
# Mac OS X Physical Memory Analysis

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BlackHat DC – February 2010

Netherlands Forensic Institute
www.forensicinstitute.nl

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# Who am I?


Researcher for the Netherlands Forensics Institute (NFI).


Microsoft Enterprise Security MVP

Speaker at various security events, such as *PacSec*, *BlackHat USA*, *Europol High Tech Crime Meeting*, *Shakacon*, etc.

Past work:

- SandMan Framework (Windows hibernation file)
- Win**32/64**dd (Windows memory acquisition utility).

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# Agenda

**Introduction**

Analysis

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# Who ?

Forensics Experts

Investigators

Incident Response Engineers

…

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# Why ?

Pros:

1. Sometimes non-volatile memory is not enough, then we need volatile memory (Physical Memory).

Cons:

1. Very complex.
2. Lack of research.

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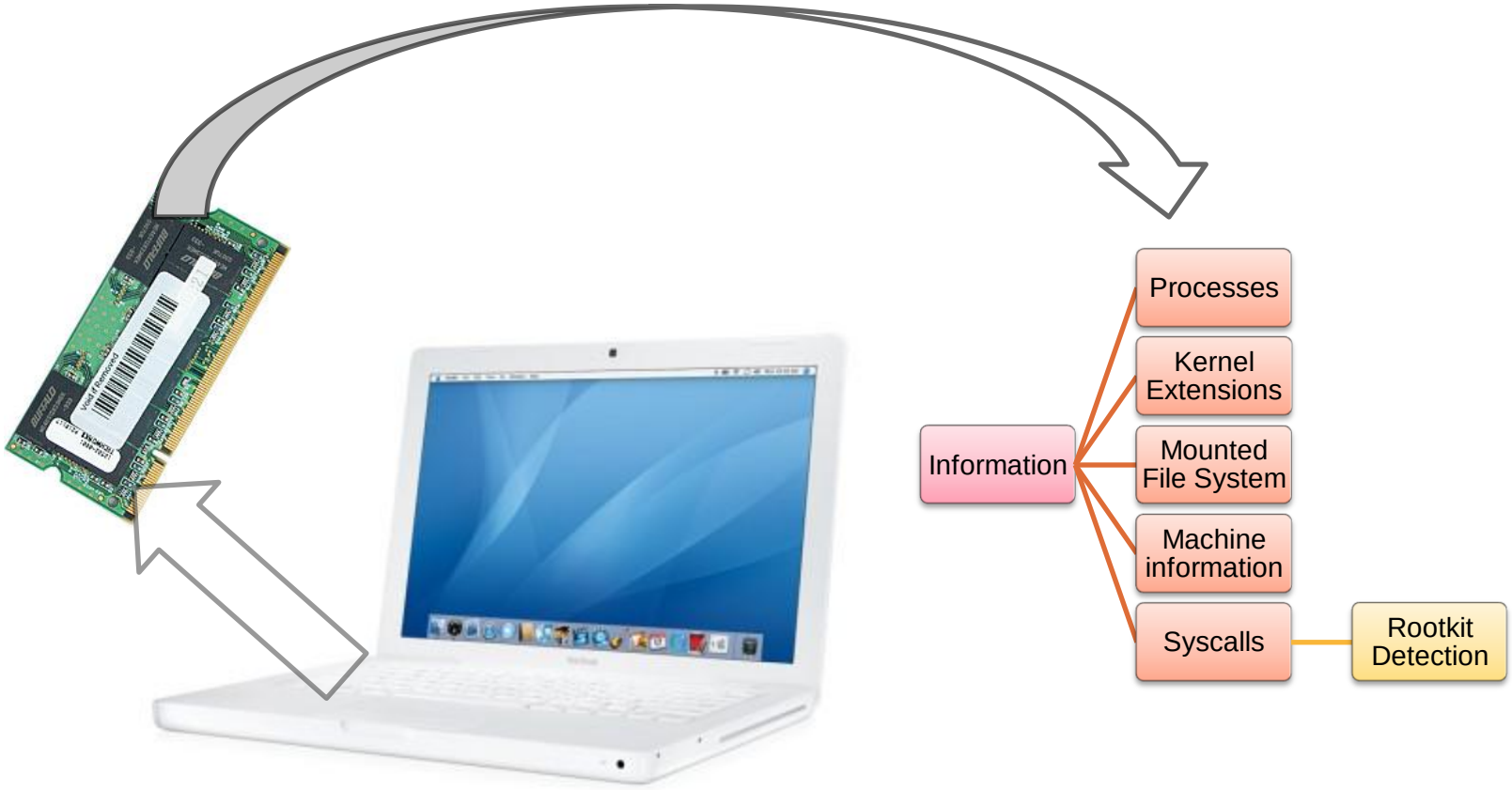
# Overview



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# Target

Intel Processor (x86/x64)

Mac OS X Leopard 10.5

Mac OS X Snow Leopard 10.6

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# Software-based acquisition

/dev/mem

- Cons: Disabled by default.
- Pros: We can write our own driver.

Hibernation a.k.a. “safe sleep”

- Pros: Present on all modern O.S.
- Cons: Compressed, and can be encrypted if *secure virtual memory* mechanism is used. (`hibernatemode == 5`)

# Agenda

Introduction

**Analysis**

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# Analysis

**Goal:** To avoid random string searching.

To be precise and efficient.

