Chapter 5:

Program Security

Many different types of programs may need to be secure programs Some common types are:

Application programs used as viewers of remote data. Programs used as viewers (such as word processors or file format viewers) are often asked to view data sent remotely by an untrusted user (this request may be automatically invoked by a web browser). Clearly, the untrusted user's input should not be allowed to cause the application to run arbitrary programs. It's usually unwise to support initialization macros (run when the data is displayed); if you must, then you must create a secure sandbox (a complex and error-prone task that almost never succeeds, which is why you shouldn't support macros in the first place). Be careful of issues such as buffer overflow which might allow an untrusted user to force the viewer to run an arbitrary program.

Application programs used by the administrator (root). Such programs shouldn't trust information that can be controlled by non-administrators.

Local servers (also called daemons).

Network-accessible servers (sometimes called network daemons).

Web-based applications (including CGI scripts). These are a special case of network-accessible servers, but they're so common they deserve their own category. Such programs are invoked indirectly via a web server, which filters out some attacks but nevertheless leaves many attacks that must be withstood.

Applets (i.e., programs downloaded to the client for automatic execution). This is something Java is especially famous for, though other languages (such as Python) support mobile code as well. There are several security viewpoints here; the implementer of the applet infrastructure on the client side has to make sure that the only operations allowed are "safe" ones, and the writer of an applet has to deal with the problem of hostile hosts (in other words, you can't normally trust the clientsetuid/setgid programs. These programs are invoked by a local user and, when executed, are immediately granted the privileges of the program's owner and/or owner's group. In many ways these are the hardest programs to secure, because so many of their inputs are under the control of the untrusted user and some of those inputs are not obvious.

Non Malicious Program Errors

Being human, programmers and other developers make many mistakes, most of which are unintentional and nonmalicious. Many such errors cause program malfunctions but do not lead to more serious security vulnerabilities. However, a few classes of errors have plagued programmers and security professionals for decades, and there is no reason to believe they will disappear. In this section we consider three classic error types that have enabled many recent security breaches. We explain each type, why it is relevant to security, and how it can be prevented or mitigated.

Buffer Overflows

A buffer overflow is the computing equivalent of trying to pour two liters of water into a one-liter pitcher: Some water is going to spill out and make a mess. And in computing, what a mess these errors have made.

A buffer (or array or string) is a space in which data can be held. A buffer resides in memory. Because memory is finite, a buffer's capacity is finite. For this reason, in many programming languages the programmer must declare the buffer's maximum size so that the compiler can set aside that amount of space.

Let us look at an example to see how buffer overflows can happen. Suppose a C language program contains the declaration:

char sample[10];

The compiler sets aside 10 bytes to store this buffer, one byte for each of the ten elements of the array, sample[0] through sample[9]. Now we execute the statement:

sample[10] = 'A';

The subscript is out of bounds (that is, it does not fall between 0 and 9), so we have a problem. The nicest outcome (from a security perspective) is for the compiler to detect the problem and mark the error during compilation. However, if the statement were

sample[i] = 'A';

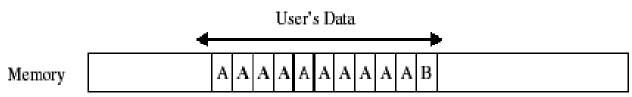
we could not identify the problem until i was set during execution to a too-big subscript. It would be useful if, during execution, the system produced an error message warning of a subscript out of bounds. Unfortunately, in some languages, buffer sizes do not have to be predefined, so there is no way to detect an out-of-bounds error. More importantly, the code needed to check each subscript against its potential maximum value takes time and space during execution, and the resources are applied to catch a problem that occurs relatively infrequently. Even if the compiler were careful in analyzing the buffer declaration and use, this same problem can be caused with pointers, for which there is no reasonable way to define a proper limit. Thus, some compilers do not generate the code to check for exceeding bounds.

