01074305 Computer Security

Chapter 3

Program Security

Charles P. Pfleeger & Shari Lawrence Pfleeger, Security in Computing, 4th Ed., Pearson Education, 2007

- **In this chapter**
  - Programming errors with security implications: buffer overflows, incomplete access control
  - Malicious code: viruses, worms, Trojan horses
  - Program development controls against malicious code and vulnerabilities: software engineering principles and practices
  - Controls to protect against program flaws in execution: operating system support and administrative controls

3.1. Secure Programs

- Security implies some degree of trust that the program enforces expected confidentiality, integrity, and availability
- An assessment of security can also be influenced by someone's general perspective on software quality
  - E.g., if your manager's idea of quality is conformance to specifications, then she might consider the code secure if it meets security requirements, whether or not the requirements are complete or correct.

- **IEEE Terminology for Quality**
  - A **bug** can be a mistake in interpreting a requirement, a syntax error in a piece of code, or the (as-yet-unknown) cause of a system crash.
  - When a human makes a mistake, called an **error**, in performing some software activity, the error may lead to a **fault**, or an incorrect step, command, process, or data definition in a computer program.
  - A **failure** is a departure from the system's required behavior.
  - a fault is an inside view of the system, as seen by the eyes of the developers, whereas a failure is an outside view: a problem that the user sees.

- **Fixing Faults**
  - A module in which 100 faults were discovered and fixed is better than another in which only 20 faults were discovered and fixed, suggesting that more rigorous analysis and testing had led to the finding of the larger number of faults (?)
  - Early work in computer security was based on the paradigm of "**penetrate and patch**," in which analysts searched for and repaired faults.

- **Fixing Faults (Cont'd)**
  - However, the patch efforts were largely useless, making the system less secure rather than more secure because they frequently introduced *new* faults.
    - The pressure to repair a specific problem encouraged a narrow focus on the fault itself and not on its context.
    - The fault often had nonobvious side effects in places other than the immediate area of the fault.
    - Fixing one problem often caused a failure somewhere else
    - The fault could not be fixed properly because system functionality or performance would suffer as a consequence

- **Unexpected Behavior**
  - To understand program security, we can examine programs to see whether they behave as their designers intended or users expected.
  - Such unexpected behavior a **program security flaw**; it is inappropriate program behavior caused by a program vulnerability.
  - Program security flaws can derive from any kind of software fault
  - Divide program flaws into two separate logical categories: **inadvertent human errors** versus **malicious, intentionally induced flaws**.

- Regrettably, we do not have techniques to eliminate or address all program security flaws.
- Security *is* fundamentally hard, security often conflicts with usefulness and performance, there is no ""silver bullet" to achieve security effortlessly, and false security solutions impede real progress toward more secure programming

- There are two reasons for this distressing situation.
  1. Program controls apply at the level of the individual program and programmer.
  2. Programming and software engineering techniques change and evolve far more rapidly than do computer security techniques.

- **Types of Flaws**
  - *validation* error (incomplete or inconsistent): permission checks
  - *domain* error: controlled access to data
  - *serialization* and *aliasing*: program flow order
  - inadequate *identification and authentication*: basis for authorization
  - *boundary condition* violation: failure on first or last case
  - other exploitable *logic errors*

3.2. Nonmalicious Program Errors

- **Buffer Overflows**
  - A buffer (or array or string) is a space in which data can be held.
  - A buffer's capacity is finite.

- Suppose a C language program contains the declaration:

```
char sample[10];
```

- Now we execute the statement:

```
sample[10] = 'B';
```

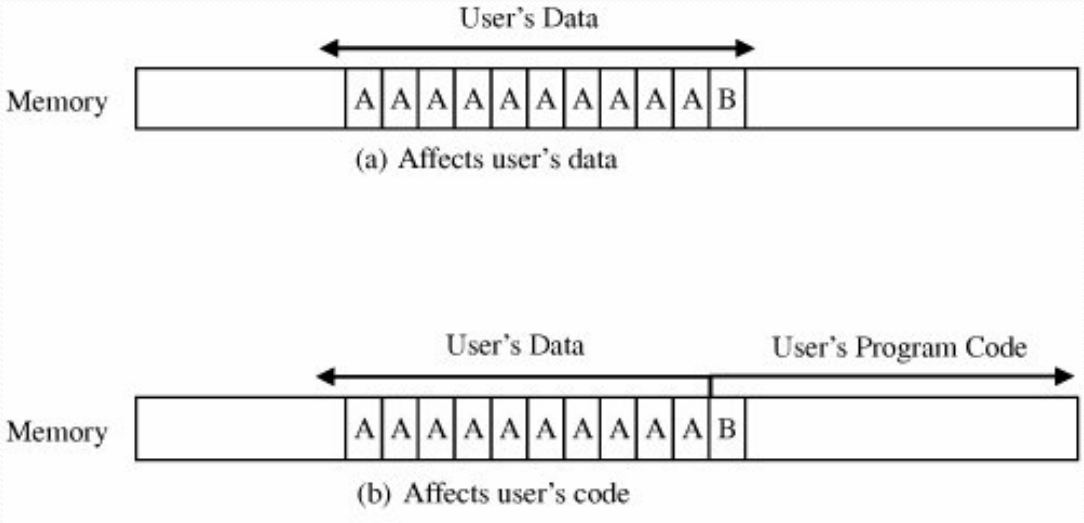
- However, if the statement were

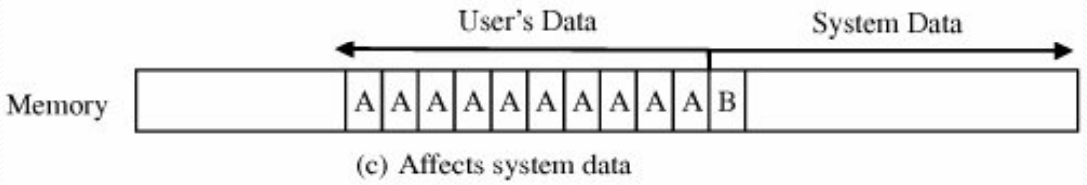
```
sample[i] = 'B';
```

we could not identify the problem until i was set during execution to a too-big subscript.

