CHAPTER 7

MALICIOUS SOFTWARE

Perhaps the most sophisticated types of threats to computer systems are presented by programs that exploit vulnerabilities in computing systems. Such threats are referred to as **malicious software**, or **malware**. In this context, we are concerned with threats to application programs as well as utility programs, such as editors and compilers, and kernel-level programs.

This chapter examines malicious software, with a special emphasis on viruses and worms. The chapter begins with a survey of various types of malware, with a more detailed look at the nature of viruses and worms. We then turn to bots and rootkits. Throughout, the discussion presents both threats and countermeasures.

7.1 TYPES OF MALICIOUS SOFTWARE

The terminology in this area presents problems because of a lack of universal agreement on all of the terms and because some of the categories overlap. Table 7.1 is a useful guide.

Malicious software can be divided into two categories: those that need a host program, and those that are independent. The former, referred to as **parasitic**, are essentially fragments of programs that cannot exist independently of some actual application program, utility, or system program. Viruses, logic bombs, and backdoors are examples. The latter are self-contained programs that can be scheduled and run by the operating system. Worms and bot programs are examples.

We can also differentiate between those software threats that do not replicate and those that do. The former are programs or fragments of programs that are activated by a trigger. Examples are logic bombs, backdoors, and bot programs. The latter consist of either a program fragment or an independent program that, when executed, may produce one or more copies of itself to be activated later on the same system or some other system. Viruses and worms are examples.

In the remainder of this section, we briefly survey some of the key categories of malicious software, deferring discussion on the key topics of viruses, worms, bots, and rootkits until the following sections.

Backdoor

A **backdoor**, also known as a **trapdoor**, is a secret entry point into a program that allows someone who is aware of the backdoor to gain access without going through the usual security access procedures. Programmers have used backdoors legitimately for many years to debug and test programs; such a backdoor is called a **maintenance hook**. This usually is done when the programmer is developing an application that has an authentication procedure, or a long setup, requiring the user to enter many different values to run the application. To debug the program, the developer may wish to gain special privileges or to avoid all the necessary setup and authentication. The programmer may also want to ensure that there is a method of activating the program should something be wrong with the authentication procedure that is being built into the application. The backdoor is code that recognizes some special sequence of input or is triggered by being run from a certain user ID or by an unlikely sequence of events.

Backdoors become threats when unscrupulous programmers use them to gain unauthorized access. The backdoor was the basic idea for the vulnerability portrayed

Table 7.1 Terminology of Malicious Programs

Name	Description
Virus	Malware that, when executed, tries to replicate itself into other executable code; when it succeeds the code is said to be infected. When the infected code is executed, the virus also executes.
Worm	A computer program that can run independently and can propagate a complete working version of itself onto other hosts on a network.
Logic bomb	A program inserted into software by an intruder. A logic bomb lies dormant until a predefined condition is met; the program then triggers an unauthorized act.
Trojan horse	A computer program that appears to have a useful function, but also has a hidden and potentially malicious function that evades security mechanisms, sometimes by exploiting legitimate authorizations of a system entity that invokes the Trojan horse program.
Backdoor (trapdoor)	Any mechanisms that bypasses a normal security check; it may allow unauthorized access to functionality.
Mobile code	Software (e.g., script, macro, or other portable instruction) that can be shipped unchanged to a heterogeneous collection of platforms and execute with identical semantics.
Exploits	Code specific to a single vulnerability or set of vulnerabilities.
Downloaders	Program that installs other items on a machine that is under attack. Usually, a downloader is sent in an e-mail.
Auto-rooter	Malicious hacker tools used to break into new machines remotely.
Kit (virus generator)	Set of tools for generating new viruses automatically.
Spammer programs	Used to send large volumes of unwanted e-mail.
Flooders	Used to attack networked computer systems with a large volume of traffic to carry out a denial-of-service (DoS) attack.
Keyloggers	Captures key strokes on a compromised system.
Rootkit	Set of hacker tools used after attacker has broken into a computer system and gained root-level access.
Zombie, bot	Program activated on an infected machine that is activated to launch attacks on other machines.
Spyware	Software that collects information from a computer and transmits it to another system.
Adware	Advertising that is integrated into software. It can result in pop-up ads or redirection of a browser to a commercial site.

in the movie *War Games*. Another example is that during the development of Multics, penetration tests were conducted by an Air Force "tiger team" (simulating adversaries). One tactic employed was to send a bogus operating system update to a site running Multics. The update contained a Trojan horse (described later) that could be activated by a backdoor and that allowed the tiger team to gain access.

The threat was so well implemented that the Multics developers could not find it, even after they were informed of its presence [ENGE80].

It is difficult to implement operating system controls for backdoors. Security measures must focus on the program development and software update activities.

Logic Bomb

One of the oldest types of program threat, predating viruses and worms, is the logic bomb. The logic bomb is code embedded in some legitimate program that is set to "explode" when certain conditions are met. Examples of conditions that can be used as triggers for a logic bomb are the presence or absence of certain files, a particular day of the week or date, or a particular user running the application. Once triggered, a bomb may alter or delete data or entire files, cause a machine halt, or do some other damage. A striking example of how logic bombs can be employed was the case of Tim Lloyd, who was convicted of setting a logic bomb that cost his employer, Omega Engineering, more than $10 million, derailed its corporate growth strategy, and eventually led to the layoff of 80 workers [GAUD00]. Ultimately, Lloyd was sentenced to 41 months in prison and ordered to pay $2 million in restitution.

Trojan Horses

A Trojan horse[1] is a useful, or apparently useful, program or command procedure containing hidden code that, when invoked, performs some unwanted or harmful function.

Trojan horse programs can be used to accomplish functions indirectly that an unauthorized user could not accomplish directly. For example, to gain access to the files of another user on a shared system, a user could create a Trojan horse program that, when executed, changes the invoking user's file permissions so that the files are readable by any user. The author could then induce users to run the program by placing it in a common directory and naming it such that it appears to be a useful utility program or application. An example is a program that ostensibly produces a listing of the user's files in a desirable format. After another user has run the program, the author of the program can then access the information in the user's files. An example of a Trojan horse program that would be difficult to detect is a compiler that has been modified to insert additional code into certain programs as they are compiled, such as a system login program [THOM84]. The code creates a backdoor in the login program that permits the author to log on to the system using a special password. This Trojan horse can never be discovered by reading the source code of the login program.

Another common motivation for the Trojan horse is data destruction. The program appears to be performing a useful function (e.g., a calculator program), but it may also be quietly deleting the user's files. For example, a CBS executive was victimized by a Trojan horse that destroyed all information contained in his computer's memory [TIME90]. The Trojan horse was implanted in a graphics routine offered on an electronic bulletin board system.

---

[1]In Greek mythology, the Trojan horse was used by the Greeks during their siege of Troy. Epeios constructed a giant hollow wooden horse in which thirty of the most valiant Greek heroes concealed themselves. The rest of the Greeks burned their encampment and pretended to sail away but actually hid nearby. The Trojans, convinced the horse was a gift and the siege over, dragged the horse into the city. That night, the Greeks emerged from the horse and opened the city gates to the Greek army. A bloodbath ensued, resulting in the destruction of Troy and the death or enslavement of all its citizens.

Trojan horses fit into one of three models:

- Continuing to perform the function of the original program and additionally performing a separate malicious activity
- Continuing to perform the function of the original program but modifying the function to perform malicious activity (e.g., a Trojan horse version of a login program that collects passwords) or to disguise other malicious activity (e.g., a Trojan horse version of a process listing program that does not display certain processes that are malicious)
- Performing a malicious function that completely replaces the function of the original program

Mobile Code

Mobile code refers to programs (e.g., script, macro, or other portable instruction) that can be shipped unchanged to a heterogeneous collection of platforms and execute with identical semantics [JANS01]. The term also applies to situations involving a large homogeneous collection of platforms (e.g., Microsoft Windows).

Mobile code is transmitted from a remote system to a local system and then executed on the local system without the user's explicit instruction. Mobile code often acts as a mechanism for a virus, worm, or Trojan horse to be transmitted to the user's workstation. In other cases, mobile code takes advantage of vulnerabilities to perform its own exploits, such as unauthorized data access or root compromise. Popular vehicles for mobile code include Java applets, ActiveX, JavaScript, and VB-Script. The most common ways of using mobile code for malicious operations on local system are cross-site scripting, interactive and dynamic Web sites, e-mail attachments, and downloads from untrusted sites or of untrusted software.

Multiple-Threat Malware

Viruses and other malware may operate in multiple ways. The terminology is far from uniform; this subsection gives a brief introduction to several related concepts that could be considered multiple-threat malware.

A **multipartite** virus infects in multiple ways. Typically, the multipartite virus is capable of infecting multiple types of files, so that virus eradication must deal with all of the possible sites of infection.

A **blended attack** uses multiple methods of infection or transmission, to maximize the speed of contagion and the severity of the attack. Some writers characterize a blended attack as a package that includes multiple types of malware. An example of a blended attack is the Nimda attack, erroneously referred to as simply a worm. Nimda uses four distribution methods:

- **E-mail:** A user on a vulnerable host opens an infected e-mail attachment; Nimda looks for e-mail addresses on the host and then sends copies of itself to those addresses.
- **Windows shares:** Nimda scans hosts for unsecured Windows file shares; it can then use NetBIOS86 as a transport mechanism to infect files on that host in the hopes that a user will run an infected file, which will activate Nimda on that host.

