Design Flaws and how to spot them

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Lecture in Software Security course

DESIGN FLAWS

3 Types of Security Design Flaws

Omission weakness

A threat is not addressed at all

Commission weakness

A threat is addressed with the wrong solution

Realization weakness

A threat is addressed with the right solution, but its implementation is wrong

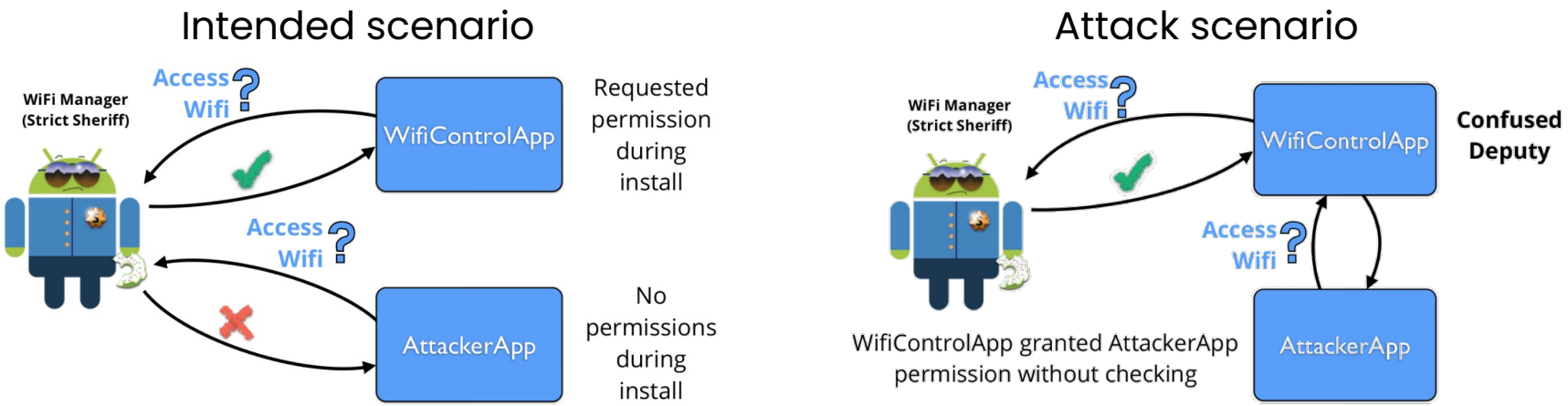
Examples

- Unprotected Storage of Credentials
- Using Weak Authentication (e.g., "API keys")
- Trust Boundary Violation (e.g., I/O validation)

Mehdi Mirakhorli: "Common Architecture Weakness Enumeration (CAWE)" http://blog.ieeesoftware.org/2016/04/common-architecture-weakness.html and Santos, Joanna C S, Katy Tarrit, and Mehdi Mirakhorli. "A Catalog of Security Architecture Weaknesses." In *International Conference of Software Architecture Workshops (ECSAW)*, 2017. https://doi.org/10.1109/ICSAW.2017.25.

Example of a Design Flaw

- CWE-926: Improper Export of Android Application Components ("confused deputy")



CWE: https://cwe.mitre.org/data/definitions/926.html
Image: https://owasp.org/www-pdf-archive/Danelon_OWASP_EU_Tour_2013.pdf

Example: Permission re-delegation in Android

The Android application exports a component for use by other applications, but **does not properly restrict** which applications can launch the component or access the data it contains.

