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Practical Assignment – Option 2

Solaris Loadable Kernel Modules and Their Use in Rootkits

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1.0 Exploit Details:

Name: Solaris Integrated Trojan Facility (sitf0.2)

Variants: linspy, heroin, itf, Knark, adore (all are for Linux)

Operating System: Solaris 7 & 8

Protocols/Services: Loadable Kernel Modules (LKMs)

Description:

The Solaris Integrated Trojan Facility enables an attacker to hide files, processes and installed kernel modules, while allowing the attacker to redirect program execution calls and grant root access to the system. The software uses loadable kernel modules, code that runs within the operating system kernel and not at the user application level.

2.0 Introduction:

The Solaris Integrated Trojan Facility (SITF) is a kernel-level rootkit. A rootkit is generally a series of steps or procedures that an attacker, once they have gained root access to a host or server, will use to hide their continued access and illicit activity. To do this, the SITF installs loadable kernel modules (LKMs) that perform these procedures by modify the functioning of the operating system itself.

In the past, a rootkit typically contained a collection of trojaned user programs that allowed them to alter the output for their own purposes. For example, a trojaned Unix “ps” program would be used to hide processes run by the attacker, or a trojaned Unix “ls” program that would not list files the attacker wanted to remain unseen by anyone else. As a defense against rootkits, system administrators began to use integrity checking, cryptographic hashes or a program like Tripwire, to ensure that critical programs were not altered.

What makes a kernel-level rootkit a particularly insidious exploit is that it is the operating system kernel, rather than user programs, which is altered. This means that integrity checking may fail to detect any modification of a system, since the user programs have not been replaced with trojaned versions, and the operating system itself may give false information to the integrity-checking program to begin with. For this reason, the LKMs provide a significant, inherent vulnerability within the Solaris operating system.

2.1 Operating Systems and the Solaris Kernel

Before giving a description of LKMs and how they can be exploited, the following is a very brief introduction to the Unix operating system, its kernel and the Solaris boot process. It is important to understand these basic concepts to fully evaluate the risk of kernel-level rootkits. References for much more thorough discussions of the Solaris kernel are listed at the end of this paper.

The operating system, simply put, is a collection of system programs, which allow users to run other application programs. By abstracting the machine hardware into a “virtual”

machine, the operating system provides a consistent environment for the software that runs on the machine and gives the user a “look and feel” to the computer system. (1)

The “kernel” is the core of the operating system whose primary functions are to manage the hardware by allocating its resources among the programs running on it, and to supply a set of system services for those programs to use. (2)

Operating systems are generally classified as having either a microkernel or monolithic design. A microkernel design has separate processes (modules) that run in a privileged mode, but communicate with each other by passing messages. The “microkernel” itself is little more than a message hub, while the modules provide the functionality. The goal of this design is to keep the microkernel as small as possible. On the other hand, the monolithic design is one large process, which may be subdivided into modules internally, but when run, is a single large binary image. Its modules do not pass messages, but communicate directly by calling functions in other modules. (3)

An advantage to a microkernel design is a potential for more efficient use of memory, as modules are loaded into memory only as they are called upon, and unneeded modules are never loaded. The LKMs mechanism provides this dynamic capability to the operating system kernel by loading or unloading modules in response to system calls, or the kernel’s resource requirements. Furthermore, modules can be developed, tested and modified, without having to add the code to the “kernel”, recompile the kernel and reboot the system.

An advantage of a monolithic kernel design is that it provides a wholly contained binary that cannot be altered without recompilation and rebooting. The security implication of this is obvious. An operating system that cannot be altered while running has a lower degree of vulnerability than one that can be modified while the system is running. However, this does not mean a monolithic kernel has no vulnerabilities.

Solaris is a Unix operating system of a microkernel design. It is not possible to create a monolithic Solaris kernel (4). The Unix operating systems Linux and BSD are originally of a monolithic kernel design, but have added the ability to dynamically load or unload modules. Although this is somewhat of a hybrid of the two kernel designs, this functionality can be ignored, and a fully monolithic kernel produced. For this reason, Solaris is more vulnerable to a kernel-rootkit exploit, but Linux and FreeBSD are also susceptible to the same kind of exploit.

2.2 Booting the Kernel

Understanding the bootstrapping and initialization of the Solaris operating system can be very helpful towards auditing and defending Solaris against kernel rootkit exploits. The following draws heavily from “Solaris Internals” by Jim Mauro and Richard McDougall, whose book is highly recommended.

Booting the Solaris operating system from a local disk can be divided into six steps.

Step 1: The boot command - loading the bootblock

The first step in the boot process is to read and load the bootblock into memory. This process uses the system's firmware in PROM, known as Open-Boot PROM (OBP) in Solaris, to load the bootblock located at physical sectors 1-15 of the boot disk, provide NVRAM for setting system parameters, build the hardware device tree, and provide bootstrap support for manual or automatic booting of the system.

Step 2: The bootblock program – loading ufsboot

The second step is for the bootblock to locate and load the secondary boot program, ufsboot (for a local disk boot) or inetboot (for a network boot). The path and name of the secondary boot program is hardcoded into the bootblock program as /platform/<arch>/ufsboot, where <arch> is the hardware architecture type and can be determined by the “uname -m” command. The bootblock program cannot be larger than 7680 bytes (15 * 512 bytes), so it contains just enough code to read a Unix file system (UFS) directory, locate a file and load it into memory. Once ufsboot is loaded, the bootblock passes control to ufsboot.

Step 3: The ufsboot program – loading the core kernel and linker

The ufsboot program locates and loads the core kernel binary at /platform/<arch>/kernel/unix and the kernel linker program at /kernel/misc/krtld. The core kernel binary, unix, is the platform dependent component of the core kernel and is an executable and linking format (ELF) binary image file. The ufsboot program can parse the ELF headers, and based on that information loads the required krtld program and passes control to krtld.

Step 4: The krtld program – loading required kernel modules

The krtld program examines the ELF header information of the unix program and determines the dependencies the program has on other binary images. For the unix program, this includes /kernel/genunix, the platform and hardware independent binaries of the core kernel, /platform/<arch>/kernel/misc/platmod, the platform specific binaries of the core kernel, and /platform/<arch>/kernel/cpu/\$CPU, the processor specific binaries of the core kernel.

As krtld encounters these dependencies, it searches for these specified modules. A key variable determines the path for which krtld will search for these modules. This variable is set in the OBP firmware or can be manually entered on the boot program's command line (boot -a). Late in the boot process, this path can be set within the /etc/system file. This is an important point from a security aspect as will be seen in section 8.2 below.

After the core kernel binaries (unix, krtld, genunix, platmod, and \$CPU) have been loaded, krtld passes control to unix.

Step 5: Initializing the kernel

At this point, the Solaris kernel is running and is using virtual memory address space, but some further initialization is required before the first real user application is started. The kernel initializes some processor registers, and makes calls to `mlsetup()`, `main()` and `startup()`. These functions create the initial processes, map and initialize hardware devices and initialize memory. When the above initializations have completed, the operating system banner is displayed.

After some additional platform checking, the `/etc/system` kernel configuration file is accessed to create a linked list of system parameter data structures in kernel memory. The `/etc/system` file contains commands used to customize the operating environment of the kernel and are useful in controlling some aspects of LKMs, notably what modules cannot or must be loaded, and what the module search path should be.