Let us examine this problem more closely. It is important to recognize that the potential overflow causes a serious problem only in some instances. The problem's occurrence depends on what is adjacent to the array sample. For example, suppose each of the ten elements of the array sample is filled with the letter A and the erroneous reference uses the letter B, as follows:

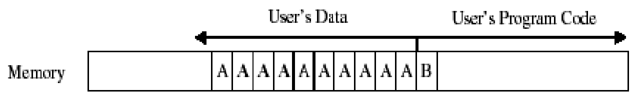
for (i=0; i<=9; i++) sample[i] = 'A';

sample[10] = 'B'

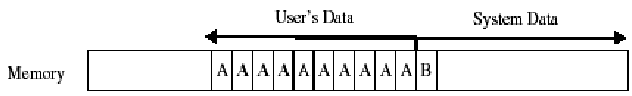
All program and data elements are in memory during execution, sharing space with the operating system, other code, and resident routines. So there are four cases to consider in deciding where the 'B' goes, as shown in Figure.



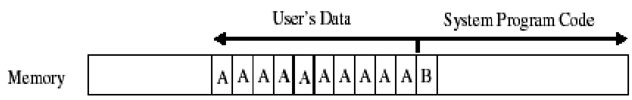
(a) Affects user's data



(b) Affects user's code



(c) Affects system data



(d) Affects system code

If the extra character overflows into the user's data space, it simply overwrites an existing variable value (or it may be written into an as-yet unused location), perhaps affecting the program's result, but affecting no other program or data.

In the second case, the 'B' goes into the user's program area. If it overlays an already executed instruction (which will not be executed again), the user should perceive no effect. If it overlays an instruction that is not yet executed, the machine will try to execute an instruction with operation code 0x42, the internal code for the character 'B'. If there is no instruction with operation code 0x42, the system will halt on an illegal instruction exception. Otherwise, the machine will use subsequent bytes as if they were the rest of the instruction, with success or failure depending on the meaning of the contents. Again, only the user is likely to experience an effect.

Note: This document is for reference purpose.

The most interesting cases occur when the system owns the space immediately after the array that overflows. Spilling over into system data or code areas produces similar results to those for the user's space: computing with a faulty value or trying to execute an improper operation.

Incomplete Mediation

Consider the example of the previous section:

http://www.somesite.com/subpage/userinput&parm1=(808)555-1212&parm2=2004Jan01
The two parameters look like a telephone number and a date. Probably the client's (user's) web browser enters those two values in their specified format for easy processing on the server's side. What would happen if parm2 were submitted as 1800Jan01? Or 1800Feb30? Or 2048Min32? Or 1Aardvark2Many?

Something would likely fail. As with buffer overflows, one possibility is that the system would fail catastrophically, with a routine's failing on a data type error as it tried to handle a month named "Min" or even a year (like 1800) which was out of range. Another possibility is that the receiving program would continue to execute but would generate a very wrong result. (For example, imagine the amount of interest due today on a billing error with a start date of 1 Jan 1800.) Then again, the processing server might have a default condition, deciding to treat 1Aardvark2Many as 3 July 1947. The possibilities are endless.

One way to address the potential problems is to try to anticipate them. For instance, the programmer in the examples above may have written code to check for correctness on the client's side (that is, the user's browser). The client program can search for and screen out errors. Or, to prevent the use of nonsense data, the program can restrict choices only to valid ones. For example, the program supplying the parameters might have solicited them by using a drop-down box or choice list from which only the twelve conventional months would have been possible choices. Similarly, the year could have been tested to ensure that the value was between 1995 and 2005, and date numbers would have to have been appropriate for the months in which they occur (no 30th of February, for example). Using these verification techniques, the programmer may have felt well insulated from the possible problems a careless or malicious user could cause.

However, the program is still vulnerable. By packing the result into the return URL, the programmer left these data fields in a place accessible to (and changeable by) the user. In particular, the user could edit the URL line, change any parameter values, and resend the line. On the server side, there is no way for the server to tell if the response line came from the client's browser or as a result of the user's editing the URL directly. We say in this case that the data values are not completely mediated: The sensitive data (namely, the parameter values) are in an exposed, uncontrolled condition.

Time-of-Check to Time-of-Use Errors

The third programming flaw we investigate involves synchronization. To improve efficiency, modern processors and operating systems usually change the order in which instructions and procedures are executed. In particular, instructions that appear to be adjacent may not actually be executed immediately after each other, either because of intentionally changed order or because of the effects of other processes in concurrent execution.

