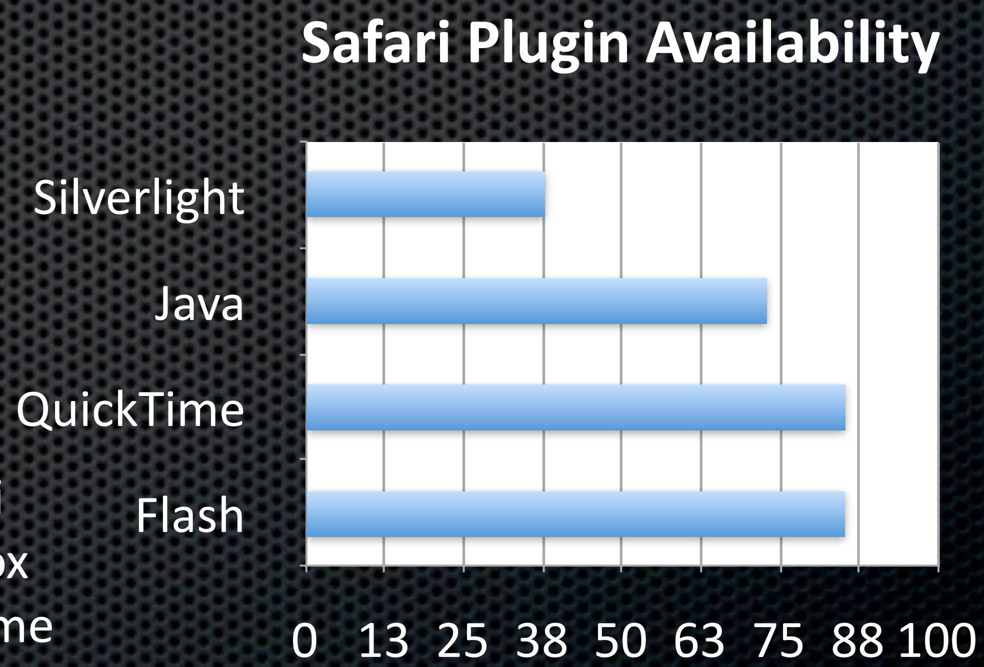
Older macs

- ...and users who launch Safari under 32 bit
- Plugins run within Safari's (32-bit) address space

```
$ vmmap PID
__TEXT                 00001000-0052b000 [ 5288K] r-x/rwx SM=COW  /
Applications/Safari.app/Contents/MacOS/Safari
...
__TEXT                 19dcb000-1a50b000 [ 7424K] r-x/rwx SM=COW  /
Users/cmiller/Library/Internet Plug-Ins/Flash Player.plugin/Contents/
MacOS/Flash Player
```

TargetShare (TM)





Statistics for June 2010, StatOwl.com

64 is 32 More Than I Need to Pwn

- 27% of Mac users use a 32-bit web browser
  - The "more secure" Firefox and Chrome browsers
- 85% of Mac Safari users have 32-bit plugins available
  - Flash Player or QuickTime Plugin
  - Both have a long history of security vulnerabilities
- Most key client-side applications are still 32-bit
  - Office, iWork, iTunes, iLife, etc.
- But Adobe CS5 is 64-bit
  - Don't have to worry about getting owned by a PSD

64-Bits Are Hard, Bro

- 64-bit exploitation has various complications
  - NULLs in every memory address
  - Subroutines take arguments in registers, not stack
  - All data memory regions are non-executable
  - No more RWX __IMPORT regions
- 64-bit exploitation techniques are not yet really needed on Mac OS X, especially for targeting client-side applications
  - Server-side attack surface is minimal and not critical

