Earlier approaches to malware classification distinguished between those that need a host program, being parasitic code such as viruses, and those that are independent, self-contained programs run on the system such as worms, trojans, and bots. Another distinction used was between malware that does not replicate, such as trojans and spam e-mail, and malware that does, including viruses and worms.

Payload actions performed by malware once it reaches a target system can include corruption of system or data files; theft of service in order to make the system a zombie agent of attack as part of a botnet; theft of information from the system, especially of logins, passwords, or other personal details by keylogging or spyware programs; and stealthing where the malware hides its presence on the system from attempts to detect and block it.

While early malware tended to use a single means of propagation to deliver a single payload, as it evolved we see a growth of blended malware that incorporates a range of both propagation mechanisms and payloads that increase its ability to spread, hide, and perform a range of actions on targets. A **blended attack** uses multiple methods of infection or propagation, to maximize the speed of contagion and the severity of the attack. Some malware even support an update mechanism that allows it to change the range of propagation and payload mechanisms utilized once it is deployed.

In the following sections, we survey these various categories of malware, and then follow with a discussion of appropriate countermeasures.

Attack Kits

Initially, the development and deployment of malware required considerable technical skill by software authors. This changed with the development of virus-creation toolkits in the early 1990s, and then later of more general attack kits in the 2000s, that greatly assisted in the development and deployment of malware [FOSS10]. These toolkits, often known as **crimeware**, now include a variety of propagation mechanisms and payload modules that even novices can combine, select, and deploy.

They can also easily be customized with the latest discovered vulnerabilities in order to exploit the window of opportunity between the publication of a weakness and the widespread deployment of patches to close it. These kits greatly enlarged the population of attackers able to deploy malware. Although the malware created with such toolkits tends to be less sophisticated than that designed from scratch, the sheer number of new variants that can be generated by attackers using these toolkits creates a significant problem for those defending systems against them.

The Zeus crimeware toolkit is a prominent, recent example of such an attack kit, which was used to generate a wide range of very effective, stealthed malware that facilitates a range of criminal activities, in particular capturing and exploiting banking credentials [BINS10]. Other widely used toolkits include Blackhole, Sakura, and Phoenix [SYMA13].

Attack Sources

Another significant malware development over the last couple of decades is the change from attackers being individuals, often motivated to demonstrate their technical competence to their peers, to more organized and dangerous attack sources. These include politically motivated attackers, criminals, and organized crime; organizations that sell their services to companies and nations; and national government agencies. This has significantly changed the resources available and motivation behind the rise of malware, and indeed has led to development of a large underground economy involving the sale of attack kits, access to compromised hosts, and to stolen information.

10.2 ADVANCED PERSISTENT THREAT

Advanced Persistent Threats (APTs) have risen to prominence in recent years. These are not a new type of malware, but rather the well-resourced, persistent application of a wide variety of intrusion technologies and malware to selected targets, usually business or political. APTs are typically attributed to state-sponsored organizations, with some attacks likely from criminal enterprises as well. We discuss these categories of intruders further in Chapter 11.

APTs differ from other types of attack by their careful target selection, and persistent, often stealthy, intrusion efforts over extended periods. A number of high profile attacks, including Aurora, RSA, APT1, and Stuxnet, are often cited as examples. They are named as a result of these characteristics:

- **Advanced:** Used by the attackers of a wide variety of intrusion technologies and malware, including the development of custom malware if required. The individual components may not necessarily be technically advanced, but are carefully selected to suit the chosen target.
- **Persistent:** Determined application of the attacks over an extended period against the chosen target in order to maximize the chance of success. A variety of attacks may be progressively, and often stealthily, applied until the target is compromised.
- **Threats:** Threats to the selected targets as a result of the organized, capable, and well-funded attackers intent to compromise the specifically chosen targets. The active involvement of people in the process greatly raises the threat level from that due to automated attacks tools and the likelihood of successful attack.

The aim of these attacks varies from theft of intellectual property or security and infrastructure related data, to the physical disruption of infrastructure. Techniques used include social engineering, spear-phishing e-mails, drive-by-downloads from selected compromised Web sites likely to be visited by personnel in the target organization, to infect the target with sophisticated malware with multiple propagation mechanisms and payloads. Once they have gained initial access to systems in the target organization, a further range of attack tools are used to maintain and extend their access.