Access control is a fundamental part of computer security; we want to make sure that only those who should access an object are allowed that access. (We explore the access control mechanisms in operating systems in greater detail in Chapter 4.) Every requested access must be governed by an access policy stating who is allowed access to what; then the request must be mediated by an access policy enforcement agent. But an incomplete mediation problem occurs when access is not checked universally. The time-of-check to time-of-use (TOCTTOU) flaw concerns mediation that is performed with a "bait and switch" in the middle. It is also known as a serialization or synchronization flaw.

To understand the nature of this flaw, consider a person's buying a sculpture that costs $100. The buyer removes five $20 bills from a wallet, carefully counts them in front of the seller, and lays them on the table. Then the seller turns around to write a receipt. While the seller's back is turned, the buyer takes back one $20 bill. When the seller turns around, the buyer hands over the stack of bills, takes the receipt, and leaves with the sculpture. Between the time when the security was checked (counting the bills) and the access (exchanging the sculpture for the bills), a condition changed: what was checked is no longer valid when the object (that is, the sculpture) is accessed.

A similar situation can occur with computing systems. Suppose a request to access a file were presented as a data structure, with the name of the file and the mode of access presented in the structure. An example of such a structure is shown in Figure

my_file	change byte 4 to "A"

Figure: Data Structure for File Access

The data structure is essentially a "work ticket," requiring a stamp of authorization; once authorized, it will be put on a queue of things to be done. Normally the access control mediator receives the data structure, determines whether the access should be allowed, and either rejects the access and stops or allows the access and forwards the data structure to the file handler for processing.

To carry out this authorization sequence, the access control mediator would have to look up the file name (and the user identity and any other relevant parameters) in tables. The mediator could compare the names in the table to the file name in the data structure to determine whether access is appropriate. More likely, the mediator would copy the file name into its own local storage area and compare from there. Comparing from the copy leaves the data structure in the user's area, under the user's control.

It is at this point that the incomplete mediation flaw can be exploited. While the mediator is checking access rights for the file my_file, the user could change the file name descriptor to your_file, the value shown in figure.

my_file	change byte 4 to "A"

Figure: Modified Data

Having read the work ticket once, the mediator would not be expected to reread the ticket before approving it; the mediator would approve the access and send the now-modified descriptor to the file handler.

The problem is called a time-of-check to time-of-use flaw because it exploits the delay between the two times. That is, between the time the access was checked and the time the result of the check was used, a change occurred, invalidating the result of the check.

VIRUSES AND OTHER MALICIOUS CODE

By themselves, programs are seldom security threats. The programs operate on data, taking action only when data and state changes trigger it. Much of the work done by a program is invisible to users, so they are not likely to be aware of any malicious activity. For instance, when was the last time you saw a bit? Do you know in what form a document file is stored? If you know a document resides somewhere on a disk, can you find it? Can you tell if a game program does anything in addition to its expected interaction with you? Which files are modified by a word processor when you create a document? Most users cannot answer these questions. However, since computer data are not usually seen directly by users, malicious people can make programs serve as vehicles to access and change data and other programs. Let us look at the possible effects of malicious code and then examine in detail several kinds of programs that can be used for interception or modification of data.

Malicious code or a rogue program is the general name for unanticipated or undesired effects in programs or program parts, caused by an agent intent on damage. This definition eliminates unintentional errors, although they can also have a serious negative effect. This definition also excludes coincidence, in which two benign programs combine for a negative effect. The agent is the writer of the program or the person who causes its distribution. By this definition, most faults found in software inspections, reviews, and testing do not qualify as malicious code, because we think of them as unintentional. However, keep in mind as you read this chapter that unintentional faults can in fact invoke the same responses as intentional malevolence; a benign cause can still lead to a disastrous effect.

You are likely to have been affected by a virus at one time or another, either because your computer was infected by one or because you could not access an infected system while its administrators were cleaning up the mess one made. In fact, your virus might actually have been a worm: The terminology of malicious code is sometimes used imprecisely. A virus is a program that can pass on malicious code to other nonmalicious programs by modifying them. The term "virus" was coined because the affected program acts like a biological virus: It infects other healthy subjects by attaching itself to the program and either destroying it or coexisting with it. Because viruses are insidious, we cannot assume that a clean program yesterday is still clean today. Moreover, a good program can be modified to include a copy of the virus program, so the infected good program itself begins to act as a virus, infecting other programs. The infection usually spreads at a geometric rate, eventually overtaking an entire computing system and spreading to all other connected systems.

