Secure Software Development

TDDC90 – Software Security

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Original slides by Marcus Bendtsen
Agenda

- Securing the software development life cycle
- Example of a formal secure development method
- Secure architectural, design and implementation patterns
Introduction

We do not simply write code, and then as an afterthought test and patch it to ensure that it fulfills a functional requirement:

*If we want a piece of code that sums integers, then we state this before we start coding and specifically write the code to sum integers. We do not randomly write code and then try and patch the code to sum integers.*
Introduction

For non-functional requirements such as quality and security, the same logic applies: *We do not patch a piece of code to ensure it fulfills a non-functional requirement.*

- Non-functional requirements are met not only by *stating* the requirements, but *activities* are required.

- Security considerations must *permeate all phases* of the software development life cycle.
Software Development Life Cycle

- **Requirements**: Gather requirements and use cases
- **Architecture and Design**: Plan how the system shall work and how code should be written
- **Implementation**: Code and make test plans
- **Verification**: Test and ensure that requirements and design are fulfilled
- **Release & Maintenance**: Release, patch, release, patch, ...
Software Development Life Cycle

Security requirements

Gather requirements and use cases

Risk analysis

Plan how the system shall work and how code should be written

Architecture and Design

Risk-based security tests

Implementation

Code and make test plans

Verification

Test and ensure that requirements and design are fulfilled

Release & Maintenance

Release, patch, release, patch, ...

Static analysis

Risk analysis and penetration testing

Risk analysis

Security requirements

Static analysis
Software Development Life Cycle

Security requirements

- Gather requirements and use cases
- Plan how the system shall work and how code should be written
- Code and make test plans
- Test and ensure that requirements and design are fulfilled
- Release, patch, release, patch, ...

Static analysis

- Risk analysis
- Risk-based security tests
- Risk analysis and penetration testing

Requirements

- Architecture and Design
- Implementation
- Verification
- Release & Maintenance
Security Requirements

- Requirements are gathered during the initial phase of the software development life cycle.

- This is an opportunity to not only gather functional requirements, but also security requirements.

- Several methods exist for gathering security requirements.

- We will look at misuse cases, which can be seen as a method in itself, but also takes part in more elaborate methods (such as SQUARE).
Use cases and Misuse cases

• A use case illustrates required usage of a system – i.e. expected functionality.

• However it is equally important to illustrate how one should not be able to use the system.

• Misuse cases are used to identify threats and required countermeasures.
Misuse case legend

- **Authorized user**
- **Insider**
- **Outside attacker**

**Use case**
- <<extend>>
- <<include>>

**Vulnerability**
- <<exploit>>

**Threat**
- <<threaten>>
- <<mitigate>>

Image from Lillian Røstad – An extended misuse case notation: Including vulnerabilities and the insider threat
Misuse case example

- Electronic Patient Record (EPR)
  - Under normal circumstances patients should be registered in the system and linked to a specific ward – only personnel with access to the patients at this ward can then read the patients records.
  - During emergencies the organization and the law allows the use of an emergency access control function – which gives immediate access to any records needed.
  - For such an emergency control to be useful, it must be available at all time. This effectively creates a backdoor in the system that insiders can use to snoop around.
  - By identifying emergency access as a vulnerability we can also consider proper countermeasures – **auditing** (enables traceability and detection) and **awareness training** (making sure that users are aware of consequences of misuse).
Electronic Patient Record

Authorized user

Access Control (AC)

<<extend>>

Normal AC

<<include>>

Read EPR

<<include>>

Emergency read EPR

<<exploit>>

Unauthorized read EPR

<<mitigate>>

Auditing

<<mitigate>>

Awareness training

Insider

Image from Lillian Røstad – An extended misuse case notation: Including vulnerabilities and the insider threat
User input in web-based systems

Diagram showing the flow of user input and potential attacks:
- Authorized user
  - Enter username
  - Enter password
  - Use system
- Attacker
  - Injection attack
  - Input validation
  - Overflow attack
An insider on the system development team

System developer

Implement system

Inject backdoor <<mitigate>>

Inject bug <<mitigate>>

Code audit <<mitigate>>

Security testing <<mitigate>>

Image from Lillian Røstad – An extended misuse case notation: Including vulnerabilities and the insider threat
Requirements

• Misuse cases is one method of gathering requirements.

• Other more complex methods exists that range up to full-fledged risk analysis methods.

• *Misuse cases are good due to their simplicity, this increases the probability that they will be used.*

• When requirements have been gathered they are transferred to the design and architecture phase.
Software Development Life Cycle

1. Gather requirements and use cases
2. Plan how the system shall work and how code should be written
3. Code and make test plans
4. Test and ensure that requirements and design are fulfilled
5. Release, patch, release, patch, ...

