Security Patterns

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Motivation

• Today's systems have various communication features
• Many security-critical dependencies exist
• Security is a non-functional requirement that is difficult to evaluate (e.g., metrics, etc.)
• Which security features are necessary in certain domains?

- It is difficult to design secure systems [Bis02]
- Expert knowledge is needed
Approach

• In order to overcome the knowledge gap among developers we use patterns to
  – provide relevant information in a structured way
  – convey experience

• We use a variation of the well-known design pattern template [Gam94] to present more security-specific information

  Our goal is to enable the reuse of security knowledge

Security Principles (1)

• References ten guiding security principles [Viega and McGraw 2002]

  Ten Security Principles
  • Secure the weakest link.
  • Practice defense in depth.
  • Fail securely.
  • Follow the principle of least privilege.
  • Compartmentalize.
  • Keep it simple.
  • Promote privacy.
  • Remember that hiding secrets is hard.
  • Be reluctant to trust.
  • Use your community resources.
Security Principles (2)

1. Secure the weakest link
   - Intruders will attack parts that are most likely to break
   - Identify and strengthen weak parts to improve overall security

2. Practice defense in depth
   - Implement overlapping security mechanisms
   - Every protection layer adds to overall security

3. Fail securely
   - Failures are not avoidable
   - Security flaws are often inherent to system failures
   - Plan failure modes that assure that the system’s security is not compromised by exceptional behavior

Security Principles (3)

4. Follow the principle of least privilege
   - Grant only the minimum set of permissions
   - Thereby reducing the risk of privilege-abuse

5. Compartmentalize
   - Structure your system in a way that protects different parts independently.
   - Reduces amount of damage that is caused by a security breach in one unit.

6. Keep it simple
   - Avoid unnecessary complexity
   - Usability is an important part of simple design
Security Principles (4)

7. Promote privacy
   • Minimize the information that can be gathered about a system and its users
   • Use misinformation to deter attackers

8. Remember that hiding secrets is hard
   • A system’s security depends on certain secrets being kept
   • Be aware of critical information that could compromise security

9. Be reluctant to trust
   • Do not extend trust unnecessarily
   • Design systems that mistrust information of other parts

Security Principles (5)

10. Use your community resources
    • Public scrutiny improves code as it exploits weaknesses and errors
    • Code written by individuals is usually less secure

Tradeoffs:

- Compartmentalize (P5) ↔ Keep it simple (P6)
- Usability (P6) ↔ Promote privacy (P7)
- Practice defense in depth (P2) ↔ Keep it simple (P6)
Patterns

“Each pattern describes a problem which occurs over and over again in our environment, and then describes the core of the solution to that problem, in such a way that you can use this solution a million times over, without ever doing it the same way twice.”

Christopher Alexander [Ale77]

- Essential elements of a pattern [GHJV94]
  - Name
  - Problem
  - Consequences
  - Solution

- Benefits
  - Improves communication and establish terminology
  - Provides structured information and captures knowledge
  - Unifies design and improves comprehensibility

Design Patterns

- “Design patterns are patterns that express solutions to recurring software design problems in terms of objects and interfaces” [GHJV94].

- Gamma et al. propose template structure
Previous work

- Other pattern-based approaches to security problems
  - Fernandez [Fer02]
    • Collection of security patterns (using few UML diagrams)
  - Kienzle et al. [KETE02]
    • Tutorial for writing security patterns
  - Schumacher and Roedig [SR01]
    • Propose the use of patterns in security engineering (no specific template)
  - Yoder and Barcalow [YB97]
    • Collection of security patterns (no diagrams)

Security Pattern Definition

"A Security Pattern describes a particular recurring security problem that arises in a specific context and presents a well-proven generic scheme for its solution."

Schumacher and Roedig [SR01]

• How can the information be structured to reflect the needs of the security domain?

