Security at Architectural Design Level

Riccardo Scandariato

Institute of Software Security, TUHH, Germany

ric***do . scanda***to @ tuhh.de

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Learning objectives

- What models are interesting for security? And what properties are represented?
- What can I do with models?
  - Analysis, testing, generation, …
- How to build a secure software architecture?

Reading material on Security Tactics
Joanna Santos, et al., An Empirical Study of Tactical Vulnerabilities, JSS, 2019

Software model

- Provides an abstraction of the system

- Software engineering perspective
  - Parts/components and interfaces
  - Funcionality/logic …

We focus on architectural design

"The software architecture of a computing system is the **structure** of the system, which comprise software **components**, the **externally visible properties** of those components, and the **relationships** among them"

Len Bass

“The fundamental concepts and properties of a system in its environment embodied in its elements, relationships, and in the principles of its design and evolution.”

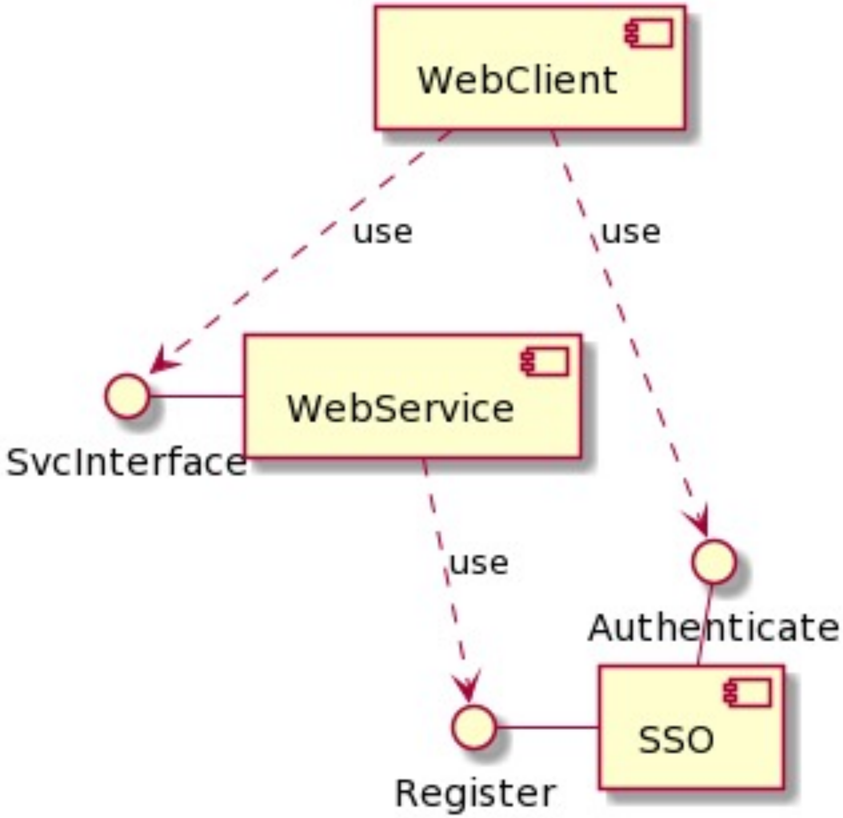
ISO/IEC/IEEE 42010
http://www.iso-architecture.org/ieee-1471/defining-architecture.html