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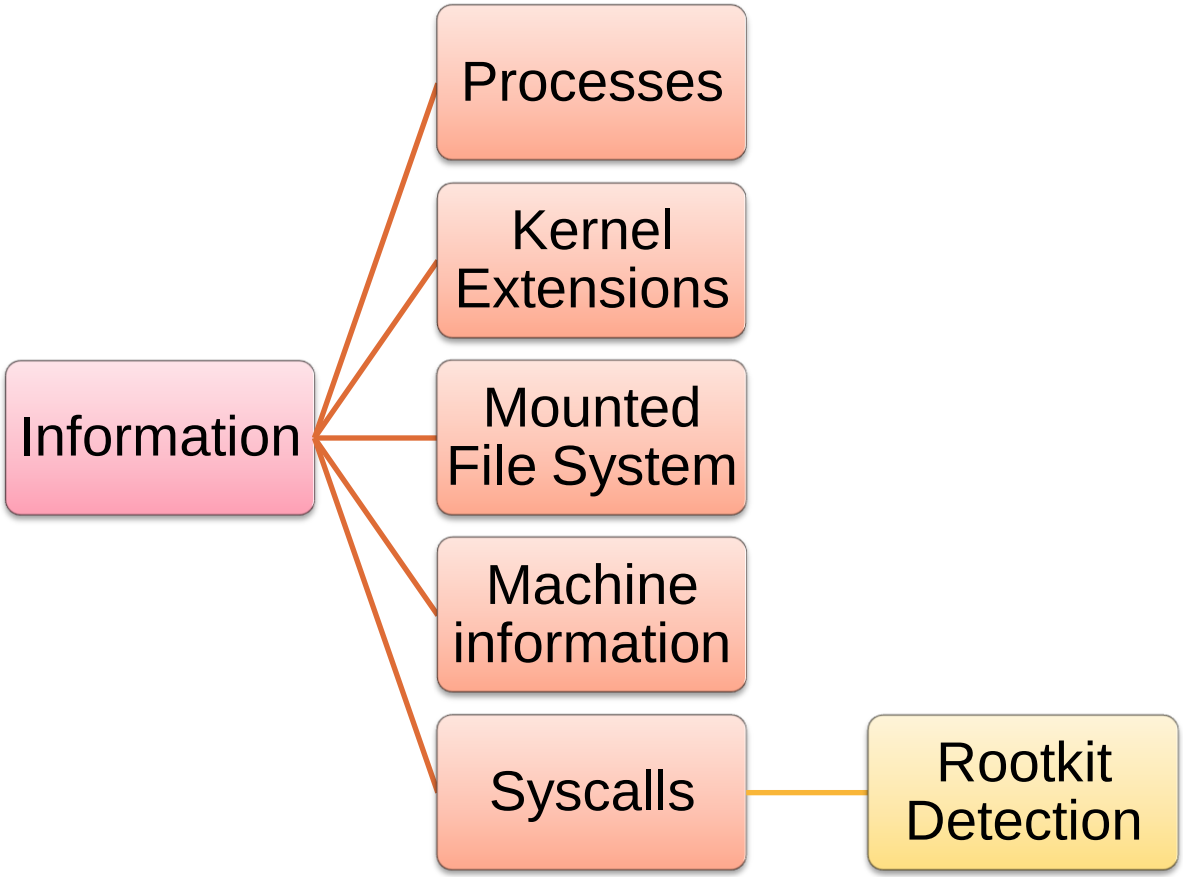
# Information Goldmine



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# Analysis

- Get kernel symbols.
- Initialize kernel memory manager.
- Browse kernel virtual address space.
- Collect information.

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# Kernel Symbols

Windows compiler stores symbols in externals files called *.PDB

Mac OS X compiler stores symbols inside a section which is part of the executable.

Mac OS X kernel executable (mach_kernel) as symbol database.

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# Kernel Symbols

**Why?**

__*KLD*, __*LINKEDIT*, __*PRELINK* and __`symtab` kernel sections are destroyed as soon as the kernel (mach_kernel) is loaded by `removeKernelLinker()` function.

**What?**

__*LINKEDIT* section contains variable names and offsets.

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# Kernel Symbols

Quick **K**ernel **V**irtual To **P**hysical **A**ddress Formula is:

| Operating System | Quick translation Formula |
|---|---|
| i386 Linux | KPA = KVA – 0xC0000000 |
| Playstation 3 Linux | KPA = KVA – 0xC000000000000000 |
| Windows | KPA = KVA & 0x1FFFF000 |
| **Mac OS X** | **KPA = KVA** |

Now we can read variables from the symbol section in the physical memory.

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# Kernel Symbols

Works only for the mapped executable kernel (__text and __data sections)

Does not work for allocated buffers.

.data interesting exported variables:

Memory manager variables

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# Memory Manager

Super interesting variables

```
_IdlePDPT
_IdlePDPT64
_IdlePML4
_IdlePTD
```

Page Map Level 4 is initialized on x86 version even if x86 only use PAE.

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# PML4 ?

Page Map Level 4 paging method.

Supports 48-bits linear/virtual addresses.

*Intel® 64 and IA-32 Architectures Software Developer's Manual Volume 3A: System Programming Guide*

4.5 IA-32E Paging

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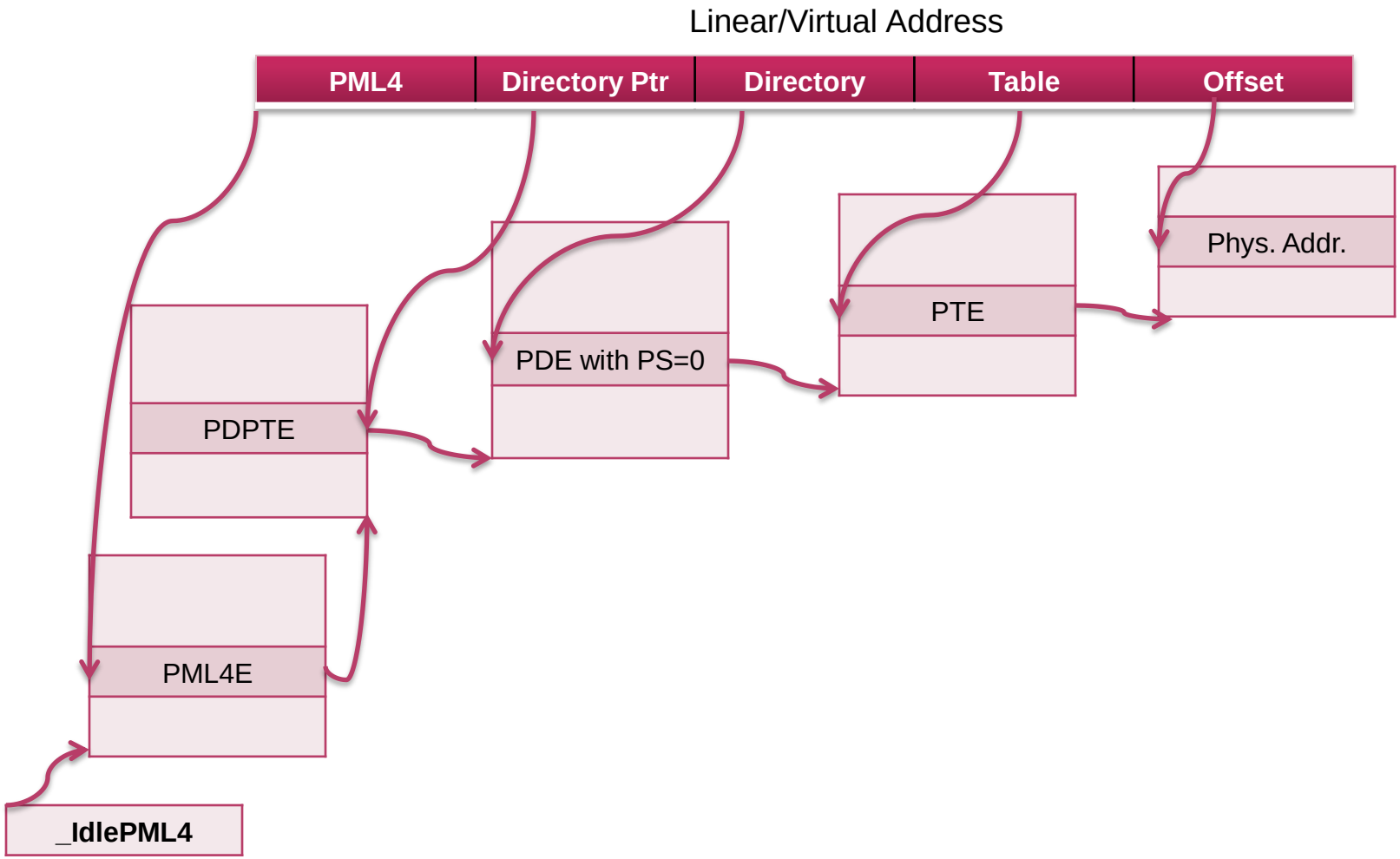
# PML4