LKMs have actually been loading at various times prior to this during the boot process. During `startup()`, the modules `swap`, `specfs`, `procsfs` and `tod` were loaded. Other times that loading occurs is during kernel subsystem or platform specific module initializations. As intended by the microkernel design, these modules are loaded as they are called, or dependencies are determined. However, once `/etc/system` has been accessed, LKMs can be force loaded into the kernel by commands within that file.

Note that at this juncture, the preliminary memory initialization determines how much physical memory is available after the core kernel modules have been loaded. This value can be seen in the boot logging information as “mem” and “avail mem.”

Step 6: The init process – the first user

The kernel function `newproc()` is called from `main()` to create the `init` process that is the first real user process. The kernel allocates user address space to `init` rather than kernel address space, so that `init` does not use or execute within the kernel’s memory address space. `init` is the last process created by the kernel to get the system running. `init` is the ancestor of all subsequent unix processes and the direct parent of login shells.

The remaining bootup processes are completed by `init`, take place within user memory address space and are determined by entries in the file `/etc/inittab`. These entries define the system’s default state and controls the execution of scripts in the `/etc/rc*.d` directories. These scripts are run to bring the system to a know status, specifying which services are to be started. `init` checks the integrity of the root and `usr` file systems first, mounts local disks, performs file system cleanup, starts system and network services, mounts remote disks, and finally, enables logins by starting `getty`.

3.0 Description of Protocols/Services:

As mentioned in the introduction, LKMs are binary object files that are code modules that can be loaded or unloaded from the running Solaris kernel based on code dependencies and resource requirements. LKMs are defined in `/usr/include/sys/modctl.h` and are one of seven types; device drivers, system calls, file systems, misc (miscellaneous), streams modules, scheduling classes and exec file type.

Pragmatic (pseudonym), who has written in-depth articles about LKMs, loosely compared them to “old DOS TSR programs, they were our gate to staying resident in memory and catching every interrupt we wanted.”

3.1 Loading and Linking LKMs

Each of the LKMs types has their own specific installation steps, but the steps are similar in nature. The module is loaded into memory and kernel address space is mapped to the modules' text and data segments.

The kernel function `modload()` starts this process, and is initiated by calls within the running kernel, or by the user program `modload(1)`. The kernel maintains a linked list of structures for all the modules loaded in the kernel. These structure are defined by `modctl` and `module` in `/usr/include/sys/modctl.h` and `/usr/include/sys/kobj.h`. Some important structure elements that will come into play are the module name, `mod_modname`, the module id, `mod_id`, and additional module information in `mod_modinfo` and `mod_linkage`.

When `modload()` is called, it will initially search the linked list of module structures to see if the desired module's structure has already been created. If it does not exist, a new structure is created and added to the linked list. It is interesting to note that even if a module is unloaded, its module structure remains in the linked list, and an element in the structure, `mod_loaded`, is cleared. Thus, all of the modules loaded while the system has been running can be determined from this linked list.

If the module does need to be loaded, the `krtld` module is called to create address space segments and bindings, and load the binary object into memory, and sets the `mod_loaded` element in the module's `modctl` structure. Finally, it executes the module's `_init()` routine to complete the task of initializing the module for use within the kernel.

3.2 Kernel Symbols and Module Information

Since modules can be loaded and unloaded as needed, the kernel's table of module symbols must remain dynamic. A pseudodevice, `/dev/ksyms`, contains the currently loaded module symbols and is maintained by the device driver `/usr/kernel/drv/ksyms`. It is important to understand that this list of module symbols is just a list of names of variables and functions contained in the modules and their associated virtual addresses. You can actually view this table using the command `nm -x /dev/ksyms`. I have found it useful to modify the output using the `awk` command, so that the address is printed first,

rather than the symbol id. The advantage is that you can sort the list by virtual address. The command is as follows: `nm -s /dev/ksyms | awk '{print $2, $1, $3, $4, $5, $6}' | sort.`

The `modinfo(1M)` command is another useful tool for listing what modules are currently loaded. The output from this command lists the module's id, the virtual address at which it was loaded (in hex), size of the module (in hex bytes), some module-specific data (info), a revision number, and the module's name. The id numbers will not necessarily be contiguous. As a module is unloaded, its id may be released for use by another module, so that at any given time, gaps in the sequence of module ids will be present. Solaris 7 typically has around 90 modules listed, while Solaris 8 has about 110 (5).

3.3 Module Coding Requirements

As stated above, a module must have an `init()` routine for the proper completion of loading and initialization. Required within the `init()` function must be a call to `modinstall` function, specific to the module type, which declares and initializes the associated `mod_linkage` structure and a generic `modlinkage` for the generic module abstraction.

In addition, a module must have `_fini()` and `_info()` functions. The `_fini()` function prepares a module for unloading, and the `_info()` function which provides information about a module while it is loaded.

The coding of LKMs is beyond the scope of this paper, but there are several sources listed in the references section that are helpful. The manual pages are worth looking at (`_info(9E)`, `mod_install(9F)`), but an excellent introduction to coding Solaris LKMs is presented in the paper by plasmoid (pseudonym) entitled "Solaris Loadable Kernel Modules."

When these modules are compiled and linked, it is necessary to include the `-D_KERNEL` switch when compiling, and the `-r` flag when linking. Furthermore, since the kernel does not contain many standard C functions, it may be necessary to extract them from the `/lib/libc.a` library using the `ar -x` command, and then linking them in manually. The process is seen below:

```
ar -x /lib/libc.a c_function.o
gcc -D_KERNEL -DSVR4 -DSOL2 -o2 module_name.c
ld -o module_name -r module_name.o c_function.o
```

The binary image file must now be placed in a directory within the kernel module search path before it can be loaded into the kernel.

4.0 Description of Variants:

This exploit has been "in the wild" for some time, though not specifically for Solaris. SunOS 4.x did have a loadable module interface, and an attack to snoop tty used LKMs called `tap` (6).

There were earlier discussions about utilizing LKMs, but the first major article was published in Prack 50 Article 5, “Abuse of the Linux Kernel for Fun and Profit” (April 9, 1997.) It was written by halflife (pseudonym) and discussed TTY hijacking using LKMs in a Linux kernel. This module was called *linspy*.

Another extensive paper written by pragmatic entitled “(nearly) Complete Linux Loadable Kernel Modules” was released in March of 1999, which went into extensive detail on writing LKMs for Linux, discussed ways in which the kernel could be subverted, and gave numerous code examples from many sources, including most of the “classic” code on which others have based their versions of this exploit. Among the many examples are the modules *heroin*, one of the first examples of an LKM used to hide files and processes, and *itf*, the Integrated Trojan Facility, which was based on *heroin* and in pragmatic’s words, “has everything you need to backdoor a system in a very effective way.” *Itf*, was published in Prack 52, Article 18, “Weakening the Linux Kernel” (January 26, 1998) and was written by plaguez (pseudonym). Another popular Linux module is *Knark*, which was written by Creed and released around November of 1999. It was based on *itf*. Also TESO has released a Linux module named *adore* that is similar to *itf*.

Pragmatic also released a paper entitled “Attacking FreeBSD with Kernel Modules” in June of 1999, which covered the same kinds of methods from the point of view of the BSD kernel.

In December of 1999, plasmoid released an article entitled “Solaris Loadable Kernel Modules” which discussed similar techniques from the point of view of Solaris. The code examples used in his paper were taken from the Solaris Integrated Trojan Facility (SITF), a small collection of coded modules that illustrate the basic exploit techniques. The module *sitf0.2* incorporates these techniques into one loadable module, providing a general kernel rootkit. *Sitf0.2* is also based on the *itf* module for Linux.