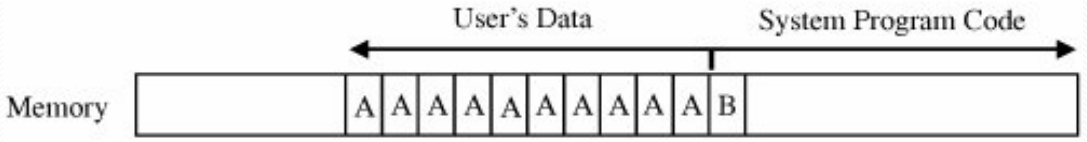
- Suppose each of the ten elements of the array sample is filled with the letter A and the erroneous reference uses the letter B, as follows:

```
for (i=0; i<=9; i++)
      sample[i] = 'A';
sample[10] = 'B‘;
```



(c) Affects system data



(d) Affects system code

- **Security Implication**
  - Two buffer overflow attacks that are used frequently
    1. The attacker may replace code in the system space. By replacing a few instructions right after returning from his or her own procedure, the attacker regains control from the operating system, possibly with raised privileges.
    2. On the other hand, the attacker may make use of the stack pointer or the return register. Subprocedure calls are handled with a stack, a data structure in which the most recent item inserted is the next one removed (last arrived, first served).

- An alternative style of buffer overflow occurs when parameter values are passed into a routine, especially when the parameters are passed to a web server on the Internet. Parameters are passed in the URL line, with a syntax similar to

```
http://www.somesite.com/subpage/userinput.asp?
parm1=(808)555-1212 &parm2=2009Jan17
```

The attacker might question what the server would do with a really long telephone number, say, one with 500 or 1000 digits.

- **Incomplete Mediation**
  - Consider the example

```
http://www.somesite.com/subpage/userinput.asp?
parm1=(808)555-1212 &parm2=2009Jan17
```

  - What would happen if parm2 were submitted as 1800Jan01? Or 1800Feb30? Or 2048Min32? Or 1Aardvark2Many?

- Security Implication
  - Consider this example

```
http://www.things.com/order.asp?custID=101&part=555A&q
y=20&price =10&ship=boat&shipcost=5&total=205
```

  - A malicious attacker may decide to exploit this peculiarity by supplying instead the following URL, where the price has been reduced from $205 to $25:

```
http://www.things.com/order.asp?custID=101&part=555A&q
y=20&price =1&ship=boat&shipcost=5&total=25
```


- **Time-of-Check to Time-of-Use Errors**
  - 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.

- **Time-of-Check to Time-of-Use Errors (Cont'd)**
  - 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.

my_file	change byte 4 to "A"

  - To carry out this authorization sequence, the access control mediator would have to look up the file name 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**

- **Time-of-Check to Time-of-Use Errors (Cont'd)**
  - While the mediator is checking access rights for the file my_file, the user could change the file name descriptor to your_file

your_file	delete file

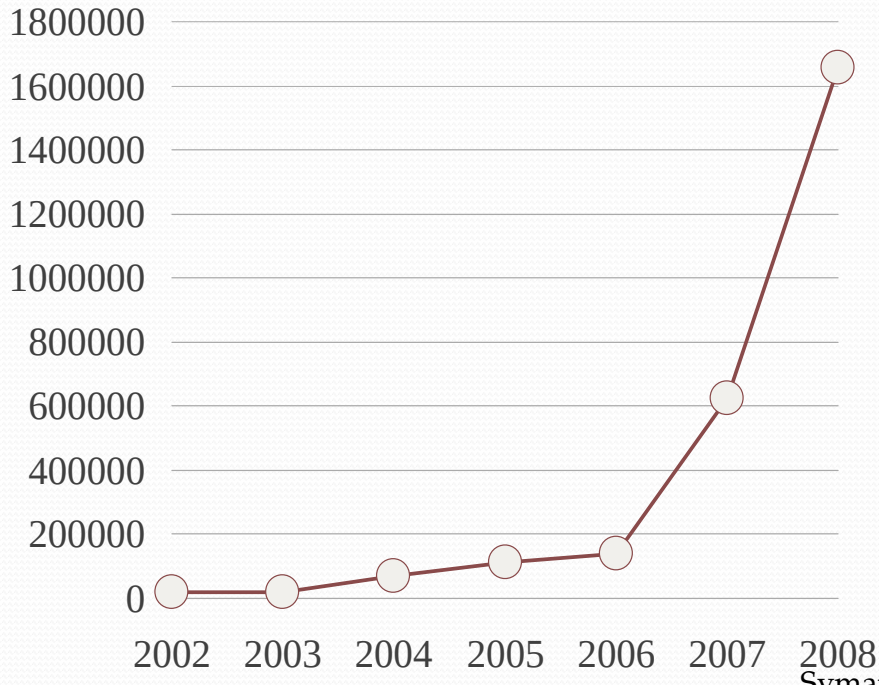
  - The problem is called a time-of-check to time-of-use flaw because **it exploits the delay between the two times**. That is, between the time the access was checked and the time the result of the check was used, a change occurred, invalidating the result of the check.

- Security Implication
  - Pretty clear
  - Checking one action and performing another is an example of ineffective access control
  - There are ways to prevent exploitation of the time lag.
    - One way is to ensure that critical parameters are not exposed during any loss of control.
    - Another way is to ensure serial integrity; that is, to allow no interruption (loss of control) during the validation.

3.3. Viruses and Other Malicious Code

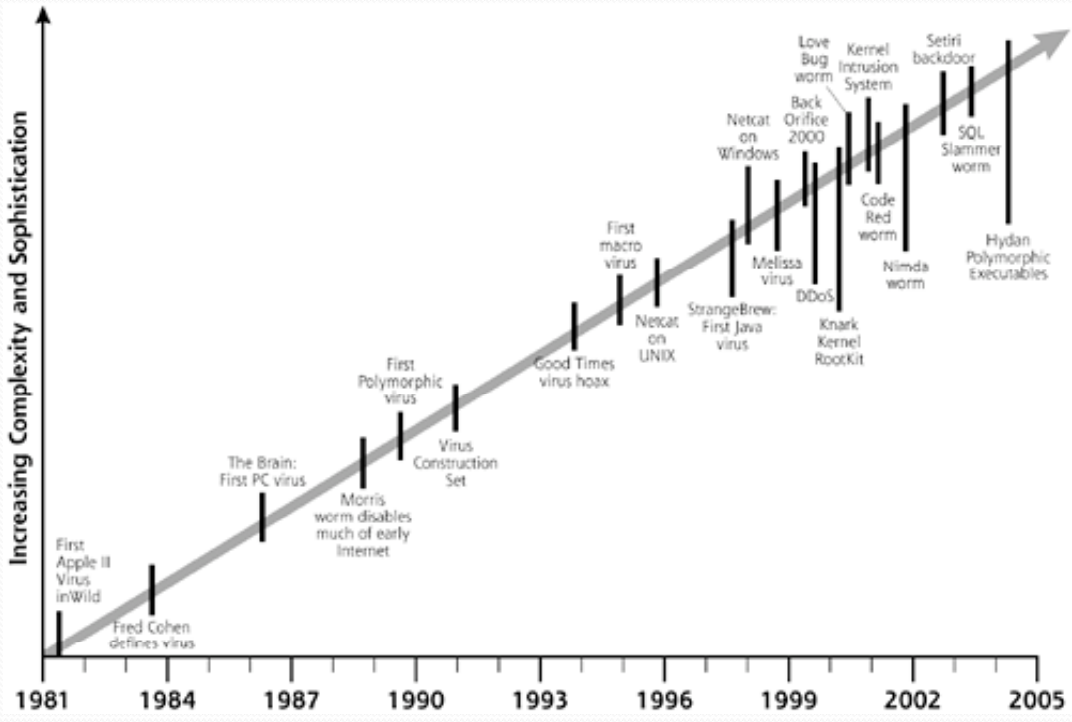
- **Malicious Code Can Do Much (Harm)**
  - Malicious code runs under the user's authority.
  - Thus, malicious code can touch everything the user can touch, and in the same ways.
  - Users typically have complete control over their own program code and data files; they can read, write, modify, append, and even delete them.
  - But malicious code can do the same, without the user's permission or even knowledge.