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# Information

Now, we can browse the kernel virtual address space.

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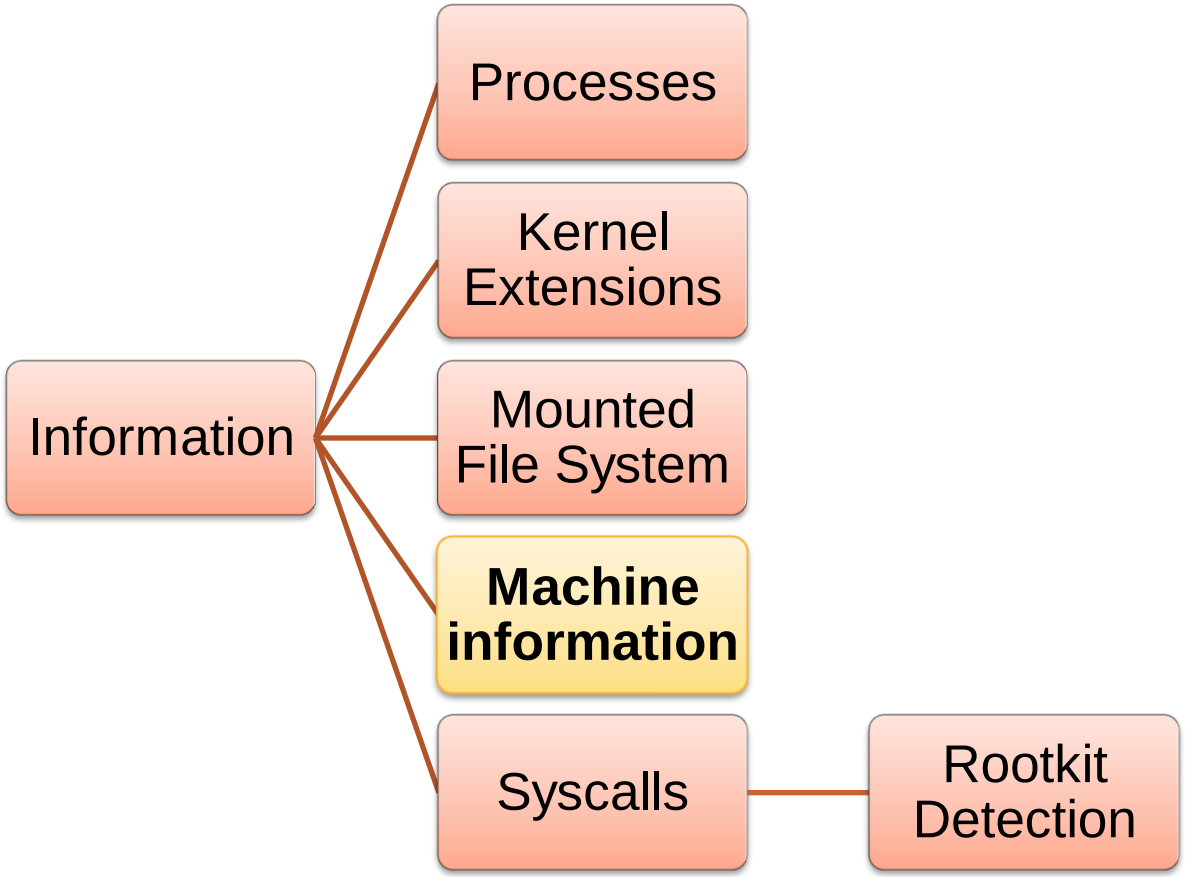
# Machine Information



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# Machine Information

`version` variable contains a string with kernel version and compilation time

`machine_info` variable / structure contains:

| Field Name | Description |
|---|---|
| major_version | Major OS Version |
| minor_version | Minor OS Version |
| max_mem | Physical Memory size |
| physical_cpu | Number of physical CPU |
| logical_cpu | Number of logical CPU |

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# Machine Information

```
Darwin Kernel Version 9.0.0: Tue Oct  9 21:35:55 PDT 2007; root:xnu-1228~1/RELEASE_I386
Major version:                  9
Minor version:                  0
Max number of CPUs:             4
Size of physical memory:        1024 MB
Number of physical CPUs:        0
Number of logical CPUs:         1
```