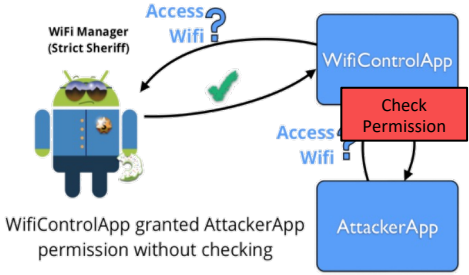
Intent spoofing: attacker sends malicious intent to an intent processor (e.g., permission re-delegation, but intent flooding also an option)

Obvious consideration: design choices/fixes have an effect on the code base

Possible Solution

Checking for permissions at the receiving side

```
public class Sender extends Service {

    public int onStartCommand(Intent intent, int flags, int startId){

    if (checkCallingPermission("android.permission.SEND_SMS") ==
    PackageManager.PERMISSION_GRANTED) {

        String phoneNumber = intent.getStringExtra("PHONE_NUMBER");

        String msg = intent.getStringExtra("MSG_CONTENT");

        SmsManager smsManager = SmsManager.getDefault();
        smsManager.sendTextMessage(phoneNumber, null, msg, null, null);

    }
```



M. Hammad, H. Bagheri, S. Malek, **DelDroid: An Automated Approach for Determination and Enforcement of Least-Privilege Architecture in Android,** *Journal of Systems and Software 2019*

More coming up in course
“Secure Software Engineering”

ARCHITECTURAL SECURITY

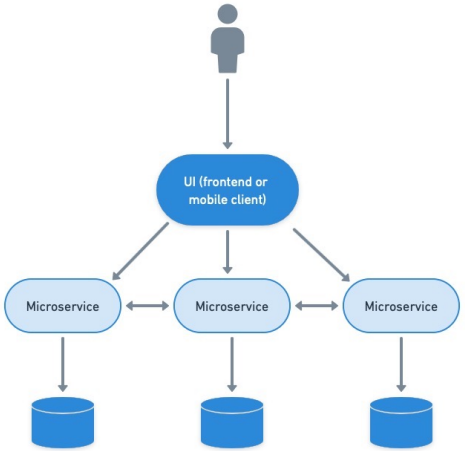
Modelling Software Systems

- Software models = abstractions of the implementation
- Architectural models: high-level overview of software components and their interconnections
- Useful to reason about architectural design and security of the system
- Some design flaws can be identified in architectural models

Microservice Architecture

"Microservices are small, autonomous services that work together" [1]

- Split application into multiple microservices, each with single functionality and dedicated resources
- Deploy them independently
- Let them communicate over the network to fulfill business logic