As a result, these attacks are much harder to defend against due to this specific targeting and persistence. It requires a combination of technical countermeasures, such as we discuss later in this chapter, as well as awareness training to assist personnel to resist such attacks. Even with current best-practice countermeasures, the use of zero-day exploits and new attack approaches means that some of these attacks are likely to succeed [SYMA13, MAND13]. Thus multiple layers of defense are needed, with mechanisms to detect, respond and mitigate such attacks. These may include monitoring for malware command and control traffic, and detection of exfiltration traffic.

10.3 PROPAGATION—INFECTED CONTENT—VIRUSES

The first category of malware propagation concerns parasitic software fragments that attach themselves to some existing executable content. The fragment may be machine code that infects some existing application, utility, or system program, or even the code used to boot a computer system. More recently, the fragment has been some form of scripting code, typically used to support active content within data files such as Microsoft Word documents, Excel spreadsheets, or Adobe PDF documents.

The Nature of Viruses

A computer virus is a piece of software that can "infect" other programs, or indeed any type of executable content, by modifying them. The modification includes injecting the original code with a routine to make copies of the virus code, which can then go on to infect other content.

A computer virus carries in its instructional code the recipe for making perfect copies of itself. The typical virus becomes embedded in a program, or carrier of executable content, on a computer. Then, whenever the infected computer comes into contact with an uninfected piece of code, a fresh copy of the virus passes into the new location. Thus, the infection can spread from computer to computer, aided by unsuspecting users, who exchange these programs or carrier files on disk or USB stick, or who send them to one another over a network. In a network environment, the ability to access documents, applications, and system services on other computers provides a perfect culture for the spread of such viral code.

A virus that attaches to an executable program can do anything that the program is permitted to do. It executes secretly when the host program is run. Once the virus code is executing, it can perform any function, such as erasing files and programs, that is allowed by the privileges of the current user. One reason viruses dominated the malware scene in earlier years was the lack of user authentication and access controls on personal computer systems at that time. This enabled a virus to infect any executable content on the system. The significant quantity of programs shared on floppy disk also enabled its easy, if somewhat slow, spread. The inclusion of tighter access controls on modern operating systems significantly hinders the ease of infection of such traditional, machine-executable code, viruses. This resulted in the development of macro viruses that exploit the active content supported by some document types, such as Microsoft Word or Excel files, or Adobe PDF documents. Such documents are easily modified and shared by users as part of their normal system use and are not protected by the same access controls as programs. Currently, a viral mode of infection is typically one of several propagation mechanisms used by contemporary malware, which may also include worm and Trojan capabilities.

A computer virus, and more generally many contemporary types of malware, includes one or more variants of each of these components:

- **Infection mechanism:** The means by which a virus spreads or propagates, 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, sometimes known as a **logic bomb**.
- **Payload:** What the virus does, besides spreading. The payload may involve damage or 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 that infect executable program files 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. Macro viruses, though, target specific document types, which are often supported on a variety of systems.

Executable Virus Structure Traditional machine-executable virus code can be prepended or postpended to some executable program, or it can be embedded into the program 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 10.1a. In this case, the virus code, V, is prepended to infected programs, and 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 labels the program, which then begins execution with the main action block of the virus. 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 seek out uninfected executable files and infect them. Next, the virus may execute its payload if the required trigger

```
program V
1234567;

procedure attach-to-program;
begin
    repeat
        file := get-random-program;
    until first-program-line ≠ 1234567;
    prepend V to file;
end;

procedure execute-payload;
begin
    (* perform payload actions *)
end;

procedure trigger-condition;
begin
    (* return true if trigger condition is true *)
end;

begin (* main action block *)
    attach-to-program;
    if trigger-condition then execute-payload;
    goto main;
end;
```

(a) A simple virus

```
program CV
1234567;

procedure attach-to-program;
begin
    repeat
        file := get-random-program;
    until first-program-line ≠ 1234567;
    compress file; (* $t_1$ *)
    prepend CV to file; (* $t_2$ *)
end;

procedure (* main action block *)
    if ask-permission then attach-to-program;
    uncompress rest of this file into tempfile; (* $t_3$ *)
    execute tempfile; (* $t_4$ *)
end;
```

(b) A compression virus

Figure 10.1 Example Virus Logic

conditions, if any, are met. 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 10.1b shows in general terms the logic required. The key lines in this virus are labeled with times, and Figure 10.2 illustrates the operation. We begin at time t_0, with program P'_1, which is program P_1 infected with virus CV, and a clean program P_2, which is not infected with CV. When P_1 is invoked, control passes to its virus, which performs the following steps:

t_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 CV.

t_2: A copy of CV is prepended to the compressed program.

t_3: The compressed version of the original infected program, P'_1 is uncompressed.

t_4: The uncompressed original program P_1 is executed.