Number of malware signatures



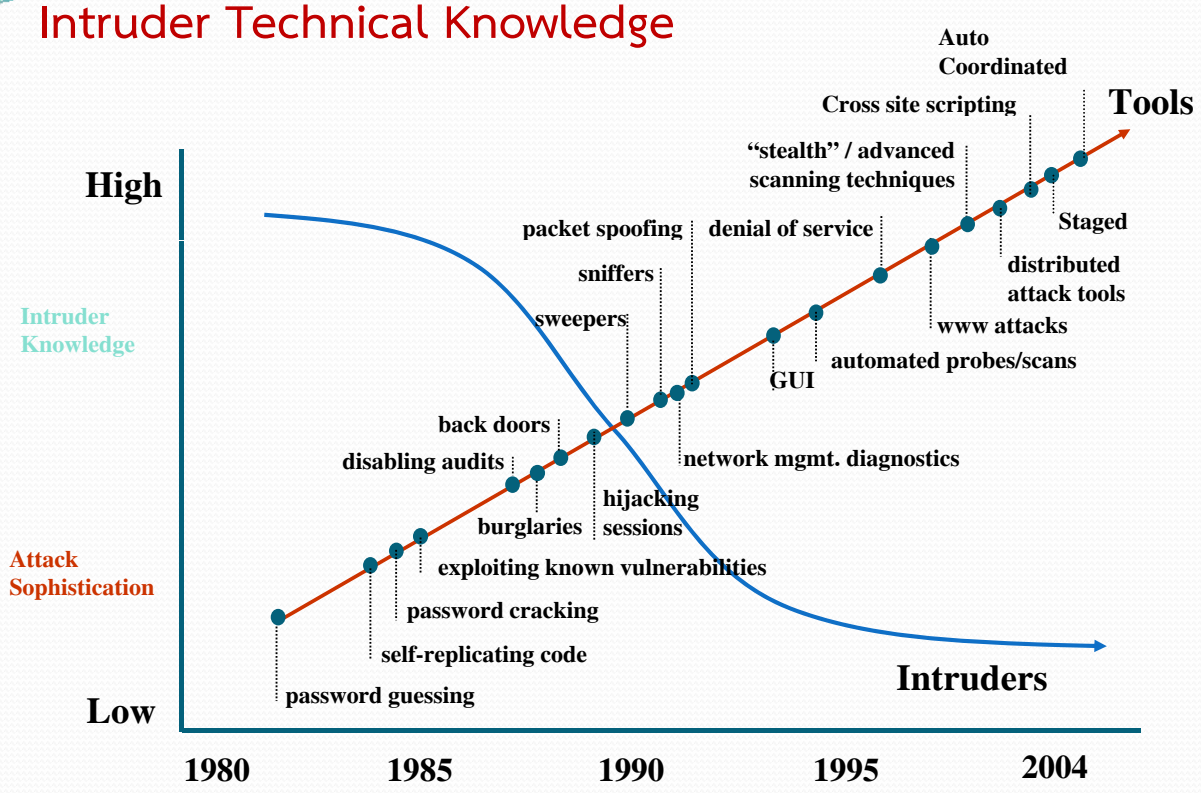
Symantec report 2009

Almost 30 years of Malware



From Malware fighting malicious code

Attack Sophistication vs. Intruder Technical Knowledge

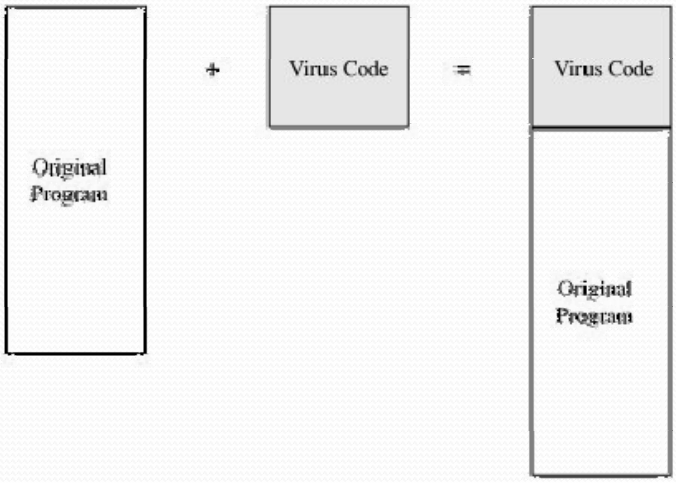


- Kinds of Malicious Code
  - **Malicious code** or **rogue program** is the general name for unanticipated or undesired effects in programs or program parts, caused by an agent intent on damage.
  - A **virus** is a program that can replicate itself and pass on malicious code to other nonmalicious programs by modifying them.
    - A **transient virus** has a life that depends on the life of its host
    - A **resident virus** locates itself in memory

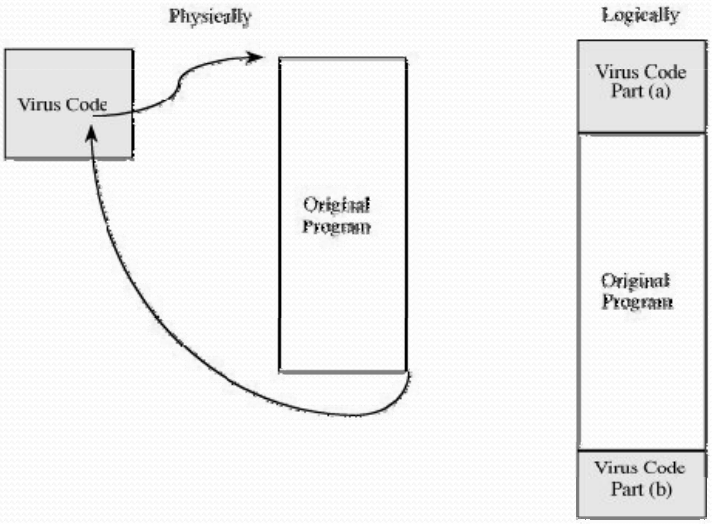
- Kinds of Malicious Code (Cont'd)
  - A **Trojan horse** is malicious code that, in addition to its primary effect, has a second, nonobvious malicious effect
  - A **logic bomb** is a class of malicious code that "detonates" or goes off when a specified condition occurs.
  - A **time bomb** is a logic 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

- Kinds of Malicious Code (Cont'd)
  - A **worm** is a program that spreads copies of itself through a network.
  - A **rabbit** is a virus or worm that self-replicates without bound, with the intention of exhausting some computing resource.