New template that is customized for use in the development of secure software
Security Pattern Template

- We use the design pattern template of Gamma et al. [GHJV94] and extend and modify it to fit our needs:

<table>
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<th>Design Pattern Template</th>
<th>Security Pattern Template</th>
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<td>Also known as</td>
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Classification

- Similar to design patterns [GHJV94] we organize security patterns by purpose in
  ➜ structural,
  ➜ behavioral, and
  ➜ creational
  patterns

- Furthermore, we denote the following abstraction levels for patterns:
  ➜ Application level (objects are deployed at a client)
  ➜ Host level (objects are running on a server)
  ➜ Network level (objects are distributed over a network)
Overview

• Several patterns were identified by the security pattern community [Fer01][YB97]

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Single Access Point (SAP) (1)

• SAP was introduced by Yoder and Barcalow [YB97]
• **Name and Classification**
  – Single Access Point, structural pattern
• **Intent**
  – Proposes single interface to the system to improve control
• **Also known as**
  – Guard Door, Login Window, One Way In, or Validation Screen
• **Motivation**
  – Various access points and hidden back doors make protection difficult
  – Monitoring of external communication should be possible
• **Applicability**
  – For self-contained systems that communicate with external entities
  – Several entry points for greater flexibility cannot be realized with this pattern
Single Access Point (SAP) (2)

- **Structure**

  ![Diagram](image)

Single Access Point (SAP) (3)

- **Participants**
  - External Entities
  - Internal Entities
  - Single Access Point

- **Collaborations**
  - SingleAccessPoint is contacted by external entities
  - It works as mediator

- **Behavior**

  ![Behavior Diagram](image)
Single Access Point (SAP) (4)

**Constraints**
- **Authenticity**: A message that is directly sent to an internal component originates either from a system internal component or the SAP
- **Confidentiality**: Communication between internal components is not disclosed to outside entities
- **Integrity**: Messages inside the system cannot be modified by external entities

**Consequences**
- **Accountability**: The SAP could perform logging tasks and thereby improve accountability
- **Confidentiality, Integrity**: SAP provides a place for monitoring of communication
- **Availability**: If the SAP cannot handle all accesses, availability might be reduced; information for the detection of DoS attacks can be gathered
- **Performance**: Substantial logging operations at the SAP can affect the performance of a system

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Single Access Point (SAP) (4)

**Consequences**
- **Cost**: Depending on the extend of communication with external parties, development can be more difficult and expensive
- **Manageability**: Security-code not be scattered over the entire system
- **Usability**: Access to system might be more inconvenient for a user

**Known uses**
- Linux telnet application
- Windows NT login application

**Related Security Patterns**
- Check Point (monitors communication that passes the SAP)
- Role-Based Access Control ((is initialized upon login)
- Session (is created upon login)

**Related Design Patterns**
- Singleton (to implement the SAP)
Single Access Point (SAP) (5)

- Related Principles
  - **Principle 1**: Secure the weakest link (the pattern considers the interface to external entities to be a possible weakness)
  - **Principle 6**: Keep it simple (the SAP pattern propagates a simplification of the systems access)
  - **Principle 9**: Reluctance to trust

Check Point (1)

- The Check Point pattern was first presented in a framework by Yoder and Barcalow [YB97]
- **Name and Classification**
  - Check Point, structural pattern
- **Intent**
  - A structure for checking incoming requests and handling violations
- **Also known as**
  - Access Verification, Authentication and Authorization, Holding off hackers, Validation and Penalization, or Make the punishment fit the crime
- **Motivation**
  - Systems that communicate with external entities have to take into account illegal requests and attacks
  - Monitoring and access validation is necessary
Check Point (2)

• **Structure**

  ![Diagram of Check Point structure](image)

Check Point (3)

• **Applicability**
  - Check Point can be applied in any system that needs to monitor communication
  - In order to perform checks the system needs a security policy

• **Participants**
  - Check Point
  - Countermeasure
  - Security Policy

• **Collaborations**
  - The Check Point monitors if messages are consistent with the Security Policy
  - Countermeasures are triggered if necessary
Check Point (4)

- **Behavior**
  - [Diagram showing interaction between components]

Check Point (5)

- **Constraints**
  - Authenticity: Check Point’s policy requests may only be answered by the Security Policy object
  - Integrity: Messages that are sent between Check Point and Security Policy cannot be modified
  - Confidentiality, Integrity: External requests are not forwarded until the Security Policy approves it
Check Point (6)