The set of design decisions that determine the quality properties of a system

Jan Bosch

Security – Commonly used models

UML Component Diagram

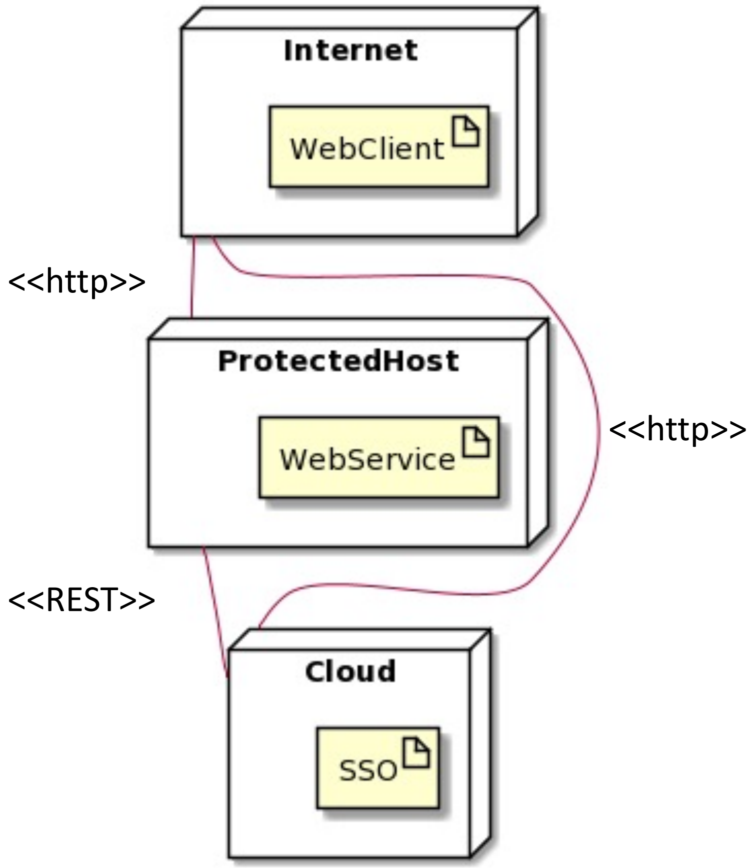


Security – Commonly used models

UML Sequence Diagram

Security – Commonly used models

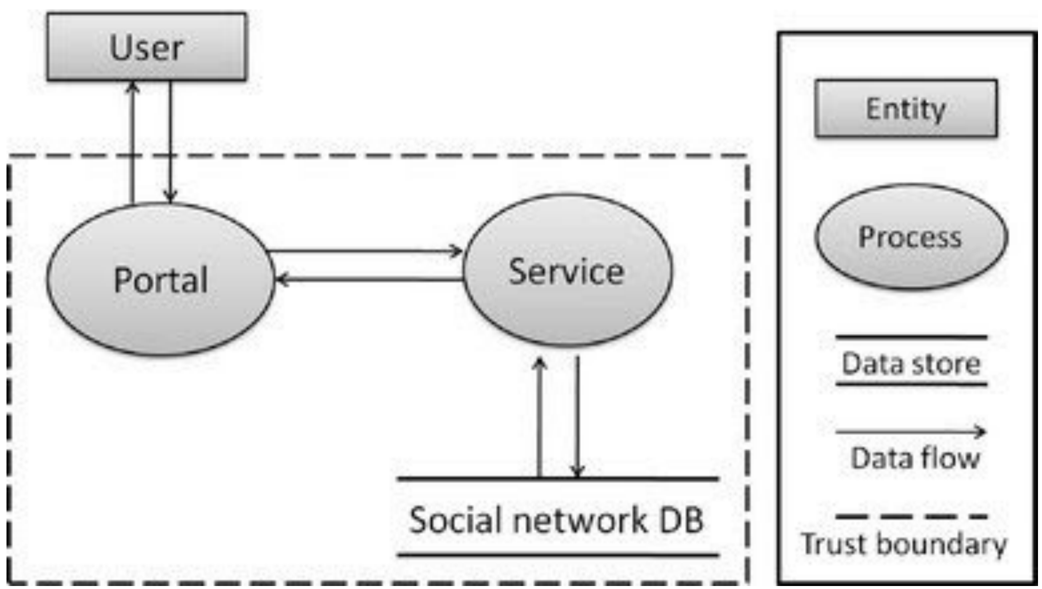
UML Deployment Diagram



Security – Commonly used models

Data Flow Diagram

We'll see this later
(cf. Threat analysis)

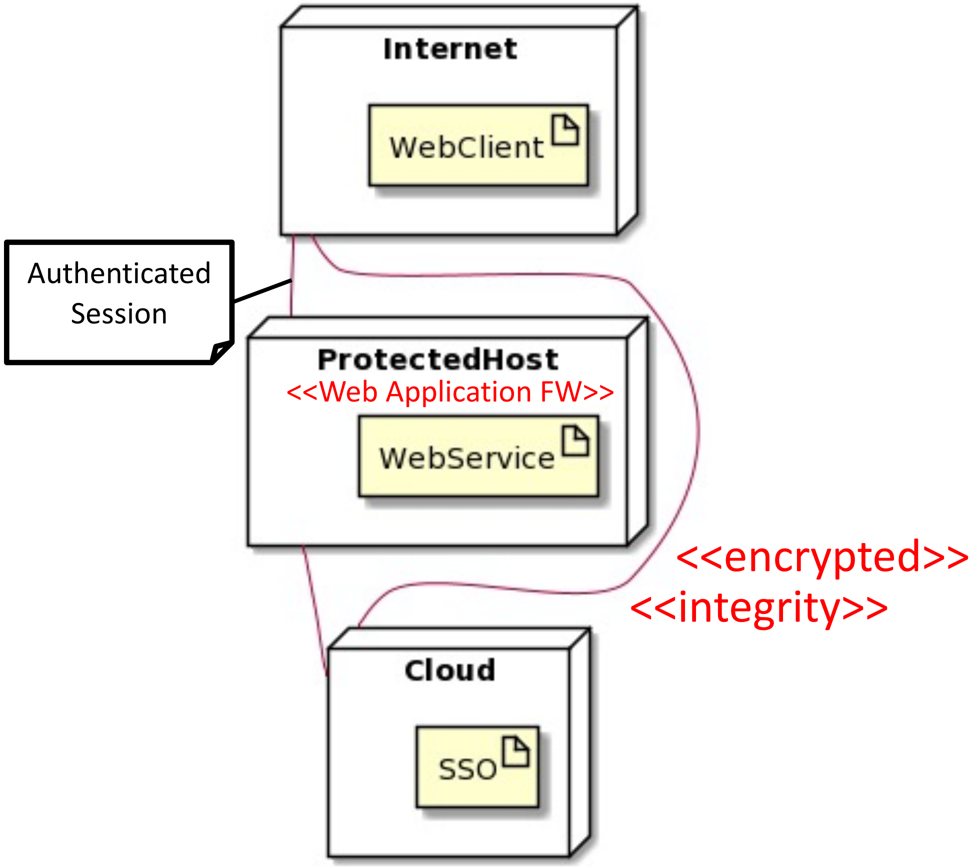


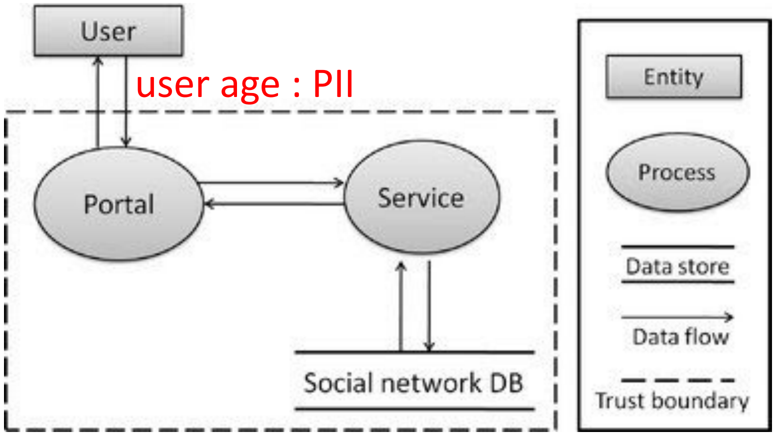
Security model

- Provides an abstraction of the system
- Software engineering perspective
  - Parts/components and interfaces
  - Funcionality/logic ...
- Security engineering perspective
  - Data/assets, their sensitivities
  - Information flows
  - Security mechanisms
  - Security assumptions/expectetions ...