- Security requirements
- Risk analysis
- Risk-based security tests
- Static analysis
- Risk analysis and penetration testing
Risk analysis

- Risk analysis is used at the **architecture & design** phase and at the **verification** phase (to some degree also at requirements stage).

- Helps to find and quantify risks and then allows us to change our architecture and design.

- We will look briefly at CORAS and in more detail about Attack Trees.
CORAS (overview)

Step 1 – Experts and clients decide upon which system is to be analyzed and what parts of the system that should be focused upon.

Step 2 – The system to be analyzed is formalized, assets are identified, high-level risk analysis.
**CORAS (overview)**

<table>
<thead>
<tr>
<th>Consequence value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catastrophic</td>
<td>1000+ health records (HRs) are affected</td>
</tr>
<tr>
<td>Major</td>
<td>100-1000 HRs are affected</td>
</tr>
<tr>
<td>Moderate</td>
<td>10-100 HRs are affected</td>
</tr>
<tr>
<td>Minor</td>
<td>1-10 HRs are affected</td>
</tr>
<tr>
<td>Insignificant</td>
<td>No HR is affected</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Likelihood value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Certain</td>
<td>Five times or more per year (50-<em>: 10y = 5-</em>: 1y)</td>
</tr>
<tr>
<td>Likely</td>
<td>Two to five times per year (21-49: 10y = 2,1-4,9: 1y)</td>
</tr>
<tr>
<td>Possible</td>
<td>Once a year (6-20: 10y = 0,6-2: 1y)</td>
</tr>
<tr>
<td>Unlikely</td>
<td>Less than once per year (2-5: 10y = 0,2-0,5: 1y)</td>
</tr>
<tr>
<td>Rare</td>
<td>Less than once per ten years (0-1:10y = 0-0,1:1y)</td>
</tr>
</tbody>
</table>

**Step 3** – Prioritize assets, create scales for consequence and likelihood values, create risk evaluation matrix.

<table>
<thead>
<tr>
<th>Asset</th>
<th>Importance</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Health records</td>
<td>2</td>
<td>Direct asset</td>
</tr>
<tr>
<td>Provision of telecardiology service</td>
<td>3</td>
<td>Direct asset</td>
</tr>
<tr>
<td>Public’s trust in system</td>
<td>(Scoped out)</td>
<td>Indirect asset</td>
</tr>
<tr>
<td>Patient’s health</td>
<td>1</td>
<td>Indirect asset</td>
</tr>
</tbody>
</table>

**Consequence**

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Insignificant</th>
<th>Minor</th>
<th>Moderate</th>
<th>Major</th>
<th>Catastrophic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rare</td>
<td>Acceptable</td>
<td>Acceptable</td>
<td>Acceptable</td>
<td>Acceptable</td>
<td>Must be evaluated</td>
</tr>
<tr>
<td>Unlikely</td>
<td>Acceptable</td>
<td>Acceptable</td>
<td>Acceptable</td>
<td>Must be evaluated</td>
<td>Must be evaluated</td>
</tr>
<tr>
<td>Possible</td>
<td>Acceptable</td>
<td>Acceptable</td>
<td>Must be evaluated</td>
<td>Must be evaluated</td>
<td>Must be evaluated</td>
</tr>
<tr>
<td>Likely</td>
<td>Acceptable</td>
<td>Must be evaluated</td>
<td>Must be evaluated</td>
<td>Must be evaluated</td>
<td>Must be evaluated</td>
</tr>
<tr>
<td>Certain</td>
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<td>Must be evaluated</td>
<td>Must be evaluated</td>
<td>Must be evaluated</td>
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Images from Braber et al. – *Model-based security analysis in seven steps – a guided tour to the CORAS method*
CORAS (overview)

**Step 4** – Create *threat diagrams* through structured brainstorming (workshop).

**Step 5** – Estimate risks (consequence and likelihood)

Images from Braber et al. – *Model-based security analysis in seven steps – a guided tour to the CORAS method*
**CORAS (overview)**

**Step 6** – Risk evaluation, estimates are confirmed or adjusted.

<table>
<thead>
<tr>
<th>Likelihood</th>
<th>Insignificant</th>
<th>Minor</th>
<th>Moderate</th>
<th>Major</th>
<th>Catastrophic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rare</td>
<td></td>
<td>CC1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unlikely</td>
<td></td>
<td></td>
<td></td>
<td>PR1</td>
<td></td>
</tr>
<tr>
<td>Possible</td>
<td></td>
<td>Cl1, SS2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Likely</td>
<td></td>
<td></td>
<td></td>
<td>SS1</td>
<td></td>
</tr>
<tr>
<td>Certain</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Step 7** – Risk treatment