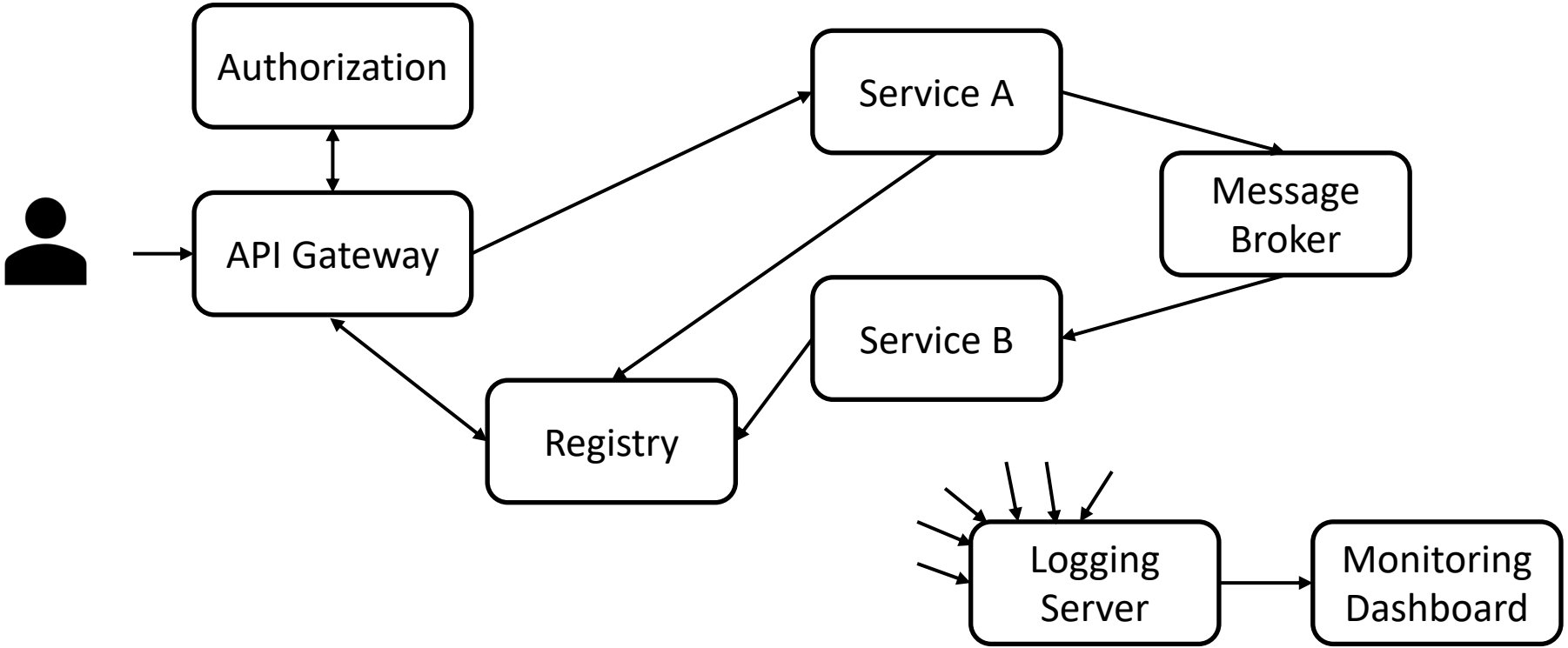


[1] Irakli Nadareishvili et al. *Microservice Architecture: Aligning Principles, Practices, and Culture*. O'Reilly Media, Inc., 2016
Image: https://semaphoreci.com/blog/microservice-architecture

Typical Components of μ-services

- Some components present in most microservices:
  - Service registry: keeps track of deployed instances
  - Authorization server: central server issuing auth tokens
  - API gateway: single entry point to the system
  - Monitoring dashboard: visualization of the system
  - Logging server: central server storing logs of all others
  - Message broker: for asynchronous communication between services