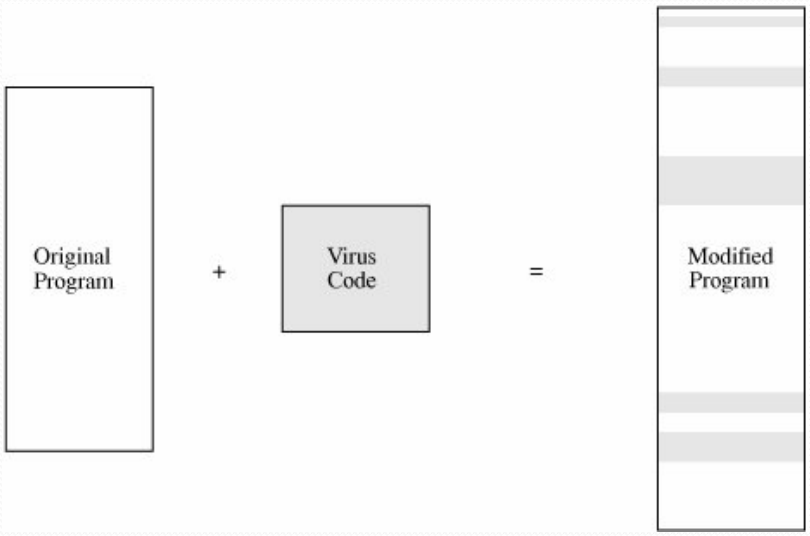
- How Viruses Attach
  - Appended Viruses



- How Viruses Attach (Cont'd)
  - Viruses That Surround a Program

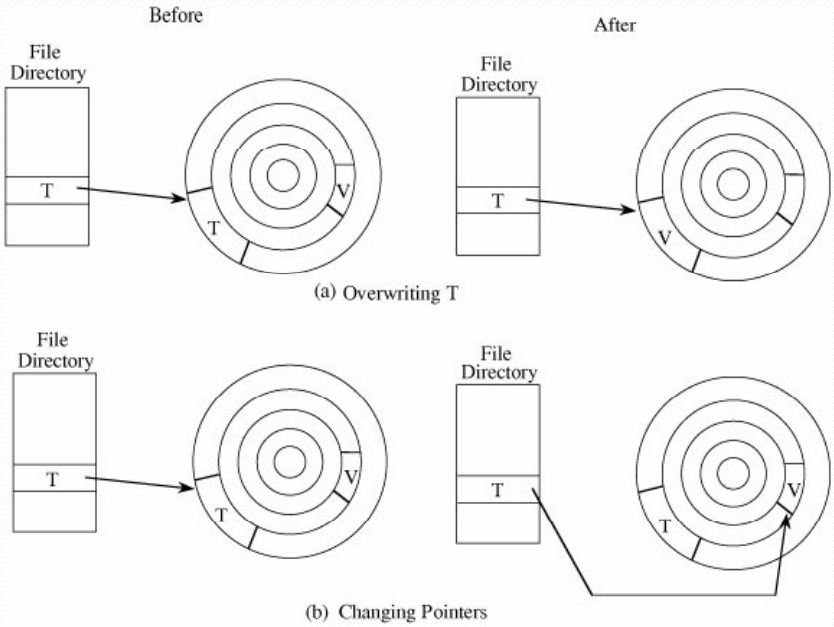


- How Viruses Attach (Cont'd)
  - Integrated Viruses and Replacements

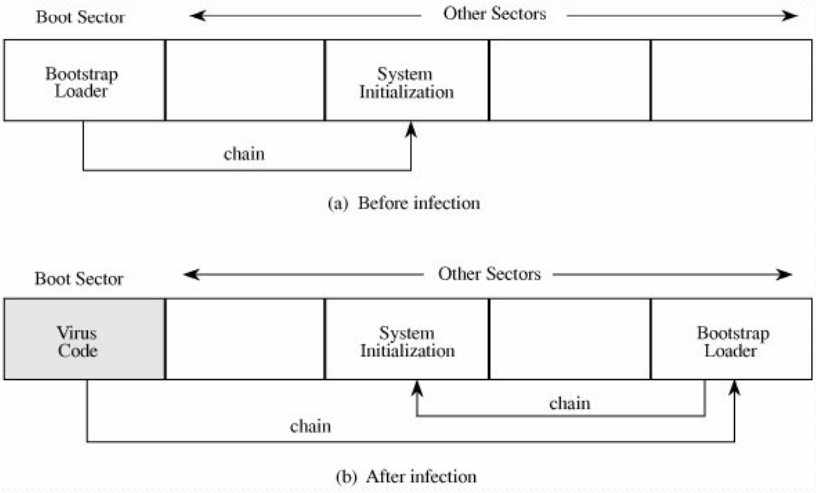


- How Viruses Attach (Cont'd)
  - Document Viruses
    - Implemented within a formatted document, such as a written document, a database, a slide presentation, a picture, or a spreadsheet.

- How Viruses Gain Control



- Homes for Viruses
  - One-Time Execution – the majority of viruses
  - Boot Sector Viruses

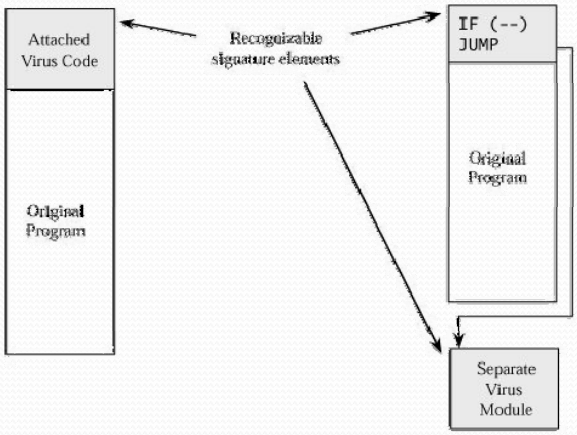


- Homes for Viruses (Cont'd)
  - Memory-Resident Viruses
  - Other Homes for Viruses
    - Application programs
    - Libraries
    - Data files – need a startup program

- Virus Signatures
  - A **signature** – a telltale pattern
    - E.g., signature for the Code Red

```
/default.ida?NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN
NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN
NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN
NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN
NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN %u9090%u6858%ucbd3
%u7801%u9090%u6858%ucdb3%u7801%u9090%u6858 %ucbd3%u7801%u9090
%u9090%u8190%u00c3%u0003%ub00%u531b%u53ff %u0078%u0000%u00=a
HTTP/1.0
```

- Virus Signatures
  - **Storage Patterns -** Most viruses attach to programs that are stored on media such as disks. The attached virus piece is invariant, so the start of the virus code becomes a detectable signature.