Images from Braber et al. – *Model-based security analysis in seven steps – a guided tour to the CORAS method*
Attack trees

Represent attacks against the system in a tree structure, with the goal as the root node and different ways of achieving that goal as leaf nodes.
Attack Trees

- **Open Safe**
  - **Pick lock**
  - **Learn combo**
  - **Cut open**
  - **Install improperly**
    - **Find written combo**
    - **Get combo from target**
      - **Threaten**
      - **Blackmail**
      - **Eavesdrop**
      - **Bribe**
        - **Listen to conversation**
        - **Get target to state combo**
Attack Trees

- Open Safe
  - Pick lock
  - Learn combo
  - Cut open
  - Install improperly
    - Find written combo
    - Get combo from target
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Attack Trees

Open Safe

Pick lock

Learn combo

Cut open

Install improperly

Find written combo

Get combo from target

Threaten

Blackmail

Eavesdrop

Bribe

Listen to conversation

Get target to state combo
Attack Trees

- Open Safe
  - Pick lock
    - Find written combo
      - Threaten
        - Listen to conversation
          - $20
  - Learn combo
    - Get combo from target
      - Eavesdrop
        - Get target to state combo
          - $40
  - Cut open
    - Install improperly
      - Bribe
        - $20
      - $100
  - $10
  - $100
Attack Trees

- We can annotate the attack tree with many different kind of Boolean and continuous values:
  - “Legal” versus “Illegal”
  - “Requires special equipment” versus “No special equipment”
  - Probability of success, likelihood of attack, etc.

- Once we have annotated the tree we can query it:
  - Which attacks cost less than $10?
  - Legal attacks that cost more than $50?
  - Would it be worth paying a person $80 so they are less susceptible to bribes? (In reality you need to also consider the probability of success)
Attack Trees

- First you identify possible attack goals.
- Each goal forms a separate tree.
- Add all attacks you can think of to the tree.
- Expand the attacks as if they were goals downwards in the tree.

- Let somebody else look at your tree, get comments from experts, iterate and re-iterate.

- Keep your trees updated and use them to make security decisions throughout the software life cycle.
Software Development Life Cycle

1. **Requirements**
   - Gather requirements and use cases

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5. **Release & Maintenance**
   - Release, patch, release, patch, ...

- Security requirements
- Risk analysis
- Risk-based security tests
- Static analysis
- Risk analysis and penetration testing
Software Development Life Cycle

- **Security requirements**
- **Gather requirements and use cases**
- **Risk analysis**
- **Plan how the system shall work and how code should be written**
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- **Code and make test plans**
- **Verification**
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- **Risk-based security tests**
- **Static analysis**
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Software Development Life Cycle

1. Gather requirements and use cases
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- Security requirements
- Risk analysis
- Architecture and Design
- Implementation
- Verification
- Release & Maintenance

Static analysis
Risk-based security tests
Risk analysis and penetration testing
Static analysis
Risk-based security tests
Risk analysis and penetration testing
Software development process

• The software development life cycle is generic, can be modified to fit into any development process:
  • Iterative (SCRUM, Kanban, etc)
  • Waterfall

• Adopting a secure software development process entails adding the security *touchpoints* discussed.

• Examples of formal development processes that include security touchpoints are: SDL, TSP, CLASP.
SECURITY DEVELOPMENT LIFECYCLE (SDL)
If a software development project is determined to be subject to the security development lifecycle (SDL) then the team must successfully complete sixteen mandatory security activities to comply with the Microsoft SDL process.

-Simplified Implementation of the Microsoft SDL
Pre-SDL: Security training

- All members must receive appropriate training to stay informed about security basics and recent trends in security and privacy.

- Topics include:
  - Threat modeling (e.g. design implications)
  - Secure coding (e.g. buffer overruns, cross-site scripting)
  - Privacy (e.g. types of privacy-sensitive data)

- This is only the baseline training, specialization and advanced training may be necessary.
**Phase 1: Requirements**

- Specify security requirements for the application *as it is designed to run in its planned operational environment*.

- A project team must define **quality gates** (e.g. *all compiler warnings must be fixed before committing code*), these are defined for each phase of the development and are **negotiated** with a security advisor.