The basic set of “features” for these modules are module hiding, file and directory hiding, process hiding, execution redirection, grant root access to a uid, and promiscuous flag hiding.

The differences between the modules have to do with the specifics of the operating system and the methods approach, rather than the concepts. Although it is a non-trivial task, these modules can be ported to various Unix operating systems that support LKMs, but attention must be paid to the details of the structures and system calls. A difference in methods is seen by *Knark*’s use of a signal 31 to hide a process, while SITF uses a remote switch to allow the attacker to hide or unhide processes based on a key embedded in their name. As with any programming, there are many solutions for a problem, so there may be a variety of modules providing a number of features, but the basic concepts of exploiting LKMs remains the same, and provides a very fertile ground for future development.

5.0 How the Exploit Works:

It should be noted right at the beginning that the user must have root access to use this kind of exploit. As mentioned above, the purpose of a rootkit is to cover the activity of an attacker once they have gained root access, and ensure that they can maintain root access.

A kernel rootkit installs LKMs that modify or replace the actions and output of other existing LKMs that are a normal part of the operating system. These modules are able to operate at a privileged level within the kernel, and can operate within the kernel memory space, and to some degree, interface with the user memory space. The LKMs can hide their presence in the running kernel, redirect kernel system calls, hide files and directories, and redirect calls of user executable binaries.

The `sitf0.2` module, within the SITF, specifically takes advantage of Solaris kernel modules and several deficiencies in some of the Solaris module code. The `sitf0.2` module is declared as a miscellaneous operations type (`misc`) module which is defined by the `mod_miscops` structure in `/usr/include/sys/modctl.h`. Once it has been loaded into the system, it is capable of the following features detailed below.

5.1 Stealth Modules

As mentioned above, the module name is stored in the module's linkage structure. Normally, the module's name is a character string and is usually a short descriptive phrase about the module's functionality. For example, the `kb` module's name is "stream module for keyboard" and the `modinfo` command would show an entry for `kb` such as:

```
41 f5a95bf0 3b19 8 1 kb (stream module for keyboard)
```

However, if the module's name is null (""), no information about the module is printed by the `modinfo` command, even though the module is loaded, has an assigned id, and is fully operational. Plasmoid admits in his paper on Solaris LKMs "even if this protection leaving the module's name blank is weak, it will fit your needs, if the system administrator is not a real system programmer."

The reason it is considered a weak technique is that when a module is loaded, its symbols are mapped and listed in the kernel symbols table, `/dev/ksyms`. Plasmoid, in his discussion of this fact, indicated a more complete method for hiding the module would be to patch the Solaris module that lists and manages all kernel symbols, and suggested he would explain the technique in a second version of his article. As yet, I have been unable to find any reference that he has ever released this second version. If the related symbols were excluded from the list in the `/dev/ksyms`, it would be much more difficult to detect a hidden module and might require "real system programmer" skills.

Another technique mentioned by pragmatic was to avoid exporting any symbols used in the LKMs, defining a symbol table within the module itself, and thus avoiding any

exposure within the kernel symbol table. However, this was specific for Linux, and I have not seen this technique used in a Solaris module, but something similar may be possible.

5.2 Redirection of System Calls

By intercepting and redirecting system calls within the kernel, it is possible to change the way the operating system reacts to various calls or commands. System calls are the basic kernel functions that are used to perform most operations on a system. They are callable interfaces available to user programs so that the user program can request the kernel to perform specific actions on their behalf. For example, the `open64()` system call opens a file in a filesystem and the `read()` system call extracts data from an opened file. A list of system calls is available in the file `/usr/include/sys/syscall.h`.

System calls are referenced through a kernel table named `sysent`. `sysent` contains structures for each system call available and is indexed by a system call number, specified in the `/etc/name_to_sysnum` file. Many of the system calls are implemented as LKMs and are stored in `/kernel/sys` and `/usr/kernel/sys` directories.

Redirection of system calls requires three things. There must be a replacement function, in jargon, a faked syscall, the `sysent` table must be modified to point to the faked syscalls structure. Finally, the LKM stores the original pointer of the syscalls so that it maintains full functionality.

An important aid to faking a system call, is the `/usr/bin/truss` command. `Truss` will output a trace of system calls that are made for a command. The command `/usr/bin/truss touch test_file` will show all the system calls that are made while executing the command to create the file `test_file`. It includes such system calls as `execve()`, `open()`, `stat()`, `fstat()`, `mmap()`, `close()`, `time()`, `stat64()`, `creat64()`, `utime()` and `_exit()`.

By determining what system calls a particular command of interest has, will determine what system calls might be affected by redirection.

5.3 File and Directory Hiding

There are actually two aspects to hiding files and directories. Not only are files and directories hidden from being listed, but the user is also prevented from even opening the file or changing the current directory to a hidden one.

Listing files and directories uses the `getdents64()` system call (syscall) from such commands as `ls` or `du`. (This can be seen by using the `truss` program mentioned above) If a faked syscall routine is created to simply not list certain files, then the output will never contain entries for those files. To avoid creating some lengthy list of files or directories to hide, the technique used by SITF is to include a “magic” string within the file or directory name that is specified by the attacker within the LKM. The default value in the

sitf2.0 module is “blah” and any name containing that string is not listed in the output. Using the methods described in 5.2 above, the attacker crafts a faked `getdents64()` routine, such as `faked_getdents64()`, stores the original pointer of `getdents64()`, and loads the new pointer to `faked_getdents64()` into the `sysent` table. When a call is made by a user program to `getdents64()`, the `faked_getdents64()` routine handles the request, using the actual `getdents64()` routine to retrieve the information, deleting any entries in the list that contain the magic string.

A similar technique is used to prevent users from opening or entering a hidden file or directory. Faked `open64()` and `chdir()` routines intercept the user request. If the request is for a file that contains the magic string, the faked routine returns the error message: “No such file or directory.” See diagram in section 6.0.

5.4 Process Hiding

Every process has an associated `prot_t` structure which is defined in `/usr/include/sys/proc.h`. The process structure provides the basis for creating and managing processes in the Solaris operating system. Within the `prot_t` structure is the structure name `user`, which is defined in `/usr/include/sys/user.h`. One of the members of the `user` structure is the member `u_psargs`, which contains the name of the binary image file and its arguments.

Solaris creates special files based on the entries in `prot_t` and places them in the `/proc` directory. This is actually a pseudo file system that exports the kernel’s process model and abstractions by providing a file-like interface to the user so that they can retrieve information about the processes and have the capability to control processes and debug system problems.

Since the name of the executable can be determined for every process, and that this information is retrieved through a filesystem type of interface, then the faked syscall for `getdents64()`, mentioned above in 5.3, can be slightly modified to include the code to search for the process name, and omit from any listing a process name which contains the magic string. Thus, neither the use of the `ps` command or a directory listing of `/proc` would indicate the presence of the hidden process.

5.5 Remote Switch

As mentioned in section 4.0, SITF makes use of a “remote switch” to toggle whether or not files, directories and processes containing the magic string will be hidden or not. This provides the attacker with a means of debugging the installed rootkit, or working with other files that have been loaded onto the compromised system.

A faked syscall is again utilized to intercept a request that contains a special string, this time referred to as a security “key.” If the key string is present, then the security bit is toggled to either turn on hiding or turn off hiding of names that contain the magic string.