Example of typical architecture



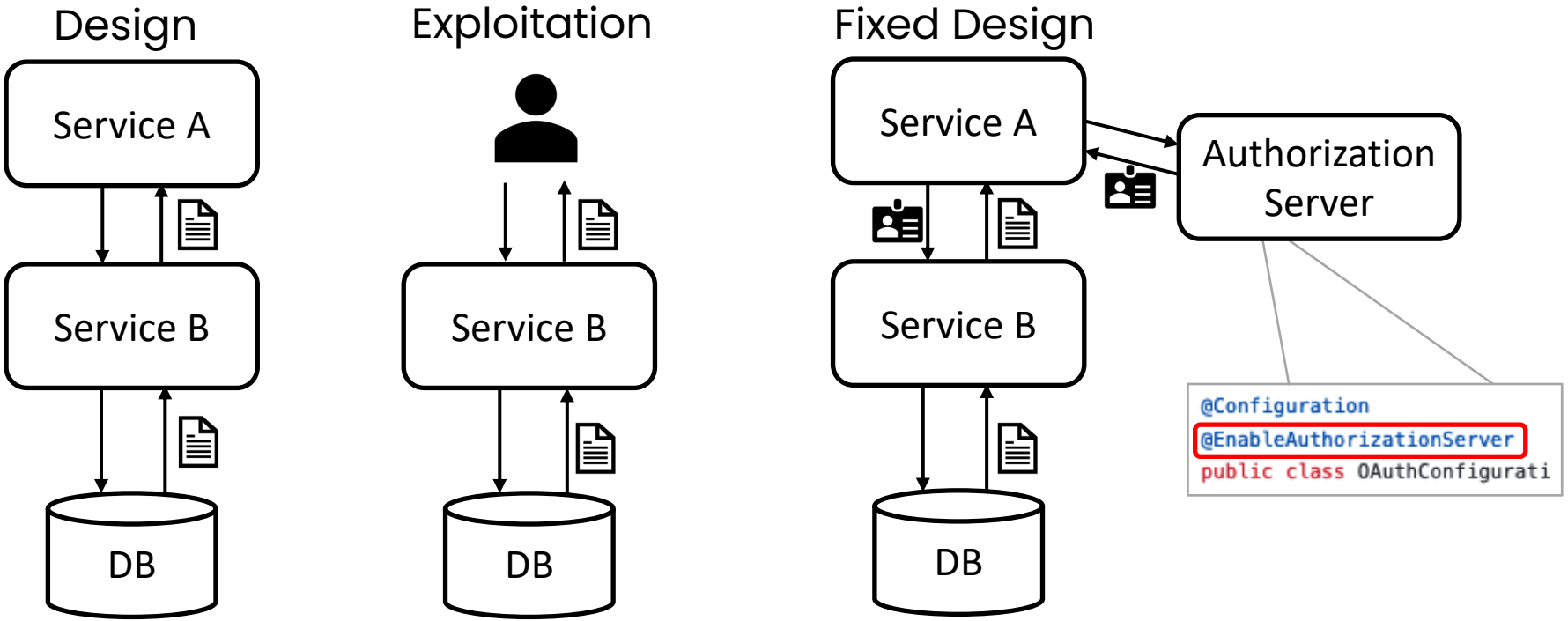
Security Challenges of Microservices

Most pressing:

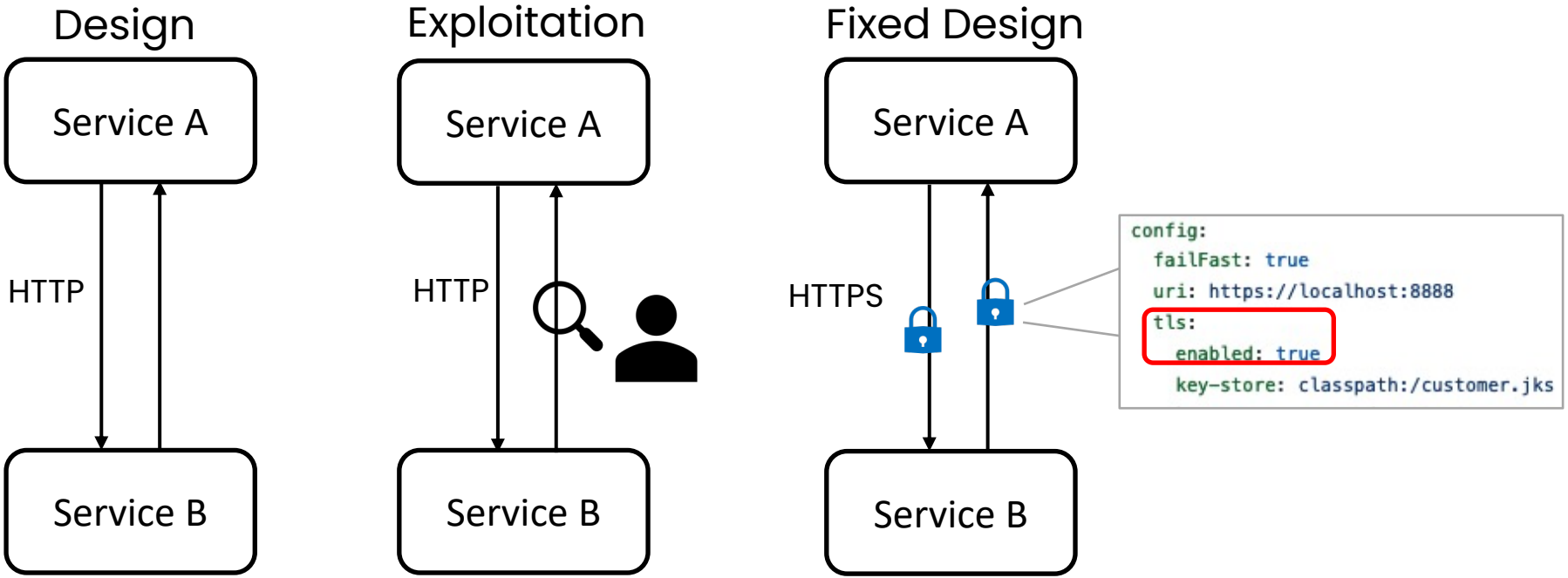
- Communication over untrusted network
- Increased attack surface
- Establishing trust between services