- **Bug bars** must be defined which can be seen as quality gates for the entire project, e.g. *no known vulnerabilities in the application with a “critical” or “important” rating at time of release*. 
Identify functional aspects of the software that require deep review:

- Which portions of the project will require security design reviews before release?
- Which portions of the project will require penetration testing by a mutually agreed upon group that is external to the project team?
- What is the privacy impact rating?
  - P1: High privacy risk, e.g. installs software
  - P2: Moderate privacy risk, e.g. one-time user initiated data-transfer
  - P3: Low privacy risk, e.g. no anonymous or personal data is transferred
Phase 2: Design

- All design specifications should describe how to securely implement all functionality provided by a given feature or function:
  - Attack surface reduction (giving attackers less opportunity to exploit a potential weak spot).
  - Defense in depth (design system with multiple layered defenses)
  - Threat modeling (risk analysis) of components or features that have meaningful security risks (can be defined by the security risk assessment during requirements).
  - Secure design patterns (discussed later)
Phase 3: Implementation

- Publish a list of **approved tools** and their associated security checks, such as compilers/linker options and warnings.
- List is to be approved by external security advisor.
- Teams should analyze all functions and APIs that will be used in conjunction with a software development project and **prohibit** those that are determined to be unsafe.
- Once a prohibited list is defined, all code should be **scanned** for these functions and APIs and modified accordingly.
- **Static analysis** of code should be performed.
Phase 4: Verification

- Dynamic program analysis, monitor application problems with memory corruption, user privilege issues, etc.

- **Fuzz testing**, deliberately introduce malformed or random data to an application during dynamic analysis.

- Update threat model and attack surface analysis, account for any design or implementation changes to the system, and assure that any new threats/attack are reviewed and mitigated.
Phase 5: Release

- An incident response plan must be in place:
  - A first point of contact in an emergency.
  - On-call contacts with decision-making authority that are available 24-hours a day.
  - Security servicing plans for code inherited from other groups in the organization.
  - Security servicing plans for third-party code (and if appropriate the right to make changes).
Phase 5: Release (cont.)

- **Final security review**: Includes an examination of threat models, tool output, performance against quality gates and bug bars.
  - Pass FSR – Good to go.
  - Pass FSR with exceptions – Issues that can be fixed in the next release.
  - FSR with escalation – Go back and address whatever SDL requirement that is not fulfilled or escalate to executive management for decision.

- Release to manufacturing (RTM) or release to web (RTW) conditional on FSR.

- If at least one component has privacy rating P1 then a privacy advisor must certify that the privacy requirements are satisfied.

- All specifications, code, binaries, threat models, plans, etc. must be archived so that service can be done on the product at a later stage.
• Security advisors can request that for some critical software additional activities are completed, e.g.:
  • Manual code review
  • Penetration testing
  • Vulnerability analysis of similar applications

• SDL is not a “one-size-fits-all” process, teams must implement SDL in a fashion that is appropriate to time and resources.

• There exists variants, such as SDL for Agile.
SECURE DESIGN PATTERNS
Software Development Life Cycle

- **Security requirements**
  - Gather requirements and use cases

- **Risk analysis**
  - Plan how the system shall work and how code should be written

- **Architecture and Design**
  - Code and make test plans

- **Implementation**
  - Test and ensure that requirements and design are fulfilled

- **Verification**
  - Risk analysis and penetration testing

- **Release & Maintenance**
  - Release, patch, release, patch, ...
Secure design patterns

• **Descriptions** or **templates** describing a general solution to a security problem that can be applied in many different situations.

• The design patterns are meant to **eliminate the accidental insertion of vulnerabilities** into code or to **mitigate the consequence of vulnerabilities**.

• Categorized by abstraction: **architecture**, **design** or **implementation**.
Categories

- **Architectural-level patterns**: Focus on high-level allocation of responsibilities between different components and define the interaction between those high-level components.
  - Privilege separation (PrivSep)

- **Design-level patterns**: Address problems in the internal design of a single high-level component.
  - Secure factory
  - Secure chain of responsibility

- **Implementation-level patterns**: Low-level security issues, applicable to specific functions or methods in the system.
  - Secure logger
  - Clear sensitive information
Privilege separation (PrivSep)

• **Intent:** Reduce the amount of code that runs with special privilege without affecting or limiting the functionality of the program.