- **Web servers:** Nimda scans Web servers, looking for known vulnerabilities in Microsoft IIS. If it finds a vulnerable server, it attempts to transfer a copy of itself to the server and infect it and its files.
- **Web clients:** If a vulnerable Web client visits a Web server that has been infected by Nimda, the client's workstation will become infected.

Thus, Nimda has worm, virus, and mobile code characteristics. Blended attacks may also spread through other services, such as instant messaging and peer-to-peer file sharing.

7.2 VIRUSES

The Nature of Viruses

A computer virus is a piece of software that can "infect" other programs by modifying them; the modification includes injecting the original program with a routine to make copies of the virus program, which can then go on to infect other programs. Computer viruses first appeared in the early 1980s, and the term itself is attributed to Fred Cohen in 1983. Cohen is the author of a groundbreaking book on the subject [COHE94].

Biological viruses are tiny scraps of genetic code—DNA or RNA—that can take over the machinery of a living cell and trick it into making thousands of flawless replicas of the original virus. Like its biological counterpart, a computer virus carries in its instructional code the recipe for making perfect copies of itself. The typical virus becomes embedded in a program on a computer. Then, whenever the infected computer comes into contact with an uninfected piece of software, a fresh copy of the virus passes into the new program. Thus, the infection can be spread from computer to computer by unsuspecting users who either swap disks or send programs to one another over a network. In a network environment, the ability to access applications and system services on other computers provides a perfect culture for the spread of a virus.

A virus can do anything that other programs do. The difference is that a virus attaches itself to another program and executes secretly when the host program is run. Once a virus is executing, it can perform any function, such as erasing files and programs.

A computer virus has three parts [AYCO06]:

- **Infection mechanism:** The means by which a virus spreads, enabling it to replicate. The mechanism is also referred to as the **infection vector**.
- **Trigger:** The event or condition that determines when the payload is activated or delivered.
- **Payload:** What the virus does, besides spreading. The payload may involve damage or may involve benign but noticeable activity.

During its lifetime, a typical virus goes through the following four phases:

- **Dormant phase:** The virus is idle. The virus will eventually be activated by some event, such as a date, the presence of another program or file, or the capacity of the disk exceeding some limit. Not all viruses have this stage.

- **Propagation phase:** The virus places a copy of itself into other programs or into certain system areas on the disk. The copy may not be identical to the propagating version; viruses often morph to evade detection. Each infected program will now contain a clone of the virus, which will itself enter a propagation phase.
- **Triggering phase:** The virus is activated to perform the function for which it was intended. As with the dormant phase, the triggering phase can be caused by a variety of system events, including a count of the number of times that this copy of the virus has made copies of itself.
- **Execution phase:** The function is performed. The function may be harmless, such as a message on the screen, or damaging, such as the destruction of programs and data files.

Most viruses carry out their work in a manner that is specific to a particular operating system and, in some cases, specific to a particular hardware platform. Thus, they are designed to take advantage of the details and weaknesses of particular systems.

Virus Structure A virus can be prepended or postpended to an executable program, or it can be embedded in some other fashion. The key to its operation is that the infected program, when invoked, will first execute the virus code and then execute the original code of the program.

A very general depiction of virus structure is shown in Figure 7.1 (based on [COHE94]). In this case, the virus code, V, is prepended to infected programs, and

```
       program V :=

{goto main;
       1234567;

       subroutine infect-executable :=
              {loop:
              file := get-random-executable-file;
              if (first-line-of-file = 1234567)
                     then goto loop
                     else prepend V to file; }

       subroutine do-damage :=
              {whatever damage is to be done}

       subroutine trigger-pulled :=
              {return true if some condition holds}

main:         main-program :=
              {infect-executable;
              if trigger-pulled then do-damage;
              goto next;}

next:

}
```

Figure 7.1 A Simple Virus

it is assumed that the entry point to the program, when invoked, is the first line of the program.

The infected program begins with the virus code and works as follows. The first line of code is a jump to the main virus program. The second line is a special marker that is used by the virus to determine whether or not a potential victim program has already been infected with this virus. When the program is invoked, control is immediately transferred to the main virus program. The virus program may first seeks out uninfected executable files and infect them. Next, the virus may perform some action, usually detrimental to the system. This action could be performed every time the program is invoked, or it could be a logic bomb that triggers only under certain conditions. Finally, the virus transfers control to the original program. If the infection phase of the program is reasonably rapid, a user is unlikely to notice any difference between the execution of an infected and an uninfected program.

A virus such as the one just described is easily detected because an infected version of a program is longer than the corresponding uninfected one. A way to thwart such a simple means of detecting a virus is to compress the executable file so that both the infected and uninfected versions are of identical length. Figure 7.2 [COHE94] shows in general terms the logic required. The key lines in this virus are numbered, and Figure 7.3 [COHE94] illustrates the operation. We assume that program P_1 is infected with the virus CV. When this program is invoked, control passes to its virus, which performs the following steps:

1. For each uninfected file P_2 that is found, the virus first compresses that file to produce P'_2, which is shorter than the original program by the size of the virus.
2. A copy of the virus is prepended to the compressed program.

```
       program CV :=

{goto main;
       01234567;

       subroutine infect-executable :=
              {loop:
                     file := get-random-executable-file;
              if (first-line-of-file = 01234567) then goto loop;
           (1)      compress file;
           (2)      prepend CV to file;
           }

main:      main-program :=
           {if ask-permission then infect-executable;
           (3)      uncompress rest-of-file;
           (4)      run uncompressed file;}
           }
```

Figure 7.2 **Logic for a Compression Virus**

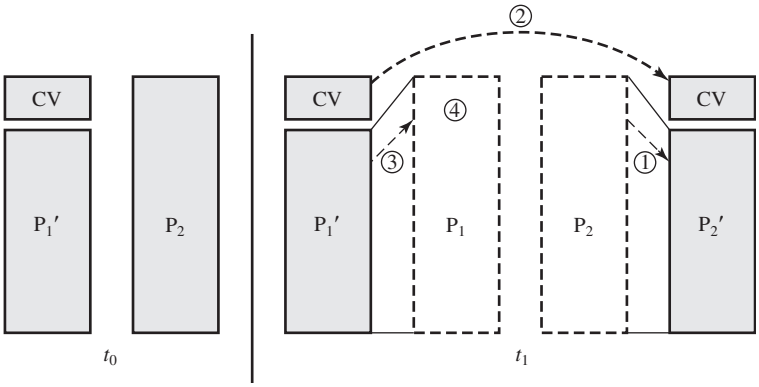


Figure 7.3 **A Compression Virus**

3. The compressed version of the original infected program, P'_1, is uncompressed.
4. The uncompressed original program is executed.

In this example, the virus does nothing other than propagate. As previously mentioned, the virus may include a logic bomb.

Initial Infection Once a virus has gained entry to a system by infecting a single program, it is in a position to potentially infect some or all other executable files on that system when the infected program executes. Thus, viral infection can be completely prevented by preventing the virus from gaining entry in the first place. Unfortunately, prevention is extraordinarily difficult because a virus can be part of any program outside a system. Thus, unless one is content to take an absolutely bare piece of iron and write all one's own system and application programs, one is vulnerable. Many forms of infection can also be blocked by denying normal users the right to modify programs on the system.

The lack of access controls on early PCs is a key reason why traditional machine code based viruses spread rapidly on these systems. In contrast, while it is easy enough to write a machine code virus for UNIX systems, they were almost never seen in practice because the existence of access controls on these systems prevented effective propagation of the virus. Traditional machine code based viruses are now less prevalent, because modern PC OSs do have more effective access controls. However, virus creators have found other avenues, such as macro and e-mail viruses, as discussed subsequently.

Viruses Classification

There has been a continuous arms race between virus writers and writers of antivirus software since viruses first appeared. As effective countermeasures are developed for existing types of viruses, newer types are developed. There is no simple or universally agreed upon classification scheme for viruses, In this section, we follow [AYCO06] and classify viruses along two orthogonal axes: the type of target the virus tries to infect and the method the virus uses to conceal itself from detection by users and antivirus software.

A virus **classification by target** includes the following categories:

- **Boot sector infector:** Infects a master boot record or boot record and spreads when a system is booted from the disk containing the virus.
- **File infector:** Infects files that the operating system or shell consider to be executable.
- **Macro virus:** Infects files with macro code that is interpreted by an application.

A virus classification by concealment strategy includes the following categories:

- **Encrypted virus:** A typical approach is as follows. A portion of the virus creates a random encryption key and encrypts the remainder of the virus. The key is stored with the virus. When an infected program is invoked, the virus uses the stored random key to decrypt the virus. When the virus replicates, a different random key is selected. Because the bulk of the virus is encrypted with a different key for each instance, there is no constant bit pattern to observe.
- **Stealth virus:** A form of virus explicitly designed to hide itself from detection by antivirus software. Thus, the entire virus, not just a payload is hidden.
- **Polymorphic virus:** A virus that mutates with every infection, making detection by the "signature" of the virus impossible.
- **Metamorphic virus:** As with a polymorphic virus, a metamorphic virus mutates with every infection. The difference is that a metamorphic virus rewrites itself completely at each iteration, increasing the difficulty of detection. Metamorphic viruses may change their behavior as well as their appearance.