A. Pereira-Vale, E. Fernández, R. Monge, H. Astudillo, G. Márquez, *Security in microservice-based systems: A multivocal literature review*, Computers & Security 103, 2021

Example: auth



Example: encryption



Best-practices to follow

- Best-practice rules for secure architectural design
  - E.g. by OWASP [1], NIST [2], or CSA [3]
- Design and implementation guidelines that should be followed by any microservice application
- E.g. how to set up logging in a distributed environment, how to handle authorization, etc.

[1] https://cheatsheetseries.owasp.org/cheatsheets/Microservices_security.html
[2] https://csrc.nist.gov/publications/detail/sp/800-204/final
[3] https://cloudsecurityalliance.org/artifacts/best-practices-in-implementing-asecure-microservices-architecture

Example rules

→ “An API Gateway should exist as single entry point to the system and perform authorization and authentication.”

→ “All communication between the services should be encrypted using secure communication protocols.”

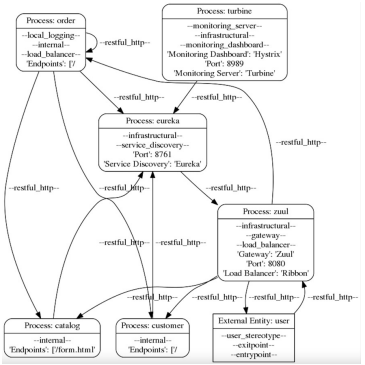
→ “A central logging subsystem which includes a monitoring dashboard should exist.”

Anusha B. Tukaram et al., *Towards a Security Benchmark for the Architectural Design of Microservice Applications.* ARES'22

How to obtain models

- If we want to check rules on the models, we need models correctly representing the application
- Unambiguous source: code of the system

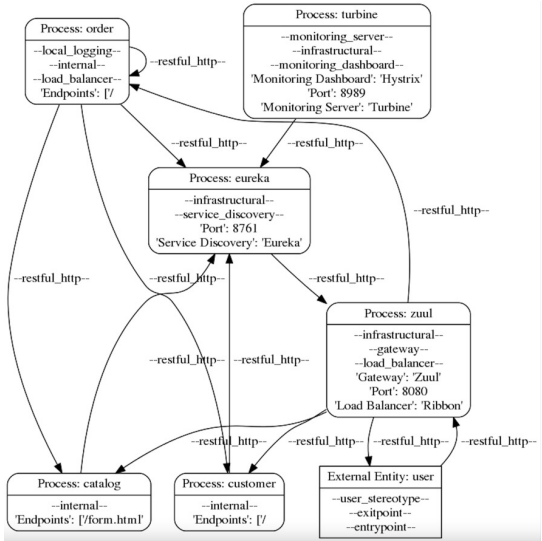
```
14   *
15   */
16
17  @EnableZuulProxy
18  @SpringBootApplication
19  public class ApiGatewayApplication {
20
21          public static void main(String[] args) {
22                  SpringApplication.run(ApiGatewayApplication.class, args);
23          }
24
25          @Bean
26          public CorsFilter corsFilter() {
27              final UrlBasedCorsConfigurationSource source = new UrlBasedCorsConfigurationSource();
28              final CorsConfiguration config = new CorsConfiguration();
29              config.setAllowCredentials(true);
30              config.addAllowedOrigin("*");
31              config.addAllowedHeader("*");
32              config.addAllowedMethod("GET");
33              source.registerCorsConfiguration("/**", config);
34              return new CorsFilter(source);
35          }
36  }
```



EXTRACTING DFDS FROM CODE

Dataflow Diagrams (DFDs)

- Directed graph (nodes and edges) depicting microservices' architecture
- Some additional components seen in literature, e.g. trust boundaries
- What can be added: annotations = additional information about security or other properties