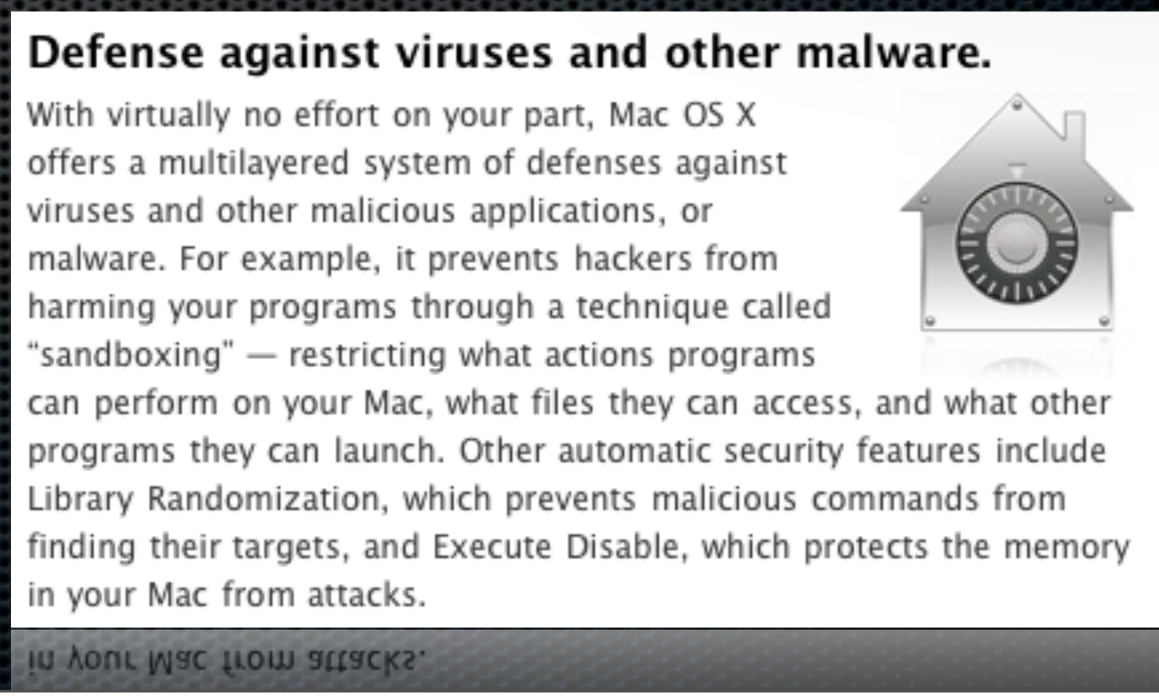
Shellcode

- x86 shellcode doesn't typically work
  - For example, no metasploit Mac OS X shellcode works on x86_64
- First public x86_64 OS X shellcode was from @fjserna
  - Connect() shellcode, contains NULL's
  - See Charlie's POC 2010 presentation for cleaner and smaller version (120 bytes vs. 165)

Tools

- Some tools won't work on 64-bit
  - pydbg
  - valgrind
- GDB still works fine

Sandboxing



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Sandboxing

- Implements fine-grained access controls
  - Accessing resources (sockets, files, shared mem)
  - Sending/receiving Mach messages
  - Sending/receiving BSD signals
- Started via sandbox_init() call (or sandbox_exec)

Mac OS X sandboxing architecture

- User process calls sandbox_init() (in libSystem)
- libSystem dynamically loads libSandbox for support functions
- Initiates action in the kernel via SYS__mac_syscall system call
- Sandbox.kext kernel module hooks syscalls via TrustedBSD interface and limits access as defined in policy

Snow Leopard sandboxing

- No client-side applications are sandboxed, including
    - Safari
    - Mail
    - iTunes
    - Plugins including Flash and QuickTime

Heap

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Welcome to the Heap of Pain

- Some significant improvements were made in the heap implementation in Snow Leopard compared to Leopard
- Check out Libc source code from opensource.apple.com
- Change from scalable_malloc.c to magazine_malloc.c

10.5 Heap Pointer Checksums

- Free list pointer checksums detect accidental overwrites, not intentional ones
  - cksum(ptr) = (ptr >> 2) | 0xC0000003
  - verify(h) = ((h->next & h->prev & 0xC0000003) == 0xC0000003)
  - uncksum(ptr) = (ptr << 2) & 0x3FFFFFFC
- Overwriting the next/prev pointers in a free block allows an attacker to write a chosen value to a chosen location when that block is removed from the free list

Heap metadata overwrites

- In Leopard it is trivial to overwrite heap metadata to get arbitrary 4-byte writes (see MHH)
  - You know how to fake the checksums
- In Snow Leopard, this can't easily be done due to security cookie

Snow Leopard

- In Snow Leopard, random security cookie used

```
...
    szone->cookie = arc4random();
...
static INLINE uintptr_t
free_list_checksum_ptr(szone_t *szone, void *ptr)
{
    uintptr_t p = (uintptr_t)ptr;
    return p | free_list_gen_checksum(p ^ szone->cookie);
}

static INLINE uintptr_t free_list_gen_checksum(uintptr_t ptr)
{
    uint8_t chk;

    chk  = (unsigned char)(ptr >>  0);
    chk += (unsigned char)(ptr >>  8);
    chk += (unsigned char)(ptr >> 16);
    chk += (unsigned char)(ptr >> 24);

    return chk & (uintptr_t)0xF;
}
```