One example of a **stealth virus** was discussed earlier: a virus that uses compression so that the infected program is exactly the same length as an uninfected version. Far more sophisticated techniques are possible. For example, a virus can place intercept logic in disk I/O routines, so that when there is an attempt to read suspected portions of the disk using these routines, the virus will present back the original, uninfected program. Thus, *stealth* is not a term that applies to a virus as such but, rather, refers to a technique used by a virus to evade detection.

A **polymorphic virus** creates copies during replication that are functionally equivalent but have distinctly different bit patterns. As with a stealth virus, the purpose is to defeat programs that scan for viruses. In this case, the "signature" of the virus will vary with each copy. To achieve this variation, the virus may randomly insert superfluous instructions or interchange the order of independent instructions. A more effective approach is to use encryption. The strategy of the encryption virus is followed. The portion of the virus that is responsible for generating keys and performing encryption/decryption is referred to as the *mutation engine*. The mutation engine itself is altered with each use.

Virus Kits

Another weapon in the virus writers' armory is the virus-creation toolkit. Such a toolkit enables a relative novice to quickly create a number of different viruses. Although viruses created with toolkits tend to be less sophisticated than viruses designed from scratch, the sheer number of new viruses that can be generated using a toolkit creates a problem for antivirus schemes.

Macro Viruses

In the mid-1990s, macro viruses became by far the most prevalent type of virus. Macro viruses are particularly threatening for a number of reasons:

1. A macro virus is platform independent. Many macro viruses infect Microsoft Word documents or other Microsoft Office documents. Any hardware platform and operating system that supports these applications can be infected.
2. Macro viruses infect documents, not executable portions of code. Most of the information introduced onto a computer system is in the form of a document rather than a program.
3. Macro viruses are easily spread. A very common method is by electronic mail.
4. Because macro viruses infect user documents rather than system programs, traditional file system access controls are of limited use in preventing their spread.

Macro viruses take advantage of a feature found in Word and other office applications such as Microsoft Excel, namely the macro. In essence, a macro is an executable program embedded in a word processing document or other type of file. Typically, users employ macros to automate repetitive tasks and thereby save keystrokes. The macro language is usually some form of the Basic programming language. A user might define a sequence of keystrokes in a macro and set it up so that the macro is invoked when a function key or special short combination of keys is input.

Successive releases of MS Office products provide increased protection against macro viruses. For example, Microsoft offers an optional Macro Virus Protection tool that detects suspicious Word files and alerts the customer to the potential risk of opening a file with macros. Various antivirus product vendors have also developed tools to detect and correct macro viruses. As in other types of viruses, the arms race continues in the field of macro viruses, but they no longer are the predominant virus threat.

E-Mail Viruses

A more recent development in malicious software is the e-mail virus. The first rapidly spreading e-mail viruses, such as Melissa, made use of a Microsoft Word macro embedded in an attachment. If the recipient opens the e-mail attachment, the Word macro is activated. Then

1. The e-mail virus sends itself to everyone on the mailing list in the user's e-mail package.
2. The virus does local damage on the user's system.

In 1999, a more powerful version of the e-mail virus appeared. This newer version can be activated merely by opening an e-mail that contains the virus rather than opening an attachment. The virus uses the Visual Basic scripting language supported by the e-mail package.

Thus we see a new generation of malware that arrives via e-mail and uses e-mail software features to replicate itself across the Internet. The virus propagates itself as soon as it is activated (either by opening an e-mail attachment or by opening the e-mail) to all of the e-mail addresses known to the infected host. As a result, whereas

viruses used to take months or years to propagate, they now do so in hours. This makes it very difficult for antivirus software to respond before much damage is done. Ultimately, a greater degree of security must be built into Internet utility and application software on PCs to counter the growing threat.

7.3 VIRUS COUNTERMEASURES

Antivirus Approaches

The ideal solution to the threat of viruses is prevention: Do not allow a virus to get into the system in the first place, or block the ability of a virus to modify any files containing executable code or macros. This goal is, in general, impossible to achieve, although prevention can reduce the number of successful viral attacks. The next best approach is to be able to do the following:

- **Detection:** Once the infection has occurred, determine that it has occurred and locate the virus.
- **Identification:** Once detection has been achieved, identify the specific virus that has infected a program.
- **Removal:** Once the specific virus has been identified, remove all traces of the virus from the infected program and restore it to its original state. Remove the virus from all infected systems so that the virus cannot spread further.

If detection succeeds but either identification or removal is not possible, then the alternative is to discard the infected file and reload a clean backup version.

Advances in virus and antivirus technology go hand in hand. Early viruses were relatively simple code fragments and could be identified and purged with relatively simple antivirus software packages. As the virus arms race has evolved, both viruses and, necessarily, antivirus software have grown more complex and sophisticated.

[STEP93] identifies four generations of antivirus software:

- First generation: simple scanners
- Second generation: heuristic scanners
- Third generation: activity traps
- Fourth generation: full-featured protection

A **first-generation** scanner requires a virus signature to identify a virus. The virus may contain "wildcards" but has essentially the same structure and bit pattern in all copies. Such signature-specific scanners are limited to the detection of known viruses. Another type of first-generation scanner maintains a record of the length of programs and looks for changes in length.

A **second-generation** scanner does not rely on a specific signature. Rather, the scanner uses heuristic rules to search for probable virus infection. One class of such scanners looks for fragments of code that are often associated with viruses. For example, a scanner may look for the beginning of an encryption loop used in a polymorphic virus and discover the encryption key. Once the key is discovered, the

scanner can decrypt the virus to identify it, then remove the infection and return the program to service.

Another second-generation approach is integrity checking. A checksum can be appended to each program. If a virus infects the program without changing the checksum, then an integrity check will catch the change. To counter a virus that is sophisticated enough to change the checksum when it infects a program, an encrypted hash function can be used. The encryption key is stored separately from the program so that the virus cannot generate a new hash code and encrypt that. By using a hash function rather than a simpler checksum, the virus is prevented from adjusting the program to produce the same hash code as before.

Third-generation programs are memory-resident programs that identify a virus by its actions rather than its structure in an infected program. Such programs have the advantage that it is not necessary to develop signatures and heuristics for a wide array of viruses. Rather, it is necessary only to identify the small set of actions that indicate an infection is being attempted and then to intervene.

Fourth-generation products are packages consisting of a variety of antivirus techniques used in conjunction. These include scanning and activity trap components. In addition, such a package includes access control capability, which limits the ability of viruses to penetrate a system and then limits the ability of a virus to update files in order to pass on the infection.

The arms race continues. With fourth-generation packages, a more comprehensive defense strategy is employed, broadening the scope of defense to more general-purpose computer security measures.

Advanced Antivirus Techniques

More sophisticated antivirus approaches and products continue to appear. In this subsection, we highlight two of the most important.

Generic Decryption Generic decryption (GD) technology enables the antivirus program to easily detect even the most complex polymorphic viruses while maintaining fast scanning speeds [NACH97]. Recall that when a file containing a polymorphic virus is executed, the virus must decrypt itself to activate. In order to detect such a structure, executable files are run through a GD scanner, which contains the following elements:

- **CPU emulator:** A software-based virtual computer. Instructions in an executable file are interpreted by the emulator rather than executed on the underlying processor. The emulator includes software versions of all registers and other processor hardware, so that the underlying processor is unaffected by programs interpreted on the emulator.
- **Virus signature scanner:** A module that scans the target code looking for known virus signatures.
- **Emulation control module:** Controls the execution of the target code.

At the start of each simulation, the emulator begins interpreting instructions in the target code, one at a time. Thus, if the code includes a decryption routine that decrypts and hence exposes the virus, that code is interpreted. In effect, the

virus does the work for the antivirus program by exposing the virus. Periodically, the control module interrupts interpretation to scan the target code for virus signatures.

During interpretation, the target code can cause no damage to the actual personal computer environment, because it is being interpreted in a completely controlled environment.

The most difficult design issue with a GD scanner is to determine how long to run each interpretation. Typically, virus elements are activated soon after a program begins executing, but this need not be the case. The longer the scanner emulates a particular program, the more likely it is to catch any hidden viruses. However, the antivirus program can take up only a limited amount of time and resources before users complain of degraded system performance.

Digital Immune System The digital immune system is a comprehensive approach to virus protection developed by IBM [KEPH97a, KEPH97b, WHIT99] and subsequently refined by Symantec [SYMA01]. The motivation for this development has been the rising threat of Internet-based virus propagation. We first say a few words about this threat and then summarize IBM's approach.

Traditionally, the virus threat was characterized by the relatively slow spread of new viruses and new mutations. Antivirus software was typically updated on a monthly basis, and this was sufficient to control the problem. Also traditionally, the Internet played a comparatively small role in the spread of viruses. But as [CHES97] points out, two major trends in Internet technology have had an increasing impact on the rate of virus propagation in recent years:

- **Integrated mail systems:** Systems such as Lotus Notes and Microsoft Outlook make it very simple to send anything to anyone and to work with objects that are received.
- **Mobile-program systems:** Capabilities such as Java and ActiveX allow programs to move on their own from one system to another.

In response to the threat posed by these Internet-based capabilities, IBM has developed a prototype digital immune system. This system expands on the use of program emulation discussed in the preceding subsection and provides a general-purpose emulation and virus-detection system. The objective of this system is to provide rapid response time so that viruses can be stamped out almost as soon as they are introduced. When a new virus enters an organization, the immune system automatically captures it, analyzes it, adds detection and shielding for it, removes it, and passes information about that virus to systems running IBM AntiVirus so that it can be detected before it is allowed to run elsewhere.