SITF implements this through the *touch* command and its use of the syscall `creat64()`. A faked version of `creat64()` checks for the security key string in the request to create a new file, and if the key string is present, it toggles the security switch.

5.6 Program Redirection

Redirecting the execution of an intended user program to another alternate program is not a new concept and there are numerous viruses and Trojan programs that exist to do this. Usually, these programs can be detected and eradicated with antiviral or integrity checking software.

In this technique, a faked `execve()` syscall is used to check the name of the requested program to execute, and replaces the name with an alternate and then lets the original `execve()` function execute.

The implication of this, is that an alternate program could be placed anywhere on the system and hidden. When a call is made to a specific program, like `passwd` for example, than an alternate program is run that would most likely perform additional functions to `passwd`'s more traditional ones, like collecting passwords in a hidden file.

In SITF, only one program is redirected, with the original, and alternate program being specified within the source code of the LKM.

5.7 Root Access

This is actually a very simple technique than can give a user full root access. A faked `setuid()` syscall merely checks to see if a specific uid is being requested, and if so, makes syscalls passing id 0 to `setuid()`, `setgid()`, `setegid()` and finally the original `setuid()` granting superuser rights to that uid.

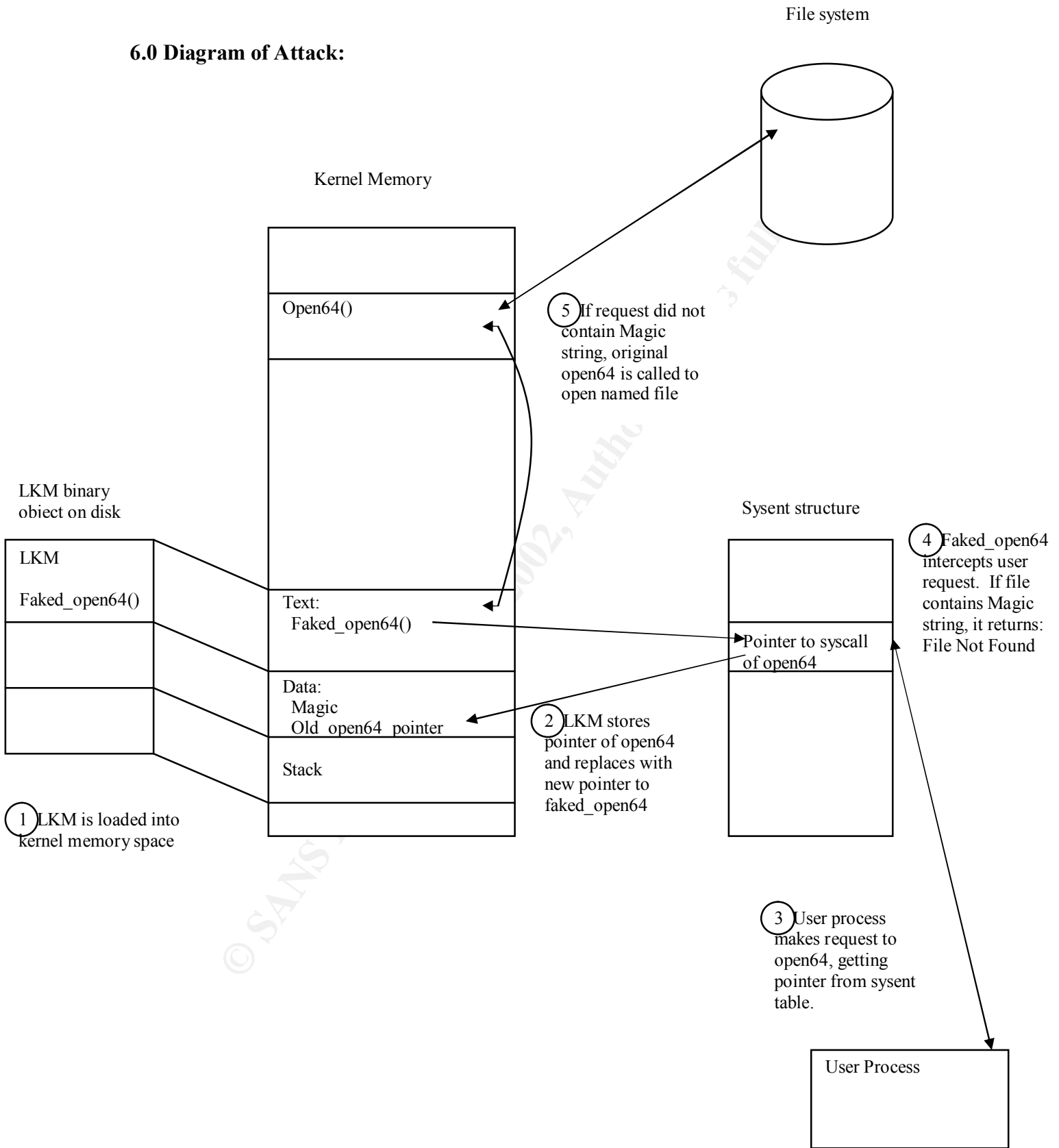
What is especially disturbing about this is that the faked function is only 13 lines of code, and if just this function was included in a LKM, it could be a very effective backdoor with a very small signature.

5.8 Promiscuous Flag Hiding

This feature follows the same scheme as those above; fake the `ioctl()` syscall, modify the output from the original `ioctl()` based on the status of the of the interface and return the results to the user.

In `sitf0.2`, this is only done once, so that if a subsequent command by a user to actually place the interface into promiscuous mode is given, the user would not detect that it had previously been hidden.

6.0 Diagram of Attack:



7.0 Signature of the Attack:

What makes this exploit difficult to detect is that you cannot always trust the output that the kernel is providing you with. Since the very heart of the operating system is being compromised, files may be hidden from any integrity checks. It may be that all the original system files have not been modified at all, it is just that their requests are being intercepted and their output altered without any indication this is occurring.

However, there appears to be several pieces of information that you could use as an audit trail, in case you suspect your system has been compromised. Additionally, I have found that comparisons of the output from `modinfo`, crossed referenced with the kernel symbol table, may be of use in trying to detect the presence of an unauthorized LKM.

7.1 Modinfo and the Kernel Symbol Table /dev/ksyms

After learning how a module could keep its information from being displayed by the command `modinfo`, I examined the output from the command `nm -x /dev/ksyms` and was able to locate module names based on the load address in virtual memory. I decided to try to correlate the output from the two commands to see if it was possible to identify all of the kernel symbols with a corresponding module id in the `modinfo` output. I wrote a simple perl program based on the following algorithm:

- Load all known modules from `modinfo` output into a hash table indexed by load address
- Sort the output of the command `nm -x /dev/ksyms` by load address
- Loop through until the symbols of the core binary modules from bootup have been passed. These are the `unix`, `krtld`, `genunix`, `platmod` and `$CPU` discussed in section 2.0
- Search for a function symbol (FUNC) of name `_init`, or a transition from an object symbol (OBJT) to a FUNC symbol
- Using the load address of the current FUNC symbol, see if an element exists in the `modinfo` hash
- If the element does not exist, flag the FUNC symbol as suspect
- If the element exists, list the FUNC symbol as a known LKM
- Using the size of the module from the `modinfo` hash, loop through the address range bounded by the module load address and that address plus the size of the module
- Start searching for new function symbols

For the most part, this algorithm worked, but did give a few false positives. By eliminating most of the symbols in the kernel symbol table, it was possible to manually compare the symbols for the flagged functions and discern whether they were symbols associate with `modinfo`-listed modules.