Security engineering perspective

Examples





PII : personally identifiable information

The problem of semantics ☺

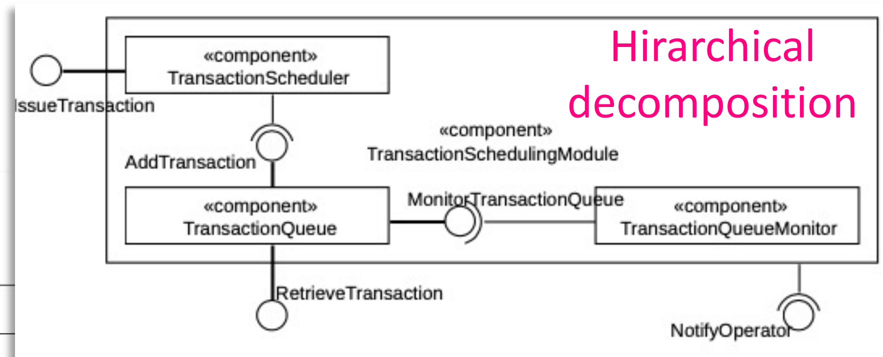
Model, where from?

- Top-down, as an up-front blueprint
  - “Security concept” developed in safety-critical domains (automotive, aviation, medical)
- Bottom-up, reconstructed by experts
  - Common case when security analysis starts
  - E.g., most web-based systems
- Bottom-up, automatically extracted from code
  - Research field (ArchSec, Gravity, etc)