Manual DFD extraction

- Sifting through codebase of an application to identify all relevant items
- E.g. microservices from docker-compose file, information flows from direct API calls, annotations from config files

```
services:
  zookeeper:
    image: wurstmeister/zookeeper:3.4.6
  kafka:
    image: wurstmeister/kafka:2.12-2.5.0
    links:
     - zookeeper
```

```
mongodb:
  host: auth-mongodb
  username: user
  password: ${MONGODB_PASSWORD}
  database: piggymetrics
  port: 27017
```

```
UserRating userRating = restTemplate.getForObject("http://ratings-data-service/ratingsdata/user/" + userId, UserRating.class);
```

Automatic DFD extraction

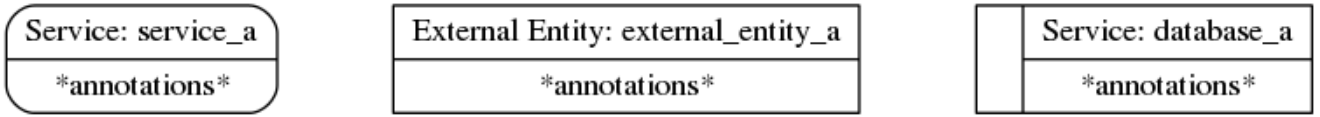
- Tools can mimic manual extraction
- Detection of keywords such as specific commands in the code can reveal items in the DFD

- An approach, based on this idea: Code2DFD [1], an automatic extractor of models for Java microservices

[1] Simon Schneider, Riccardo Scandariato, *Automatic Extraction of Security-Rich Dataflow Diagrams for Microservice Applications written in Java.* UNDER SUBMISSION: Journal of Systems and Software

Nodes in the DFDs (for microservices)

- Nodes are (micro)services, external entities, or databases
- Visualization:



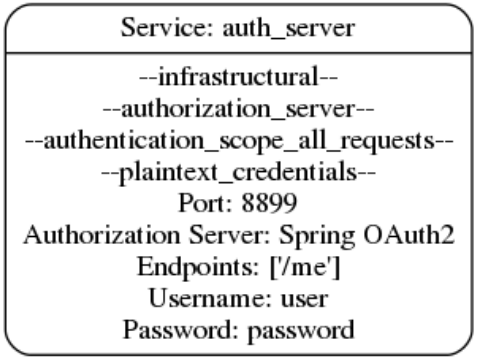
- Found mainly in build files (Maven, Gradle) and IaC files (Docker, Docker Compose)

Flows in the DFDs (for microservices)

- Information flows represent connections between two nodes over which some data is exchanged
- Direct API calls between nodes or communication from infrastructural workings
  - (e.g. authorization procotol, heartbeat messages, periodic logging…)
- Found in code via direct invocations or implicitly by knowing how infrastructural components operate

Additional Annotations in the DFDs

- What we do differently than others in Code2DFD
- Show additional properties of nodes and flows
- Stereotypes and tagged values (key/value-pairs)
- Stereotypes show, what a node's functional purpose is or what properties it has
- Found throughout the codebase, in code and config files



SECURITY ASSESSMENT

Technique 1: Examining Code

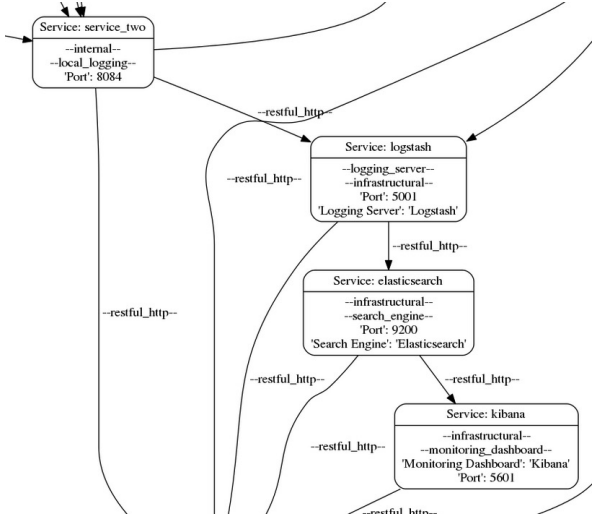
- Source code and configuration determine the system behaviour
- Security properties can thus be checked directly in code
- E.g.: “Is there hard-coded confidential data in the code?” → look for plaintext passwords

```
security.oauth2.client:
  clientId: acme
  clientSecret: acmesecret
```

```
ssl:
  key-store: classpath:server.jks
  key-store-password: password
  key-password: password
```

