Hybrid Taint Analysis for Java EE

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About Me

- Florian Loch
  - Based in Karlsruhe, Germany
  - M. Sc. in computer science
  - Avid software engineer
  - Focus on applied security (research)
  - Currently taking a year off, looking for new opportunities in 2021
  - https://fdlo.ch

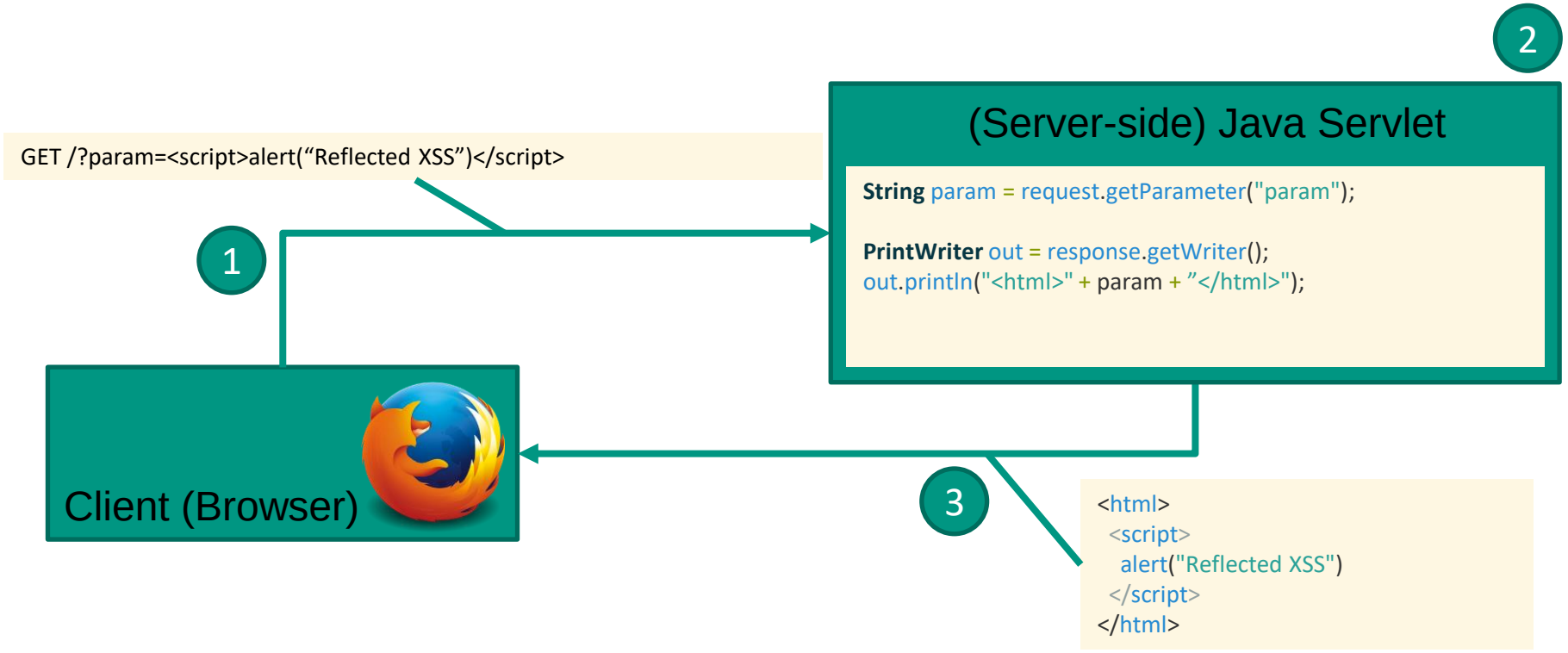
- This work is based on my master thesis *"Juturna: Lightweight, Pluggable and Selective Taint Tracking for Java"*

Motivation

- **Injection attacks** are emerging together with modern web applications
- → Attacker is able to control applications behaviour in malicious ways
- Underlying problem: **Improper Input Validation** (CWE-20)
- Many manifestations
  - Cross-Site-Scripting (XSS) (CWE-79)
  - OS Command Injection (CWE-78)
  - SQL Injection (CWE-89)
  - …