Figure 7.4 illustrates the typical steps in digital immune system operation:

1. A monitoring program on each PC uses a variety of heuristics based on system behavior, suspicious changes to programs, or family signature to infer that a virus may be present. The monitoring program forwards a copy of any program thought to be infected to an administrative machine within the organization.
2. The administrative machine encrypts the sample and sends it to a central virus analysis machine.

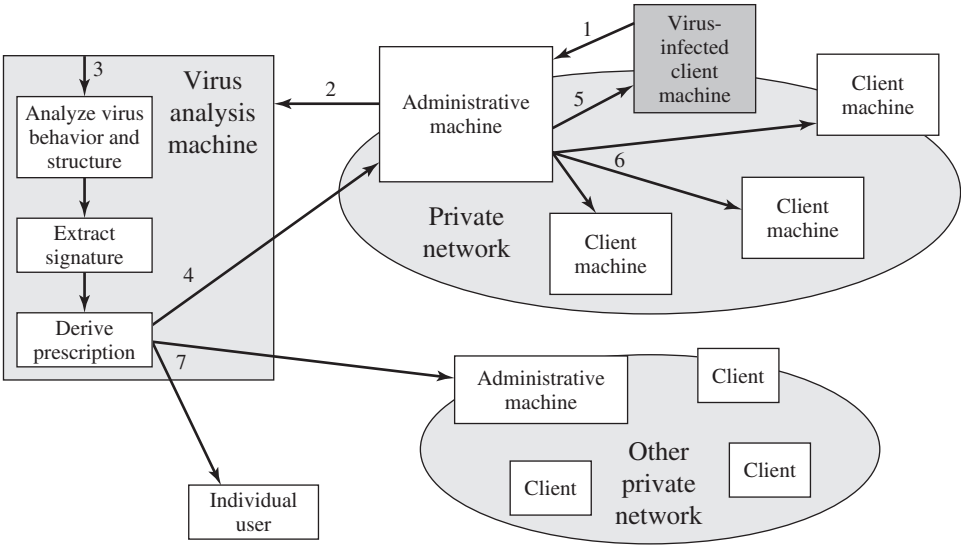


Figure 7.4 **Digital Immune System**

3. This machine creates an environment in which the infected program can be safely run for analysis. Techniques used for this purpose include emulation, or the creation of a protected environment within which the suspect program can be executed and monitored. The virus analysis machine then produces a prescription for identifying and removing the virus.
4. The resulting prescription is sent back to the administrative machine.
5. The administrative machine forwards the prescription to the infected client.
6. The prescription is also forwarded to other clients in the organization.
7. Subscribers around the world receive regular antivirus updates that protect them from the new virus.

The success of the digital immune system depends on the ability of the virus analysis machine to detect new and innovative virus strains. By constantly analyzing and monitoring the viruses found in the wild, it should be possible to continually update the digital immune software to keep up with the threat.

Behavior-Blocking Software

Unlike heuristics or fingerprint-based scanners, behavior-blocking software integrates with the operating system of a host computer and monitors program behavior in real-time for malicious actions [CONR02, NACH02]. The behavior-blocking software then blocks potentially malicious actions before they have a chance to affect the system. Monitored behaviors can include

- Attempts to open, view, delete, and/or modify files;
- Attempts to format disk drives and other unrecoverable disk operations;
- Modifications to the logic of executable files or macros;

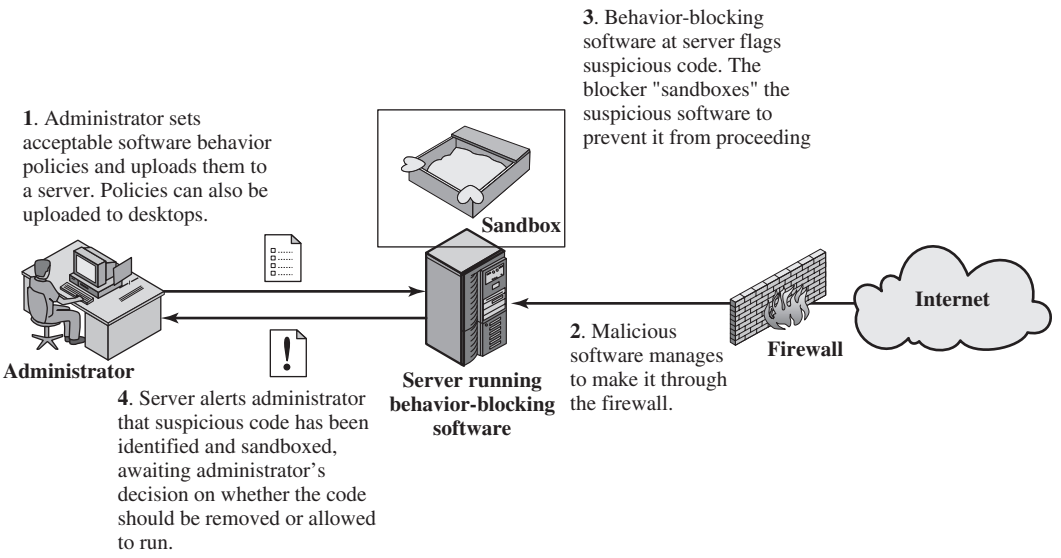


Figure 7.5 Behavior-Blocking Software Operation
Source: Based on [MESS02].

- Modification of critical system settings, such as start-up settings;
- Scripting of e-mail and instant messaging clients to send executable content; and
- Initiation of network communications.

Figure 7.5 illustrates the operation of a behavior blocker. Behavior-blocking software runs on server and desktop computers and is instructed through policies set by the network administrator to let benign actions take place but to intercede when unauthorized or suspicious actions occur. The module blocks any suspicious software from executing. A blocker isolates the code in a sandbox, which restricts the code's access to various OS resources and applications. The blocker then sends an alert.

Because a behavior blocker can block suspicious software in real-time, it has an advantage over such established antivirus detection techniques as fingerprinting or heuristics. While there are literally trillions of different ways to obfuscate and rearrange the instructions of a virus or worm, many of which will evade detection by a fingerprint scanner or heuristic, eventually malicious code must make a well-defined request to the operating system. Given that the behavior blocker can intercept all such requests, it can identify and block malicious actions regardless of how obfuscated the program logic appears to be.

Behavior blocking alone has limitations. Because the malicious code must run on the target machine before all its behaviors can be identified, it can cause harm before it has been detected and blocked. For example, a new virus might shuffle a number of seemingly unimportant files around the hard drive before infecting a single file and being blocked. Even though the actual infection was blocked, the user may be unable to locate his or her files, causing a loss to productivity or possibly worse.

7.4 WORMS

A worm is a program that can replicate itself and send copies from computer to computer across network connections. Upon arrival, the worm may be activated to replicate and propagate again. In addition to propagation, the worm usually performs some unwanted function. An e-mail virus has some of the characteristics of a worm because it propagates itself from system to system. However, we can still classify it as a virus because it uses a document modified to contain viral macro content and requires human action. A worm actively seeks out more machines to infect and each machine that is infected serves as an automated launching pad for attacks on other machines.

The concept of a computer worm was introduced in John Brunner's 1975 SF novel *The Shockwave Rider*. The first known worm implementation was done in Xerox Palo Alto Labs in the early 1980s. It was nonmalicious search for idle systems to use to run a computationally intensive task.

Network worm programs use network connections to spread from system to system. Once active within a system, a network worm can behave as a computer virus or bacteria, or it could implant Trojan horse programs or perform any number of disruptive or destructive actions.

To replicate itself, a network worm uses some sort of network vehicle. Examples include the following:

- **Electronic mail facility:** A worm mails a copy of itself to other systems, so that its code is run when the e-mail or an attachment is received or viewed.
- **Remote execution capability:** A worm executes a copy of itself on another system, either using an explicit remote execution facility or by exploiting a program flaw in a network service to subvert its operations (as we discuss in Chapters 11 and 12).
- **Remote login capability:** A worm logs onto a remote system as a user and then uses commands to copy itself from one system to the other, where it then executes.

The new copy of the worm program is then run on the remote system where, in addition to any functions that it performs at that system, it continues to spread in the same fashion.

A network worm exhibits the same characteristics as a computer virus: a dormant phase, a propagation phase, a triggering phase, and an execution phase. The propagation phase generally performs the following functions:

1. Search for other systems to infect by examining host tables or similar repositories of remote system addresses.
2. Establish a connection with a remote system.
3. Copy itself to the remote system and cause the copy to be run.

The network worm may also attempt to determine whether a system has previously been infected before copying itself to the system. In a multiprogramming

system, it may also disguise its presence by naming itself as a system process or using some other name that may not be noticed by a system operator.

As with viruses, network worms are difficult to counter.