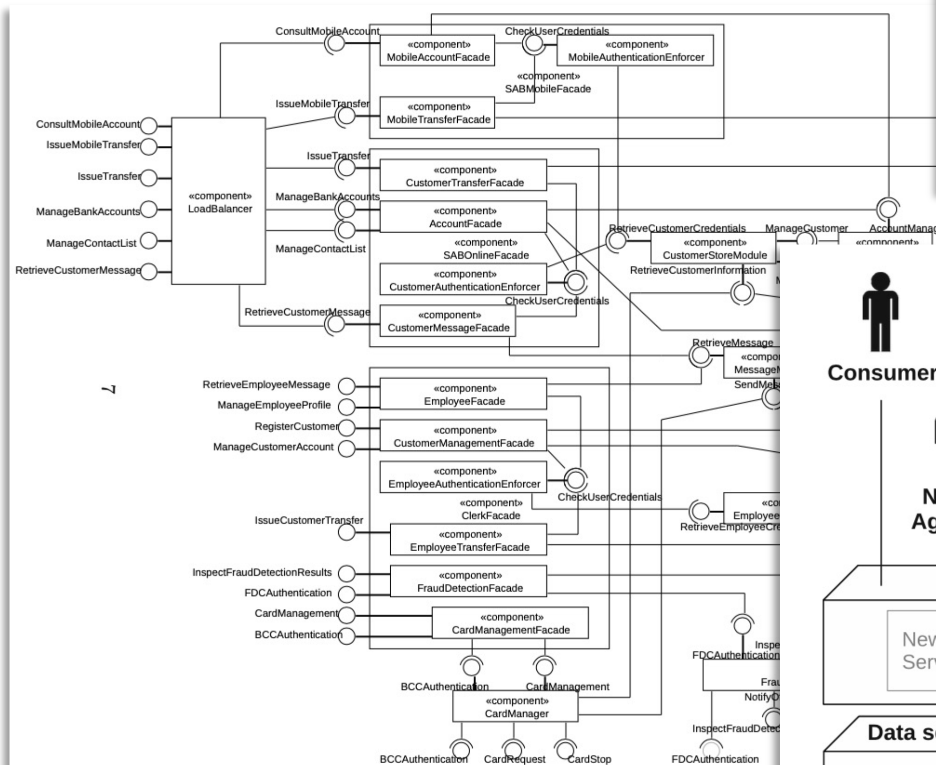
Only for your info

Architectural documentation

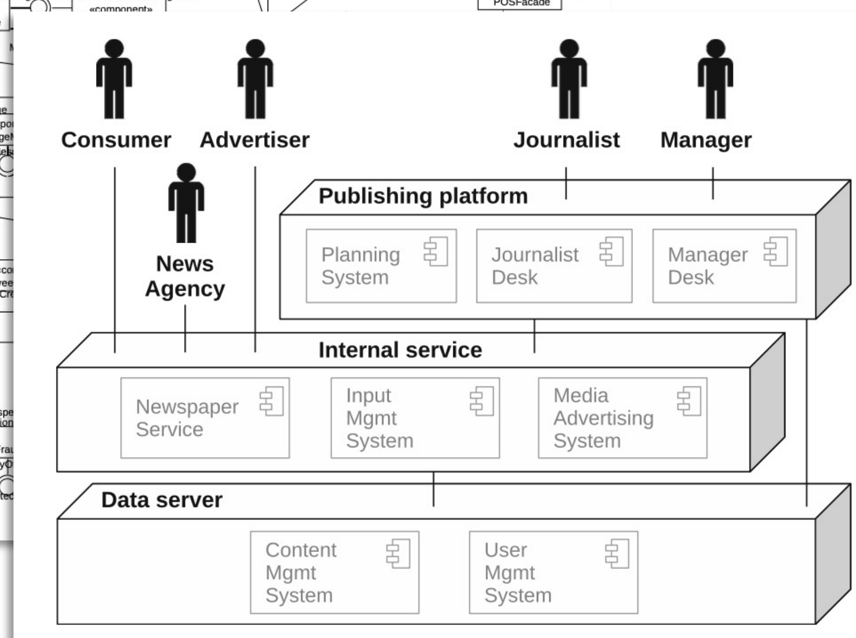
Academic dream



Hirarchical decomposition



Component diagram

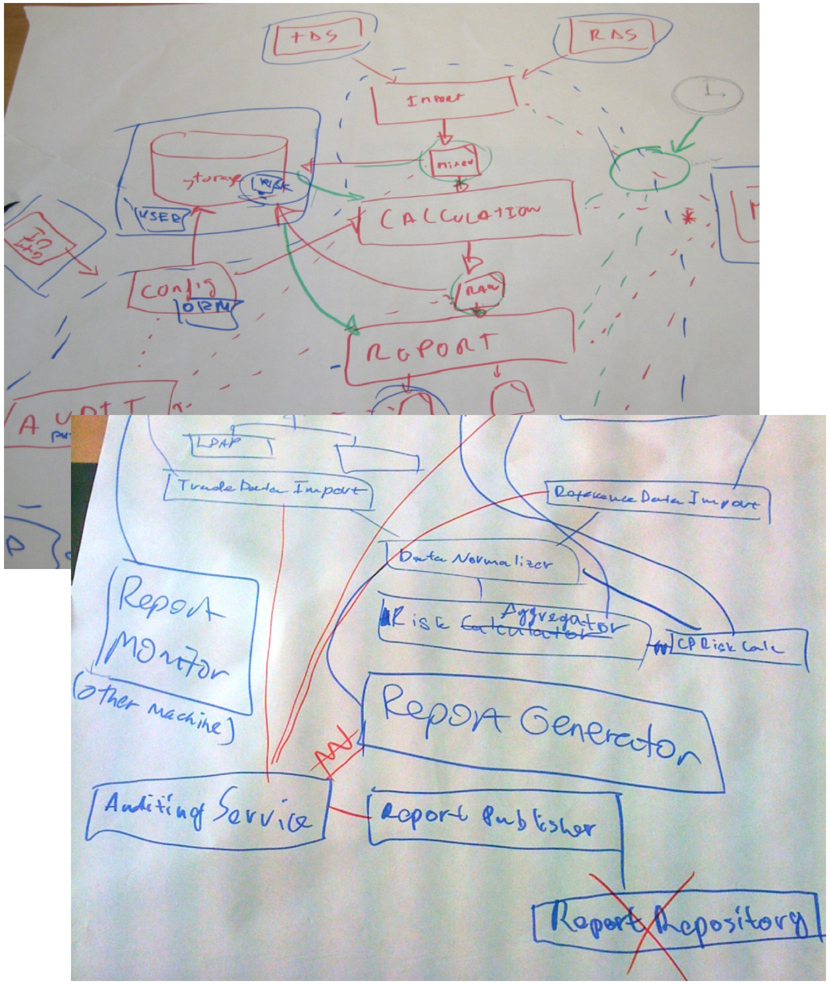


Deployment diagram

Only for your info

Architectural documentation

Real life



Credit: https://c4model.com

Models, what for?

- Model analysis

Next week

- Code generation
- Model-based code generation

- More (e.g., monitoring, metrics...)

Model-based code generation

- Derive (draft) implementation code and configuration
- E.g., code: Authorization pattern → Security aspect woven in code
- E.g., config: access control policy
  - derive roles from context/component diagrams
  - derive permissions from use cases, workflows, etc.

Model-based test generarion

- Functional security testing
  - E.g., test rules in a firewall, given the components that are present in the model
  - E.g., test access control rules, provided the roles in the model
- Security vulnerability testing (penetration)
  - Generate attack sequences using the system topology
  - Model-based fuzzing (e.g., alter order of messages in a protocol), from a sequence diagram

Other uses

- Model-based runtime monitoring
  - Monitoring the security assumptions made in the model
  - E.g., communication is encrypted, communication is only allowed between A and B, …
- Model-to-model transformations
  - Hardening the model by adding security countermeasures
  - Making the functionality more GDPR compliant
- Compute security metrics
  - Mostly for for certification, but also prediction, etc