In this example, the virus does nothing other than propagate. As previously mentioned, the virus may also include one or more payloads.

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

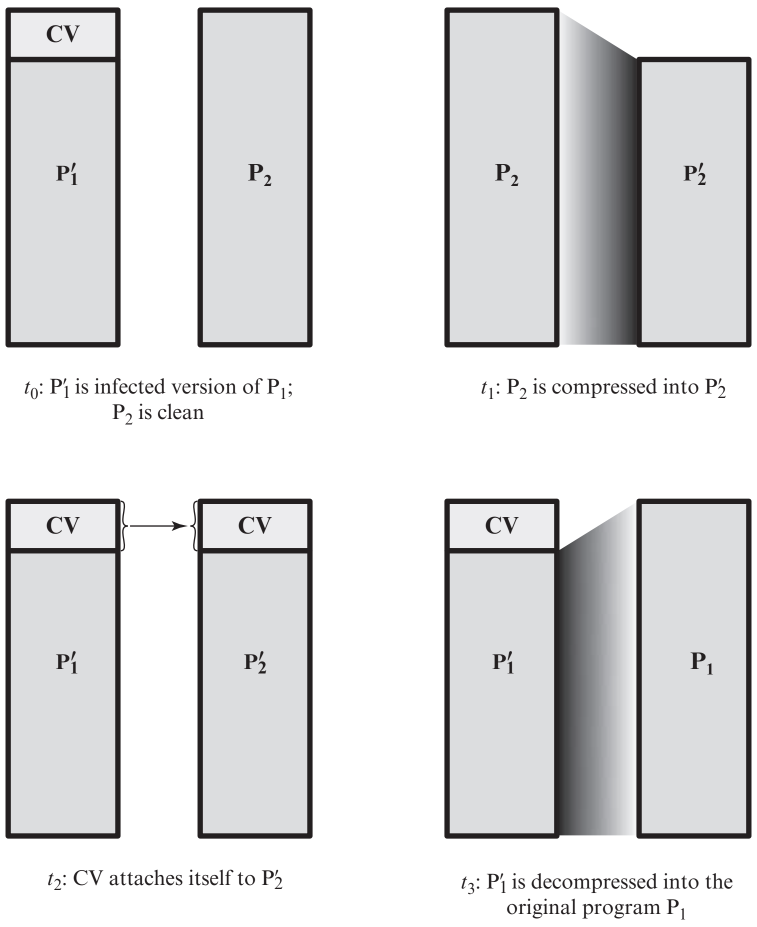
CV
P'_1
P_2
P_2
P'_2
t_0: P'_1 is infected version of P_1; P_2 is clean
t_1: P_2 is compressed into P'_2
CV
P'_1
CV
P'_2
CV
P'_1
P_1
t_2: CV attaches itself to P'_2
t_3: P'_1 is decompressed into the original program P_1

Figure 10.2 A Compression Virus

when the infected program executes, depending on the access permissions the infected program has. Thus, viral infection can be completely prevented by blocking 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.

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 or scripting code that is interpreted by an application.
- **Multipartite virus:** Infects files 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 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. It may use both code mutation, for example, compression, and rootkit techniques to achieve this.
- **Polymorphic virus:** A form of virus that creates copies during replication that are functionally equivalent but have distinctly different bit patterns, in order 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.
- **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.

Macro and Scripting Viruses

Macro viruses infect scripting code used to support active content in a variety of user document types. Macro viruses are particularly threatening for a number of reasons:

1. A macro virus is platform independent. Many macro viruses infect active content in commonly used applications, such as macros in Microsoft Word documents or other Microsoft Office documents, or scripting code in Adobe PDF

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 documents rather than programs.
3. Macro viruses are easily spread, as the documents they exploit are shared in normal use. 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, since users are expected to modify them.