Technique 2: Examining Model

- Models derived from source code depict system components and properties
- Some security properties can thus be checked in models
- E.g.: “Is logging data collected centrally?”



Technique 3: Examining Code and Model

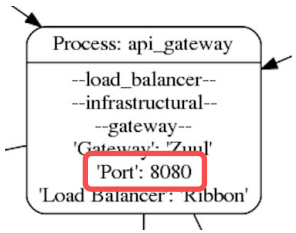
- Some properties are hard to depict nuanced enough in models
- Looking at specific implementation of item found in the model might be needed to grasp details
- E.g.: “Are outgoing connections of a service guarded by a circuit breaker?”

  → Model shows a circuit breaker for the service, code reveals that not all outgoing flows are covered

Traceability Information for Technique 3

- Traceability information: link from model item to place in code where evidence for this item is found
- Identify relevant model item → follow traceability information → examine code for details

Model



Traceability file

```
{'item': 'api-gateway',
        'file': […],
        'sub_items':
                {'0':
                        {'item': 'Port',
                        'file': *link to GitHub*,
                        'line': 19,
                        'span': '(8, 12)'}
[…]
```

Target of link

```
16
17  server:
18    contextPath: /
19    port: 8080
20
```

NEXT LAB SESSIONS

Research Experiment

Next two Lab Sessions

- Collect data for scientific publication
  - If you consent, we'll evaluate your answers anonymously
- Preparation for exam as usual
  - Material is relevant for final exam
- Important:
  - There are no negative or positive consequences if you participate or not ("only miss one lab"-rule still applies)

Requirements Eng (2015) 20:163–180
DOI 10.1007/s00766-013-0195-2

ORIGINAL ARTICLE

A descriptive study of Microsoft's threat modeling technique

Riccardo Scandariato · Kim Wuyts · Wouter Joosen

Received: 28 January 2013 / Accepted: 21 November 2013 / Published online: 3 December 2013

Abstract Microsoft's STRIDE is a popular threat modeling technique commonly used to discover the security weaknesses of a software system. In turn, discovered weaknesses are a major driver for incepting security requirements. Despite its successful adoption, to date no empirical study has been carried out to quantify the cost and effectiveness of STRIDE. The contribution of this paper is the evaluation of STRIDE via a descriptive study that involved 57 students in their last master year in computer science. The study addresses three research questions. First, it assesses how many valid threats per hour are produced on average. Second, it evaluates the correctness of the analysis results by looking at the average number of false positives, i.e., the incorrect threats. Finally, it determines the completeness of the analysis results by looking at the average number of false negatives, i.e., the overlooked threats.

Keywords Secure software · Empirical study · Threat modeling · STRIDE · Anti-requirements

1 Introduction

Threat modeling is recognized as one of the most important activities in software security [26]. A threat modeling technique guides the security analyst to the discovery of the actions that a malicious agent (insider or outsider) might perform in order to misuse a software system. Threats are often referred to as anti-requirements and are an important driver for the definition of the security requirements of a system [31, 42, 47].

Threat modeling is based on the identification of the system's valuable assets, such as sensitive information or the availability of certain processing facilities. Therefore, threat modeling can be applied at several levels of abstraction, depending on the type of assets considered. From a requirements engineering perspective, the assets become more tangible when some design decisions are made and an initial decomposition of the system functionality is chosen. Therefore, early threat elicitation is best performed as soon as an initial architectural model of the system is available. For instance, a solution strategy that opts for data centralization is affected by different security issues than a system where the data is fully distributed. Moreover, threats depend on the security assumptions underlying a given decomposition, as the use of public networks to interconnect the subsystems. These assumptions are only precisely understood when the high-level decomposition of the system becomes more concrete.