The Morris Worm

Until the current generation of worms, the best known was the worm released onto the Internet by Robert Morris in 1988 [ORMA03]. The Morris worm was designed to spread on UNIX systems and used a number of different techniques for propagation. When a copy began execution, its first task was to discover other hosts known to this host that would allow entry from this host. The worm performed this task by examining a variety of lists and tables, including system tables that declared which other machines were trusted by this host, users' mail forwarding files, tables by which users gave themselves permission for access to remote accounts, and a program that reported the status of network connections. For each discovered host, the worm tried a number of methods for gaining access:

1. It attempted to log on to a remote host as a legitimate user. In this method, the worm first attempted to crack the local password file and then used the discovered passwords and corresponding user IDs. The assumption was that many users would use the same password on different systems. To obtain the passwords, the worm ran a password-cracking program that tried
   (a) Each user's account name and simple permutations of it
   (b) A list of 432 built-in passwords that Morris thought to be likely candidates[2]
   (c) All the words in the local system dictionary
2. It exploited a bug in the UNIX finger protocol, which reports the whereabouts of a remote user.
3. It exploited a trapdoor in the debug option of the remote process that receives and sends mail.

If any of these attacks succeeded, the worm achieved communication with the operating system command interpreter. It then sent this interpreter a short bootstrap program, issued a command to execute that program, and then logged off. The bootstrap program then called back the parent program and downloaded the remainder of the worm. The new worm was then executed.

Worm Propagation Model

[ZOU05] describes a model for worm propagation based on an analysis of recent worm attacks. The speed of propagation and the total number of hosts infected depend on a number of factors, including the mode of propagation, the vulnerability or vulnerabilities exploited, and the degree of similarity to preceding attacks. For the latter factor, an attack that is a variation of a recent previous attack may be countered more effectively than a more novel attack. Figure 7.6 shows the dynamics for one typical set of parameters. Propagation proceeds through three phases. In the

[2]The complete list is provided at this book's Web site.

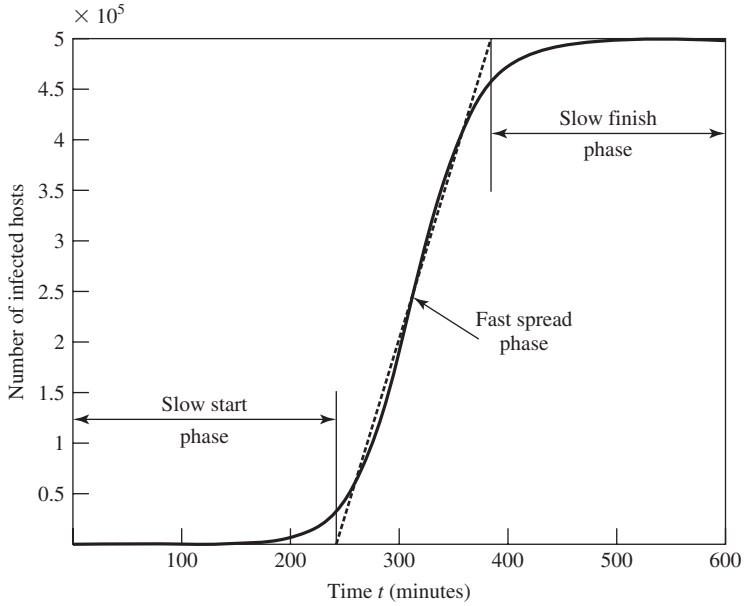


Figure 7.6 **Worm Propagation Model**

initial phase, the number of hosts increases exponentially. To see that this is so, consider a simplified case in which a worm is launched from a single host and infects two nearby hosts. Each of these hosts infects two more hosts, and so on. This results in exponential growth. After a time, infecting hosts waste some time attacking already infected hosts, which reduces the rate of infection. During this middle phase, growth is approximately linear, but the rate of infection is rapid. When most vulnerable computers have been infected, the attack enters a slow finish phase as the worm seeks out those remaining hosts that are difficult to identify.

Clearly, the objective in countering a worm is to catch the worm in its slow start phase, at a time when few hosts have been infected.

Recent Worm Attacks

The contemporary era of worm threats began with the release of the Code Red worm in July of 2001. Code Red exploits a security hole in the Microsoft Internet Information Server (IIS) to penetrate and spread. It also disables the system file checker in Windows. The worm probes random IP addresses to spread to other hosts. During a certain period of time, it only spreads. It then initiates a denial-of-service attack against a government Web site by flooding the site with packets from numerous hosts. The worm then suspends activities and reactivates periodically. In the second wave of attack, Code Red infected nearly 360,000 servers in 14 hours. In addition to the havoc it caused at the targeted server, Code Red consumed enormous amounts of Internet capacity, disrupting service.

Code Red II is a variant that targets Microsoft IISs. In addition, this newer worm installs a backdoor, allowing a hacker to remotely execute commands on victim computers.

In early 2003, the SQL Slammer worm appeared. This worm exploited a buffer overflow vulnerability in Microsoft SQL server. The Slammer was extremely compact and spread rapidly, infecting 90% of vulnerable hosts within 10 minutes. Late 2003 saw the arrival of the Sobig.f worm, which exploited open proxy servers to turn infected machines into spam engines. At its peak, Sobig.f reportedly accounted for one in every 17 messages and produced more than one million copies of itself within the first 24 hours.

Mydoom is a mass-mailing e-mail worm that appeared in 2004. It followed a growing trend of installing a backdoor in infected computers, thereby enabling hackers to gain remote access to data such as passwords and credit card numbers. Mydoom replicated up to 1000 times per minute and reportedly flooded the Internet with 100 million infected messages in 36 hours.

A recent worm that rapidly became prevalent in a variety of versions is the Warezov family of worms [KIRK06]. When the worm is launched, it creates several executable in system directories and sets itself to run every time Windows starts, by creating a registry entry. Warezov scans several types of files for e-mail addresses and sends itself as an e-mail attachment. Some variants are capable of downloading other malware, such as Trojan horses and adware. Many variants disable security related products and/or disable their updating capability.

State of Worm Technology

The state of the art in worm technology includes the following:

- **Multiplatform:** Newer worms are not limited to Windows machines but can attack a variety of platforms, especially the popular varieties of UNIX.
- **Multiexploit:** New worms penetrate systems in a variety of ways, using exploits against Web servers, browsers, e-mail, file sharing, and other network-based applications.
- **Ultrafast spreading:** One technique to accelerate the spread of a worm is to conduct a prior Internet scan to accumulate Internet addresses of vulnerable machines.
- **Polymorphic:** To evade detection, skip past filters, and foil real-time analysis, worms adopt the virus polymorphic technique. Each copy of the worm has new code generated on the fly using functionally equivalent instructions and encryption techniques.
- **Metamorphic:** In addition to changing their appearance, metamorphic worms have a repertoire of behavior patterns that are unleashed at different stages of propagation.
- **Transport vehicles:** Because worms can rapidly compromise a large number of systems, they are ideal for spreading other distributed attack tools, such as distributed denial of service bots.
- **Zero-day exploit:** To achieve maximum surprise and distribution, a worm should exploit an unknown vulnerability that is only discovered by the general network community when the worm is launched.

Mobile Phone Worms

Worms first appeared on mobile phones in 2004. These worms communicate through Bluetooth wireless connections or via the multimedia messaging service (MMS). The target is the smartphone, which is a mobile phone that permits users to install software applications from sources other than the cellular network operator. Mobile phone malware can completely disable the phone, delete data on the phone, or force the device to send costly messages to premium-priced numbers.

An example of a mobile phone worm is CommWarrior, which was launched in 2005. This worm replicates by means of Bluetooth to other phones in the receiving area. It also sends itself as an MMS file to numbers in the phone's address book and in automatic replies to incoming text messages and MMS messages. In addition, it copies itself to the removable memory card and inserts itself into the program installation files on the phone.

Worm Countermeasures

There is considerable overlap in techniques for dealing with viruses and worms. Once a worm is resident on a machine, antivirus software can be used to detect it. In addition, because worm propagation generates considerable network activity, network activity and usage monitoring can form the basis of a worm defense.

To begin, let us consider the requirements for an effective worm countermeasure scheme:

- **Generality:** The approach taken should be able to handle a wide variety of worm attacks, including polymorphic worms.
- **Timeliness:** The approach should respond quickly so as to limit the number infected systems and the number of generated transmissions from infected systems.
- **Resiliency:** The approach should be resistant to evasion techniques employed by attackers to evade worm countermeasures.
- **Minimal denial-of-service costs:** The approach should result in minimal reduction in capacity or service due to the actions of the countermeasure software. That is, in an attempt to contain worm propagation, the countermeasure should not significantly disrupt normal operation.
- **Transparency:** The countermeasure software and devices should not require modification to existing (legacy) OSs, application software, and hardware.
- **Global and local coverage:** The approach should be able to deal with attack sources both from outside and inside the enterprise network.

No existing worm countermeasure scheme appears to satisfy all these requirements. Thus, administrators typically need to use multiple approaches in defending against worm attacks.

Countermeasure Approaches Following [JHI07], we list six classes of worm defense:

A. **Signature-based worm scan filtering:** This type of approach generates a worm signature, which is then used to prevent worm scans from entering/leaving a network/host. Typically, this approach involves identifying suspicious flows and generating a worm signature. This approach is vulnerable to the use of polymorphic worms: Either the detection software misses the worm or, if it is sufficiently sophisticated to deal with polymorphic worms, the scheme may take a long time to react. [NEWS05] is an example of this approach.

B. **Filter-based worm containment:** This approach is similar to class A but focuses on worm content rather than a scan signature. The filter checks a message to determine if it contains worm code. An example is Vigilante [COST05], which relies on collaborative worm detection at end hosts. This approach can be quite effective but requires efficient detection algorithms and rapid alert dissemination.