Application data overflows

```
#include <iostream>
using namespace std;

class Base
{
public:
     virtual void function1() {};
     virtual void function2() {};
};

int main()
{
     int *buf = (int *)malloc(4*sizeof(int));;
     memset(buf, 0x41, 4*sizeof(int));

     Base *pClass = new Base();
     buf[4] = (int) buf;  // overflow into pClass on heap

     pClass->function1();
}
```

```
(gdb) r
Starting program: /Users/cmiller/test2
Reading symbols for shared libraries ++. done

Program received signal EXC_BAD_ACCESS, Could not access memory.
Reason: KERN_INVALID_ADDRESS at address: 0x41414141
0x41414141 in ?? ()
```

10.5 Zones, Regions, and Allocations

- A process has a number of malloc zones
- Each malloc zone manages allocations in tiny, small, large, and huge size ranges
- Tiny and small range allocations are managed in regions
- Huge and large allocations are managed directly
- A region contains allocations of sizes bounded by the region type

10.6 Magazine Malloc

- Each zone has a magazine per CPU-core (or virtual CPU-core if hyperthreading is used)
- Regions are now specific to the magazine of the CPU core that created them
- Allocations are stored in the region specific to the CPU core running the thread that allocated them

Exploiting Magazine Malloc (10.6)

- Free block free list pointer checksums are now XOR'd with a randomly generated security cookie
  - Effectively defeats heap block metadata overwrites
- Per-CPU regions complicate reliable exploitation if overflown or freed object is "tiny" or "small"
  - Non-deterministic use of different regions complicates heap manipulation
  - Reliability may become dependent on number of CPU cores on target (i.e. new MBP has 8 b/c of HyperThreading)

ASLR

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Library Randomization

- No significant change from Leopard
- Library load locations are randomized per machine periodically when new apps or updates are installed
  - Not per application or application launch
  - See /var/db/dyld/
- dyld, application binary, heap, stack are not randomized
- 64-bit memory space allows for “more” randomization

Fixed RX areas (ROP targets)

- dyld: 0x7fff5fc00000
- binary: 0x100000000
- commpage 64-bit: 0x7fffffe00000

Fun with wild writes

- Many times with exploitation, the “primitive” is to be able to write a DWORD to memory
- This write should eventually lead to getting control of $pc

32-bit processes

- Still use lazy symbol binding
- At fixed, predictable location in memory
- Is writable

```
__la_symbol_ptr:0000201C ; ===========================================================================
__la_symbol_ptr:0000201C
__la_symbol_ptr:0000201C ; Segment type: Pure data
__la_symbol_ptr:0000201C __la_symbol_ptr segment dword public 'DATA' use32
__la_symbol_ptr:0000201C                 assume cs:__la_symbol_ptr
__la_symbol_ptr:0000201C                 ;org 201Ch
__la_symbol_ptr:0000201C _exit_ptr       dd offset __imp__exit   ; DATA XREF: _exit↑r
__la_symbol_ptr:0000201C __la_symbol_ptr ends
__la_symbol_ptr:0000201C
```

32-bit example

```
int main(){
     int *p = 0x201c;
     *p = 0xdeadbeef;
}

$ gcc -g -m32 -o test test.c


Program received signal EXC_BAD_ACCESS, Could not access memory.
Reason: KERN_INVALID_ADDRESS at address: 0xdeadbeef
0xdeadbeef in ?? ()
```

64-bit

- No easy function pointers like in 32-bit (no __IMPORT)
- However, the heap is not randomized
- szone pointers are available starting at predictable address following main executable's __DATA segment
  - Memory management pointers
- In particular szone_malloc()