Threat modeling can be used to analyze the soundness of (initial) software architectures and to spot flaws early on. The discovered flaws represent an opportunity to elaborate upon the security requirements of the system and, consequently, revisit the design choices or refine the architectural model. A popular technique for threat modeling is Microsoft's STRIDE [46], which is routinely used on all of Microsoft's products [13]. It is endorsed by the most recognized secure software processes, such as Touchpoints [26], OWASP's CLASP [4] and Microsoft's SDL [19]. It is also taught in certification programs such as CSSLP (http://www.isc2.org) and used in the industry [20].

STRIDE is also the subject of ongoing research. For instance, the technique is being augmented by OWASP in order to become applicable to the domain of mobile

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Springer

Informed Consent

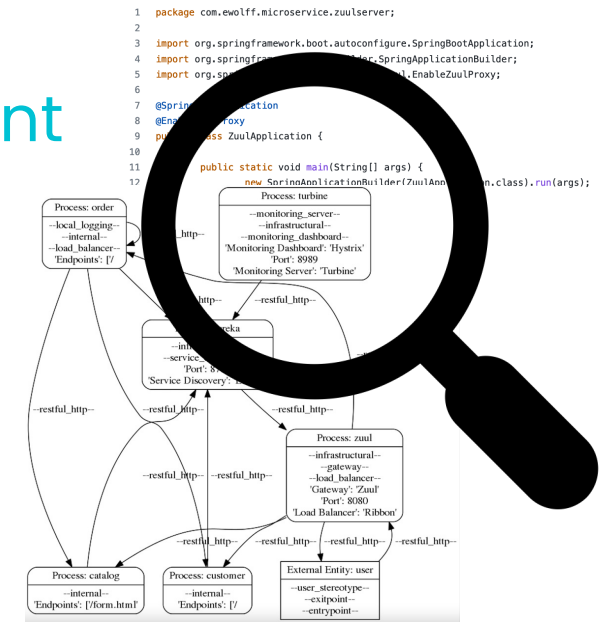
- You have to read and sign the provided “informed consent” form
  (available physically in lecture and labs plus digitally on ANONYMIZED)

Please do this at the end of this lecture!
(if you haven’t already)

- If you don’t sign, we won’t collect your data. You still have to perform the tasks to get your bonus

Tasks

- Perform tasks for security assessment of microservice applications
- Inspect code (and DFD in one week)
- Give evidence for your answers by referring to place in code




```java
package com.ewolff.microservice.zuulserver;

import org.springframework.boot.autoconfigure.SpringBootApplication;
import org.springframework.boot.builder.SpringApplicationBuilder;
import org.springframework.cloud.netflix.zuul.EnableZuulProxy;

@SpringBootApplication
@EnableZuulProxy
public class ZuulApplication {

	public static void main(String[] args) {
		new SpringApplicationBuilder(ZuulApplication.class).run(args);
	}

}
```

Material provided in the labs

- In the lab sessions, you'll receive:
  - Source code of a microservice application (on GitHub)
  - Short textual documentation of the app
  - Dataflow Diagram of the app (only in one week)
  - Traceability information corresponding to DFD (only in one week)
  - Task sheet

Process of next two labs

- You perform similar tasks in both weeks, but on two different apps and with different material
- One week: all material listed in previous slide
- Other week: same without the DFD
- We will tell you, what to use in each week (half of you will do the same in each week)

Important Notes

The tasks are individual work.

Please, do not talk to your peers about the tasks until the end of the study!

(which is AFTER the second week's session, on the 18th / 19th)

TODO for you

- For the next lab sessions, you need to do two things:
  - Read the supplementary material
  - Read and sign the informed consent sheet if not done yet

(both available on ANONYMIZED, informed consent also physically here in the lecture)