C. **Payload-classification-based worm containment:** These network-based techniques examine packets to see if they contain a worm. Various anomaly detection techniques can be used, but care is needed to avoid high levels of false positives or negatives. An example of this approach is reported in [CHIN05], which looks for exploit code in network flows. This approach does not generate signatures based on byte patterns but rather looks for control and data flow structures that suggest an exploit.

D. **Threshold random walk (TRW) scan detection:** TRW exploits randomness in picking destinations to connect to as a way of detecting if a scanner is in operation [JUNG04]. TRW is suitable for deployment in high-speed, low-cost network devices. It is effective against the common behavior seen in worm scans.

E. **Rate limiting:** This class limits the rate of scanlike traffic from an infected host. Various strategies can be used, including limiting the number of new machines a host can connect to in a window of time, detecting a high connection failure rate, and limiting the number of unique IP addresses a host can scan in a window of time. [CHEN04] is an example. This class of countermeasures may introduce longer delays for normal traffic. This class is also not suited for slow, stealthy worms that spread slowly to avoid detection based on activity level.

F. **Rate halting:** This approach immediately blocks outgoing traffic when a threshold is exceeded either in outgoing connection rate or diversity of connection attempts [JHI07]. The approach must include measures to quickly unblock mistakenly blocked hosts in a transparent way. Rate halting can integrate with a signature- or filter-based approach so that once a signature or filter is generated, every blocked host can be unblocked; Rate halting appears to offer a very effective countermeasure. As with rate limiting, rate halting techniques are not suitable for slow, stealthy worms.

We look now at two approaches in more detail.

Proactive Worm Containment The PWC scheme [JHI07] is host based rather than being based on network devices such as honeypots, firewalls, and network IDSs. PWC is designed to address the threat of worms that spread rapidly. The software on a host looks for surges in the rate of frequency of outgoing connection attempts and the diversity of connections to remote hosts. When such a surge is detected, the software immediately blocks its host from further connection attempts. The developers estimate that only a few dozen infected packets may be sent out to other systems before PWC quarantines that attack. In contrast, the Slammer worm on average sent out 4000 infected packets per second.

A deployed PWC system consists of a PWC manager and PWC agents in hosts. Figure 7.7 is an example of an architecture that includes PWC. In this example, the security manager, signature extractor, and PWC manager are implemented in a single network device. In practice, these three modules could be implemented as two or three separate devices.

The operation of the PWC architecture can be described as follows:

A. A PWC agent monitors outgoing traffic for scan activity, determined by a surge in UDP or TPC connection attempts to remote hosts. If a surge is detected, the agent performs the following actions: (1) issues an alert to local system; (2) blocks all outgoing connection attempts; (3) transmits the alert to the PWC manager; and (4) starts a relaxation analysis, described in E.

B. A PWC manager receives an alert. The PWC propagates the alert to all other agents (beside the originating agent).

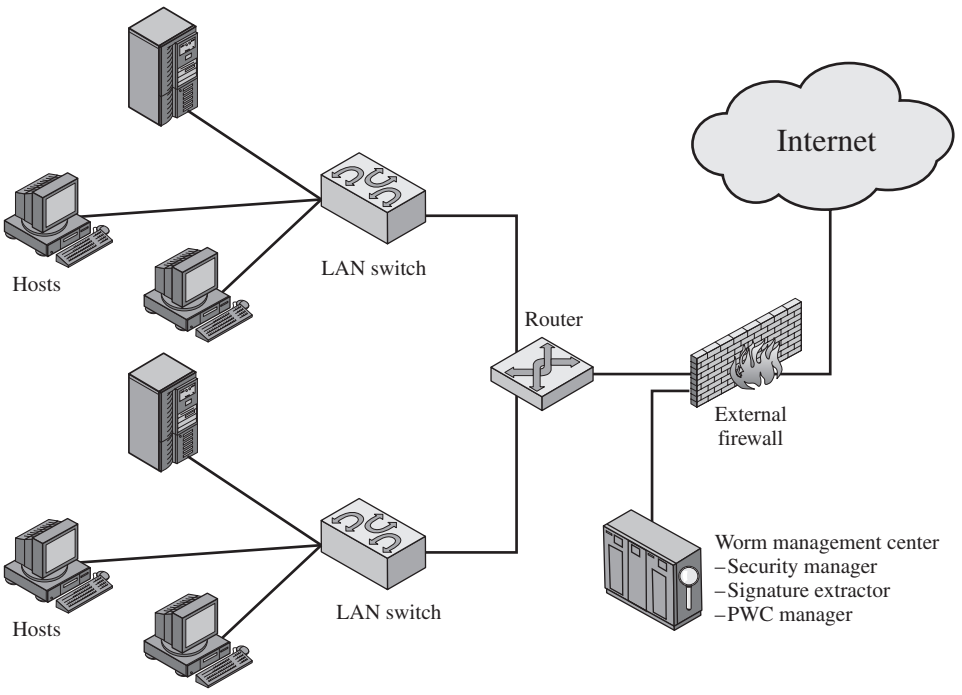


Figure 7.7 Example PWC Deployment

C. The host receives an alert. The agent must decide whether to ignore the alert, in the following way. If the time since the last incoming packet has been sufficiently long so that the agent would have detected a worm if infected, then the alert is ignored. Otherwise, the agent assumes that it might be infected and performs the following actions: (1) blocks all outgoing connection attempts from the specific alerting port; and (2) starts a relaxation analysis, described in E.

D. Relaxation analysis is performed as follows. An agent monitors outgoing activity for a fixed window of time to see if outgoing connections exceed a threshold. If so, blockage is continued and relaxation analysis is performed for another window of time. This process continues until the outgoing connection rate drops below the threshold, at which time the agent removes the block. If the threshold continues to be exceeded over a sufficient number of relaxation windows, the agent isolates the host and reports to the PWC manager.

Meanwhile, a separate aspect of the worm defense system is in operation. The signature extractor functions as a passive sensor that monitors all traffic and attempts to detect worms by signature analysis. When a new worm is detected, its signature is sent by the security manager to the firewall to filter out any more copies of the worm. In addition, the PWC manager sends the signature to PWC agents, enabling them to immediately recognize infection and disable the worm.

Network-Based Worm Defense The key element of a network-based worm defense is worm monitoring software. Consider an enterprise network at a site, consisting of one or an interconnected set of LANs. Two types of monitoring software are needed:

- **Ingress monitors:** These are located at the border between the enterprise network and the Internet. They can be part of the ingress filtering software of a border router or external firewall or a separate passive monitor. A honeypot can also capture incoming worm traffic. An example of a detection technique for an ingress monitor is to look for incoming traffic to unused local IP addresses.
- **Egress monitors:** These can be located at the egress point of individual LANs on the enterprise network as well as at the border between the enterprise network and the Internet. In the former case, the egress monitor can be part of the egress filtering software of a LAN router or switch. As with ingress monitors, the external firewall or a honeypot can house the monitoring software. Indeed, the two types of monitors can be collocated. The egress monitor is designed to catch the source of a worm attack by monitoring outgoing traffic for signs of scanning or other suspicious behavior.

Worm monitors can act in the manner of intrusion detection systems and generate alerts to a central administrative system. It is also possible to implement a system that attempts to react in real time to a worm attack, so as to counter zero-day exploits effectively. This is similar to the approach taken with the digital immune system (Figure 7.4).

Figure 7.8 shows an example of a worm countermeasure architecture [SIDI05]. The system works as follows (numbers in figure refer to numbers in the following list):

1. Sensors deployed at various network locations detect a potential worm. The sensor logic can also be incorporated in IDS sensors.

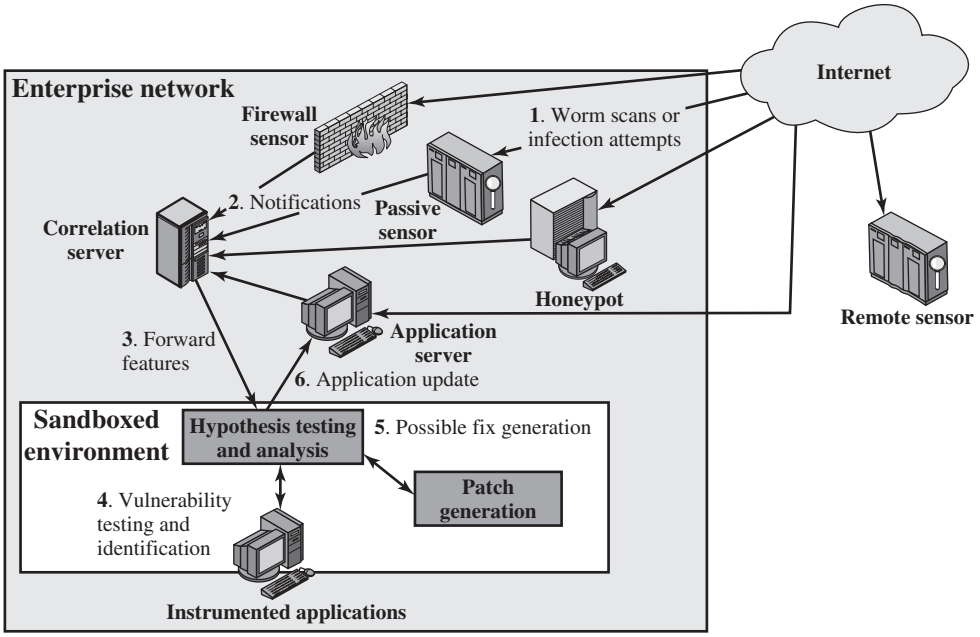


Figure 7.8 **Placement of Worm Monitors**
Source: Based on [SIDI05].