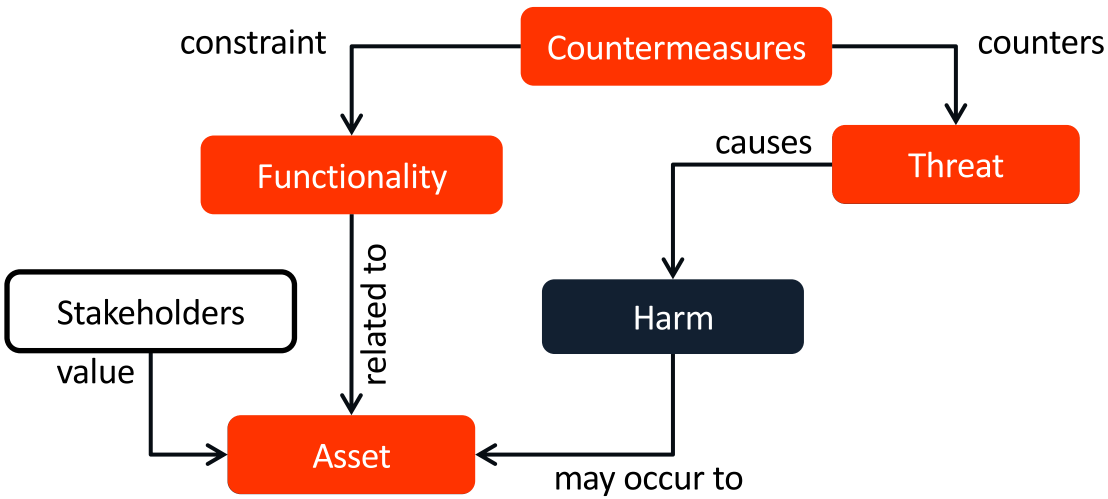
BUILDING SECURITY-AWARE ARCHITECTURAL DESIGN

Secure architectural design

- Identify the *assets* of interest (by interacting with the stakeholders)
- Understand the relationship *asset ↔ functionality*
- Identify *threats* and their importance (impact, likelihood)
- Implement constraints (i.e., *countermeasures)* to deal with threats
- Hence achieving the security goals

Threat analysis and risk analysis (TARA)

Secure design



In the toolbox

- Previous slide has a “magic” step ☺

  “Implement constraints (i.e., countermeasures) to deal with threats”

- What security knowledge do we use?
  - Security principles
  - Security tactics
  - Security patterns / security solutions

SECURITY DESIGN PRINCIPLES

Security Meta Principles

A. Simplicity
   - Fewer components and cases to fail
   - Fewer possible inconsistencies
   - Easy to understand
B. Restriction
   - Minimize access and inhibit communication
C. Minimal assumptions
   - Avoid trust

Security Design Principles

1. Least Privilege
2. Fail-Safe Defaults
3. Economy of Mechanism
4. Complete Mediation
5. Open Design
6. Separation of Privilege
7. Least Common Mechanism
8. Psychological Acceptability

(VERY old)
J. Saltzer , D. Schroeder, The Protection of Information in Computer Systems, *Proceedings of the IEEE 63(*9), 1975

1. Least Privilege

- A subject/process should be given only those privileges necessary to complete its task
  - Function, not identity, controls
  - Rights added as needed, discarded after use
- **Architecture**: component only has privileges to interact with other appropriate components
- Common violation:
  - Browsing the Internet while logged as ***administrator*** or ***root***

2. Fail-Safe Defaults

- Default action is to deny access
- When an action fails, system must be restored to a state as secure as the state it was in when it started the action

- Example
  - Card looked up in vendor database to check for stolen cards
  - If no connectivity, no authentication, but transaction is logged -> NO!

3. Economy of Mechanism

- Keep it as simple as possible (KISS)
  - Use the simplest solution that works.
  - Fewer cases and components to fail.
  - Minimal retained state (harder for program to get ‘confused’)
- Reuse known secure solutions
  - i.e., don’t write your own cryptography.

Study at home

4. Open Design

- Security should not depend on secrecy of design or implementation
  - No "Security through obscurity"
  - Refers to security policy and mechanism (not secrets like passwords and crypto keys)

- E.g., do not rely on obfuscation

5. Complete Mediation

- Check every access
- Usually checked once, on first access:
  - UNIX: File ACL checked on `open()`, but not on subsequent accesses to file
- If permissions change after initial access, unauthorized access may be permitted

- Also important for auditing!

Study at home

6. Separation of Privilege

Require multiple conditions to grant access

- Separation of duty
- Compartmentalization
- Defense in depth (or multiple layers of security)

Study at home

Separation of Duty

- Functions are divided so that one entity does not have control over all parts of a transaction.
- Example:
  - Different persons must initiate a purchase and authorize a purchase.
  - Two different people may be required to arm and fire a nuclear missile.

Compartmentalization

- Problem: A security violation in one process should not affect others.
- Solution: isolate components in deployment
  - Physically
  - Through virtual machines

- Also: Self-limit consumption of resources
- Also: Divide system into parts which are limited to the specific privileges they require in order to perform a specific task (**privilege separation**)

Defense in Depth

- Diverse defensive strategies
  - Different types of defenses (protection, detection, reaction)
  - Different implementations of defenses (variety)
  - If one layer pierced, next layer may stop
  - Avoid “crunchy on the outside, chewy on the inside” security
- Contradicts “Economy of Mechanism”
  - Think hard about more than 2 layers

Study at home

7. Least Common Mechanism

- Mechanisms used to access different resources should not be shared
  - Error or compromises of the mechanism while accessing one resource allow compromise of all other resources
  - Use separate machines, separate networks
  - All data in a blackboard mediated by a blackboard component?
- Contradicts “Economy of Mechanism”?