- Virus Signatures
  - **Execution Patterns** - A virus writer may want a virus to do several things at the same time, namely, spread infection, avoid detection, and cause harm.
  - **Transmission Patterns** - A virus is effective only if it has some means of transmission from one location to another.

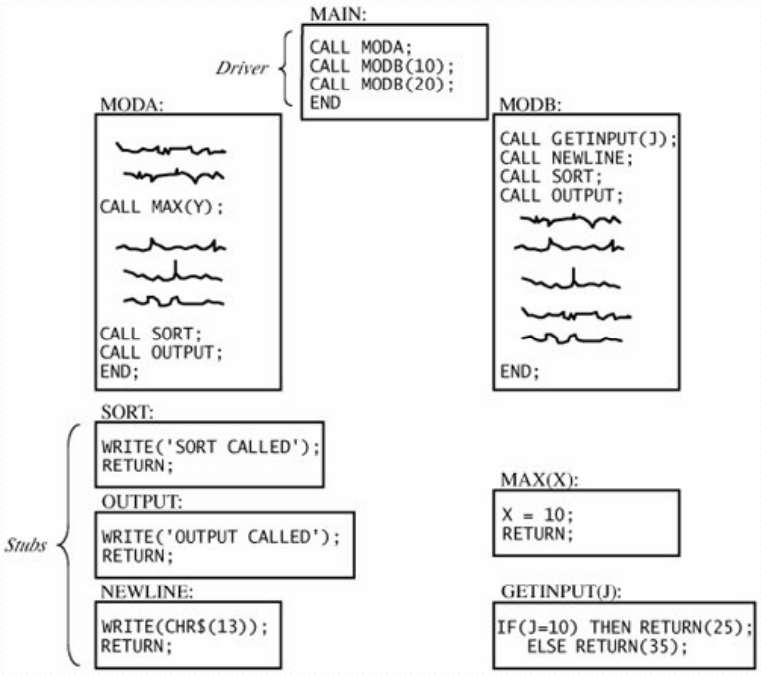
- **Polymorphic Viruses**
  - A virus that can change its appearance
  - **Encrypting viruses**
    - Uses encryption under various keys to make the stored form of the virus different.
    - Contain three distinct parts:
      - a decryption key,
      - the (encrypted) object code of the virus
      - the (unencrypted) object code of the decryption routine.

- **Prevention of Virus Infection**
  - The only way to prevent the infection of a virus is not to receive executable code from an infected source.

- **Prevention of Virus Infection (Cont'd)**
  - Several techniques for building a reasonably safe community for electronic contact, including the following:
    - *Use only commercial software acquired from reliable, well-established vendors.*
    - *Test all new software on an isolated computer.*
    - *Open attachments only when you know them to be safe*
    - *Make a recoverable system image and store it safely.*
    - *Make and retain backup copies of executable system files.*
    - *Use virus detectors (often called virus scanners) regularly and update them daily.*

3.4. Targeted Malicious Code

- **Trapdoors** - an undocumented entry point to a module
  - **Examples**
    - A system is composed of modules or components.
      - Programmers first test each small component of the system separate from the other components, in a step called **unit testing**, to ensure that the component works correctly by itself.
      - Then, developers test components together during **integration testing**, to see how they function as they send messages and data from one to the other.



- **Trapdoors** - an undocumented entry point to a module
  - **Examples**
    - Hardware processor design
      - The **undefined opcodes** sometimes implement peculiar instructions, either because of an intent to test the processor design or because of an oversight by the processor designer.
      - Undefined opcodes are the hardware counterpart of poor error checking for software.

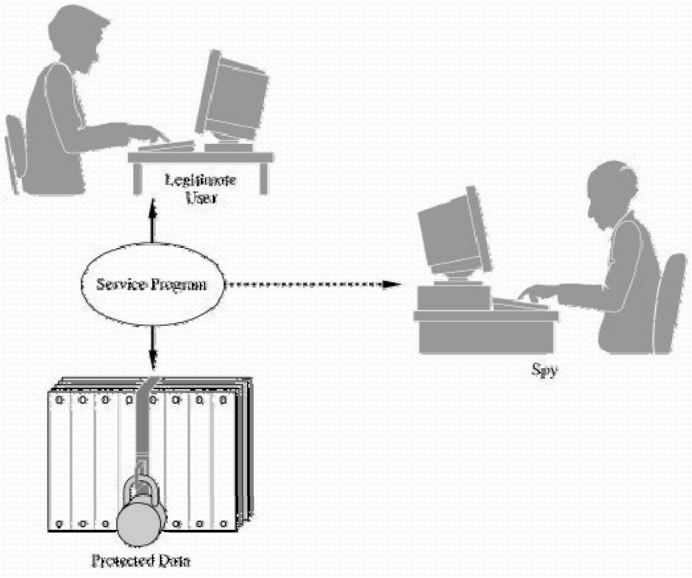
- **Causes of Trapdoors**
  - *forget* to remove them
  - intentionally leave them in the program for *testing*
  - intentionally leave them in the program for *maintenance* of the finished program, or
  - intentionally leave them in the program as a *covert means of access* to the component after it becomes an accepted part of a production system

- **Salami Attack**
  - merges bits of seemingly inconsequential data to yield powerful results.

- **Why Salami Attacks Persist**
  - Computer computations are notoriously subject to small errors involving rounding and truncation, especially when large numbers are to be combined with small ones.