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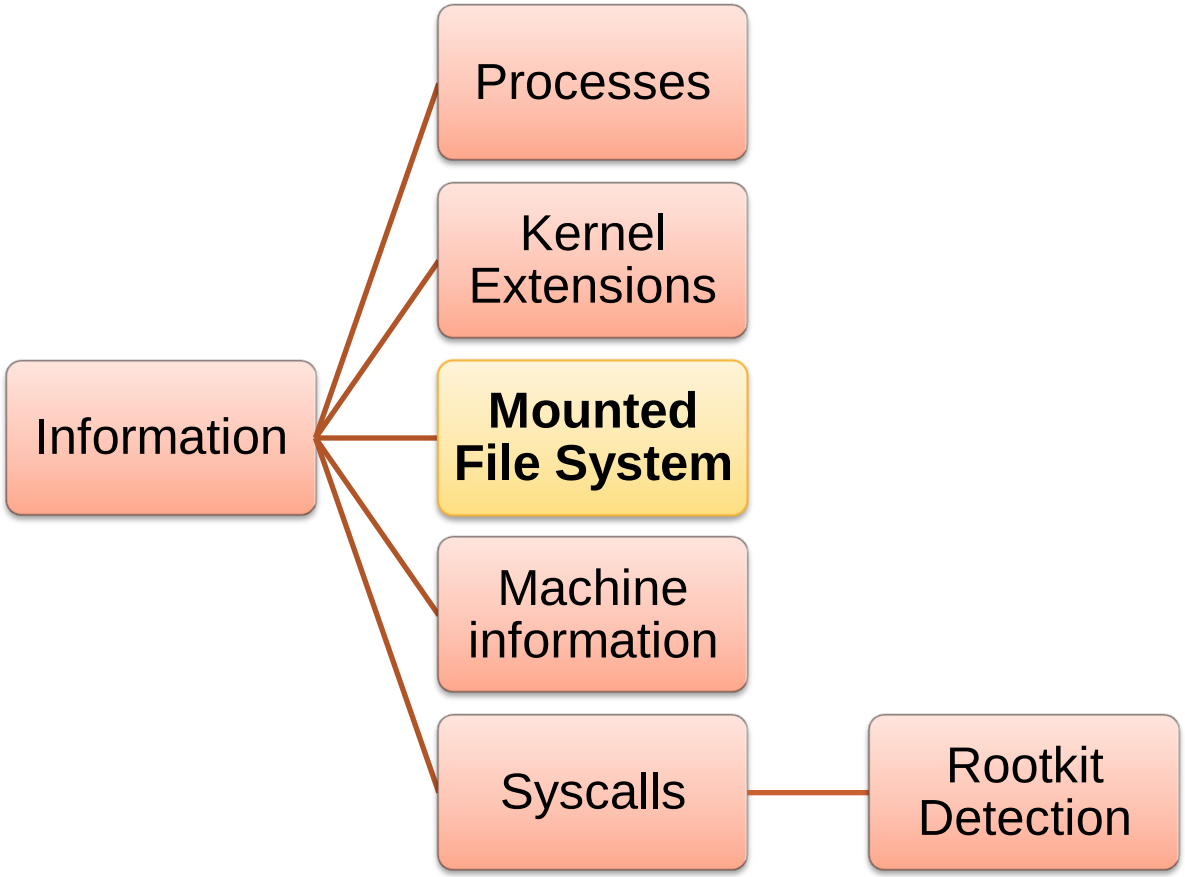
# Mounted File System



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# Mounted File System

Link-list called `mountlist`, defined by `mount` structure.

| Field Name | Description |
|---|---|
| f_fstypename | File system type |
| f_mntonname | Mounted directory |
| f_mntfromname | Mounted file system |

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# Mounted File System

| id# | type | mounted on | mounted from |
|---|---|---|---|
| 0 | hfs | / | nfo |
| 1 | devfs | /dev | devfs |
| 2 | fdesc | /dev | fdesc |
| 3 | autofs | /net | map -hosts |
| 4 | autofs | /home | map auto_home |
| 5 | hfs | /Volumes/VMware Tools | né |
| 6 | hfs | /Volumes/OSXBAK | /dev/disk2s1 |
| 7 | msdos | /Volumes/FATBACK | /dev/disk2s2 |

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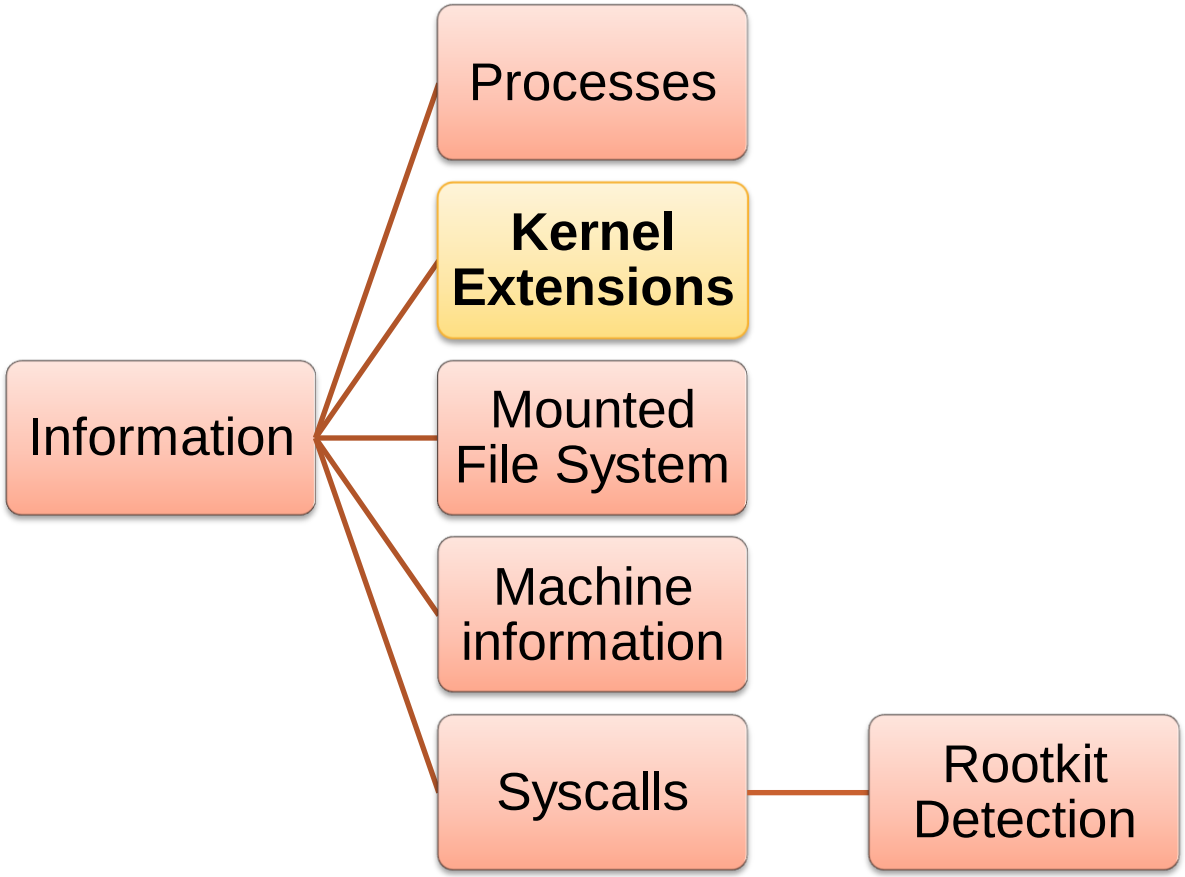
# Kernel Extensions