Study at home

8. Psychological Acceptability

- *Security mechanisms should not add to the difficulty of accessing a resource*

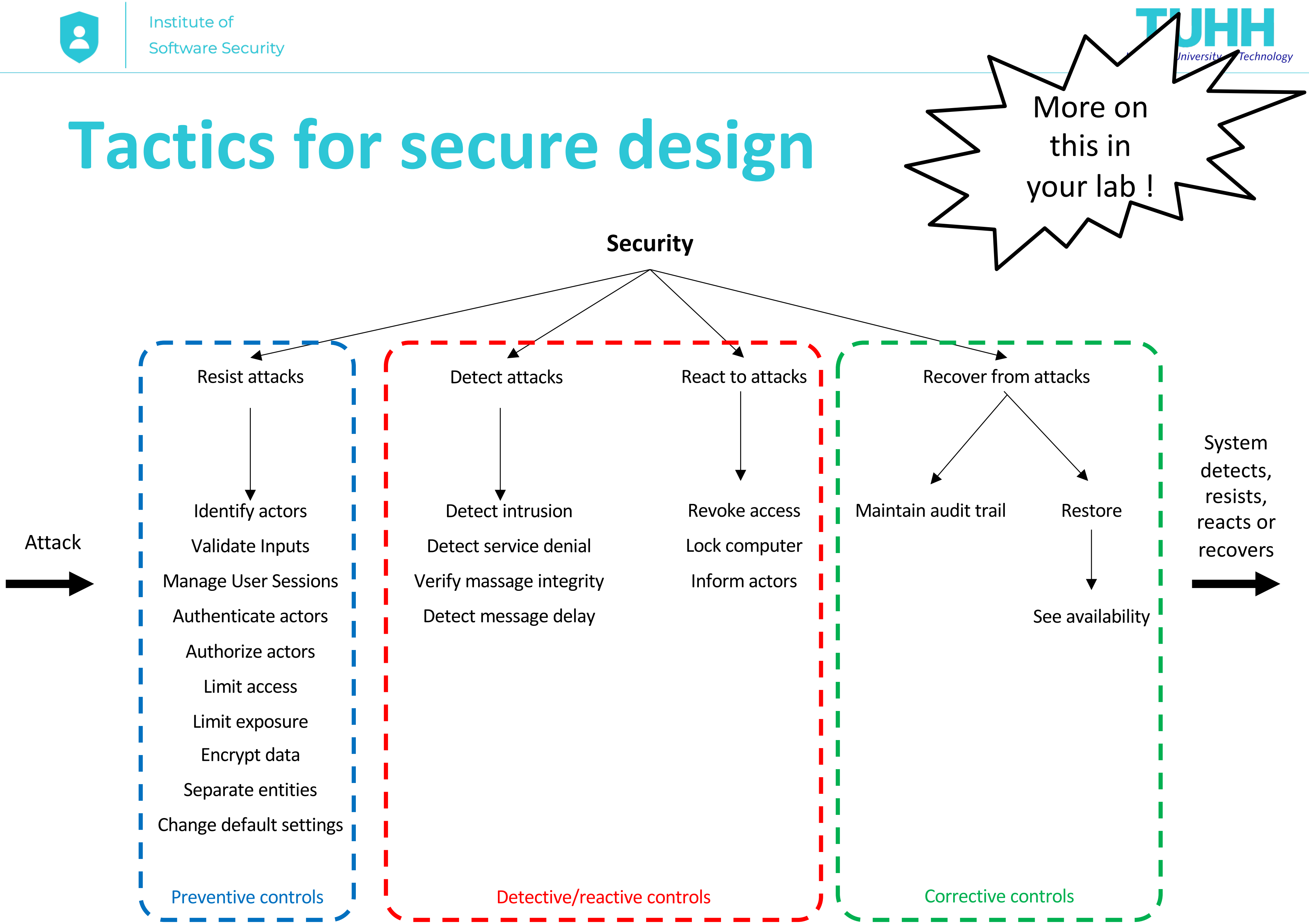
- Human factors are critical here
  - Hide complexity introduced by security mechanisms
  - Make system secure in default configuration

- Security vs Usability

Upcoming lecture on this topic

SECURITY TACTICS

Tactics for secure design



Tactics for secure design

Category	Tactic	Description
Resist Attacks	Identify Actors	*Identifies the external agents that provide inputs into the systems*
	Validate Inputs	*Sanitizes, neutralizes and validates any externally provided inputs to minimize malformed data from entering the system and preventing code injection in the input data*
	Manage User Sessions	*Retains the information or status about each user and his/her access rights for the duration of multiple requests*
	Authenticate Actors	*Verifies the authenticity of actors (i.e. to check if the actor is indeed who it claims to be).*
	Authorize Actors	*Enforces that agents have the required permissions before performing certain operations, such as modifying data*
	Limit Access	*Limits the amount of resources that are accessed by actors, such as memory, network connections, CPU, etc.*
	Limit Exposure	*Minimizes the attack surface through designing the system with the least needed amount of entry points*
	Encrypt Data	*Maintains data confidentiality through use of encryption libraries*
	Separate Entities	*Places processes, resources or data entities in separate boundaries to minimize the impacts attacks*
	Change Default Settings	*Forces users to configure the system before use by changing the default (and potentially less secure) configuration.*
React to Attacks	Revoke Access	*In case of attacks, the system denies access to resources to everyone until the malicious behavior ends*
	Lock Computer	*Lockout mechanism that takes effect in case of multiple failed attempts to access a given resource*
	Inform Actors	*In case of malicious activities, the users/administrators or other entities that are in charge of the system are notified.*
Detect Attacks	Detect Intrusion	*Monitors network traffic for detecting abnormal traffic patterns caused by intrusion attempts*
	Detect Service Denial	*Monitors incoming traffic for detecting Denial Of Services (DoS) attacks.*
	Verify Message Integrity	*Ensures integrity of data, such as messages, resource files, deployment files, and configuration files*
	Detect Message Delay	*Detects malicious behavior through observing the time spent on delivering messages. In case messages are taking unexpected times to be received, the system may detect a potential data leakage.*
Recover from Attacks	Audit	*Logs user activities in order to identify attackers and modifications to the system*

Risk-aware design

- Preventive: avoid incidents before they occur
  - E.g., access control to avoid disclosure

E.g., First line of defense

- Detective/Reactive: respond to incidents while they occur
  - E.g., detect anomalous activity and lock down the network