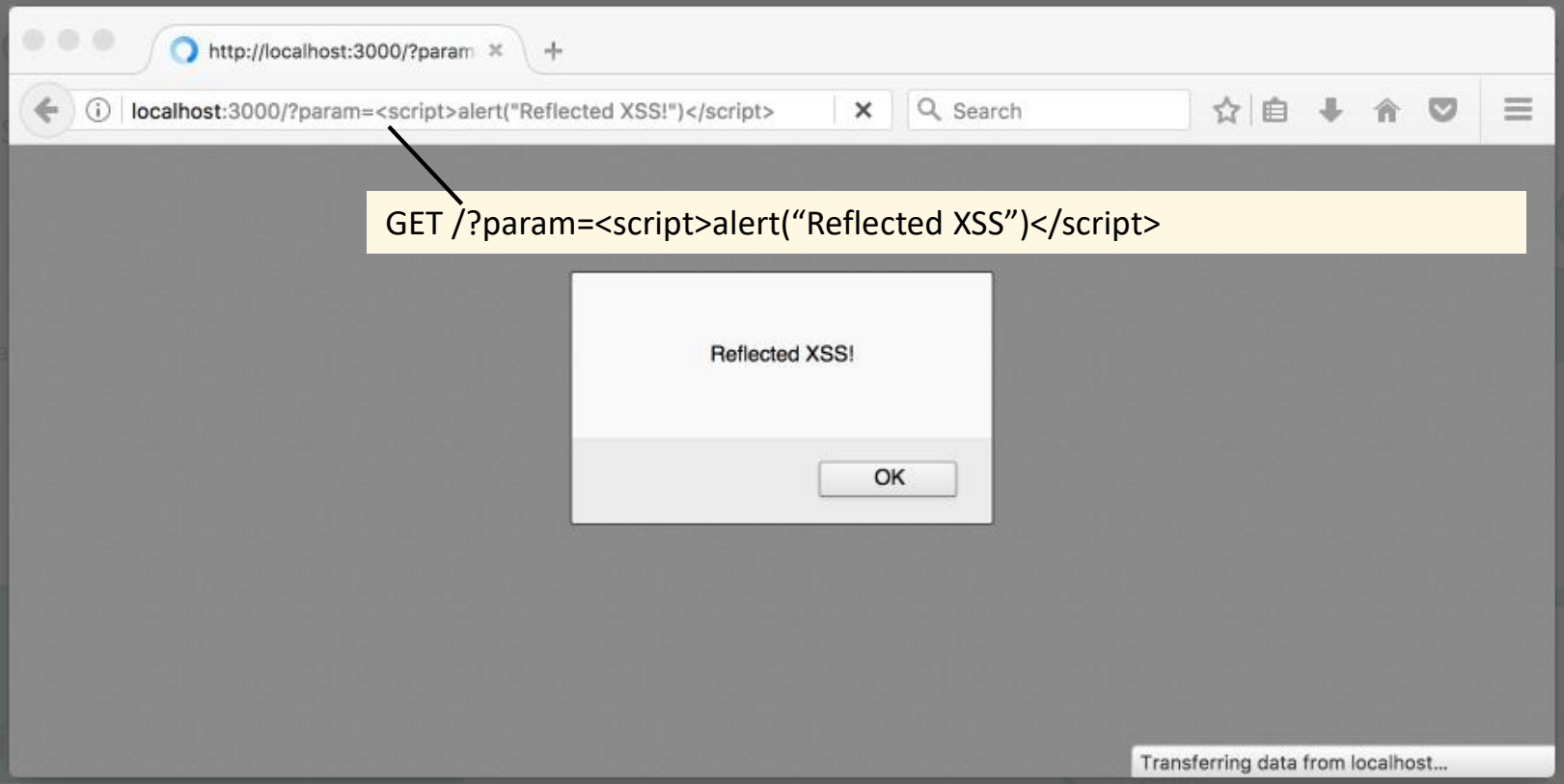
XSS: Injection Attacks in the Web

- XSS: *Cross-site Scripting*
- Goal: Attacker tries to execute JavaScript code in a users browser (in a specific security-context)