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# Kernel Extensions

`kmod` variable is the list-head of every loaded kernel extensions defined by `kmod` structure.

| Field Name | Description |
|---|---|
| address | Base Address |
| size | Total Size |
| hdr_size | Header Size |
| name | Extension Name |
| version | Version |
| next | Pointer to the next entry |

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# Kernel Extensions

```
 43    0 0x20AAA000 0x0000C000 0x0000B000 com.apple.driver.AppleUSBHub (3.4.0)
 42    0 0x20A3F000 0x00002000 0x00001000 com.apple.iokit.IOUSBUserClient (3.3.1)
 41    0 0x209DE000 0x00012000 0x00011000 com.apple.driver.AppleUSBEHCI (3.4.3)
 40    0 0x20935000 0x0000E000 0x0000D000 com.apple.driver.AppleUSBUHCI (3.3.5)
 39    8 0x2085B000 0x00029000 0x00028000 com.apple.iokit.IOUSBFamily (3.4.3)
 38    0 0x2076E000 0x00013000 0x00012000 com.apple.driver.AppleLSIFusionMPT (2.0.3)
 37    1 0x20737000 0x00008000 0x00007000 com.apple.iokit.IOSCSIParallelFamily (1.5.2)
 36    6 0x20710000 0x00019000 0x00018000 com.apple.iokit.IOSCSIArchitectureModelFamily (2.0.9)
 35    0 0x2064C000 0x00009000 0x00008000 com.apple.driver.AppleIntelPIIXATA (2.0.0)
 34    2 0x20633000 0x0000D000 0x0000C000 com.apple.iokit.IOATAFamily (2.0.1)
 33    0 0x2058B000 0x00004000 0x00003000 com.apple.driver.AppleACPIButtons (1.2.4)
 31    9 0x2047D000 0x00018000 0x00017000 com.apple.iokit.IOStorageFamily (1.5.6)
 30    0 0x20359000 0x00005000 0x00004000 com.apple.driver.AppleRTC (1.2.3)
 29    0 0x20317000 0x00003000 0x00002000 com.apple.driver.AppleACPIPCI (1.2.4)
 28    0 0x201B8000 0x00004000 0x00003000 com.apple.driver.AppleSMBIOS (1.4)
 27    0 0x1AFF7000 0x00003000 0x00002000 com.apple.driver.AppleAPIC (1.4)
 26    0 0x1AFD1000 0x00018000 0x00017000 com.apple.security.seatbelt (107.12)
 25    0 0x1AF91000 0x00008000 0x00007000 com.apple.nke.applicationfirewall (1.6.77)
 24    0 0x1AF77000 0x00003000 0x00002000 com.apple.security.TMSafetyNet (3)
 23    0 0x1AF2A000 0x0001F000 0x0001E000 com.apple.driver.AppleIntelCPUPowerManagement (76.0.0)
 22    2 0x1AE87000 0x00039000 0x00038000 com.apple.iokit.IOHIDFamily (1.5.5)
 21    0 0x1ADC3000 0x00005000 0x00004000 com.apple.BootCache (30.4)
 20    0 0x1AD81000 0x00002000 0x00001000 com.yourcompany.driver.NullCPUPowerManagement (1.0.0d1)
 19    2 0x1AD1B000 0x0003E000 0x0003D000 com.apple.driver.AppleACPIPlatform (1.2.4)
 18    8 0x1ACCC000 0x00004000 0x00003000 com.apple.iokit.IOACPIFamily (1.2.0)
 17   12 0x1ACB5000 0x00011000 0x00010000 com.apple.iokit.IOPCIFamily (2.6)
 16    1 0x00000000 0x00000000 0x00000000 com.apple.kernel.mach (7.9.9)
 15    1 0x00000000 0x00000000 0x00000000 com.apple.kernel.libkern (7.9.9)
 14    1 0x00000000 0x00000000 0x00000000 com.apple.kernel.iokit (7.9.9)
 13    1 0x00000000 0x00000000 0x00000000 com.apple.kernel.bsd (7.9.9)
 12   12 0x00000000 0x00000000 0x00000000 com.apple.kernel.6.0 (7.9.9)
 11    1 0x00000000 0x00000000 0x00000000 com.apple.iokit.ApplePlatformFamily (9.7.0)
 10    1 0x00000000 0x00000000 0x00000000 com.apple.iokit.IOSystemManagementFamily (9.7.0)
  9    1 0x00000000 0x00000000 0x00000000 com.apple.driver.AppleNMI (9.7.0)
  8    1 0x00000000 0x00000000 0x00000000 com.apple.iokit.IONVRAMFamily (9.7.0)
  7   29 0x00000000 0x00000000 0x00000000 com.apple.kpi.unsupported (9.7.0)
  6   44 0x00000000 0x00000000 0x00000000 com.apple.kpi.mach (9.7.0)
  5   51 0x00000000 0x00000000 0x00000000 com.apple.kpi.libkern (9.7.0)
  4   48 0x00000000 0x00000000 0x00000000 com.apple.kpi.iokit (9.7.0)
  3    3 0x00000000 0x00000000 0x00000000 com.apple.kpi.dsep (9.7.0)
  2   31 0x00000000 0x00000000 0x00000000 com.apple.kpi.bsd (9.7.0)
  1    1 0x00000000 0x00000000 0x00000000 com.apple.kernel (9.7.0)
```