Below is an example of the signature I was able to detect when I loaded the `sitf0.2` module on a Solaris 7, 32-bit, sparc architecture. Section 7.2 lists the output of the

modinfo command, sorted by load address in virtual memory. Section 7.3 lists the search results from the perl program mentioned above. The initial four functions are false positives, but the last entry is the *sitf0.2* LKM. By looking at the sorted kernel symbol table output, and examining the symbols around the address indicated by the unknown *_init()* function, it can be quickly seen that this is not a normal module. The extracted output is listed in section 7.4. Note the references to *newioctl*, *newcreat64*, *newchdir*, *newopen64*, *newgetdents64*, *newexecve*, and *newsetuid*. Definitely symbols to be concerned about.

A couple of notes about this output are in order. This was produced right after the system had been rebooted. Other times that I repeated this process, the unknown module would appear at addresses mixed in between existing modules. This method also worked on Solaris 7 64-bit as well as Solaris 8, though with more false positives.

As long as the kernel symbol table contains the module symbols and has not been subverted by patching the kernel symbol table device driver, then the above concept may be useful in locating unauthorized modules. However, additional techniques should be attempted. These are discussed in section 7.5 below.

7.2 Sorted Modinfo Output with *sit0.2* Module Installed:

Load Addr	ID	Load Addr	Size	Module Name
f59e1000	-- 5	f59e1000	4577	specfs
f59e5994	-- 78	f59e5994	1c19	tlimod
f59e7378	-- 80	f59e7378	2d8	ipc
f59e7670	-- 7	f59e7670	2ddc	TS
f59ea45c	-- 8	f59ea45c	4f0	TS_DPTBL
f59ea94c	-- 9	f59ea94c	27c28	ufs
f5a12574	-- 10	f5a12574	ec4c	rpcmod
f5a211c0	-- 11	f5a211c0	28f84	ip
f5a4bfb8	-- 12	f5a4bfb8	ce3	rootnex
f5a4cc9c	-- 13	f5a4cc9c	1ec	options
f5a4ce88	-- 14	f5a4ce88	76c	dma
f5a4d5f4	-- 15	f5a4d5f4	cb7	sbus
f5a4e2ac	-- 16	f5a4e2ac	1ae7	iommu
f5a4fd94	-- 17	f5a4fd94	1648	sad
f5a513e8	-- 18	f5a513e8	61f	pseudo
f5a51a0c	-- 19	f5a51a0c	103bc	sd
f5a61dc8	-- 20	f5a61dc8	7136	scsi
f5a68f18	-- 21	f5a68f18	d6f5	esp
f5a78378	-- 28	f5a78378	12926	procfs
f5a89cac	-- 35	f5a89cac	45d0	udp
f5a8d27c	-- 77	f5a8d27c	92a3	rpcsec
f5a93ef0	-- 87	f5a93ef0	163b	ptem
f5a952dc	-- 71	f5a952dc	7f6	kstat
f5a95e44	-- 32	f5a95e44	616	clone
f5a9afd4	-- 34	f5a9afd4	11a1	md5
f5a9d178	-- 86	f5a9d178	e53	pts
f5a9dd04	-- 64	f5a9dd04	4c5	intpexec
f5a9e094	-- 90	f5a9e094	5dd	ledma
f5a9e94c	-- 26	f5a9e94c	15c3	dada
f5a9ff60	-- 30	f5a9ff60	d008	sockfs
f5aac528	-- 33	f5aac528	17b50	tcp
f5abf500	-- 38	f5abf500	45b7	timod
f5ac3ab8	-- 85	f5ac3ab8	f0f	ptm
f5ac4da4	-- 40	f5ac4da4	868f	zs
f5acd434	-- 41	f5acd434	58b	obio
f5ad1290	-- 81	f5ad1290	29b	connld
f5ad13cc	-- 82	f5ad13cc	105	IA

```

f5ad1444 -- 43 f5ad1444 1800 ms
f5ad2c44 -- 44 f5ad2c44 a1c consms
f5ad3660 -- 45 f5ad3660 3d42 kb
f5ad73a4 -- 46 f5ad73a4 b55 conskbd
f5ad7efc -- 47 f5ad7efc 1955 wc
f5ad9854 -- 48 f5ad9854 d64 iwscn
f5ada5b8 -- 49 f5ada5b8 234f elfexec
f5adc908 -- 50 f5adc908 103d mm
f5add948 -- 51 f5add948 328c fifofs
f5ae0cf0 -- 52 f5ae0cf0 5926 ldterm
f5ae6618 -- 53 f5ae6618 2381 ttcompat
f5ae899c -- 54 f5ae899c 14d0 ptsl
f5ae9e6c -- 55 f5ae9e6c 2053 ptc
f5aebec0 -- 84 f5aebec0 1670 hwc
f5aed6f8 -- 88 f5aed6f8 259 redirmod
f5aed848 -- 61 f5aed848 4683 tl
f5af1ecc -- 62 f5af1ecc 160a sysmsg
f5af34d8 -- 63 f5af34d8 6d8 cn
f5af4078 -- 65 f5af4078 2fc pipe
f5af51c4 -- 68 f5af51c4 d70 fdfs
f5af71f4 -- 67 f5af71f4 730e ufs_log
f5afdc88 -- 69 f5afdc88 3e12 doorfs
f5b0153c -- 70 f5b0153c 1488 namefs
f5b026d4 -- 72 f5b026d4 d8a2 tmpfs
f5b0ff78 -- 73 f5b0ff78 9db log
f5b10954 -- 74 f5b10954 8c3 sy
f5b11218 -- 75 f5b11218 4f90 vol
f5b161a8 -- 76 f5b161a8 262f4 nfs
f5b3b138 -- 79 f5b3b138 2290 semsys
f5b3d1a8 -- 83 f5b3d1a8 2ea6 pm
f5b3fbc8 -- 42 f5b3fbc8 3c34 cgsix
f5b43230 -- 89 f5b43230 5f0e le
f5b49140 -- 37 f5b49140 51a7 arp
f5b4e2e8 -- 59 f5b4e2e8 1988 rts
f5b4fc70 -- 36 f5b4fc70 3b58 icmp
f5b537c8 -- 91 f5b537c8 858 ksyms