XSS: injection attacks in the Web

- XSS: *Cross-Site-Scripting*

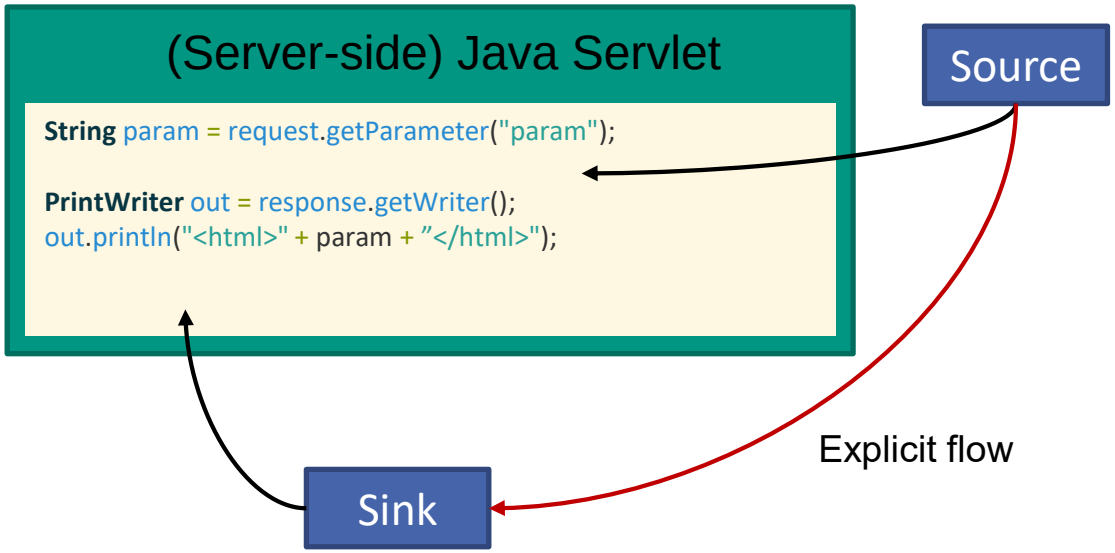


Analyzing the problem

- Untrusted input influences behavior of application inadvertently
- → Typical **Information Flow Control (IFC)** problem
  - Need to check application for **integrity**

- **Static** and **dynamic** techniques available
- Dynamic approach has been chosen as foundation, static methods as extension
- **Taint tracking** has been proven to be an effective measure to detect/block such attacks [2, 3, 4]
  - Adds metadata to a variable's content and tracks it during program execution

Analyzing the problem (II)



Current state

- Taint tracking is not a new concept, also there are implementations in Java
- But: present taint tracking systems got some serious drawbacks
  - Adds (massive) **memory and computation overhead**
  - Often needs **modifications to the runtime** on a low level; most nowadays implementations massively **touch the JRE or require special JREs/JVMs**
- Objective of this work was to tackle these issues and integrate new concepts

Implementation of the Taint Tracking System

- **Augmentation** of Java's standard class library
  - Adding code for storing and propagating taint information (**taint ranges**)
  - **String-only tracking**, considering the scenario this trade-off between **correctness**, **recall** and **performance** seems acceptable.
  - **Character-granularity** allows very high precision
  - Using "**bootclasspath override**", no modifications to JRE
  - Support for **Java Reflection**
- **Bytecode instrumentation**
  - Instrumenting sources, sinks and sanitization functions
  - Happens on-the-fly (**Java Agent**)**,** no pre-processing step needed

Selective Taint Tracking

- **Overhead intrinsic** to taint tracking, so how to reduce it significantly?
- Idea: reduce overhead by **reduced taint tracking/reduced augmentation**!
- Some parts of the application are not relevant for security and do not need to be taint-aware
  - Parts that provably never get in touch with tainted data
  - Parts operating on tainted-data that provably never reaches a sink
  - → Deactivate taint tracking for these parts
  - → But dynamic analysis cannot deliver these insights a priori