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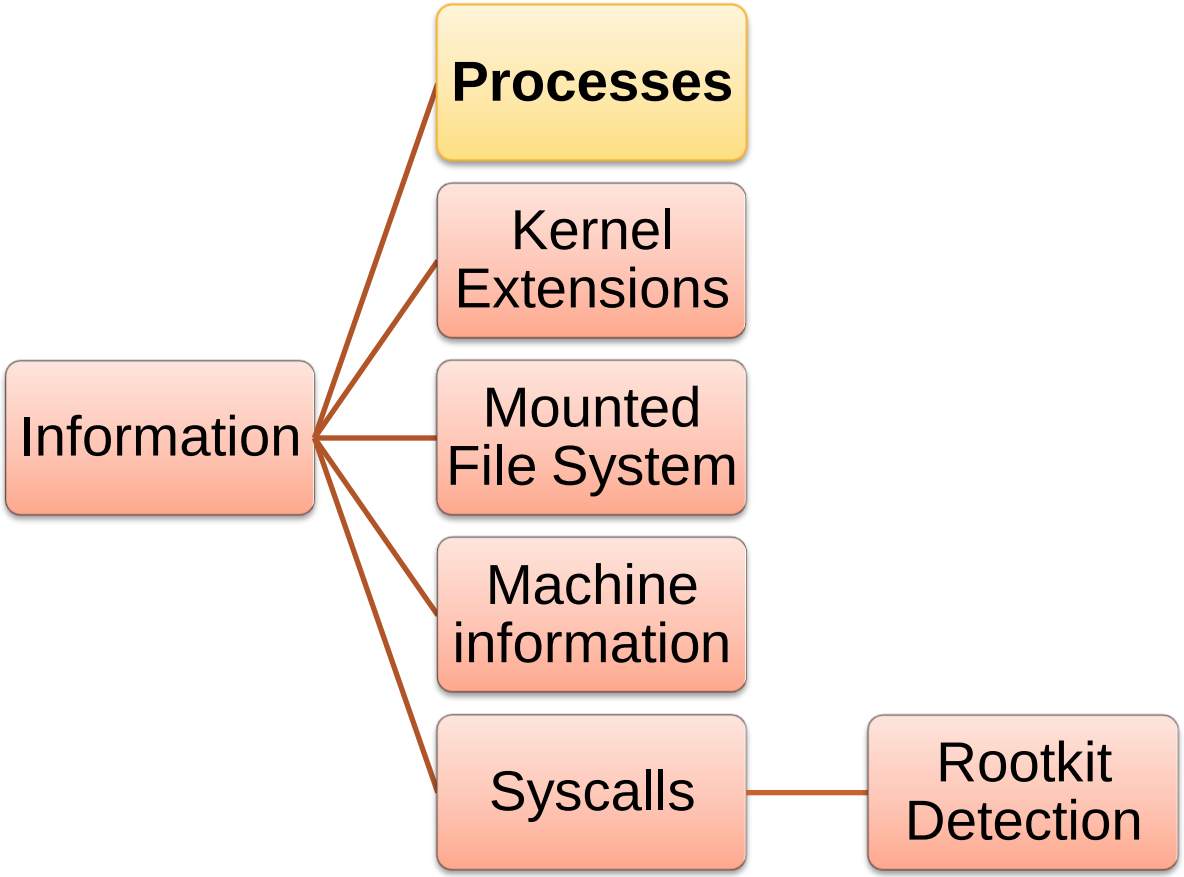
# Processes



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# Processes

`kernproc` variable is list-head of every BSD processes defined by `proc` structure.

Contains PID, Parent PID, open files (file descriptors), children, threads, name and a pointer (`p_pgrp` field) to process group (`pgrp` structure).

`pgrp` structure contains a pointer to `session` structure (`pg_session` field).

`session` structure contains username (`s_login` field) who launched the process.

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# Processes

| task# | pid | parent pid | name | username | started time |
|---|---|---|---|---|---|
| 0 | 0 | 0 | kernel_task | | Sat 2001-January-20 05:08:31 (W. Europe Standard Time) |
| 1 | 1 | 0 | launchd | nfi | Sat 2001-January-20 05:08:31 (W. Europe Standard Time) |
| 2 | 10 | 1 | kextd | root | Sat 2001-January-20 05:08:33 (W. Europe Standard Time) |
| 3 | 11 | 1 | notifyd | root | Sat 2001-January-20 05:08:33 (W. Europe Standard Time) |
| 4 | 12 | 1 | syslogd | root | Sat 2001-January-20 05:08:34 (W. Europe Standard Time) |
| 5 | 16 | 1 | update | root | Sat 2001-January-20 05:08:35 (W. Europe Standard Time) |
| 6 | 19 | 1 | securityd | root | Sat 2001-January-20 05:08:35 (W. Europe Standard Time) |
| 7 | 21 | 1 | mds | root | Sat 2001-January-20 05:08:35 (W. Europe Standard Time) |
| 8 | 22 | 1 | mDNSResponder | | <Invalid date> |
| 9 | 23 | 1 | loginwindow | nfi | Sat 2001-January-20 05:08:35 (W. Europe Standard Time) |
| 10 | 24 | 1 | KernelEventAgent | root | Sat 2001-January-20 05:08:35 (W. Europe Standard Time) |
| 11 | 26 | 1 | hidd | root | Sat 2001-January-20 05:08:35 (W. Europe Standard Time) |
| 12 | 27 | 1 | fseventsd | root | Sat 2001-January-20 05:08:35 (W. Europe Standard Time) |
| 13 | 28 | 1 | dynamic_pager | root | Sat 2001-January-20 05:08:35 (W. Europe Standard Time) |
| 14 | 31 | 1 | diskarbitrationd | root | Sat 2001-January-20 05:08:35 (W. Europe Standard Time) |
| 15 | 32 | 1 | DirectoryService | root | Sat 2001-January-20 05:08:35 (W. Europe Standard Time) |
| 16 | 34 | 1 | configd | root | Sat 2001-January-20 05:08:35 (W. Europe Standard Time) |
| 17 | 37 | 1 | autofsd | root | Sat 2001-January-20 05:08:35 (W. Europe Standard Time) |
| 18 | 38 | 1 | socketfilterfw | root | Sat 2001-January-20 05:08:35 (W. Europe Standard Time) |
| 19 | 41 | 1 | distnoted | root | Sat 2001-January-20 05:08:38 (W. Europe Standard Time) |
| 20 | 47 | 1 | coreservicesd | nfi | Sat 2001-January-20 05:08:39 (W. Europe Standard Time) |
| 21 | 48 | 1 | WindowServer | root | Sat 2001-January-20 05:08:39 (W. Europe Standard Time) |
| 22 | 65 | 1 | coreaudiod | nfi | Sat 2001-January-20 05:08:46 (W. Europe Standard Time) |
| 23 | 69 | 1 | launchd | nfi | Sat 2001-January-20 05:08:46 (W. Europe Standard Time) |
| 24 | 76 | 69 | Spotlight | nfi | Sat 2001-January-20 05:08:46 (W. Europe Standard Time) |
| 25 | 77 | 69 | UserEventAgent | nfi | Sat 2001-January-20 05:08:46 (W. Europe Standard Time) |
| 26 | 79 | 69 | pboard | nfi | Sat 2001-January-20 05:08:48 (W. Europe Standard Time) |
| 27 | 80 | 69 | Dock | nfi | Sat 2001-January-20 05:08:49 (W. Europe Standard Time) |
| 28 | 81 | 69 | SystemUIServer | nfi | Sat 2001-January-20 05:08:49 (W. Europe Standard Time) |
| 29 | 82 | 69 | Finder | nfi | Sat 2001-January-20 05:08:49 (W. Europe Standard Time) |
| 30 | 83 | 69 | ATSServer | nfi | Sat 2001-January-20 05:08:49 (W. Europe Standard Time) |
| 31 | 95 | 69 | Terminal | nfi | Sat 2001-January-20 05:09:33 (W. Europe Standard Time) |
| 32 | 96 | 95 | └♥:§ | | Thu 1970-January-01 01:00:00 (W. Europe Standard Time) |
| 33 | 97 | 96 | bash | nfi | Sat 2001-January-20 05:09:34 (W. Europe Standard Time) |
| 34 | 158 | 69 | Xcode | nfi | Sat 2001-January-20 05:34:21 (W. Europe Standard Time) |
| 35 | 853 | 80 | DashboardClient | nfi | Sat 2001-January-20 07:22:47 (W. Europe Standard Time) |
| 36 | 1134 | 69 | Property List Ed | nfi | Sun 2001-January-21 00:27:20 (W. Europe Standard Time) |
| 37 | 2578 | 69 | Safari | nfi | Sun 2001-January-21 06:03:21 (W. Europe Standard Time) |
| 38 | 2588 | 95 | login | nfi | Sun 2001-January-21 06:04:33 (W. Europe Standard Time) |
| 39 | 2589 | 2588 | bash | nfi | Sun 2001-January-21 06:04:34 (W. Europe Standard Time) |
| 40 | 3714 | 1 | ntpd | nfi | Wed 2009-September-09 11:12:27 (W. Europe Daylight Time) |
| 41 | 3837 | 1 | mdworker | nobody | Wed 2009-September-09 15:34:55 (W. Europe Daylight Time) |
| 42 | 3898 | 1 | mdworker | nfi | <Invalid date> |
| 43 | 3906 | 69 | AppleSpell | | <Invalid date> |
| 44 | 3908 | 97 | dd | nfi | Thu 2009-September-10 10:45:39 (W. Europe Daylight Time) |