2. The sensors send alerts to a central server that correlates and analyzes the incoming alerts. The correlation server determines the likelihood that a worm attack is being observed and the key characteristics of the attack.
3. The server forwards its information to a protected environment, where the potential worm may be sandboxed for analysis and testing.
4. The protected system tests the suspicious software against an appropriately instrumented version of the targeted application to identify the vulnerability.
5. The protected system generates one or more software patches and tests these.
6. If the patch is not susceptible to the infection and does not compromise the application's functionality, the system sends the patch to the application host to update the targeted application.

The success of such an automated patching system depends on maintaining a current list of potential attacks and developing general tools for patching software to counter such attacks. Examples of approaches are as follows:

- Increasing the size of buffers
- Using minor code-randomization techniques [BHAT03] so that the infection no longer works because the code to be attacked is no longer in the same form and location
- Adding filters to the application that enable it to recognize and ignore an attack

7.5 BOTS

A bot (robot), also known as a zombie or drone, is a program that secretly takes over another Internet-attached computer and then uses that computer to launch attacks that are difficult to trace to the bot's creator. The bot is typically planted on hundreds or thousands of computers belonging to unsuspecting third parties. The collection of bots often is capable of acting in a coordinated manner; such a collection is referred to as a **botnet**.

A botnet exhibits three characteristics: the bot functionality, a remote control facility, and a spreading mechanism to propagate the bots and construct the botnet. We examine each of these characteristics in turn.

Uses of Bots

[HONE05] lists the following uses of bots:

- **Distributed denial-of-service attacks:** A DDoS attack is an attack on a computer system or network that causes a loss of service to users. We examine DDoS attacks in Chapter 8.
- **Spamming:** With the help of a botnet and thousands of bots, an attacker is able to send massive amounts of bulk e-mail (spam).
- **Sniffing traffic:** Bots can also use a packet sniffer to watch for interesting cleartext data passing by a compromised machine. The sniffers are mostly used to retrieve sensitive information like usernames and passwords.
- **Keylogging:** If the compromised machine uses encrypted communication channels (e.g., HTTPS or POP3S), then just sniffing the network packets on the victim's computer is useless because the appropriate key to decrypt the packets is missing. But by using a keylogger, which captures keystrokes on the infected machine, an attacker can retrieve sensitive information. An implemented filtering mechanism (e.g., "I am only interested in key sequences near the keyword 'paypal.com' ") further helps in stealing secret data.
- **Spreading new malware:** Botnets are used to spread new bots. This is very easy since all bots implement mechanisms to download and execute a file via HTTP or FTP. A botnet with 10,000 hosts that acts as the start base for a worm or mail virus allows very fast spreading and thus causes more harm.
- **Installing advertisement add-ons and browser helper objects (BHOs):** Botnets can also be used to gain financial advantages. This is done by setting up a fake Web site with some advertisements; the operator of this Web site negotiates a deal with some hosting companies that pay for clicks on ads. With the help of a botnet, these clicks can be "automated" so that instantly a few thousand bots click on the pop-ups. This process can be further enhanced if the bot hijacks the start-page of a compromised machine so that the "clicks" are executed each time the victim uses the browser.

- **Attacking IRC chat networks:** Botnets are also used for attacks against Internet relay chat (IRC) networks. Popular among attackers is especially the so-called clone attack: In this kind of attack, the controller orders each bot to connect a large number of clones to the victim IRC network. The victim is flooded by service request from thousands of bots or thousands of channel-joins by these cloned bots. In this way, the victim IRC network is brought down, similar to a DDoS attack.
- **Manipulating online polls/games:** Online polls/games are getting more and more attention and it is rather easy to manipulate them with botnets. Since every bot has a distinct IP address, every vote will have the same credibility as a vote cast by a real person. Online games can be manipulated in a similar way.

Remote Control Facility

The remote control facility is what distinguishes a bot from a worm. A worm propagates itself and activates itself, whereas a bot is controlled from some central facility, at least initially.

A typical means of implementing the remote control facility is on an IRC server. All bots join a specific channel on this server and treat incoming messages as commands. More recent botnets tend to avoid IRC mechanisms and use covert communication channels via protocols such as HTTP. Distributed control mechanisms are also used, to avoid a single point of failure.

Once a communications path is established between a control module and the bots, the control module can activate the bots. In its simplest form, the control module simply issues command to the bot that causes the bot to execute routines that are already implemented in the bot. For greater flexibility, the control module can issue update commands that instruct the bots to download a file from some Internet location and execute it. The bot in this latter case becomes a more general-purpose tool that can be used for multiple attacks.

Constructing the Attack Network

The first step in a botnet attack is for the attacker to infect a number of machines with bot software that will ultimately be used to carry out the attack. The essential ingredients in this phase of the attack are the following:

1. Software that can carry out the attack. The software must be able to run on a large number of machines, must be able to conceal its existence, must be able to communicate with the attacker or have some sort of time-triggered mechanism, and must be able to launch the intended attack toward the target.
2. A vulnerability in a large number of systems. The attacker must become aware of a vulnerability that many system administrators and individual users have failed to patch and that enables the attacker to install the bot software.
3. A strategy for locating and identifying vulnerable machines, a process known as **scanning** or **fingerprinting**.

In the scanning process, the attacker first seeks out a number of vulnerable machines and infects them. Then, typically, the bot software that is installed in the infected machines repeats the same scanning process, until a large distributed network of infected machines is created. [MIRK04] lists the following types of scanning strategies:

- **Random:** Each compromised host probes random addresses in the IP address space, using a different seed. This technique produces a high volume of Internet traffic, which may cause generalized disruption even before the actual attack is launched.
- **Hit-list:** The attacker first compiles a long list of potential vulnerable machines. This can be a slow process done over a long period to avoid detection that an attack is underway. Once the list is compiled, the attacker begins infecting machines on the list. Each infected machine is provided with a portion of the list to scan. This strategy results in a very short scanning period, which may make it difficult to detect that infection is taking place.
- **Topological:** This method uses information contained on an infected victim machine to find more hosts to scan.
- **Local subnet:** If a host can be infected behind a firewall, that host then looks for targets in its own local network. The host uses the subnet address structure to find other hosts that would otherwise be protected by the firewall.

Countermeasures

A number of the countermeasures discussed in this and the preceding chapter make sense against bots, including IDSs, honeypots, and digital immune systems. Once bots are activated and an attack is underway, these countermeasures can be used to detect the attack. But the primary objective is to try to detect and disable the botnet during its construction phase.

7.6 ROOTKITS

A rootkit is a set of programs installed on a system to maintain administrator (or root) access[3] to that system. Root access provides access to all the functions and services of the operating system. The rootkit alters the host's standard functionality in a malicious and stealthy way. With root access, an attacker has complete control of the system and can add or changes programs and files, monitor processes, send and receive network traffic, and get backdoor access on demand.

A rootkit can make many changes to a system to hide its existence, making it difficult for the user to determine that the rootkit is present and to identify what changes have been made. In essence, a rootkit hides by subverting the mechanisms that monitor and report on the processes, files, and registries on a computer.

Rootkits can be classified based on whether they can survive a reboot and execution mode. A rootkit may be

[3]On UNIX systems, the administrator, or *superuser*, account is called root; hence the term *root access.*

- **Persistent:** Activates each time the system boots. The rootkit must store code in a persistent store, such as the registry or file system, and configure a method by which the code executes without user intervention.
- **Memory based:** Has no persistent code and therefore cannot survive a reboot.
- **User mode:** Intercepts calls to APIs (application program interfaces) and modifies returned results. For example, when an application performs a directory listing, the return results don't include entries identifying the files associated with the rootkit.
- **Kernel mode:** Can intercept calls to native APIs in kernel mode.[4] The rootkit can also hide the presence of a malware process by removing it from the kernel's list of active processes.

Rootkit Installation

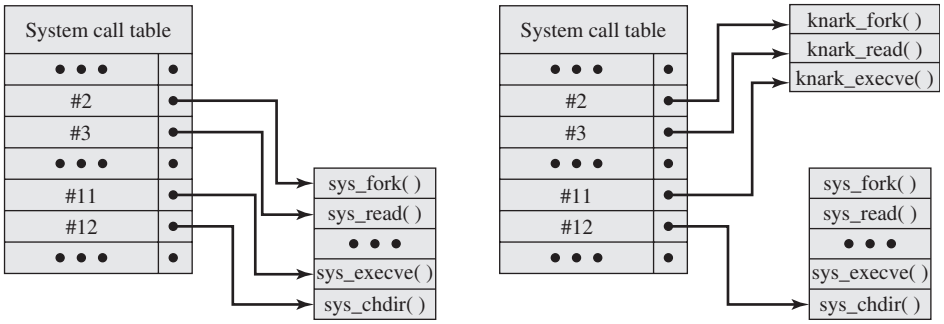
Unlike worms or bots, rootkits do not directly rely on vulnerabilities or exploits to get on a computer. One method of rootkit installation is via a Trojan horse program. The user is induced to load the Trojan horse, which then installs the rootkit. Another means of rootkit installation is by hacker activity. The following sequence is representative of a hacker attack to install a rootkit [GEER06].