- **Privilege Escalation -** a means for malicious code to be launched by a user with lower privileges but run with higher privileges.
- **Interface Illusions -** a spoofing attack in which all or part of a web page is false.
- **Keystroke Logging -** retains a surreptitious copy of all keys pressed.
- **Man-in-the-Middle Attacks -** interjects itself between two other programs

- **Covert Channels: Programs That Leak Information**



```
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ACCOUNT CODE:[  ]040095   DEPT. NO: 741        CONSULTANT: LORETTA HAACK

                          *** JOB SUMMARY MODEL/30R1 ***
                           (HRS)   (KB*HRS)        (EXCP)                 (STD)        (TOTAL)
 DATE   JOB# JOB-NAME CPU# PGMER#   CPU  CORE--CPU  3330--DISK--3380  TAPE   READER  PAGES  PRINTER  PAGES   MACHINE
 TIME  CLASS PROGRAMMER-NAME      PLOTTER CORE-EXCP 3350-          TP  3480 LOCATION CARDS   PUNCH   6670     COST
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     2/15/87 13.29.4  FCB-6       UCS-GN  FORM-0316 UNIT-COST-0.0110 UNITS-  2 COST-  0.022   33 RM1,PR1
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     2/21/87 13.30.2  FCB-6       UCS-GN  FORM-0316 UNIT-COST-0.0110 UNITS-  2 COST-  0.022   14 RM1,PR1
      21 JOBS                     0.0000   0.00     0      0     0     925     54      925      54    0.6951
                                  0.0000   0.00     0      0     0              0        0       0
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                                  0.0000   0.00     0      0     0              0        0       0
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2/05/87 2759 MAIL$000 MVS1 007579 0.0000   0.00     0      0     0      46      2       46       2    0.0335
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11.05.08  (P) MCCARTER            0.0000   0.00     0      0     0 L31.SR1      0        0       0
```

① Number of spaces after :

② Last digit in field that would not be checked

③ Presence or absence of word (TOTAL) in header line

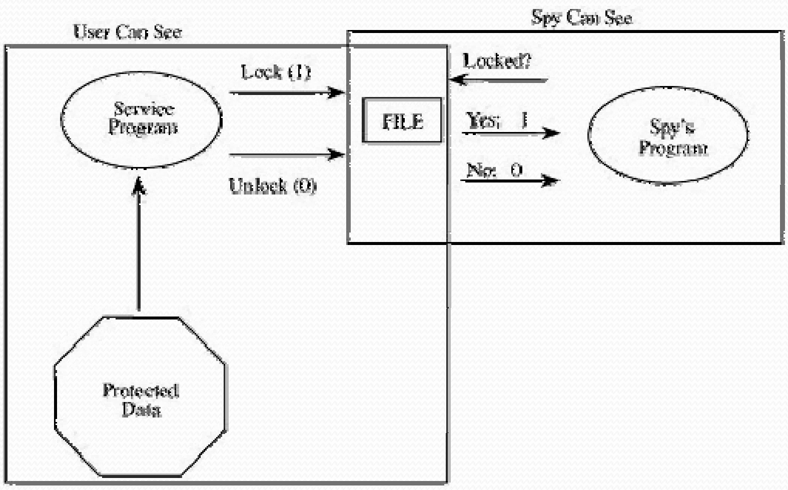
④ No space after last line of subtotal

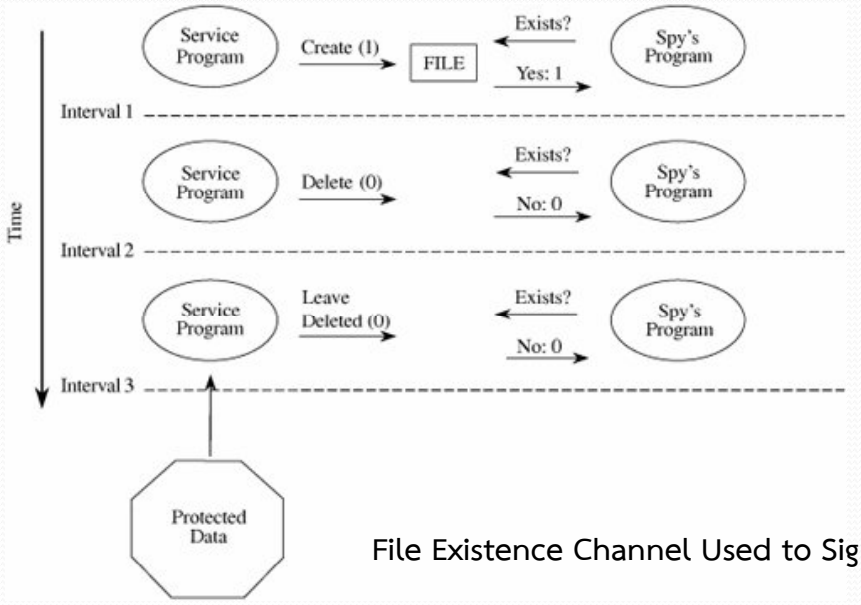
⑤ Last digit in insignificant field

⑥ Number of lines per page

⑦ Use of . instead of :

- **Storage Channels** - pass information by using the presence or absence of objects in storage.





File Existence Channel Used to Signal 100

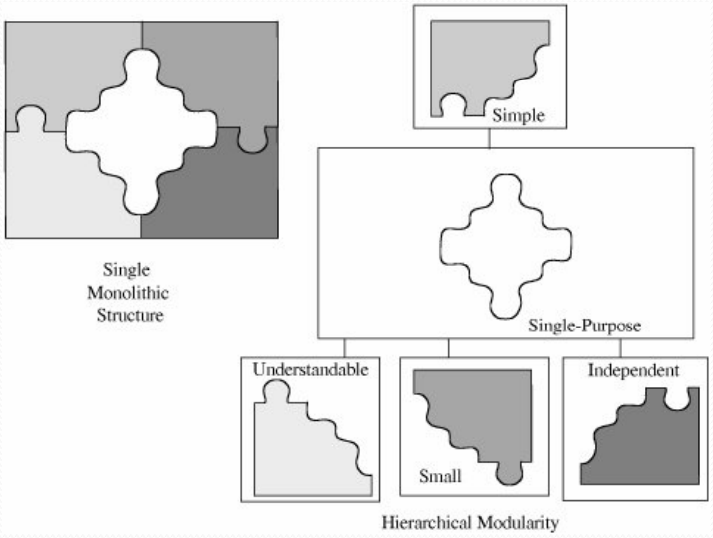
3.5. Controls Against Program Threats

- Three types of controls:
  - Developmental
  - Operating system
  - Administrative

- Developmental Controls
  - The Nature of Software Development
    - Collaborative effort, involving people with different skill sets who combine their expertise to produce a working product
    - Development requires people who can *specify*, *design*, *implement*, *test*, *review*, document, manage, *maintain* the system.

- Developmental Controls (Cont'd)
  - Modularity, Encapsulation, and Information Hiding
    - A key principle of software engineering is to create a design or code in small, self-contained units, called **components** or **modules**
    - If a component is isolated from the effects of other components, then it is easier to trace a problem to the fault that caused it and to limit the damage the fault causes. This isolation is called **encapsulation**.
    - **Information hiding** is another characteristic of modular software.