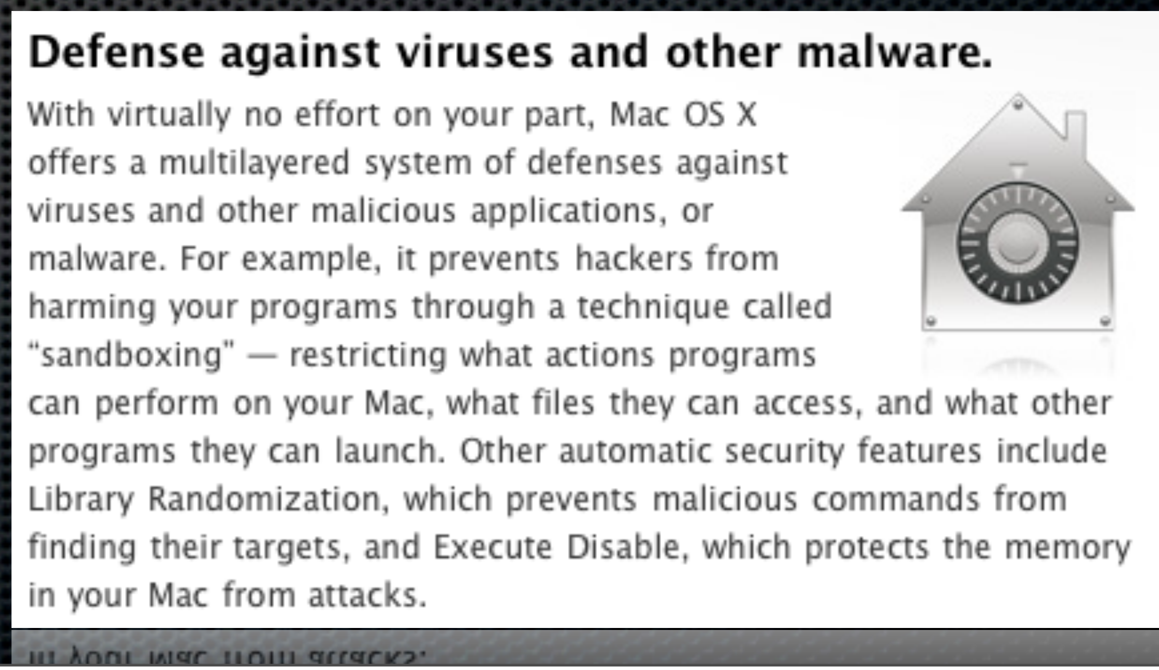
64-bit example

```
int main(){
        long int *p = 0x100004018;
        *p = 0xdeadbeefbabecafe;
        malloc(16);
}

gcc -g -o test test.c

Program received signal EXC_BAD_ACCESS, Could not access memory.
Reason: 13 at address: 0x0000000000000000
0x00007fff821ddf06 in malloc_zone_malloc ()
(gdb) x/i $pc
0x7fff821ddf06 <malloc_zone_malloc+78>:    call   QWORD PTR [r13+0x18]
(gdb) x/4wx $r13+0x18
0x100004018: 0xbabecafe   0xdeadbeef   0x821e01da   0x00007fff
```

Execute Disable



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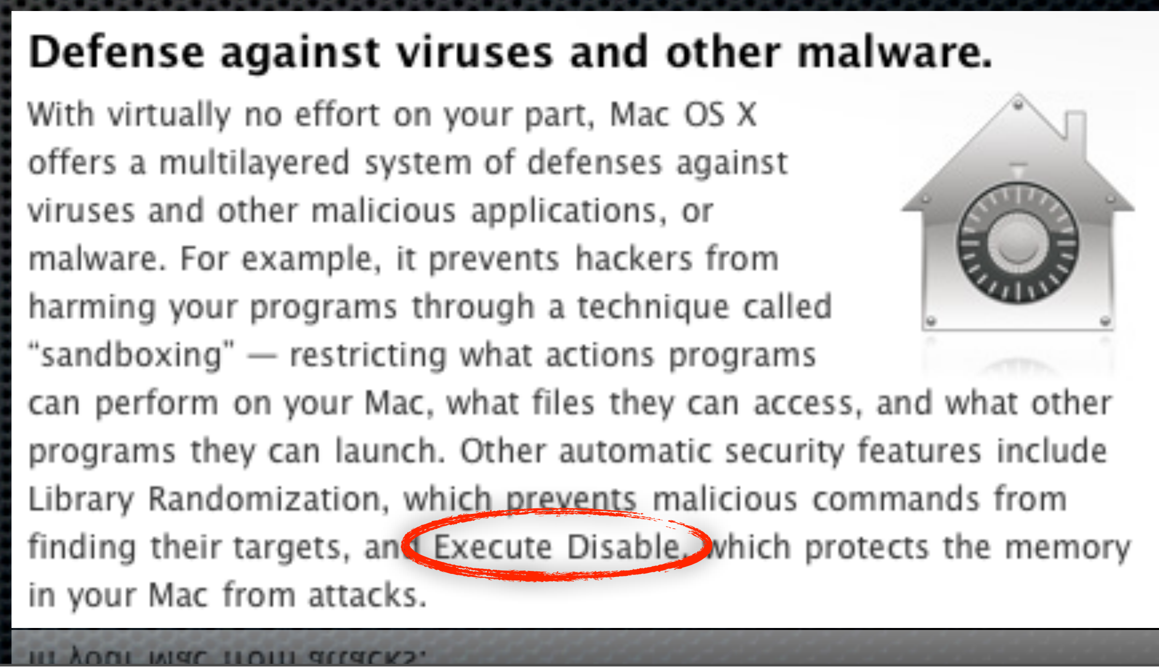