```

7.3 Output from Perl Search Program

Status	Modinfo entry ID Loadaddr Size	Mod Name	Kernel Symbol Table entry Load addr size Type	symbol name
UNKNOWN	--		-- 0xf007e700 0x00000b20 FUNC	__kobj_boot
UNKNOWN	--		-- 0xf008dda8 0x000001a0 FUNC	__true_add
UNKNOWN	--		-- 0xf012f8f0 0x00000020 FUNC	tsu_module_identify
UNKNOWN	--		-- 0xf027c694 0x00000010 FUNC	__mul
FOUND	-- 5 f59e1000 4577	specfs	-- 0xf59e1000 0x00000270 FUNC	__specvp
FOUND	-- 78 f59e5994 1c19	tlimod	-- 0xf59e5994 0x000019b4 FUNC	__init
FOUND	-- 80 f59e7378 2d8	ipc	-- 0xf59e7378 0x00000234 FUNC	__init
FOUND	-- 7 f59e7670 2ddc	TS	-- 0xf59e7670 0x000026c4 FUNC	__init
FOUND	-- 8 f59ea45c 4f0	TS_DPTBL	-- 0xf59ea45c 0x00000050 FUNC	__init
FOUND	-- 9 f59ea94c 27c28	ufs	-- 0xf59ea94c 0x000001dc FUNC	__alloc
FOUND	-- 10 f5a12574 ec4c	rpcmod	-- 0xf5a12574 0x0000c9f4 FUNC	__init
FOUND	-- 11 f5a211c0 28f84	ip	-- 0xf5a211c0 0x00020178 FUNC	__init
FOUND	-- 12 f5a4bfb8 ce3	rootnex	-- 0xf5a4bfb8 0x00000a1c FUNC	__init
FOUND	-- 13 f5a4cc9c 1ec	options	-- 0xf5a4cc9c 0x00000118 FUNC	__init
FOUND	-- 14 f5a4ce88 76c	dma	-- 0xf5a4ce88 0x000004fc FUNC	__init
FOUND	-- 15 f5a4d5f4 cb7	sbus	-- 0xf5a4d5f4 0x00000990 FUNC	__init
FOUND	-- 16 f5a4e2ac 1ae7	iommu	-- 0xf5a4e2ac 0x00001764 FUNC	__init
FOUND	-- 17 f5a4fd94 1648	sad	-- 0xf5a4fd94 0x000011b0 FUNC	__init
FOUND	-- 18 f5a513e8 61f	pseudo	-- 0xf5a513e8 0x000003b8 FUNC	__init
FOUND	-- 19 f5a51a0c 103bc	sd	-- 0xf5a51a0c 0x0000da28 FUNC	__init
FOUND	-- 20 f5a61dc8 7136	scsi	-- 0xf5a61dc8 0x00000010 FUNC	scsi_ifgetcap
FOUND	-- 21 f5a68f18 d6f5	esp	-- 0xf5a68f18 0x0000babc FUNC	__init
PROCFS	-- 28 f5a78378 12926	procfs	-- 0xf5a783e8 0x000000b4 FUNC	__ctlsize
FOUND	-- 35 f5a89cac 45d0	udp	-- 0xf5a89cac 0x000035c4 FUNC	__init
FOUND	-- 77 f5a8d27c 92a3	rpcsec	-- 0xf5a8d27c 0x000068d0 FUNC	__init
FOUND	-- 87 f5a93ef0 163b	ptem	-- 0xf5a93ef0 0x000013c0 FUNC	__init
FOUND	-- 71 f5a952dc 7f6	kstat	-- 0xf5a952dc 0x0000062c FUNC	__init
FOUND	-- 32 f5a95e44 616	clone	-- 0xf5a95e44 0x000003e0 FUNC	__init

FOUND	--	34	f5a9afd4	11a1	md5	--	0xf5a9afd4 0x00000fa4	FUNC	_init
FOUND	--	86	f5a9d178	e53	pts	--	0xf5a9d178 0x00000b80	FUNC	_init
FOUND	--	64	f5a9dd04	4c5	intpexec	--	0xf5a9dd04 0x00000380	FUNC	_init
FOUND	--	90	f5a9e094	5dd	ledma	--	0xf5a9e094 0x00000364	FUNC	_init
FOUND	--	26	f5a9e94c	15c3	dada	--	0xf5a9e94c 0x00000074	FUNC	dcd_initialize_hba_interface
FOUND	--	30	f5a9ff60	d008	sockfs	--	0xf5a9ff60 0x000000f0	FUNC	sogetvp
FOUND	--	33	f5aac528	17b50	tcp	--	0xf5aac528 0x00012a64	FUNC	_init
FOUND	--	38	f5abf500	45b7	timod	--	0xf5abf500 0x00003674	FUNC	_init
FOUND	--	85	f5ac3ab8	f0f	ptm	--	0xf5ac3ab8 0x00000bec	FUNC	_init
FOUND	--	40	f5ac4da4	868f	zs	--	0xf5ac4da4 0x0000002c	FUNC	zsa_null
FOUND	--	41	f5acd434	58b	obio	--	0xf5acd434 0x0000038c	FUNC	_init
FOUND	--	81	f5ad1290	29b	connld	--	0xf5ad1290 0x00000138	FUNC	_init
FOUND	--	82	f5ad13cc	105	IA	--	0xf5ad13cc 0x0000004c	FUNC	_init
FOUND	--	43	f5ad1444	1800	ms	--	0xf5ad1444 0x000014dc	FUNC	_init
FOUND	--	44	f5ad2c44	a1c	consm	--	0xf5ad2c44 0x000006a4	FUNC	_init
FOUND	--	45	f5ad3660	3d42	kb	--	0xf5ad3660 0x000028c8	FUNC	_init
FOUND	--	46	f5ad73a4	b55	conskbd	--	0xf5ad73a4 0x000007b4	FUNC	_init
FOUND	--	47	f5ad7efc	1955	wc	--	0xf5ad7efc 0x00000d38	FUNC	_init
FOUND	--	48	f5ad9854	d64	iwscn	--	0xf5ad9854 0x00000ab4	FUNC	_init
FOUND	--	49	f5ada5b8	234f	elfexec	--	0xf5ada5b8 0x000009d8	FUNC	elfexec
FOUND	--	50	f5adc908	103d	mm	--	0xf5adc908 0x000000e8	FUNC	mm_attach
FOUND	--	51	f5add948	328c	fifofs	--	0xf5add948 0x00002db0	FUNC	_init
FOUND	--	52	f5ae0cf0	5926	ldterm	--	0xf5ae0cf0 0x00004d40	FUNC	_init
FOUND	--	53	f5ae6618	2381	ttcompat	--	0xf5ae6618 0x00002120	FUNC	_init
FOUND	--	54	f5ae899c	14d0	ptsl	--	0xf5ae899c 0x00001124	FUNC	_init
FOUND	--	55	f5ae9e6c	2053	ptc	--	0xf5ae9e6c 0x00001cf4	FUNC	_init
FOUND	--	84	f5aebec0	1670	hwc	--	0xf5aebec0 0x0000156c	FUNC	_init
FOUND	--	88	f5aed6f8	259	redirmod	--	0xf5aed6f8 0x000000f4	FUNC	_init
FOUND	--	61	f5aed848	4683	tl	--	0xf5aed848 0x00004174	FUNC	_init
FOUND	--	62	f5af1ecc	160a	sysmsg	--	0xf5af1ecc 0x00000de4	FUNC	_init
FOUND	--	63	f5af34d8	6d8	cn	--	0xf5af34d8 0x000004ac	FUNC	_init
FOUND	--	65	f5af4078	2fc	pipe	--	0xf5af4078 0x000001d8	FUNC	_init
FOUND	--	68	f5af51c4	d70	fdfs	--	0xf5af51c4 0x00000a6c	FUNC	_init
FOUND	--	67	f5af71f4	730e	ufs_log	--	0xf5af71f4 0x0000002c	FUNC	lufs_sv_constructor
FOUND	--	69	f5afdc88	3e12	doorfs	--	0xf5afdc88 0x00000008	FUNC	door_open
FOUND	--	70	f5b0153c	1488	namefs	--	0xf5b0153c 0x00000024	FUNC	nameinsert
FOUND	--	72	f5b026d4	d8a2	tmpfs	--	0xf5b026d4 0x00000040	FUNC	tmpfs_hash_init
FOUND	--	73	f5b0ff78	9db	log	--	0xf5b0ff78 0x00000040	FUNC	log_info
FOUND	--	74	f5b10954	8c3	sy	--	0xf5b10954 0x000006a8	FUNC	_init
FOUND	--	75	f5b11218	4f90	vol	--	0xf5b11218 0x00003c38	FUNC	_init
FOUND	--	76	f5b161a8	262f4	nfs	--	0xf5b161a8 0x00000138	FUNC	nfs_validate_caches
FOUND	--	79	f5b3b138	2290	semsys	--	0xf5b3b138 0x00001fd0	FUNC	_init
FOUND	--	83	f5b3d1a8	2ea6	pm	--	0xf5b3d1a8 0x00002788	FUNC	_init
FOUND	--	42	f5b3fbc8	3c34	cgsys	--	0xf5b3fbc8 0x00003570	FUNC	_init
FOUND	--	89	f5b43230	5f0e	le	--	0xf5b43230 0x000050a4	FUNC	_init
FOUND	--	37	f5b49140	51a7	arp	--	0xf5b49140 0x00003e04	FUNC	_init
FOUND	--	59	f5b4e2e8	1988	rts	--	0xf5b4e2e8 0x000011a0	FUNC	_init
FOUND	--	36	f5b4fc70	3b58	icms	--	0xf5b4fc70 0x00002a7c	FUNC	_init
FOUND	--	91	f5b537c8	858	ksyms	--	0xf5b537c8 0x000000d4	FUNC	ksyms_mapin
UNKNOWN	--					--	0xf5b54354 0x00000b5c	FUNC	_init