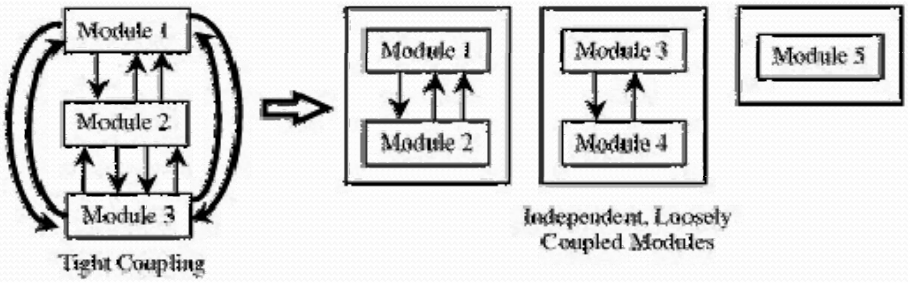
- Developmental Controls (Cont'd)
  - **Modularization** is the process of dividing a task into subtasks.



- Developmental Controls (Cont'd)
  - Modularization
    - The goal is to have each component meet four conditions:
      1. ***single-purpose***: performs one function
      2. ***small***: consists of an amount of information for which a human can readily grasp both structure and content
      3. ***simple***: is of a low degree of complexity so that a human can readily understand the purpose and structure of the module
      4. ***independent***: performs a task isolated from other modules

- Developmental Controls (Cont'd)
  - Modularization
    - Several advantages to having small, independent components.
      - *Maintenance*. If a component implements a single function, it can be replaced easily with a revised one if necessary.
      - *Understandability*
      - *Reuse*
      - *Correctness*
      - *Testing*.

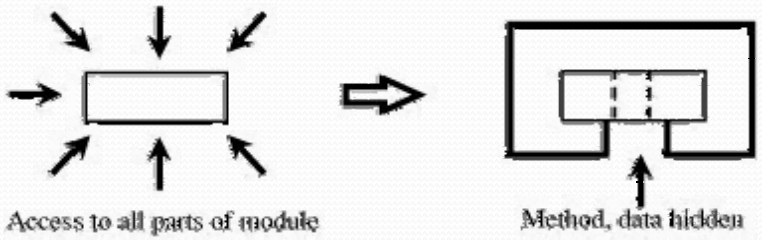
- Developmental Controls (Cont'd)
  - Modularization
    - A modular component usually has **high cohesion** and **low coupling**
    - Cohesion, we mean that all the elements of a component have a logical and functional reason for being there.
    - Coupling refers to the degree with which a component depends on other components in the system.



- Developmental Controls (Cont'd)
  - Encapsulation
    - Encapsulation hides a component's implementation details, but it does not necessarily mean complete isolation
    - Berard [BER00] notes that encapsulation is the "*technique for packaging the information [inside a component] in such a way as to hide what should be hidden and make visible what is intended to be visible.*"

- Developmental Controls (Cont'd)
  - Information Hiding
    - Think of a component as a kind of black box, with certain well-defined inputs and outputs and a well-defined function.
    - Other components' designers do not need to know *how* the module completes its function; it is enough to be assured that the component performs its task in some correct manner.
    - This concealment is the information hiding.
    - Information hiding is desirable because developers cannot easily and maliciously alter the components of others if they do not know how the components work.

- Developmental Controls (Cont'd)
  - Information Hiding (Cont'd)



- Developmental Controls (Cont'd)
  - Mutual Suspicion
    - Mutually suspicious programs operate as if other routines in the system were malicious or incorrect.
    - A calling program cannot trust its called subprocedures to be correct, and a called subprocedure cannot trust its calling program to be correct.
    - Each protects its interface data so that the other has only limited access.

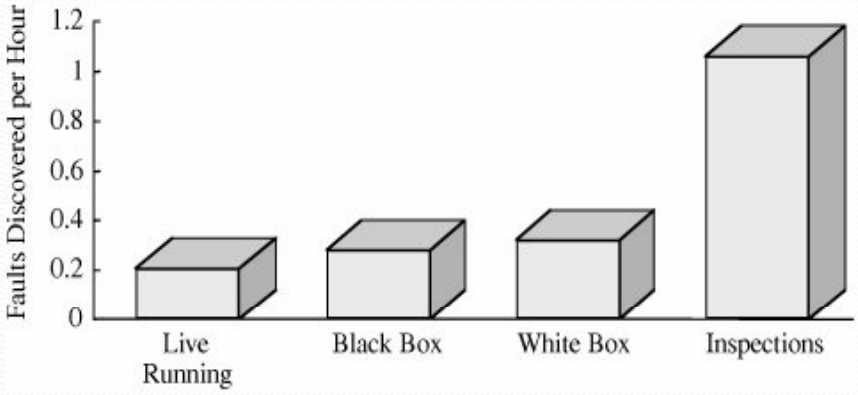
- Developmental Controls (Cont'd)
  - Confinement
    - A **confined** program is strictly limited in what system resources it can access. If a program is not trustworthy, the data it can access are strictly limited.
  - Genetic Diversity
    - Tight integration of products is a concern.
    - A vulnerability in one of these can also affect the others.
    - Fixing a vulnerability in one can have an impact on the others.

- Developmental Controls (Cont'd)
  - Pfleeger et al. [PFL01] recommend several key techniques for building what they call "solid software":
    - peer reviews
    - hazard analysis
    - testing
    - good design
    - prediction
    - static analysis
    - configuration management
    - analysis of mistakes

- **Developmental Controls (Cont'd)**
  - Peer review
    - *Review:* The artifact is presented informally to a team of reviewers; the goal is consensus and buy-in before development proceeds further.
    - *Walk-through:* The artifact is presented to the team by its creator, who leads and controls the discussion. Here, education is the goal, and the focus is on learning about a single document.
    - *Inspection*: The artifact is checked against a prepared list of concerns. The creator does not lead the discussion, and the fault identification and correction are often controlled by statistical measurements.

- **Developmental Controls (Cont'd)**
  - Peer review (Cont'd)
    - A wise engineer who finds a fault can deal with it in at least three ways:
      1. by learning how, when, and why errors occur
      2. by taking action to prevent mistakes
      3. by scrutinizing products to find the instances and effects of errors that were missed

- Developmental Controls (Cont'd)
  - Peer review (Cont'd)



Fault Discovery Rate Reported at Hewlett-Packard

- Developmental Controls (Cont'd)
  - Peer review (Cont'd)

Discovery Activity	Faults Found (Per Thousand Lines of Code)
Requirements review	2.5
Design review	5.0
Code inspection	10.0
Integration test	3.0
Acceptance test	2.0

- Developmental Controls (Cont'd)
  - Hazard analysis
    - A set of systematic techniques intended to expose potentially hazardous system states.
    - Usually involves developing hazard lists, as well as procedures for exploring "what if" scenarios to trigger consideration of nonobvious hazards.
    - A variety of techniques support the identification and management of potential hazards. Among the most effective are
      - Hazard and operability studies (HAZOP)
      - Failure modes and effects analysis (FMEA)
      - Fault tree analysis (FTA)

- Developmental Controls (Cont'd)
  - Hazard analysis (Cont'd)

	Known Cause	Unknown Cause
Known effect	Description of system behavior	Deductive analysis, including fault tree analysis
Unknown effect	Inductive analysis, including failure modes and effects analysis studies	Exploratory analysis, including hazard and operability

- Developmental Controls (Cont'd)
  - Testing
    - A process activity that homes in on product quality: making the product failure free or failure tolerant.