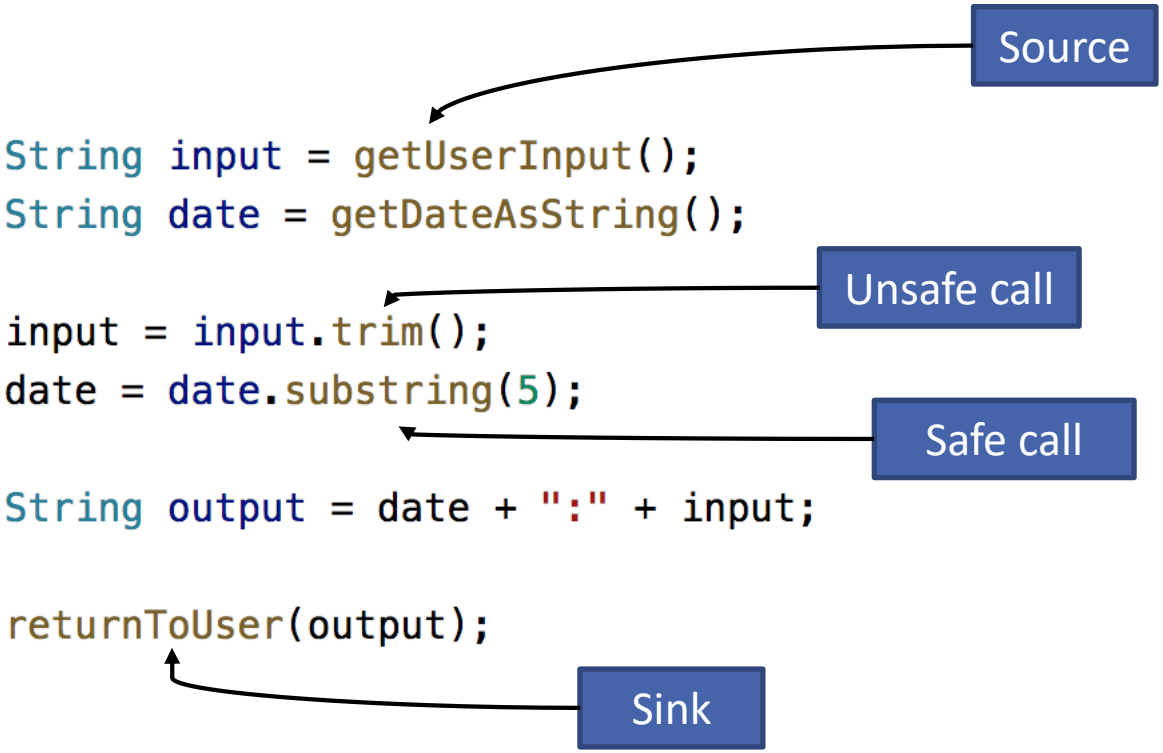
- → Use **static IFC** to determine such parts!

Selective Taint Tracking (II)

- Due to modified standard classes all operations on strings are taint-aware by default (“secure by default”)
- Invocations of an augmented method on a variable (not an instance!) v can be replaced with calls to an unaugmented method in case:
  - o $\notin chop(S_{source}, S_{sink})$; $\forall o \in pointsTo(v)$
  - S_{source} and S_{sink} are sets comprising all sources and sinks
- Such invocations can be determined by the JOANA-Adapter using JOANA’s PDG-based analysis

- An additional bytecode instrumenter modifies call instructions
- Prerequisite: Unaugmented methods need to be available

Selective Taint Tracking (III)