7.4 Kernel Symbol Table Entries for sitf0.2 Module

Data Segment			
Load addr	Size	Type	Symbol name
0xf5af6eb0	0x00000005	OBJT	magic
0xf5af6eb8	0x00000006	OBJT	key
0xf5af6ec0	0x00000009	OBJT	oldcmd
0xf5af6ed0	0x0000001d	OBJT	newcmd
0xf5af6ef0	0x00000004	OBJT	security
0xf5af6ef4	0x00000004	OBJT	promisc
0xf5af6ef8	0x00000008	OBJT	modlmisc
0xf5af6f00	0x00000014	OBJT	modlinkage

Text Segment			
Load addr	Size	Type	Symbol name
0xf5b53db8	0x00000000	NOTY	gcc2_compiled.
0xf5b53db8	0x0000006c	FUNC	check_process
0xf5b53e24	0x0000003c	FUNC	check_for_process
0xf5b53e60	0x00000054	FUNC	sitf_isdigit

0xf5b53eb4 0x0000007c FUNC	sitf_atoi
0xf5b53f30 0x000000c4 FUNC	newioctl
0xf5b53ff4 0x00000084 FUNC	newcreat64
0xf5b54078 0x00000074 FUNC	newchdir
0xf5b540ec 0x00000080 FUNC	newopen64
0xf5b5416c 0x0000010c FUNC	newgetdents64
0xf5b54278 0x0000008c FUNC	newexecve
0xf5b54304 0x00000050 FUNC	newsetuid
0xf5b54354 0x00000b5c FUNC	_init
0xf5b54434 0x0000001c FUNC	_info
0xf5b54450 0x00000b5c FUNC	_fini
0xf5b544dc 0x000001f4 FUNC	_memmove
0xf5b544dc 0x000001f4 FUNC	memmove
0xf5b54518 0x00000000 NOTY	s1algn
0xf5b54538 0x00000000 NOTY	s2algn
0xf5b54554 0x00000000 NOTY	aldst
0xf5b54558 0x00000000 NOTY	ald
0xf5b54568 0x00000000 NOTY	w3cp
0xf5b545c0 0x00000000 NOTY	w1cp
0xf5b5460c 0x00000000 NOTY	w2cp
0xf5b54660 0x00000000 NOTY	w4cp
0xf5b54684 0x00000000 NOTY	dbytecp
0xf5b546a8 0x00000000 NOTY	ovbc
0xf5b546d0 0x000001b0 FUNC	_memcpy
0xf5b546d0 0x000001b0 FUNC	memcpy
0xf5b54880 0x00000094 FUNC	strstr

7.5 Additional Auditing

The dynamic nature of LKMs, and the number of LKMs that may be loaded make it difficult to get a nice clean audit trail. It is worth looking at the output from modinfo, and getting some idea of what may be considered normal for a system. Keep in mind that hidden modules will not show, and often, the activities of the unauthorized LKMs will be using the standard modules as well.

In section 2.2, step 5, I mentioned that as the kernel is initializing, it displays the total physical memory and the total available memory after the core kernel was loaded. On the test system I was using, the values were:

```
unix: mem = 49152K (0x3000000)
```

```
unix: avail mem = 44257280
```

The installed core kernel image was 5932K. This value is worth noting, as this size should not usually change for a stable hardware configuration.

Another interesting audit that could be performed, but would take some system programming, is to walk through the linked list of module structures (see section 3.1) after the system had been running normally for some period of time. This could produce a list of all the modules commonly accessed by the running system. It would also be worthwhile to check this linked list occasionally for any modules with names set to null or other strange names.

Auditing system calls might detect unusual calls to suspicious system functions, such as newcreat64(). Performance might be a big issue if all processes had all system calls logged. Again, I have not encountered a tool to do this and would require some system level programming. Also, it would not be too difficult to create your own LKM that intercepts system calls specifically to create modules, so that each time a module is

loaded, it could be logged using the `cmn_err()` syscall. An auditing technique similar to auditing system calls is to monitor and log `execve()` calls and trigger actions as a result of irregular activity. Finally, an initial audit of the system call table *sysent* itself after boot up would provide the basis for monitoring changes to the table.

There is a method available to watch, in real time, the automatic loading and unloading of kernel modules by setting the variable *moddebug* in the kernel using the *adb* command according as follows:

```
# adb -kw /dev/ksyms /dev/mem
physmem 1661
moddebug /W 0x80000000
moddebug: 0x0 = 0x80000000
```

While running this on my test system, the output showed the following when I loaded the *sitf0.2* module:

```
unix: load '/home/gcih/slkm-1.0/sitf0.2' id 92 loaded @ 0xf5b53db4/0xf5af6eac size 2985/108
unix: installing sitf0.2, module id 92.
```

As seen in sections 7.2 – 7.4 above, the module was not listed by `modinfo`. It does correlate with the above load addresses. The first load address indicates the text segment of the module while the second segment indicates the data segment of the module. This is a good indication that a useful monitoring tool or script could be developed.

8.0 How to Protect Against it

I have found no specific tools or articles that focus on hardening the kernel to protect against unauthorized module loading, but this topic appears to be gaining attention. The following suggestions come from a variety of sources listed in the references section. Some of them come from those who are “exposing” this exploit to the Internet community and after detailing what mischief can be done, offer a few suggestions on possible techniques to protect the kernel. Others come from reliable sources within the security community. Most are in the realm of possibilities, or proof of concept stage at this point, rather than actual procedures available for download.

8.1 Creating a Monolithic Kernel is Not an Option

The most common suggestion I encountered was to disable the LKMs capability. This is not possible for Solaris (4), and even for a system like Linux, this seems unfeasible, since more modules are created as LKMs to keep the core kernel to a size that would fit on a floppy disk.