Defense against viruses and other malware.

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XD, DEP, PAGEEXEC

- On 32-bit x86, OS memory page permissions are a lie
  - Operating System shows R/W/X permissions
  - Hardware only supports RO or RW page protections
  - XD (Intel) and NX (AMD) added extra page protection bit for eXecute
- PaX PAGEEXEC feature used ITLB/DTLB desync to simulate support of R/W/X memory page permissions

XD < DEP < PAGEEXEC

- Mac OS X "Execute Disable" on 32-bit x86 procs
  - Only thread stacks are non-executable
- Windows DEP
  - Covers stack/heap/data unless a DLL opts out
  - Can be disabled with one function call
- PaX PAGEEXEC
  - The original implementation and most thorough

Leopard

- Stacks were non-executable
- Heap was executable, even though page permissions indicated it was not
- Heap could always be executed, even if explicitly set to not allow execution
- Same for data pages and new pages allocated from the operating system via mmap(), vm_allocate(), etc.

64-bit Non-Executable Memory

- Support for non-executable page protections are required as part of the 64-bit ABI
- 64-bit processes under Snow Leopard are good about keeping memory RW, RX, or RO
  - no RWX except for JIT

Snow Leopard

- Stack and heap are protected (64-bit processes)
  - This is the biggest security difference between Leopard and Snow Leopard
- 32 bit processes (i.e. Flash and QT plugin) have executable heap
  - Exploiting QT or Flash is very easy!
- 32 bit processes (old macs) have executable heaps

What about a Flash JIT spray?

- Flash runs in a separate process, so can’t be used for JIT spray for (non-Flash) browser bugs

JIT spray within Safari

- Potential candidates are Java and Javascript

```
$ vmmap 27581 | grep 'rwx/rwx'
Java                   000000011e001000-0000000121001000 [ 48.0M] rwx/rwx SM=PRV
JS JIT generated code  0000451ca3200000-0000451cab200000 [128.0M] rwx/rwx SM=PRV
JS JIT generated code  0000451cab200000-0000451d23200000 [  1.9G] rwx/rwx SM=NUL
```

Java

- Java memory region is allocated at the “top” of the heap
- Heap is not randomized so you have a reasonable idea of where to find it
- Region is only 48mb and cannot be expanded
- Not a reliable choice for exploitation

Javascript

- Webkit JS RWX region is much larger: 1.9 gb
- However, Webkit randomizes the load address, those bastards