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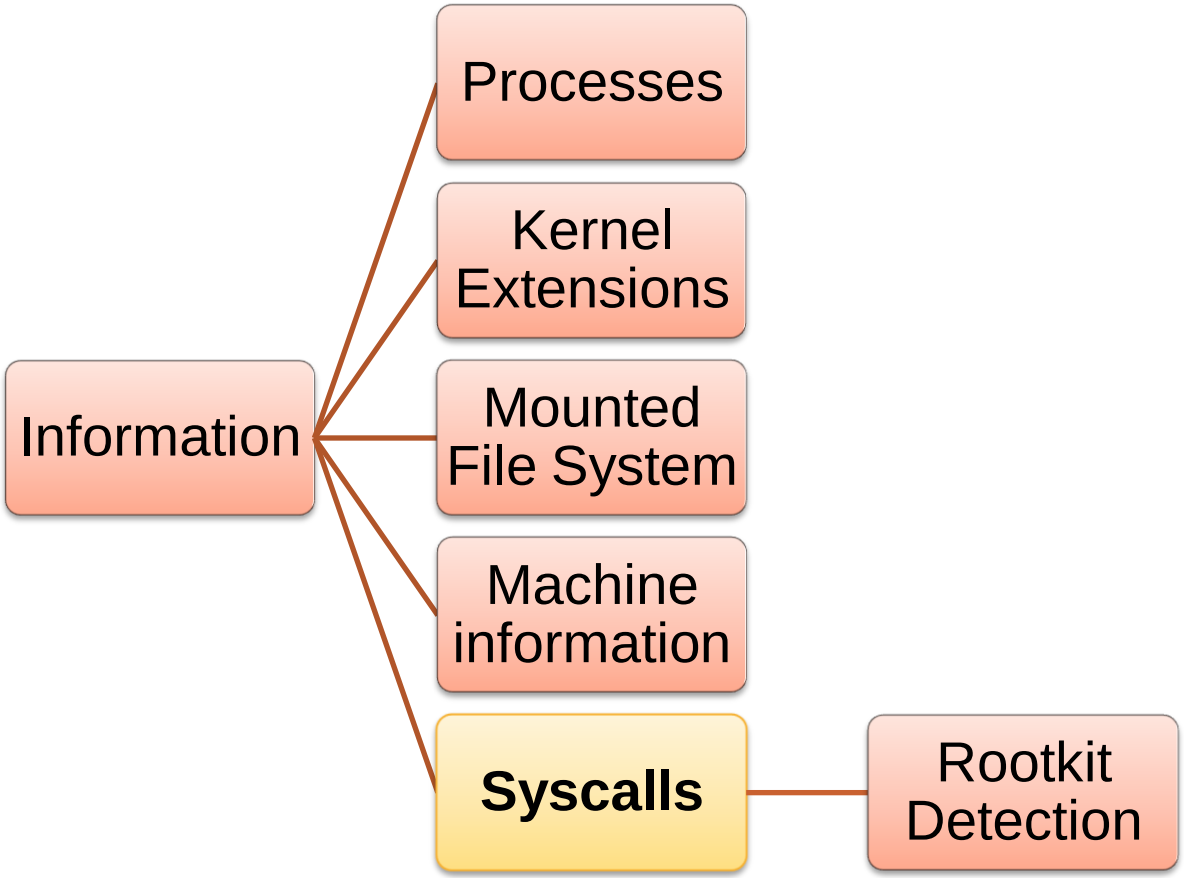
# Syscalls



