Foundations of Software Engineering

Security Development Lifecycles

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(Based on slides by Michael Maass)
Administrativa

• No class Nov 20, but HW6a deadline on Nov 20
• HW 5 extended until Nov 13
• In-class interview Thursday
Learning goals

• Understand basic concepts of vulnerabilities and secure software
• Implement security mechanisms across the entire software development lifecycle
• Design and inspect architecture for security with threat modeling
• Decide how do adopt security practices and educate participants. Who, when, and how much?
Vulnerability

• A **vulnerability** is a set of conditions that allows an attacker to violate an explicit or implicit security policy
  – Not all software security flaws lead to vulnerabilities. Vulnerabilities require an avenue of attack known as an attack vector

• A software security flaw can cause a program to be vulnerable to attack
  – Software security flaws that do not result in vulnerabilities should still be corrected so that they do not propagate
Attack Surfaces

Universe of Computation
Attack Surfaces

Universe of Computation

Intended Computations

“Weird Machine” Border
Attack Surfaces

Universe of Computation

Vulnerabilities

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Exploit
Attack Surfaces

Universe of Computation

Intended Computations

Vulnerabilities

Exploit

Key: Attack Surface

"Weird Machine" Border
Vulnerabilities Have Utility

- Bugs and vulnerabilities are typically accidentally introduced
- Both can cause a system to fail
- **Bugs** typically cause failures through innocent interactions
- **Bugs** often result in a loss of control with no utility
- **Vulnerabilities** cause failures through intentional and clever interactions initiated by a malicious actor
- **Vulnerabilities** give an attacker a route to seize control
An Airplane Example

• The wings fall off in violent turbulence
• Power shuts off when crossing the international date line
• Ground control channels allow anyone to re-route active flights
• The fuel system can be trivially ordered to dump fuel at altitude

BUGS

VULNERABILITIES
Vulnerabilities and Programming Errors

• 64% of the vulnerabilities in NISTs National Vulnerability Database (NVD) in 2004 are due to programming errors.
  – 51% of those due to classic errors like buffer overflows, cross-site-scripting, injection flaws

• “We wouldn't need so much network security if we didn't have such bad software security.”
  – Bruce Schneier
Vulnerability Root-cause Categories
(non-exhaustive list)

• Logic errors
• Synchronization and timing errors
• Insecure configurations
• Protocol errors
• Cryptographic vulnerabilities
• Input validation errors
  – Buffer overflow
  – Integer errors
  – SQL injection
Security Issues
Security

- Confidentiality: Data is only available to the people intended to access it.
- Integrity: Data and system resources are only changed in appropriate ways by appropriate people.
- Availability: Systems are ready when needed and perform acceptably.
- Authentication: The identity of users is established (or you’re willing to accept anonymous users).
- Authorization: Users are explicitly allowed or denied access to resources.
- Nonrepudiation: Users can’t perform an action and later deny performing it.
Sources of Software Insecurity

• Complexity, inadequacy, and change
• Incorrect or changing assumptions (capabilities, inputs, outputs)
• Flawed specifications and designs
• Poor implementation of software interfaces (input validation, error and exception handling)
• Inadequate knowledge of secure coding practices
Sources of Software Insecurity - 2

• Unintended, unexpected interactions
  – with other elements
  – with the software’s execution environment

• Absent or minimal consideration of security during all life cycle phases

• Not thinking like an attacker
What Is a Buffer Overflow?