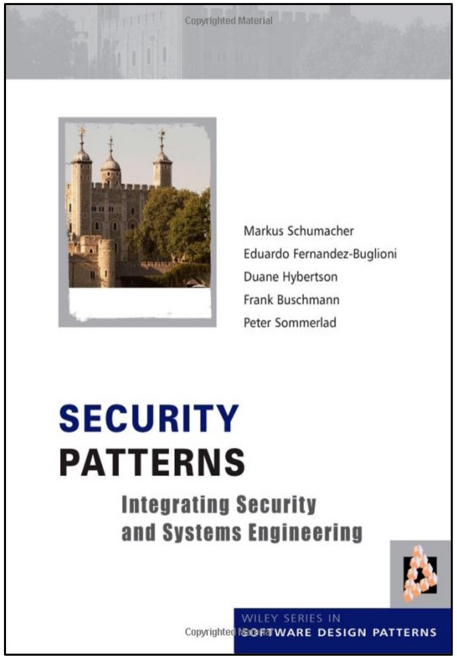
E.g., Second line of defense

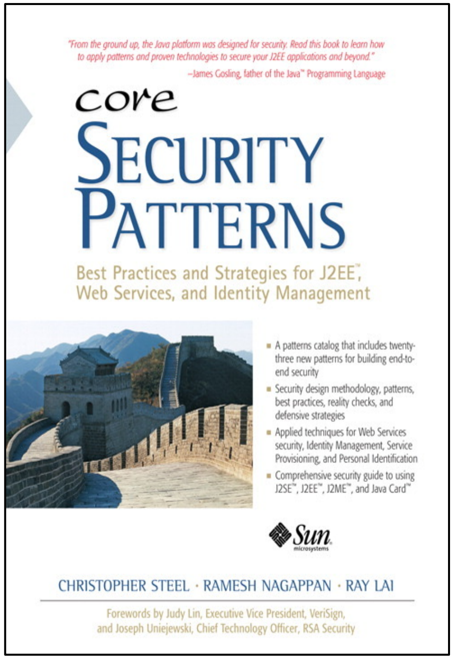
- Corrective: handle incidents after they have occurred (cf. **resilience**)
  - E.g., restore correct state from backup

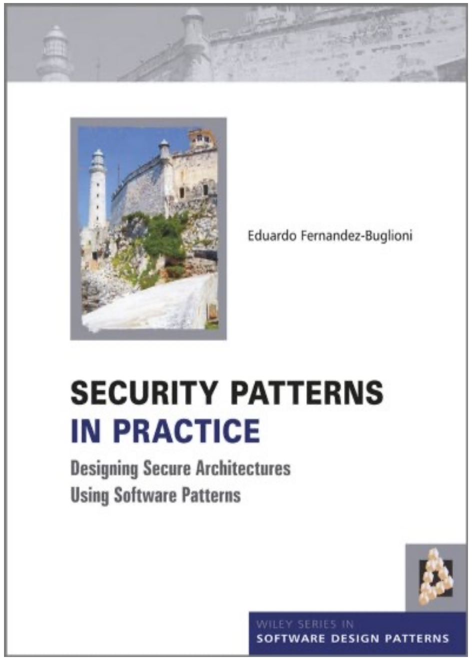
E.g., Third line of defense

SECURITY DESIGN PATTERNS

Security patterns – Fashion items ?







More on this in your lab !

Single Access Point
Example

Problem

A security model is difficult to validate when it has multiple "front doors", "back doors", and "side doors" for entering the application