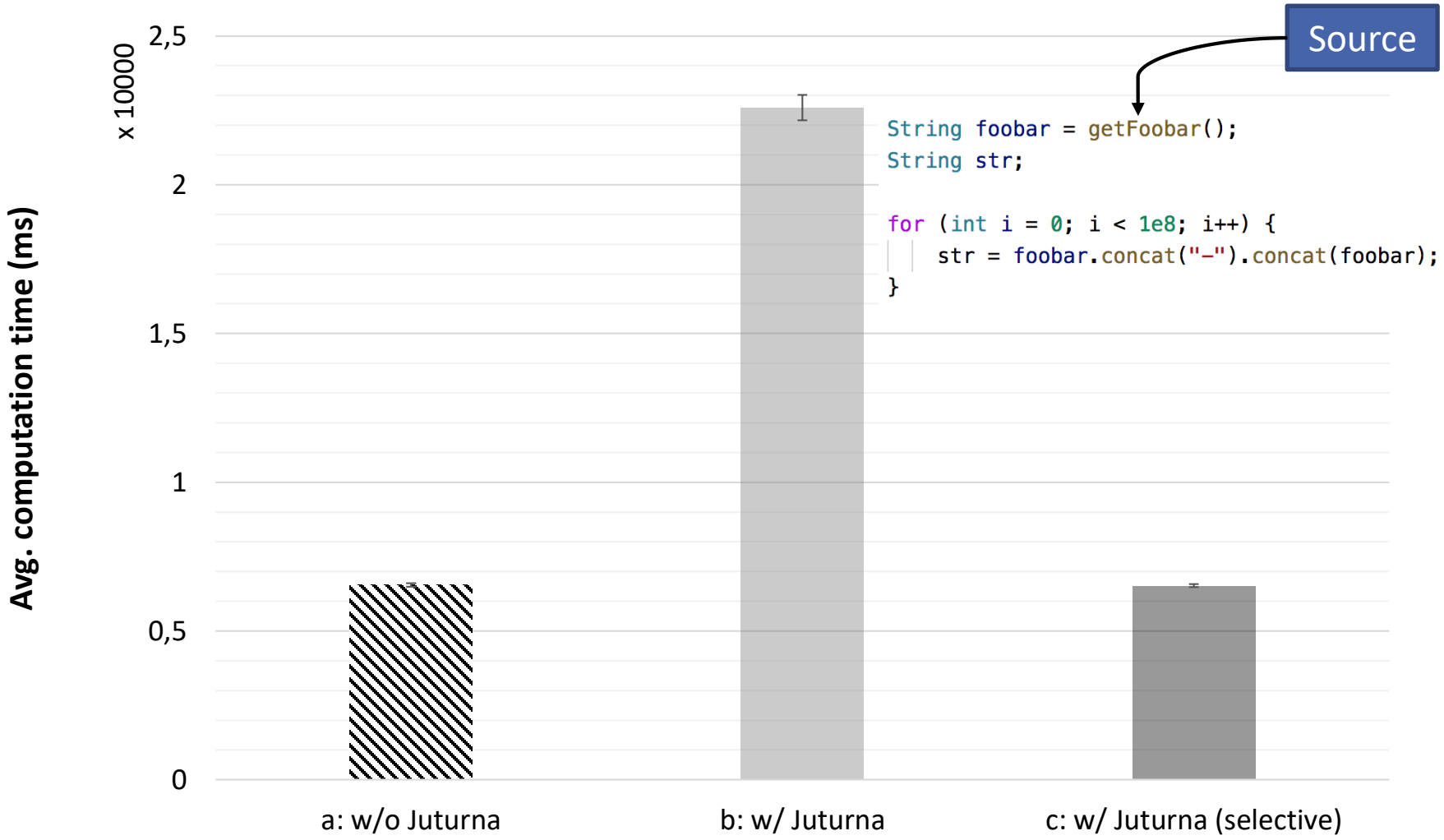


Selective Taint Tracking (IV)

```
 0 invokestatic #2 <Mixed.getUserInput>
 3 astore_1
 4 invokestatic #3 <Mixed.getDateAsString>
 7 astore_2
 8 aload_1
 9 invokevirtual #4 <java/lang/String.trim>
12 astore_1
13 aload_2
14 iconst_5
15 invokevirtual #5 <java/lang/String.substring>
18 astore_2
19 new #6 <java/lang/StringBuilder>
22 dup
23 invokespecial #7 <java/lang/StringBuilder.<init>>
26 aload_2
27 invokevirtual #8 <java/lang/StringBuilder.append>
30 ldc #9 <:>
32 invokevirtual #8 <java/lang/StringBuilder.append>
35 aload_1
36 invokevirtual #8 <java/lang/StringBuilder.append>
39 invokevirtual #10 <java/lang/StringBuilder.toString>
42 astore_3
43 aload_3
44 invokestatic #11 <Mixed.returnToUser>
47 return
```

```
 0 invokestatic #15 <Mixed.getUserInput>
 3 astore_1
 4 invokestatic #18 <Mixed.getDateAsString>
 7 astore_2
 8 aload_1
 9 invokevirtual #23 <java/lang/String.trim>
12 astore_1
13 aload_2
14 iconst_5
15 istore 5
17 astore 4
19 aconst_null
20 astore 6
22 aload 4
24 iload 5
26 invokevirtual #27 <java/lang/String.___substring>
29 astore 6
31 aload 6
33 astore_2
34 new #29 <java/lang/StringBuilder>
37 dup
38 invokespecial #30 <java/lang/StringBuilder.<init>>
41 aload_2
42 invokevirtual #34 <java/lang/StringBuilder.append>
45 ldc #36 <:>
47 invokevirtual #34 <java/lang/StringBuilder.append>
50 aload_1
51 invokevirtual #34 <java/lang/StringBuilder.append>
54 invokevirtual #39 <java/lang/StringBuilder.toString>
57 astore_3
58 aload_3
59 invokestatic #43 <Mixed.returnToUser>
62 return
```

Selective Taint Tracking (V)



Summary

- **Reduced memory footprint** by using taint ranges
- **Portable** and **non-invasive**, JRE never gets touched
- Flexible, configurable and extensible
- Evaluation of the taint tracking system showed **reasonable performance**
- Vulnerabilities in test cases have been detected, interoperation with Java EE Servlet Container is working
- **Hybrid approach** is working, depending on scenario it might reduce overhead massively
  - Joining Juturna's dynamic capabilities with JOANA's static analysis

Thank you for your kind attention!

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References

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Pictorial Sources

Picture on title slide: https://www.pexels.com/de/foto/bohnen-koffein-kaffee-tasse-34079/

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Logo of JOANA: IPD Snelting, https://pp.ipd.kit.edu/projects/joana/joana-logo-250.png