A virus can be either transient or resident. A transient virus has a life that depends on the life of its host; the virus runs when its attached program executes and terminates when its attached program ends. (During its execution, the transient virus may have spread its infection to other programs.) A resident virus locates itself in memory; then it can remain active or be activated as a stand-alone program, even after its attached program ends.

A Trojan horse is malicious code that, in addition to its primary effect, has a second, nonobvious malicious effect.1 As an example of a computer Trojan horse,

A logic bomb is a class of malicious code that "detonates" or goes off when a specified condition occurs. A time bomb is a logic bomb whose trigger is a time or date.

A trapdoor or backdoor is a feature in a program by which someone can access the program other than by the obvious, direct call, perhaps with special privileges. For instance, an automated bank teller program might allow anyone entering the number 990099 on the keypad to process the log of everyone's transactions at that machine. In this example, the trapdoor could be intentional, for maintenance purposes, or it could be an illicit way for the implementer to wipe out any record of a crime.

A worm is a program that spreads copies of itself through a network. The primary difference between a worm and a virus is that a worm operates through networks, and a virus can spread through any medium (but usually uses copied program or data files). Additionally, the worm spreads copies of itself as a stand-alone program, whereas the virus spreads copies of itself as a program that attaches to or embeds in other programs.

Note: This document is for reference purpose.

Types of Malicious Code.

Code Type	**Characteristics**
Virus	Attaches itself to program and propagates copies of itself to other programs
Trojan horse	Contains unexpected, additional functionality
Logic bomb	Triggers action when condition occurs
Time bomb	Triggers action when specified time occurs
Trapdoor	Allows unauthorized access to functionality
Worm	Propagates copies of itself through a network
Rabbit	Replicates itself without limit to exhaust resource

How Viruses Attach

A printed copy of a virus does nothing and threatens no one. Even executable virus code sitting on a disk does nothing. What triggers a virus to start replicating? For a virus to do its malicious work and spread itself, it must be activated by being executed. Fortunately for virus writers, but unfortunately for the rest of us, there are many ways to ensure that programs will be executed on a running computer.

For example, recall the SETUP program that you initiate on your computer. It may call dozens or hundreds of other programs, some on the distribution medium, some already residing on the computer, some in memory. If any one of these programs contains a virus, the virus code could be activated. Let us see how. Suppose the virus code were in a program on the distribution medium, such as a CD; when executed, the virus could install itself on a permanent storage medium (typically, a hard disk), and also in any and all executing programs in memory. Human intervention is necessary to start the process; a human being puts the virus on the distribution medium, and perhaps another initiates the execution of the program to which the virus is attached. (It is possible for execution to occur without human intervention, though, such as when execution is triggered by a date or the passage of a certain amount of time.) After that, no human intervention is needed; the virus can spread by itself.

A more common means of virus activation is as an attachment to an e-mail message. In this attack, the virus writer tries to convince the victim (the recipient of an e-mail message) to open the attachment. Once the viral attachment is opened, the activated virus can do its work. Some modern e-mail handlers, in a drive to "help" the receiver (victim), will automatically open attachments as soon as the receiver opens the body of the e-mail message. The virus can be executable code embedded in an executable attachment, but other types of files are equally dangerous. For example, objects such as graphics or photo images can contain code to be executed by an editor, so they can be transmission agents for viruses. In general, it is safer to force users to open files on their own rather than automatically; it is a bad idea for programs to perform potentially security-relevant actions without a user's consent.

Appended Viruses

A program virus attaches itself to a program; then, whenever the program is run, the virus is activated. This kind of attachment is usually easy to program.

In the simplest case, a virus inserts a copy of itself into the executable program file before the first executable instruction. Then, all the virus instructions execute first; after the last virus instruction, control flows naturally to what used to be the first program instruction. Such a situation is shown in Figure.