**Consequences**
- Confidentiality: unauthorized access can be prevented
- Integrity: malicious modification can be filtered
- Availability: Check Point can trigger countermeasures to prevent DoS attacks (e.g. delays, blacklists)
- Performance: Complex checks slow down the system
- Cost: Development of an effective check algorithm is difficult and expensive
- Manageability: combining security code in one place simplifies maintenance
- Usability: depending on the check algorithm, harmless requests may be blocked if they match a certain pattern

Check Point (7)

**Known Uses**
- During the login to an ftp server a Check Point is usually used to control the access of users

**Related Security Patterns**
- Single Access Point
- Session
- Role-Based Access Control

**Related Design Patterns**
- Strategy (decouple Check Point from actual implementation of the security policy)
Check Point (8)

- **Related Principles**
  - Principle 1: *Secure the weakest link* (by applying the Check Point)
  - Principle 2: *Practice defense in depth* (further security measures should be considered in addition to the Check Point)
  - Principle 4: *Principle of least privilege* (should be reflected in the Security Policy)
  - Principle 9: *Reluctance to trust* (that all requests are harmless)

Role-Based Access Control (1)

- The Role-Based Access Control pattern was first presented in [YB97] and later in [Fer01]
- **Name and Classification**
  - Role-Based Access Control, structural pattern
- **Intent**
  - Facilitates the representation and maintenance of access structures
- **Also known as**
  - Roles, Actors, Groups, Projects, Profiles, Jobs, or User Types
- **Motivation**
  - The use of resources usually underlies certain restrictions
  - In order to facilitate enforcement restrictions need to be represented in some structure inside the system
- **Applicability**
  - Applicable in any system that restricts subjects’ access on resources
Role-Based Access Control (2)

- **Structure**

```
+-----------------+    +-----------------+
| Manager         |    | Submitter       |
+-----------------+    +-----------------+
     \               \                                    
      +-----------------+        +-----------------+    
      | Checkpoint      |        | CheckPoint      |
      +-----------------+        +-----------------+    
      +-----------------+        +-----------------+    
      | Role-Based       |        | Role-Based      |
      +-----------------+        +-----------------+    
      \               \                                    
       +-----------------+    +-----------------+    
       | Right            |    | Right           |
       +-----------------+    +-----------------+    
                                    \               
                                    \               
                                    +-----------------+    
                                    | ProtectionObject |
                                    +-----------------+    
```

Role-Based Access Control (3)

- **Participants**
  - ProtectionObject
  - Right
  - Role
  - Roles
  - User

- **Collaborations**
  - Roles are associated to a set of Objects; a Right object defines the properties of each relationship (type, constraint, transferable)
  - Each user can be associated to Roles that determine his/her privileges
  - This information about access privileges can be queried by other system components
Role-Based Access Control (4)

• Behavior

Role-Based Access Control (5)

• Constraints
  – To be determined

• Consequences
  – Confidentiality, Integrity: An right structure enables definition of access privileges that protect confidentiality and integrity
  – Availability: Restriction of access to resources enhances availability
  – Performance: can be improved by reducing the overall amount of relationships that reflect the access structure
  – Cost: higher development cost, reduced maintenance
  – Manageability: Maintenance is simplified as subjects can be managed in groups

• Known Uses
  – Several applications, including various Database Management Systems (DBMS) and Windows 2000
Role-Based Access Control (6)

- **Related Security Patterns**
  - Check Point
  - Session
  - Limited View

- **Related Design Patterns**
  - Strategy (implement different behavior depending on users role)
  - Observer (keep structure consistent)

- **Related Principles**
  - Principle 4: *Principle of least privilege* (should be reflected in the right structure)
  - Principle 6: *Keep it simple* (by reducing relationships)
  - Principle 7: *Promote privacy* (by restricting access)

Conclusions

- Security patterns help to keep track of non-functional security requirements from the beginning of design
- A well-structured template can enhance the effectiveness of the pattern approach
- Avoiding errors is extremely important in security critical applications
Open problems

• Facilitate formal verification during the application of security patterns by providing formalized constraints that can be checked against the system model
• Continue to scan for security patterns
• Look at security patterns at requirements level.
• Explore how extending modeling languages (such as UML) can/should be extended for security.

References

• [GHJV94] Erich Gamma, Richard Helm, Ralph Johnson, and John Vlissides. Design Patterns: Elements of Reusable Object-Oriented Software. Addison-Wesley, 1994.