- Developmental Controls (Cont'd)
  - Testing (Cont'd)
    - Usually involves several stages.
      - **Unit testing** is done in a controlled environment whenever possible so that the test team can feed a predetermined set of data to the component being tested and observe what output actions and data are produced.
      - **Integration testing** is the process of verifying that the system components work together as described in the system and program design specifications.

- Developmental Controls (Cont'd)
  - Testing (Cont'd)
    - Usually involves several stages. (Cont'd)
      - A **function test** evaluates the system to determine whether the functions described by the requirements specification are actually performed by the integrated system.
      - A **performance test** compares the system with the remainder of these software and hardware requirements.
      - An **acceptance test**, in which the system is checked against the customer's requirements description.

- Developmental Controls (Cont'd)
  - Testing (Cont'd)
    - Usually involves several stages. (Cont'd)
      - A final **installation test** is run to make sure that the system still functions as it should.
      - After a change is made to enhance the system or fix a problem, **regression testing** ensures that all remaining functions are still working and that performance has not been degraded by the change.

- Developmental Controls (Cont'd)
  - Testing (Cont'd)
    - Each of the types of tests listed here can be performed from two perspectives
      - **Black-box testing** treats a system or its components as black boxes; testers cannot "see inside" the system
      - **Clear-box testing** (a.k.a. **white box**). - testers can examine the design and code directly, generating test cases based on the code's actual construction

- Developmental Controls (Cont'd)
  - Testing (Cont'd)
    - Olsen [OLS93] describes the development at Contel IPC of a system containing 184,000 lines of code and tracked faults discovered during various activities, and found differences:
      - 17.3 percent of the faults were found during inspections of the system design
      - 19.1 percent during component design inspection
      - 15.1 percent during code inspection
      - 29.4 percent during integration testing
      - 16.6 percent during system and regression testing
      - Only 0.1 percent of the faults were revealed after the system was placed in the field.

- Developmental Controls (Cont'd)
  - Testing (Cont'd)
    - From a security standpoint **independent testing** is desirable for the testing
    - **Penetration testing** is unique to computer security – the testers try to see if the software does what it is not supposed to do, which is to fail or fail to enforce security.

- Developmental Controls (Cont'd)
  - Good Design
    - Designers should try to anticipate faults and handle them in ways that minimize disruption and maximize safety and security.
      - **Passive fault detection** - construct the system so that it reacts in an acceptable way to a failure's occurrence.
      - **Active fault detection** - adopting a philosophy of mutual suspicion. Instead of assuming that data passed from other systems or components are correct, we always check that the data are within bounds and of the right type or format.
      - We can also use **redundancy**, comparing the results of two or more processes to see that they agree, before we use their result in a task.

- Developmental Controls (Cont'd)
  - Good Design
    - Fault tolerance: isolating the damage caused by the fault and minimizing disruption to users.
    - Typically, failures include
      - failing to provide a service
      - providing the wrong service or data
      - corrupting data

- Developmental Controls (Cont'd)
  - Good Design
    - We can build into the design a particular way of handling each problem
      1. *Retrying*: restoring the system to its previous state and performing the service again, using a different strategy
      2. *Correcting*: restoring the system to its previous state, correcting some system characteristic, and performing the service again, using the same strategy
      3. *Reporting*: restoring the system to its previous state, reporting the problem to an error-handling component, and not providing the service again

- Developmental Controls (Cont'd)
  - Static Analysis - examine its design and code to locate and repair security flaws before a system is up and running
  - several aspects of the design and code:
    - control flow structure - the sequence in which instructions are executed, including iterations and loops.
    - data flow structure - follows the trail of a data item as it is accessed and modified by the system
    - data structure - the way in which the data are organized, independent of the system itself.

- Developmental Controls (Cont'd)
  - **Configuration Management -** the process by which we control changes during development and maintenance
    - It is important to know who is making which changes to what and when:
      - *corrective changes*: maintaining control of the system's day-to-day functions
      - *adaptive changes*: maintaining control over system modifications
      - *perfective changes*: perfecting existing acceptable functions
      - *preventive changes*: preventing system performance from degrading to unacceptable levels

- Developmental Controls (Cont'd)
  - Configuration Management (Cont'd)
    - Four activities are involved in configuration management:
      - configuration identification
      - configuration control and change management
      - configuration auditing
      - status accounting

- Developmental Controls (Cont'd)
  - Configuration Management (Cont'd)
    - Configuration identification
      - Sets up baselines to which all other code will be compared after changes are made that is building and document an inventory of all components that comprise the system.
      - "Freeze" the baseline and carefully control what happens to it.
      - When a change is proposed and made, it is described in terms of how the baseline changes.

- Developmental Controls (Cont'd)
  - Configuration Management (Cont'd)
    - **Configuration control and configuration management** - ensure we can coordinate separate, related versions.
      - Three ways to control the changes
        - **Separate files** - have different files for each release or version.
        - **Delta** - designate a particular version as the main version of a system and then define other versions in terms of what is different.
        - **Conditional compilation**, whereby a single code component addresses all versions , relying on the compiler to determine which statements to apply to which versions.

- Developmental Controls (Cont'd)
  - Configuration Management (Cont'd)
    - A **configuration audit** confirms that the baseline is complete and accurate, that changes are recorded, that recorded changes are made, and that the actual software (that is, the software as used in the field) is reflected accurately in the documents
    - Finally, **status accounting** records information about the components: where they came from (for instance, purchased, reused, or written from scratch), the current version, the change history, and pending change requests.

- Developmental Controls (Cont'd)
  - Configuration Management (Cont'd)
    - All activities are performed by a configuration and change control board, or CCB.
    - The CCB contains representatives from all organizations with a vested interest in the system
    - The board reviews all proposed changes and approves changes based on need, design integrity, future plans for the software, cost, and more.

- Developmental Controls (Cont'd)
  - Proofs of Program Correctness
    - **Program verification** can demonstrate formally the "correctness" of certain specific programs.
      - Making initial assertions about the inputs and then checking to see if the desired output is generated.
      - Each program statement is translated into a logical description about its contribution to the logical flow of the program.
      - Finally, the terminal statement of the program is associated with the desired output.

- Developmental Controls (Cont'd)
  - Proofs of Program Correctness
    - Proving program correctness is hindered by several factors.
      - Correctness proofs depend on a programmer or logician to translate a program's statements into logical implications.
      - Deriving the correctness proof from the initial assertions and the implications of statements is difficult, and the logical engine to generate proofs runs slowly.
      - The current state of program verification is less well developed than code production.