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# Syscalls

- Syscall address is not exported

Leopard

As explained by Jesse D'Aguanno at BH US 2008

```
&sysent = &nsysent + 0x20
```

Snow Leopard

```
&sysent = &nsysent - ((nsysent) * sizeof(sysent))
```

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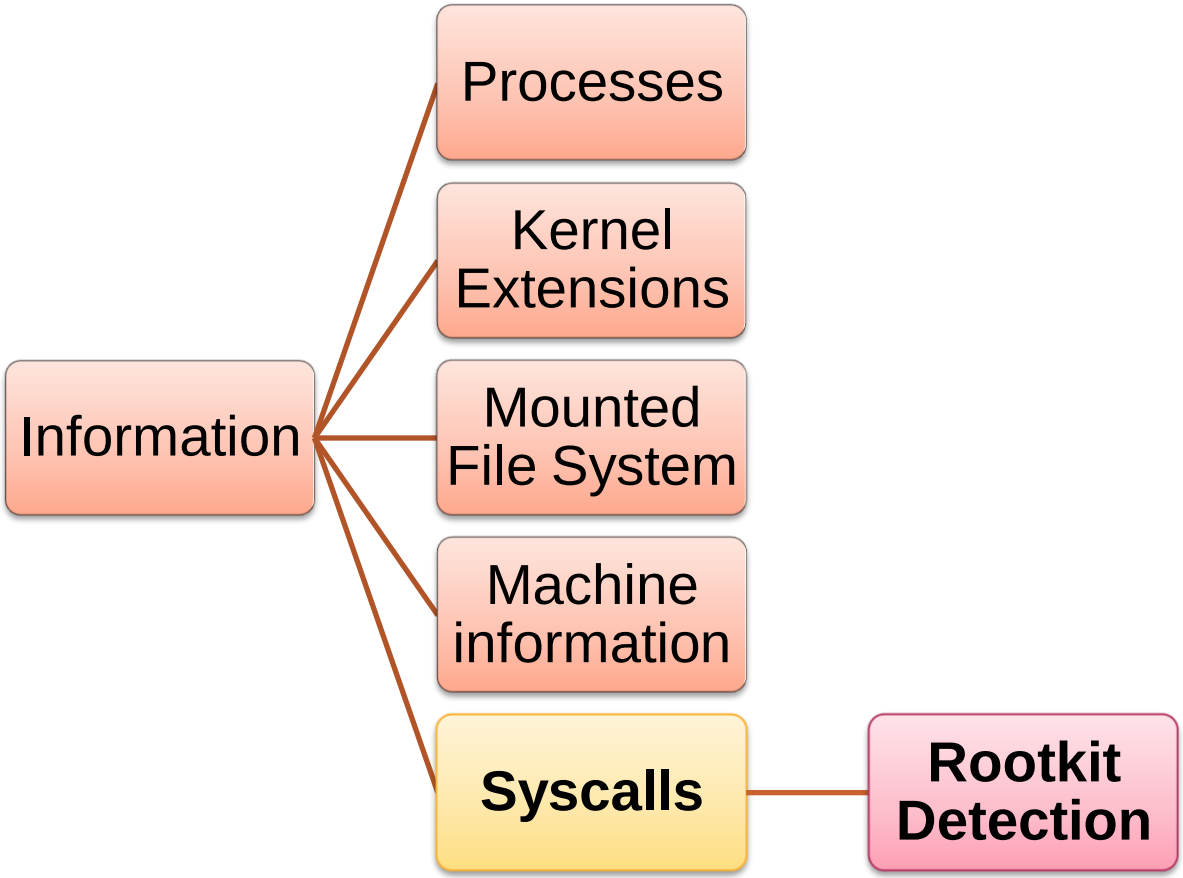
# Syscalls



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# Syscalls

If an offset from a syscall entry is not in kernel symbols.

Then, this is not normal ☺

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| id# | offset | name | table |
|---|---|---|---|
| 0 | 0x003907F5 | _nosys | [OK] |
| 1 | 0x00376F34 | _exit | [OK] |
| 2 | 0x00378B4A | _fork | [OK] |
| 3 | 0x00390CAE | _read | [OK] |
| 4 | 0x0039134C | _write | [OK] |
| 5 | 0x001E425C | _open | [OK] |
| 6 | 0x0036C75E | _close | [OK] |
| 7 | 0x00375EB2 | _wait4 | [OK] |
| 8 | 0x003907F5 | _nosys | [OK] |
| 9 | 0x001E4932 | _link | [OK] |
| 10 | 0x001E5540 | _unlink | [OK] |
| 11 | 0x003907F5 | _nosys | [OK] |
| 12 | 0x001E3925 | _chdir | [OK] |
| 13 | 0x001E3723 | _fchdir | [OK] |
| 14 | 0x001E43E8 | _mknod | [OK] |
| 15 | 0x001E6FD1 | _chmod | [OK] |
| 16 | 0x001E74B7 | _chown | [OK] |
| 17 | 0x0037A52D | _obreak | [OK] |
| 18 | 0x001E335E | _getfsstat | [OK] |
| 19 | 0x003907F5 | _nosys | [OK] |
| 20 | 0x0037DE30 | _getpid | [OK] |
| 21 | 0x003907F5 | _nosys | [OK] |
| 22 | 0x003907F5 | _nosys | [OK] |
| 23 | 0x0037E92E | _setuid | [OK] |
| 24 | 0x0037DF0D | _getuid | [OK] |
| 25 | 0x0037DF21 | _geteuid | [OK] |
| 26 | 0x0038C823 | _ptrace | [OK] |
| 27 | 0x003B0A4E | _recvmsg | [OK] |
| 28 | 0x003B1701 | _sendmsg | [OK] |
| 29 | 0x003B07D8 | _recvfrom | [OK] |
| 30 | 0x003AFE73 | _accept | [OK] |
| 31 | 0x003B0EC4 | _getpeername | [OK] |
| 32 | 0x003B0CDA | _getsockname | [OK] |
| 33 | 0x001E5D2D | _access | [OK] |
| 34 | 0x001E6BD7 | _chflags | [OK] |
| 35 | 0x001E6C88 | _fchflags | [OK] |
| 36 | 0x001E22B5 | _sync | [OK] |
| 37 | 0x003836B2 | _kill | [OK] |
| 38 | 0x003907F5 | _nosys | [OK] |
| 39 | 0x0037DE42 | _getppid | [OK] |
| 40 | 0x003907F5 | _nosys | [OK] |
| 41 | 0x0036E487 | _dup | [OK] |
| 42 | 0x00394912 | _pipe | [OK] |
| 43 | 0x0037DFC7 | _getegid | [OK] |
| 44 | 0x0038FBA6 | _profil | [OK] |
| 45 | 0x003907F5 | _nosys | [OK] |
| 46 | 0x00382075 | _sigaction | [OK] |
| 47 | 0x0037DFB3 | _getgid | [OK] |
| 48 | 0x003829F2 | _sigprocmask | [OK] |
| 49 | 0x0037E544 | _getlogin | [OK] |
| 50 | 0x0037E5E5 | _setlogin | [OK] |
| 51 | 0x003582A7 | _acct | [OK] |
| 52 | 0x00381125 | _sigpending | [OK] |
| 53 | 0x00381539 | _sigaltstack | [OK] |
| 54 | 0x0039160C | _ioctl | [OK] |
| 55 | 0x0038C732 | _reboot | [OK] |
| 56 | 0x001E9F24 | _revoke | [OK] |
| 57 | 0x001E4E09 | _symlink | [OK] |
| 58 | 0x001E6923 | _readlink | [OK] |

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# DEMO

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# Special thanks to

- Dino Dai Zovi
  - (Co-Author of **The Mac Hacker's Handbook**)
- Vincenzo Iozzo

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Thanks for your attention

# QUESTIONS ?