• **Motivation:** In many applications, a small set of simple operations require elevated privileges, while a much larger set of complex and security error-prone operations can run in the context of normal privileged user.
  - PrivSep is applicable when high-privilege and low-privilege code can be separated into *separate components*, and there is a *small amount of interaction* between these components
  - If continuous interaction is required **Defer to Kernel** (see course literature) is more appropriate
Privilege separation (PrivSep)

- **root**
  - Open socket and listen for connections

- **root**
  - Spawn a child process that has least possible privilege

- **Unprivileged**
  - Authenticate (complex code)

- **User**
  - Do some work as user

- **Return identity**

*Request from unauthorized user*
Privilege separation (PrivSep)

- The majority of the code is run without elevated privileges.
- If there is a vulnerability and somebody gets control of the process, then they are confined within the same level of privilege.
- Extra testing, verification, reviews etc. can be focused on the code that runs with elevated privileges.
Secure Factory

• **Intent:** Separate the security dependent logic involved in creating an object from the basic functionality of the created object.

• **Motivation:** An application may make use of an object whose behavior is dependent on the privileges of the user running the application.
Getting SomeObject is done by making the call:
AbstractSecureFactory.getInstance().getObject(securityCredentials)

The returned object, SomeObject, is an object that operates with the correct privileges.
Secure Factory

• Inside the factory:
  1. Using the current concrete implementation of AbstractSecureFactory
  2. Look at security credentials that were passed in the call
  3. Create an instance of the appropriate concrete version of SomeObject
  4. Further specialise settings in SomeObject
Secure Factory

• The caller and SomeObject does not have to contain logic for checking privileges. It is always returned by the factory, and the factory picks the SomeObject with correct behavior.

• Concrete versions of SomeObject does not have to implement code for functions that are not callable by the level of privilege to which it is developed.
  • The LowPrivilegeSomeObject does not need to implement the Write function.
Secure Chain of Responsibility

- **Intent:** Decouple the logic that determines privileges from the portion of the program that is requesting the functionality.

- **Motivation:** Applications sometimes need to allow and disallow certain functions depending on the role of the user.
Secure Chain of Responsibility

Supply request and user credentials → Manager Report Generator → Sale Analyst Report Generator → Sales Intern Report Generator

Handle request → Handle request → Handle or reject request

Pass request if credential check fails → Pass request if credential check fails
Secure Chain of Responsibility

- The selection of functionality is hidden from the caller, it will be selected based on the user credentials.
- The caller is not aware of which handler has dealt with the request.
- Easy to change the behavior of the system (add/remove handlers). Can even be done dynamically at runtime by changing the links.
Secure Logger

• **Intent:** Prevent an attacker from gathering potentially useful information about the system from system logs and to prevent an attacker from hiding their actions by editing system logs.

• **Motivation:** System logs usually contain a great deal of information about the system itself and its users.
Secure Logger

Application → Log → Secure Logger

Log Viewer ← Log Reader

Protected data

Unprotected data
Secure Logger

- Standard mechanisms for reading log files will not work as the data will be somehow encrypted.
- The reader is necessary to access log files, and it requires authentication and authorization.
- Any adversary that gets a hold of log files can not use their content.
- (A possible implementation could use existing disk encryption systems).
Clear Sensitive Information

- **Intent:** It is possible that sensitive information has been stored in reusable resources after a user session or application has run. Sensitive information should be cleared from reusable resources.

- **Motivation:** In many cases the action of returning a reusable resource to the pool of resources simply marks the resource as available. The contents of the resource are left intact until the resource is actually reused. This could potentially lead to leaking of private information.

(Resources include files, memory allocations, etc.)
Clear Sensitive Information

Release data → Scrub data → Return to pool

Application → Pool

Get resource

Do not simply release back
Clear Sensitive Information

ClientInfo::~ClientInfo() {
    this->ipAddr = 0;
    this->trustLevel = BOGUS;
    this->numFaultyRequests = 0;
}

An example of clearing sensitive information in the destructor of an object. In this way the information stored in memory is made insensitive before destroying the object.
Secure Design Patterns

- Secure design patterns are important for all developers, regardless of platform or language.
- Their main purpose is to:
  - Eliminate the accidental insertion of vulnerabilities into code or to mitigate the consequence of vulnerabilities.
- Using design patterns you are taking advantage of many years of learning from mistakes made by others, and you are using best practices.
- It also helps when communicating about code with other developers.
- There are many more very useful patterns:
Software Development Life Cycle

### Misuse cases
- Gather requirements and use cases

### CORAS/Attack Trees
- Security requirements
- Risk analysis
- Risk analysis and penetration testing

### Static analysis
- Risk-based security tests

### SDL
- Release, patch, release, patch, ...

### Secure design patterns
- CORAS/
- Attack Trees
- Static analysis
- SDL
- Secure design patterns

### Requirements
- Secure design patterns

### Architecture and Design
- Plan how the system shall work and how code should be written

### Implementation
- Code and make test plans

### Verification
- Test and ensure that requirements and design are fulfilled