1. The attacker uses a utility to identify open ports or other vulnerabilities.
2. The attacker uses password cracking, malware, or a system vulnerability to gain initial access and, eventually, root access.
3. The attacker uploads the rootkit to the victim's machine.
4. The attacker can add a virus, denial of service, or other type of attack to the rootkit's payload.
5. The attacker then runs the rootkit's installation script.
6. The rootkit replaces binaries, files, commands, or system utilities to hide its presence.
7. The rootkit listens at a port in the target server, installs sniffers or keyloggers, activates a malicious payload, or takes other steps to compromise the victim.

System-Level Call Attacks

Programs operating at the user level interact with the kernel through system calls. Thus, system calls are a primary target of kernel-level rootkits to achieve concealment. As an example of how rootkits operate, we look at the implementation of system calls in Linux. In Linux, each system call is assigned a unique *syscall number*. When a user-mode process executes a system call, the process refers to the system call by this number. The kernel maintains a system call table with one entry per system call routine; each entry contains a pointer to the corresponding routine. The syscall number serves as an index into the system call table.

[4]The kernel is the portion of the OS that includes the most heavily used and most critical portions of software. Kernel mode is a privileged mode of execution reserved for the kernel. Typically, kernel mode allows access to regions of main memory that are unavailable to processes executing in a less privileged mode and also enables execution of certain machine instructions that are restricted to the kernel mode.



(a) Normal kernel memory layout (b) After nkark install

Figure 7.9 System Call Table Modification by Rootkit
Source: Based on [LEVI06].

[LEVI06] lists three techniques that can be used to change system calls:

- **Modify the system call table:** The attacker modifies selected syscall addresses stored in the system call table. This enables the rootkit to direct a system call away from the legitimate routine to the rootkit's replacement. Figure 7.9 shows how the knark rootkit achieves this.
- **Modify system call table targets:** The attacker overwrites selected legitimate system call routines with malicious code. The system call table is not changed.
- **Redirect the system call table:** The attacker redirects references to the entire system call table to a new table in a new kernel memory location.

Countermeasures

Rootkits can be extraordinarily difficult to detect and neutralize, particularly so for kernel-level rootkits. Many of the administrative tools that could be used to detect a rootkit or its traces can be compromised by the rootkit precisely so that it is undetectable.

Countering rootkits requires a variety of network- and computer-level security tools. Both network-based and host-based intrusion detection systems can look for the code signatures of known rootkit attacks in incoming traffic. Host-based antivirus software can also be used to recognize the known signatures.

Of course, there are always new rootkits and modified versions of existing rootkits that display novel signatures. For these cases, a system needs to look for behaviors that could indicate the presence of a rootkit, such as the interception of system calls or a keylogger interacting with a keyboard driver. Such behavior detection is far from straightforward. For example, antivirus software typically intercepts system calls.

Another approach is to do some sort of file integrity check. An example of this is RootkitRevealer, a freeware package from SysInternals. The package compares the results of a system scan using APIs with the actual view of storage using instructions that do not go through an API. Because a rootkit conceals itself by modifying the view of storage seen by administrator calls, RootkitRevealer catches the discrepancy.

If a kernel-level rootkit is detected, by any means, the only secure and reliable way to recover is to do an entire new OS install on the infected machine.

7.7 RECOMMENDED READING AND WEB SITES

For a thorough understanding of viruses, the book to read is [SZOR05]. Another excellent treatment is [AYCO06]. Good overview articles on viruses and worms are [CASS01], [FORR97], [KEPH97a], and [NACH97]. [MEIN01] provides a good treatment of the Code Red worm. [WEAV03] is a comprehensive survey of worm characteristics. [HYPP06] discusses worm attacks on mobile phones.

[LEVY05] and [MCLA04] provide overviews of bots. Two useful overviews of rootkits are [LEVI06] and [GEER06]. [LEVI04] provides a more detailed description of rootkit operation.

AYCO06 Aycock, J. *Computer Viruses and Malware.* New York: Springer, 2006.

CASS01 Cass, S. "Anatomy of Malice." *IEEE Spectrum*, November 2001.

FORR97 Forrest, S.; Hofmeyr, S.; and Somayaji, A. "Computer Immunology." *Communications of the ACM*, October 1997.

GEER06 Geer, D. "Hackers Get to the Root of the Problem." *Computer*, May 2006.

HYPP06 Hypponen, M. "Malware Goes Mobile." *Scientific American*, November 2006.

KEPH97a Kephart, J.; Sorkin, G.; Chess, D.; and White, S. "Fighting Computer Viruses." *Scientific American*, November 1997.

LEVI04 Levine, J.; Grizzard, J.; and Owen, H. " A Methodology to Detect and Characterize Kernel Level Rootkit Exploits Involving Redirection of the System Call Table." *Proceedings, Second IEEE International Information Assurance Workshop*, 2004.

LEVI06 Levine, J.; Grizzard, J.; and Owen, H. "Detecting and Categorizing Kernel-Level Rootkits to Aid Future Detection." *IEEE Security and Privacy*, May-June 2005.

LEVY05 Levy, E., and Arce, I. "A Short Visit to the Bot Zoo." *IEEE Security and Privacy*, January-February 2006.

MCLA04 McLaughlin, L. "Bot Software Spreads, Causes New Worries." *IEEE Distributed Systems Online*, June 2004.

MEIN01 Meinel, C. "Code Red for the Web." *Scientific American*, October 2001.

NACH97 Nachenberg, C. "Computer Virus-Antivirus Coevolution." *Communications of the ACM*, January 1997.

SZOR05 Szor, P., *The Art of Computer Virus Research and Defense.* Reading, MA: Addison-Wesley, 2005.

WEAV03 Weaver, N., et al. "A Taxonomy of Computer Worms." *The First ACM Workshop on Rapid Malcode (WORM)*, 2003.

Recommended Web sites:

- **AntiVirus Online:** IBM's site on virus information.
- **Vmyths:** Dedicated to exposing virus hoaxes and dispelling misconceptions about real viruses.
- **VirusList:** Site maintained by commercial antivirus software provider. Good collection of useful information.

7.8 KEY TERMS, REVIEW QUESTIONS, AND PROBLEMS

Key Terms

backdoor	logic bomb	scanning
behavior-blocking software	macro virus	stealth virus
blended attack	malicious software	trapdoor
boot-sector virus	malware	Trojan horse
bot	metamorphic virus	virus
digital immune system	mobile code	worm
e-mail virus	parasitic virus	zombie
keylogging	polymorphic virus	zero-day exploit
	rootkit	

Review Questions

7.1 What is the role of compression in the operation of a virus?
7.2 What is the role of encryption in the operation of a virus?
7.3 What are typical phases of operation of a virus or worm?
7.4 What is a digital immune system?
7.5 How does behavior-blocking software work?
7.6 In general terms, how does a worm propagate?
7.7 Describe some worm countermeasures.
7.8 What is the difference between a bot and a rootkit?

Problems

7.1 There is a flaw in the virus program of Figure 7.1. What is it?

7.2 The question arises as to whether it is possible to develop a program that can analyze a piece of software to determine if it is a virus. Consider that we have a program D that is supposed to be able to do that. That is, for any program P, if we run D(P), the result returned is TRUE (P is a virus) or FALSE (P is not a virus). Now consider the following program:

```
Program CV :=
  {...
  main-program :=
         {if D(CV) then goto next:
                else infect-executable;
          }
next:
  }
```

In the preceding program, infect-executable is a module that scans memory for executable programs and replicates itself in those programs. Determine if D can correctly decide whether CV is a virus.

7.3 The point of this problem is to demonstrate the type of puzzles that must be solved in the design of malicious code and therefore, the type of mindset that one wishing to counter such attacks must adopt.

a. Consider the following C program:

```
begin
      print (*begin print (); end.*);
end
```

What do you think the program was intended to do? Does it work?

b. Answer the same questions for the following program:

```
char [] = {'0', ' ', '}', ';', 'm', 'a', 'i', 'n',
'(', ')', '{',
and so on... 't', ')', '0'};

main ()
{
   int I;
   printf(*char t[] = (*);
   for (i=0; t[i]!=0; i=i+1)
       printf("%d, ", t[i]);
   printf("%s", t);
}
```

c. What is the specific relevance of this problem to this chapter?

7.4 Consider the following fragment:

```
legitimate code
if data is Friday the 13th;
     crash_computer();
legitimate code
```

What type of malicious software is this?

7.5 Consider the following fragment in an authentication program:

```
username = read_username();
password = read_password();
if username is "133t h4ck0r"
    return ALLOW_LOGIN;
if username and password are valid
    return ALLOW_LOGIN
else return DENY_LOGIN
```

What type of malicious software is this?

7.6 The following code fragments show a sequence of virus instructions and a metamorphic version of the virus. Describe the effect produced by the metamorphic code.

Original Code	Metamorphic Code

mov eax, 5
add eax, ebx
call [eax]
	mov eax, 5
	push ecx
	pop ecx
	add eax, ebx
	swap eax, ebx
	swap ebx, eax
	call [eax]
	nop

7.7 The list of passwords used by the Morris worm is provided at this book's Web site.
- **a.** The assumption has been expressed by many people that this list represents words commonly used as passwords. Does this seem likely? Justify your answer.
- **b.** If the list does not reflect commonly used passwords, suggest some approaches that Morris may have used to construct the list.

7.8 Suggest some methods of attacking the PWC worm defense that could be used by worm creators and suggest countermeasures to these methods.