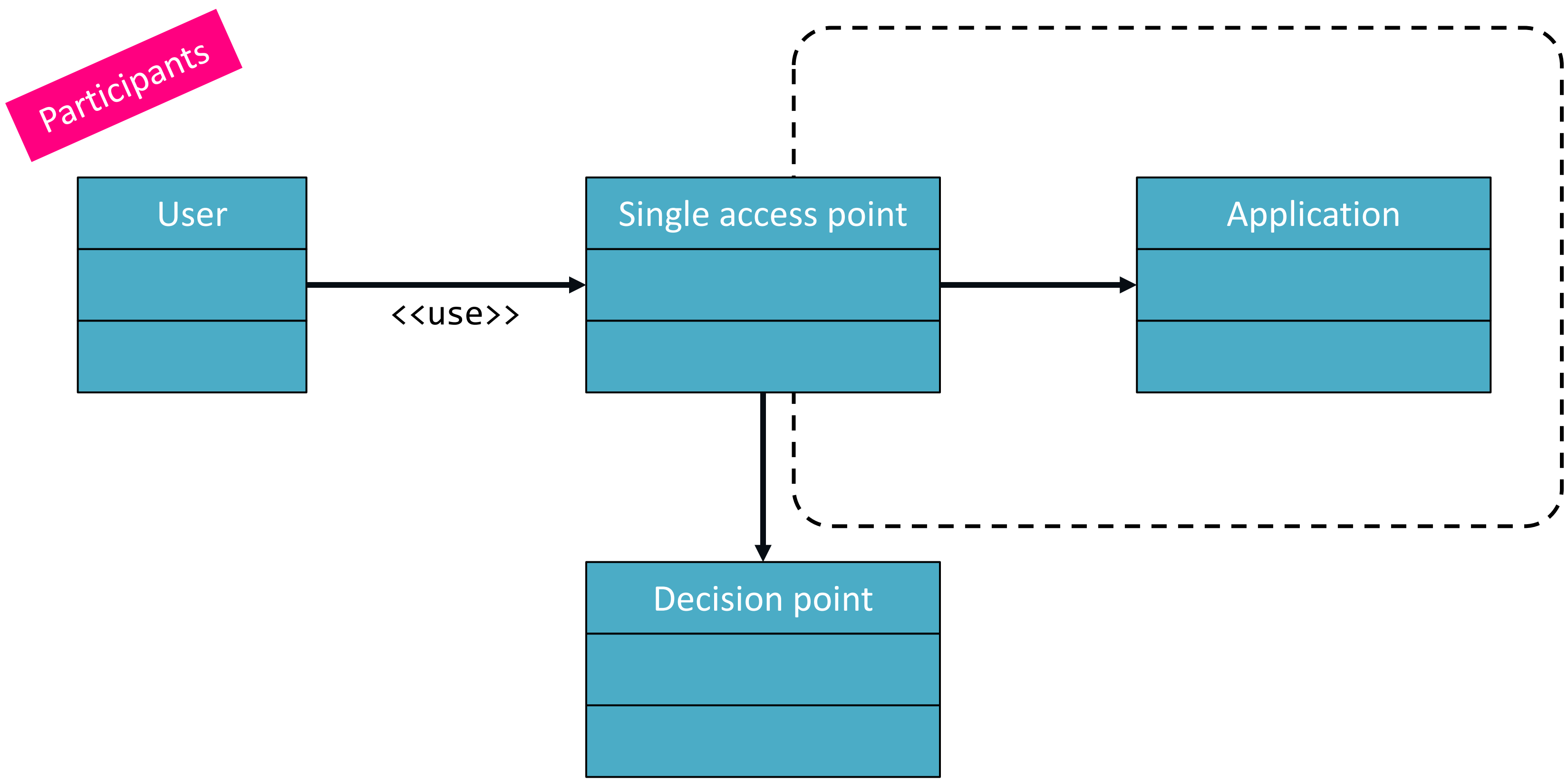
Solution

Reduce the attack surface by setting up only one way to get into the system and if necessary, create a mechanism to decide which sub-application to launch.

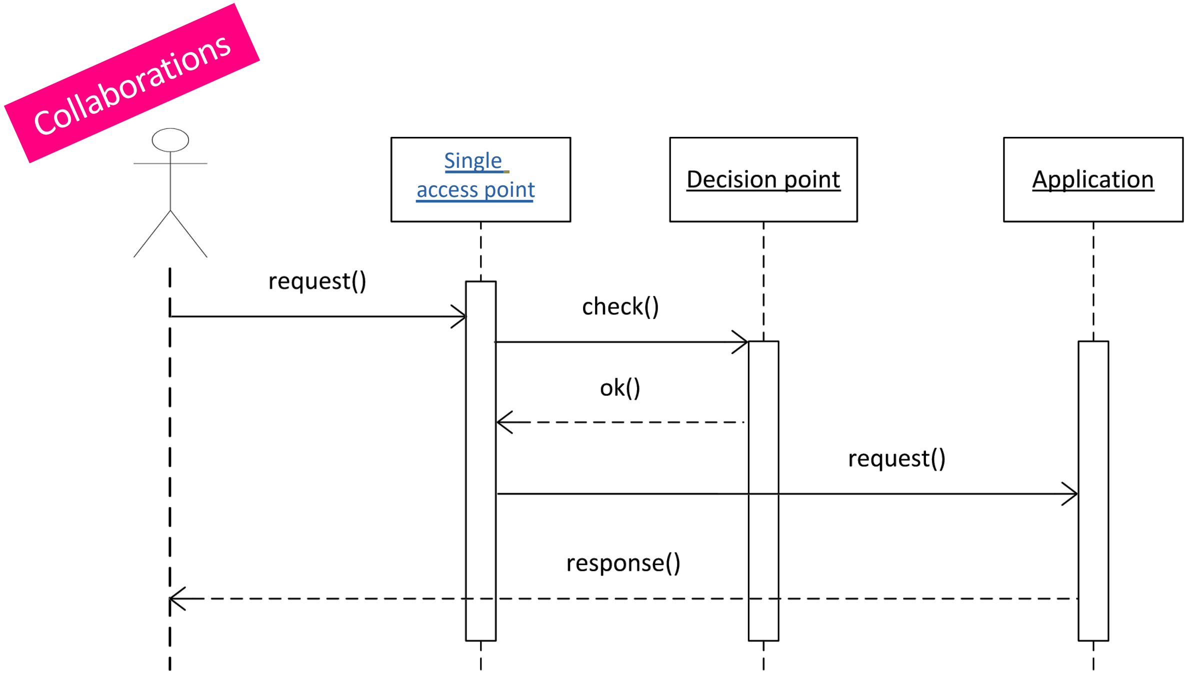
Known Uses. UNIX telnet and Windows NT login applications use Single Access Point for logging into the system.

Source: Wiley Book

Single Access Point

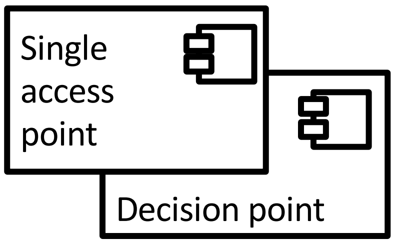


Single Access Point



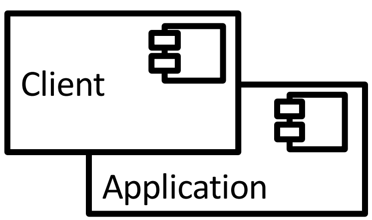
Some "theoretical" underpinning

What is a (security) design pattern?



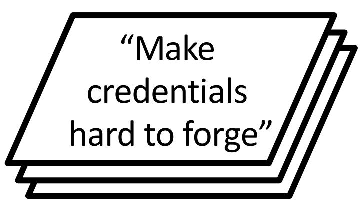
New components

Added to the design to fulfill new security functionality



Roles

Connect generic solution (pattern) to specific design. Wire the newly added components to existing ones



Expectations

Impose constraints on the rest of the design (assumptions!). Need to either modify existing components (or "wires") to satisfy expectations, or modify design "at large" (e.g., the account creation functionality, so that a good password is chosen)

T. Heyman, et al, **The security twin peaks**, ESSoS 2011

Instantiating a pattern

Single Access Point