8.2 The Kernel Search Path

When a call is made to load a LKM, the kernel searches for it based on a search path variable as mentioned in section 2.2, step 4. By narrowly defining and protecting this path, it may be possible to limit where the LKMs binary images may be loaded from.

Initially, the path is retrieved from PROM. The OBP program has two security modes, one which prevents EEPROM changes and hardware command execution while at the OPB level, and a full security mode that adds the additional requirement that the system will not boot without the correct OBP password. This can be set from the OBP prompt using the command:

```
Ok setenv security-mode level  where level is either command or full
```

This can also be done from a root shell using the command:

```
# eeprom security-mode=level  where level is either command or full
```

At a later stage, the path variable is read in from the kernel configuration file `/etc/system`. Obviously if the attacker already has root privilege, this file could be modified, so its integrity would be critical.

8.3 LKMs Loading from Readonly Media

If the search path can be secured, then limiting LKMs loading from readonly media could secure these modules. Running a system from a CD has been suggested as a general defense against rootkits, and is used in the incident handler's jumpkit to maintain known good system command.

8.4 Disabling Specific LKMs Loading

Another aspect of the `/etc/system` file is the ability to not only forceload an LKM, but to exclude an LKM from being loaded. A list of modules to exclude is created from all of the exclude statements in this kernel configuration file. This might be useful in disabling certain capabilities of a system, but is probably of limited use, based on the types of exploit features mentioned in section 5.0.

Unfortunately, the default is to include a LKM as loadable. What would be useful is to specify which modules could be loaded, and once loaded, which module could not be unloaded. This generally defeats the purpose of LKMs, and is a backwards way of creating a monolithic kernel, but it could be a way of securing critical modules during the initial booting of a system. Pragmatic give some example code for the scheme in his Linux paper.

8.5 Encryption and Authentication

A fellow system administrator put the need for encryption and authentication succulently. "What is needed it a tool that verifies the kernel and LKMs signatures (md5 hashes) before loading into memory, and that can verify these signatures on the fly. It would provide a means of determining if the system was executing truly known code, without having to reboot the system to get it back to a known good state." (7)

Again, pragmatic gives some example code as a starting point for authenticating module loading in his Linux paper and some thoughts on using md5 hashes in his FreeBSD paper. I have not seen anything for Solaris as yet.

8.6 Kernel Hypervisors to Secure Applications

An interesting paper I came across entitled “Using Kernel Hypervisors to Secure Applications” by Mitchem, Lu and O’Brien written in December of 1997, proposed the concept of using LKMs to provide security wrappers for user application. In essence, this is a tcp_wrappers idea, implemented at the kernel level. Another avenue of research might be whether this concept could be extended to wrapping other LKMs. They might intercept system calls to other modules, verify the integrity of the module, do any additional fine grained security controls or authentication, and logging. Their URL is: www.securecomputing.com/khyper.

8.7 Runtime Kernel Patching

What makes defense against this kind of exploit extremely difficult is that, first of all, the attacker has root level access, and secondly, is working with kernel processes which have privileged access to all the kernel objects. What could be worse?

An paper released in November of 1998 by Silvio Cesare entitled “Runtime Kernel Kmem Patching” described the technique of modifying a running Linux kernel using direct access to kernel memory. Even a monolithic kernel would be vulnerable to such techniques.

8.8 Final Comments

Kernel rootkits are an extremely difficult and insidious exploit to detect and defend against. Although it requires a higher skill level, it is not that difficult, and others will develop the nice kinds of interfaces that will broaden the base of potential attackers. For these reasons, plus the role that Solaris servers play in the corporate world, Solaris kernel rootkits are going to be a severe problem if counter measures are not taken. Research and development along the lines discussed above could provide some additional lines of defense against kernel exploits. As one individual at a website that “exposes” vulnerabilities stated, “Security is an illusion. It’s really just called ‘risk management.’” (8)

9.0 Sited References

(1) Rusling, David A. “The Linux Kernel.” 1999.
<http://www.linuxHQ.com/guides/TLK/tlk.html> (April 4, 2001)

(2) Mauro, Jim, Richard McDougall. *Solaris Internals*. Palo Alto, CA: Sun Microsystems Press, 2001.

- (3) Maxwell, Scott. *Linux Core Kernel Commentary*. Scottsdale, AZ: Coriolis Open Press, 1999.
- (4) Mauro, Jim. Sun Microsystems. Personal Correspondence. March 27, 2001. solaris-internals-feedback@devnull.eng.sun.com.
- (5) Boran, Sean. "Weekly Solaris Security Digest 2001/01/22 to 2001/01/28." January 29, 2001. <http://securityportal.com/topnews/weekly/solaris20010129.html> (April 4, 2001)
- (6) Dittrich, Dave. "Root Kits and hiding files/directories/processes after a break-in." March 7, 2001. <http://staff.washington.edu/dittrich/misc/faqs/rootkits.faq> (April 4, 2001)
- (7) Plotner, Steffen. Yankee Environment Systems. Turners Falls, MA. Personal Correspondence. April 3, 2001.
- (8) Hoglund, Greg. "A Moment of Clarity." Unspecified 2001. <http://www.rootkit.com/> (February 23, 2001)

9.1 Additional References:

- Cesare, Silvio. "Runtime Kernel KMEM Patching." November, 1998. URL: <http://www.big.net.au/~silvio/runtime-kernel-kmem-patching.txt> (April 4, 2001)
- Clemens, Jonathan. "Knark: Linux Kernel Subversion." Unspecified 2000. URL: <http://www.sans.org/newlook/resources/IDFAQ/knark.htm> (April 4, 2001)
- Mauro, Jim. "The dynamic Solaris kernel" February, 2000. URL: <http://www.unixinsider.com/swol-02-2000/swol-02-insidesolaris.html> (March 5, 2001)
- Mauro, Jim. "The kernel directory" April, 2000. URL: <http://www.unixinsider.com/swol-04-2000/swol-04-insidesolaris.html> (March 5, 2001)
- Mitchem, Terrence, Raymond Lu, and Richard O'Brien. "Using Kernel Hypervisors to Secure Applications." December, 1997. URL: <http://www.securecomputing.com/khyper/acsac97.pdf> (April 4, 2001)
- Plaguez (pseud.). "Weakening the Linux Kernel." Phrack. No. 52. January 26, 1998. URL: <http://packetstorm.securify.com/mag/phrack/phrack52/P52-18> (April 4, 2001)
- Plasmoid (pseud.). "Solaris Loadable Kernel Modules." Unspecified 1999. <http://packetstorm.securify.com/groups/thc/slkm-1.0.html> (April 4, 2001)
- Pragmatic (pseud.). "(nearly) Complete Linux Loadable Kernel Modules", March, 1999. URL: http://packetstorm.securify.com/docs/hack/LKM_HACKING.html (April 4, 2001)

Pragmatic (pseud.). "Attacking FreeBSD with Kernel Modules." June, 1999. URL:
<http://packetstorm.securify.com/groups/thc/bsdkern.html> (April 4, 2001)

9.2 Useful Man Pages:

adb(1)
dump(1)
_info(9E)
ksyms(7D)
modinfo(1)
mod_install(9F)
modldr(9S)
nm(1)
savecore(1M)
system(4)

9.3 Location of Exploit Source Code:

Plasmoid (pseud.) *slkm-1.0.tar.gz* December 20, 1999. URL:
<http://packetstorm.securify.com/groups/thc/slkm-1.0.tar.gz> (April 4, 2001)

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