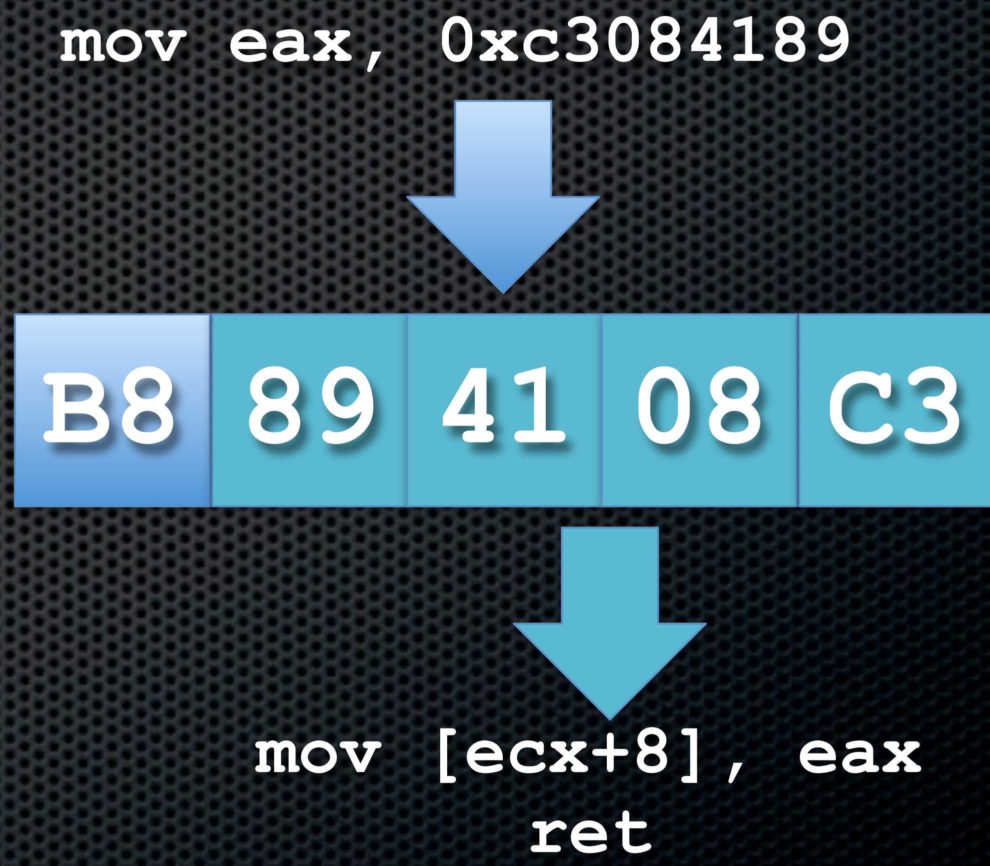
```
#define INITIAL_PROTECTION_FLAGS (PROT_READ | PROT_WRITE | PROT_EXEC)
...
        // Cook up an address to allocate at, using the following recipe:
        //   17 bits of zero, stay in userspace kids.
        //   26 bits of randomness for ASLR.
        //   21 bits of zero, at least stay aligned within one level of the pagetables.
        //
        // But! - as a temporary workaround for some plugin problems (rdar://problem/6812854),
        // for now instead of 2^26 bits of ASLR lets stick with 25 bits of randomization plus
        // 2^24, which should put up somewhere in the middle of usespace (in the address range
        // 0x200000000000 .. 0x5fffffffffff).
        intptr_t randomLocation = arc4random() & ((1 << 25) - 1);
        randomLocation += (1 << 24);
        randomLocation <<= 21;
        m_base = mmap(reinterpret_cast<void*>(randomLocation), m_totalHeapSize,
INITIAL_PROTECTION_FLAGS, MAP_PRIVATE | MAP_ANON, VM_TAG_FOR_EXECUTABLEALLOCATOR_MEMORY
, 0);
```

The good news (for us)

- The location of dyld is not randomized
- The location of the binary is not randomized
- The location of the commpage is not randomized
- We can perform Return Oriented Programming (ROP) to allocate new executable memory or change page permissions for our shellcode

Return-Oriented Programming

- Instead of returning to functions, return to instruction sequences followed by a return instruction
- Can return into middle of existing instructions to simulate different instructions
- All we need are useable byte sequences anywhere in executable memory pages



"The Geometry of Innocent Flesh on the Bone: Return-Into-Libc without Function Calls (on the x86)", Hovav Shacham (ACM CCS 2007)

Return-Oriented Programming

is a lot like a ransom note, but instead of cutting out letters from magazines, you are cutting out instructions from .text segments

Credit: Dr. Raid's Girlfriend

64-Bit Mac OS X ROP

- Passing parameters by register makes things harder than in x86, requiring more “returns”
- Code segments in dyld and commpage are not very large
- Main executable binary may be large enough, but hard to fingerprint
- Problems with rbp
- See Charlie’s presentation at POC 2010 for full ROP details for Snow Leopard x86_64

Wrapping Up

Snow Leopard vs. Leopard

- More secure than ever?
  - Yes, but not by that much since Snow Leopard still only implements a cheap imitation of ASLR
- Safe from attackers?
  - Depends on who your attackers are
  - May stay safe from mass malware, but not from targeted attacks
  - Will APT switch to Mac?

Mac OS X 10.7 “Lion”

- Will Mac OS X 10.7 Lion be the King of the Internet Jungle?
  - Yes, if they implement full ASLR and code signing enforcement for built-in and Mac App Store applications
  - Pre-releases are under NDA, so who knows?

Questions

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