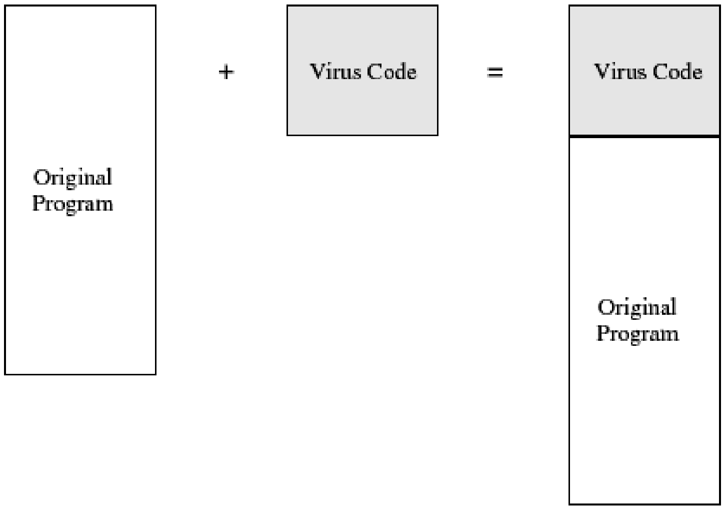


Figure: Virus Appended to a Program.

This kind of attachment is simple and usually effective. The virus writer does not need to know anything about the program to which the virus will attach, and often the attached program simply serves as a carrier for the virus. The virus performs its task and then transfers to the original program. Typically, the user is unaware of the effect of the virus if the original program still does all that it used to. Most viruses attach in this manner.

Viruses That Surround a Program

An alternative to the attachment is a virus that runs the original program but has control before and after its execution. For example, a virus writer might want to prevent the virus from being detected. If the virus is stored on disk, its presence will be given away by its file name, or its size will affect the amount of space used on the disk. The virus writer might arrange for the virus to attach itself to the program that constructs the listing of files on the disk. If the virus regains control after the listing program has generated the listing but before the listing is displayed or printed, the virus could eliminate its entry from the listing and falsify space counts so that it appears not to exist. A surrounding virus is shown in Figure.

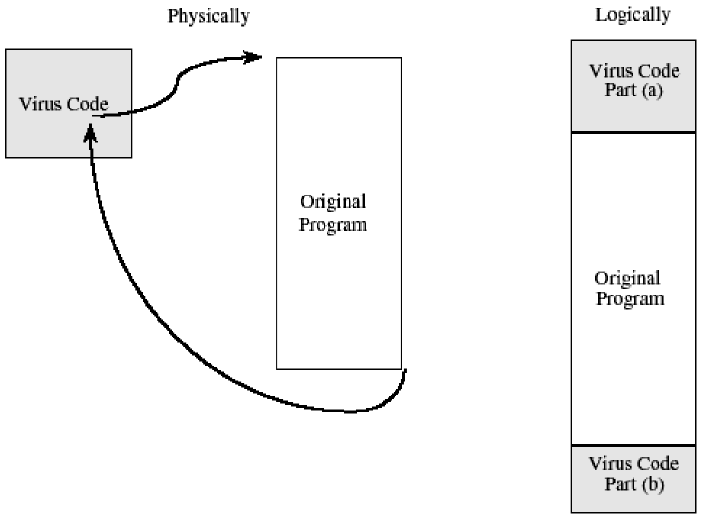


Figure: Virus Surrounding a Program.

Integrated Viruses and Replacements

A third situation occurs when the virus replaces some of its target, integrating itself into the original code of the target. Such a situation is shown in Figure. Clearly, the virus writer has to know the exact structure of the original program to know where to insert which pieces of the virus.

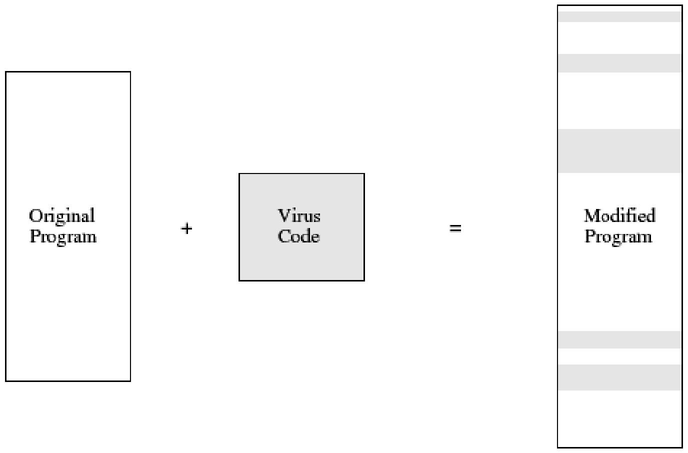


Figure: Virus Integrated into a Program.