- A buffer overflow occurs when data is written outside of the boundaries of the memory allocated to a particular data structure.
Why Buffer Overflows Matter

• Buffer overflows can allow an attacker to corrupt memory to execute arbitrary code
  – With the privileges of the running process

• Pervasive
  – Legacy code
  – Insecure coding practices
  – Changing environments

https://nvd.nist.gov
SQL Injection

http://xkcd.com/327/
Mitigations
Mitigations

- Mitigations are methods, techniques, processes, tools, or runtime libraries that can prevent or limit exploits against vulnerabilities
  - Sometimes called a workaround

- What are some strategies to eliminate software vulnerabilities?
Two General Strategies

• Find and fix vulnerabilities in existing software
  – Reactive
  – Costly in terms of money and reputation
• Prevent vulnerabilities from occurring in new software
  – Proactive
  – Develop processes to find and eliminate vulnerabilities during software development
Strategies: Finding Vulnerabilities

• Security-focused testing
  – Fuzzing
  – Penetration testing
• Inspection/auditing
• Static analysis
• Read the news
Security Development Lifecycles (SDL)
Security Development Lifecycles (SDLs) prescribe **security practices** for each phase of a software development project.
Security Practice Goals

• Find vulnerabilities early
• Identify risks and mitigate them
• Reduce attack surface
• Prepare to fix future vulnerabilities quickly
• Gain confidence that the system is secure
• Build security in!
Microsoft Trustworthy Computing Initiative (2002)

• see memo
Microsoft SDLs

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<tr>
<th>Training</th>
<th>Requirements</th>
<th>Design</th>
<th>Implementation</th>
<th>Verification</th>
<th>Release</th>
<th>Response</th>
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<td>Analysis</td>
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<tr>
<td>Gates / Bug Bars</td>
<td>Surface Analysis /</td>
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<td>Security Review</td>
<td>Response Plan</td>
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<td>Security and</td>
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<td>Analysis</td>
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<td>Privacy Risk</td>
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<td>Assessments</td>
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CERT: Secure Coding Standards

• https://www.securecoding.cert.org/
(Academic) Design Principles

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<th>Principle</th>
<th>Explanation</th>
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</thead>
<tbody>
<tr>
<td>Open design</td>
<td>Assume the attackers have the sources and the specs.</td>
</tr>
<tr>
<td>Fail-safe defaults</td>
<td>Fail closed; no single point of failure.</td>
</tr>
<tr>
<td>Least privilege</td>
<td>No more privileges than what is needed.</td>
</tr>
<tr>
<td>Economy of mechanism</td>
<td>Keep it simple, stupid.</td>
</tr>
<tr>
<td>Separation of privileges</td>
<td>Don’t permit an operation based on a single condition.</td>
</tr>
<tr>
<td>Total mediation</td>
<td>Check everything, every time.</td>
</tr>
<tr>
<td>Least common mechanism</td>
<td>Beware of shared resources.</td>
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<tr>
<td>Psychological acceptability</td>
<td>Will they use it?</td>
</tr>
</tbody>
</table>

Saltzer and Schroeder's design principles

1. Take Responsibility
2. Never Trust Data
3. Model Threats against Your Code
4. Stay One Step Ahead
5. Fuzz!
6. Don’t Write Insecure Code
7. Recognize the Strategic Asymmetry
8. Use the Best Tools You Can
Microsoft SDLs

1. Core Security Training
2. Establish Security Requirements
3. Create Quality Gates/Bug Bars
4. Perform Security and Privacy Risk Assessments
5. Establish Design Requirements
6. Perform Attack Surface Analysis/Reduction
7. Use Threat Modeling
8. Use Approved Tools
9. Deprecate Unsafe Functions
10. Perform Static Analysis
11. Perform Dynamic Analysis
12. Perform Fuzz Testing
13. Conduct Attack Surface Review
14. Create an Incident Response Plan
15. Conduct Final Security Review
16. Certify Release and Archive

Execute Incident Response Plan
Security Requirements

• Security requirements are as important as any other requirement category
• Must include individuals with security expertise
• Deploy vulnerability tracking system
  – Can be the same as the bug tracker for most projects
Example

• “The application shall provide passwords, smart cards, and one-time passwords to support user authentication.”