Macro viruses take advantage of support for active content using a scripting or macro language, embedded in a word processing document or other type of file. Typically, users employ macros to automate repetitive tasks and thereby save keystrokes. They are also used to support dynamic content, form validation, and other useful tasks associated with these documents.

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 remove 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.

Another possible host for macro virus–style malware is in Adobe's PDF documents. These can support a range of embedded components, including Javascript and other types of scripting code. Although recent PDF viewers include measures to warn users when such code is run, the message the user is shown can be manipulated to trick them into permitting its execution. If this occurs, the code could potentially act as a virus to infect other PDF documents the user can access on his or her system. Alternatively, it can install a Trojan, or act as a worm, as we discuss later.

10.4 PROPAGATION—VULNERABILITY EXPLOIT—WORMS

A worm is a program that actively seeks out more machines to infect, and then each infected machine serves as an automated launching pad for attacks on other machines. Worm programs exploit software vulnerabilities in client or server programs to gain access to each new system. They can use network connections to spread from system to system. They can also spread through shared media, such as USB drives or optical data disks. E-mail worms spread in macro or script code included in documents attached to e-mail or to instant messenger file transfers. Upon activation, the worm may replicate and propagate again. In addition to propagation, the worm usually carries some form of payload, such as those we discuss later.

To replicate itself, a worm uses some means to access remote systems. These include the following, most of which are still seen in active use [SYMA13]:

- **Electronic mail or instant messenger facility:** A worm e-mails a copy of itself to other systems or sends itself as an attachment via an instant message service, so that its code is run when the e-mail or attachment is received or viewed.
- **File sharing:** A worm either creates a copy of itself or infects other suitable files as a virus on removable media such as a USB drive; it then executes when the drive is connected to another system using the autorun mechanism by exploiting some software vulnerability or when a user opens the infected file on the target system.
- **Remote execution capability:** A worm executes a copy of itself on another system, either by using an explicit remote execution facility or by exploiting a program flaw in a network service to subvert its operations.
- **Remote file access or transfer capability:** A worm uses a remote file access or transfer service to another system to copy itself from one system to the other, where users on that system may then execute it.
- **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 payload functions that it performs on that system, it continues to propagate.

A worm typically uses the same phases as a computer virus: dormant, propagation, triggering, and execution. The propagation phase generally performs the following functions:

- Search for appropriate access mechanisms to other systems to infect by examining host tables, address books, buddy lists, trusted peers, and other similar repositories of remote system access details; by scanning possible target host addresses; or by searching for suitable removable media devices to use.
- Use the access mechanisms found to transfer a copy of itself to the remote system and cause the copy to be run.

The worm may also attempt to determine whether a system has previously been infected before copying itself to the system. In a multiprogramming system, it can 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. More recent worms can even inject their code into existing processes on the system and run using additional threads in that process, to further disguise their presence.

Target Discovery

The first function in the propagation phase for a network worm is for it to search for other systems to infect, a process known as **scanning** or **fingerprinting**. For such worms, which exploit software vulnerabilities in remotely accessible network services, it must identify potential systems running the vulnerable service, and then infect them. Then, typically, the worm code now installed on the infected machines repeats the same scanning process, until a large distributed network of infected machines is created.

[MIRK04] lists the following types of network address scanning strategies that such a worm can use:

- **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 is 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.

Worm Propagation Model

A well-designed worm can spread rapidly and infect massive numbers of hosts. It is useful to have a general model for the rate of worm propagation. Computer viruses and worms exhibit similar self-replication and propagation behavior to biological viruses. Thus we can look to classic epidemic models for understanding computer virus and worm propagation behavior. A simplified, classic epidemic model can be expressed as follows:

$$\frac{\mathrm{d}I(t)}{\mathrm{d}t} = \beta I(t)S(t)$$

where

$I(t)$ = number of individuals infected as of time t
$S(t)$ = number of susceptible individuals (susceptible to infection but not yet infected) at time t
β = infection rate
N = size of the population, $N = I(t) + S(t)$

Figure 10.3 shows the dynamics of worm propagation using this model. Propagation proceeds through three phases. In the 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