Finally, the virus can replace the entire target, either mimicking the effect of the target or ignoring the expected effect of the target and performing only the virus effect. In this case, the user is most likely to perceive the loss of the original program.

Note: This document is for reference purpose.

Types of Viruses:

Document Viruses

Currently, the most popular virus type is what we call the document virus, which is implemented within a formatted document, such as a written document, a database, a slide presentation, or a spreadsheet. These documents are highly structured files that contain both data (words or numbers) and commands (such as formulas, formatting controls, links). The commands are part of a rich programming language, including macros, variables and procedures, file accesses, and even system calls. The writer of a document virus uses any of the features of the programming language to perform malicious actions.

The ordinary user usually sees only the content of the document (its text or data), so the virus writer simply includes the virus in the commands part of the document, as in the integrated program virus.

Boot Sector Viruses

A special case of virus attachment, but formerly a fairly popular one, is the so-called boot sector virus. When a computer is started, control begins with firmware that determines which hardware components are present, tests them, and transfers control to an operating system. A given hardware platform can run many different operating systems, so the operating system is not coded in firmware but is instead invoked dynamically, perhaps even by a user's choice, after the hardware test.

The operating system is software stored on disk. Code copies the operating system from disk to memory and transfers control to it; this copying is called the bootstrap (often boot) load because the operating system figuratively pulls itself into memory by its bootstraps. The firmware does its control transfer by reading a fixed number of bytes from a fixed location on the disk (called the boot sector) to a fixed address in memory and then jumping to that address (which will turn out to contain the first instruction of the bootstrap loader). The bootstrap loader then reads into memory the rest of the operating system from disk. To run a different operating system, the user just inserts a disk with the new operating system and a bootstrap loader. When the user reboots from this new disk, the loader there brings in and runs another operating system. This same scheme is used for personal computers, workstations, and large mainframes.

To allow for change, expansion, and uncertainty, hardware designers reserve a large amount of space for the bootstrap load. The boot sector on a PC is slightly less than 512 bytes, but since the loader will be larger than that, the hardware designers support "chaining," in which each block of the bootstrap is chained to (contains the disk location of) the next block. This chaining allows big bootstraps but also simplifies the installation of a virus. The virus writer simply breaks the chain at any point, inserts a pointer to the virus code to be executed, and reconnects the chain after the virus has been installed. This situation is shown in figure.