• “The mechanisms for performing cryptographic operations shall be easily replaceable at runtime.”
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Certify Security Requirements in Design

• Traceability from security requirements to design (and implementation)
• Inspection of design
• Involve security experts
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Threat Modeling

• A structured approach to find threat scenarios that apply to a product

• Typically:
  – Create a data flow diagram showing system components and the data flowing between them (requires some expertise in deciding what to model)
  – Apply the STRIDE threat model at each data flow to enumerate threats
STRIDE

- **Spoofing** – can an actor use someone else's data as their own or trick the system into using fake data?
- **Tampering** – is malicious modification of data possible?
- **Repudiation** – can an actor claim they didn't perform an action or easily make it look like someone else did it?
- **Information Disclosure** – is an actor given private or sensitive information they don't need?
- **Denial of Service** – can an actor prevent valid users from using the system?
- **Elevation of Privilege** – can an actor gain higher privileges than they should have?

**Inspection per component**
### STRIDE vs Security Properties

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<th>Threat</th>
<th>Security Property</th>
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<tr>
<td>Spoofing</td>
<td>Authentication</td>
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<tr>
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<td>Integrity</td>
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<td>Authorization</td>
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STRIDE process

• Identify relevant components and data flows

• Analyze each component for each threat

• Mitigate threats

• -> Gain confidence (no proof)
Data Flow Diagram

Data flows, data stores, processes, interactors, and trust boundaries
Use case: Sales entry

• Collect accounting files from sales force
• Compute sales data
• Produce weekly reports

for details see
Use case: Sales entry

Client

Sales001

SalesNNN

Server

List of Sales Systems

Collection and Analysis

Analysis Process

Report Generation

Manager

Client Server
Use case: Sales entry

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Any unhandled threats turned up by threat modeling must be tracked!
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Execute Incident Response Plan
Use Approved Tools

• Some libraries are vulnerable and have safe alternatives (e.g. string.h bad vs strsafe.h good)
• Modern compilers automatically mitigate a number of vulnerabilities (e.g. stack canaries, heap integrity checks, SAFESEH, etc.)
• Appropriate static and dynamic analysis tools automate the enforcement of security practices
Static Analysis, Deprecation

• Microsoft runs static checkers at checking (quality gates)
• Banned over 100 C functions for new code
Microsoft SDLs
Conduct Attack Surface Review

• What is every source of input to the application?
• Are there any new sources since the last milestone?
• Much more fine grained than threat modeling
• All sources of input must have a defensive approach applied
• Tools help automate this practice
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11. Perform Dynamic Analysis
12. Perform Fuzz Testing
13. Conduct Attack Surface Review
14. Create an Incident Response Plan
15. Conduct Initial Security Review
16. Certify Release and Archive

Execute Incident Response Plan
Create Incidence Response Plan

• Attacks always get better
• New threats emerge every day
• Vulnerabilities always exist in non-trivial systems
• Who should be contacted when an incident occurs?
• Who should deal with third-party code?
• What priority should be applied to fixing new vulnerabilities?
Who should implement these security practices?
Security Roles

• **Everyone**: “security awareness” – buy into the process

• **Developers**: know the security capabilities of development tools and use them, know how to spot and avoid *relevant*, common vulnerabilities

• **Managers**: *enable* the use of security practices

• **Security specialists**: everything security
Organizational Architectures

- **Centralized**: development teams consult with a core group of security specialists when they need help.
- **Distributed**: development teams hire security specialists to be a first-class member of the team.
- **Weak Hybrid**: centralized group of security specialists and teams with security critical applications hire specialists.
- **Strong Hybrid**: centralized group of security specialists and most teams also hire specialists.
Tuning SDLs

• No one set of security practices work across every industry... or even for every project in a given company

• Expertise is required to determine what set of practices is the most cost effective
BSIMM

- Building Security In Maturity Model
- See what practices other companies utilize
- Understand, measure, and plan software security initiatives

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<td>Security Testing</td>
<td>Configuration Management and Vulnerability Management</td>
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None of this is scientifically validated.
Future: Measures and Standards

• NHTSA inspired star ratings
• Building Codes for Software
• Security Guarantees
• Liability
• Science
Summary

• Security is a quality among others, often very important
• As all QA, design security QA throughout the process, not only after the fact
• Security requires special expertise, awareness by developers + experts
• Use tools, modeling, automate, …