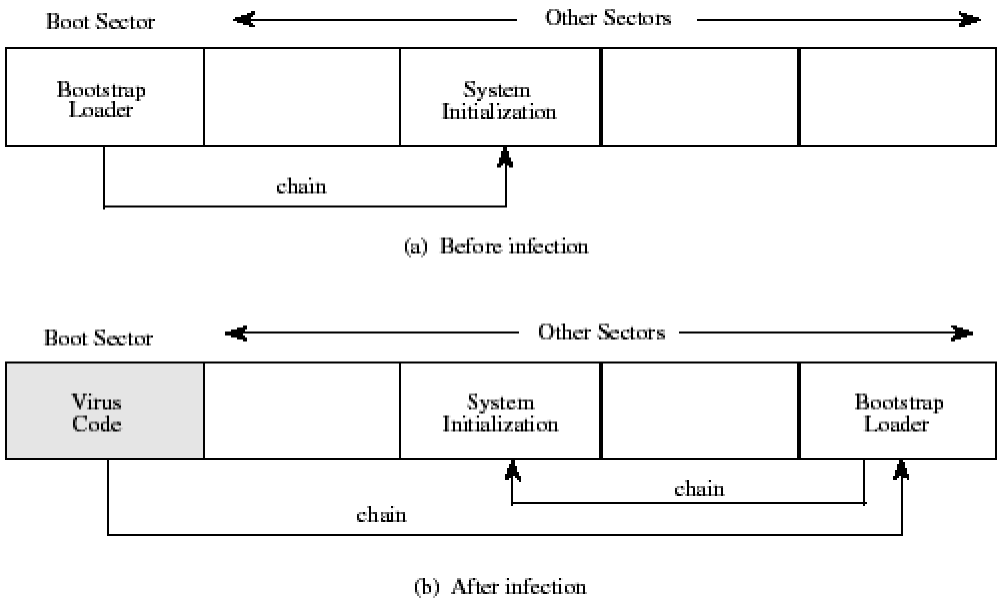


Figure: Boot Sector Viruses

he boot sector is an especially appealing place to house a virus. The virus gains control very early in the boot process, before most detection tools are active, so that it can avoid, or at least complicate, detection. The files in the boot area are crucial parts of the operating system. Consequently, to keep users from accidentally modifying or deleting them with disastrous results, the operating system makes them "invisible" by not showing them as part of a normal listing of stored files, preventing their deletion. Thus, the virus code is not readily noticed by users.

Memory-Resident Viruses

Some parts of the operating system and most user programs execute, terminate, and disappear, with their space in memory being available for anything executed later. For very frequently used parts of the operating system and for a few specialized user programs, it would take too long to reload the program each time it was needed. Such code remains in memory and is called "resident" code. Examples of resident code are the routine that interprets keys pressed on the keyboard, the code that handles error conditions that arise during a program's execution, or a program that acts like an alarm clock, sounding a signal at a time the user determines. Resident routines are sometimes called TSRs or "terminate and stay resident" routines.

Virus writers also like to attach viruses to resident code because the resident code is activated many times while the machine is running. Each time the resident code runs, the virus does too. Once activated, the virus can look for and infect uninfected carriers. For example, after activation, a boot sector virus might attach itself to a piece of resident code. Then, each time the virus was activated it might check whether any removable disk in a disk drive was infected and, if not, infect it. In this way the virus could spread its infection to all removable disks used during the computing session.

Attack mechanism of viruses

The virus (V) has to be invoked instead of the target (T). Essentially, the virus either has to seem to be T, saying effectively "I am T" (like some rock stars, where the target is the artiste formerly known as T) or the virus has to push T out of the way and become a substitute for T, saying effectively "Call me instead of T." A more blatant virus can simply say "invoke me [you fool]." The virus can assume T's name by replacing (or joining to) T's code in a file structure; this invocation technique is most appropriate for ordinary programs. The virus can overwrite T in storage (simply replacing the copy of T in storage, for example). Alternatively, the virus can change the pointers in the file table so that the virus is located instead of T whenever T is accessed through the file system. These two cases are shown in figure.

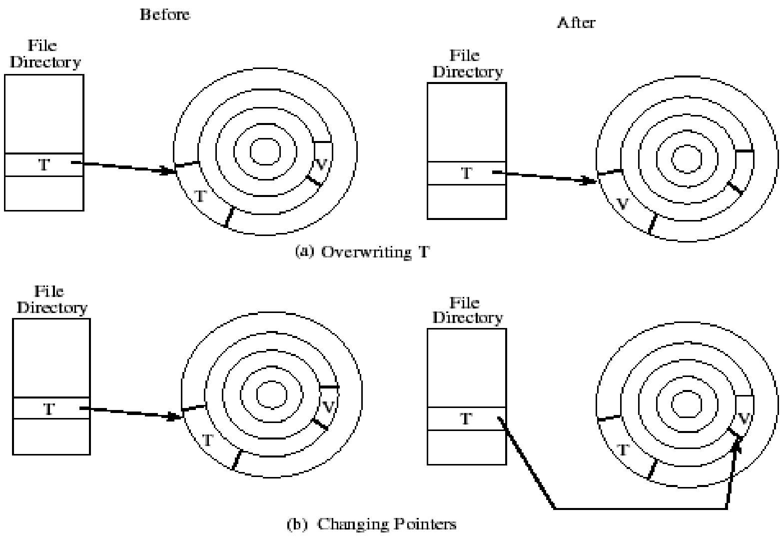


Figure Virus Completely Replacing a Program.

The virus can supplant T by altering the sequence that would have invoked T to now invoke the virus V; this invocation can be used to replace parts of the resident operating system by modifying pointers to those resident parts, such as the table of handlers for different kinds of interrupts.