Static Analysis

The Workhorse of a End-to-End Securitye Testing Strategy

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The University Of Sheffield.

SECENTIS

A European Industrial Doctorate on Security and Trust

Static Analysis: The Workhorse of a End-to-End Securitye Testing Strategy

Abstract

Security testing is an important part of any security development lifecycle (SDL) and, thus, should be a part of any software (development) lifecycle. Still, security testing is often understood as an activity done by security testers in the time between “end of development” and “offering the product to customers.”
Learning from traditional testing that the fixing of bugs is the more costly the later it is done in development, security testing should be integrated, as early as possible, into the daily development activities. The fact that static analysis can be deployed as soon as the first line of code is written, makes static analysis the right workhorse to start security testing activities.
In this lecture, I will present a risk-based security testing strategy that is used at a large European software vendor. While this security testing strategy combines static and dynamic security testing techniques, I will focus on static analysis. This lecture provides a introduction to the foundations of static analysis as well as insights into the challenges and solutions of rolling out static analysis to more than 20000 developers, distributed across the whole world.

Our Plan

Our Plan

- Today:

Background and how it works ideally

Our Plan

- Today:

Background and how it works ideally

- Tomorrow:

(Ugly) real world problems and challenges
(or why static analysis is “undecideable” in practice)

Part I

Background, Motivation, and An Introduction to Pragmatic Static Analysis

Outline

1. Background
2. Motivation
3. An Introduction to Pragmatic Static Analysis (Code Scanning)
4. Conclusion

Outline

Personal Background

From Academia to Industry and Back Again . . .

- **Until 11/2007:**
  - PhD student and PostDoc stay at ETH Zurich, Switzerland
- **Until 11/2015:**
  - Member of the central security team, SAP SE (Germany)
    - **(Global) Security Testing Strategist**
    - Security Research Expert/Architect
  - Work areas:
    - Defining the risk-based Security Testing Strategy of SAP
    - Introducing SAST and DAST tools at SAP
    - Identify white spots and evaluate and improve tools/methods
    - Secure Software Development Lifecycle integration
    - Applied security research
    - . . .
- **Since 12/2015:**
  - Senior Lecturer (Security, Testing & Verification, Formal Methods), The University of Sheffield, UK

http://www.brucker.ch/

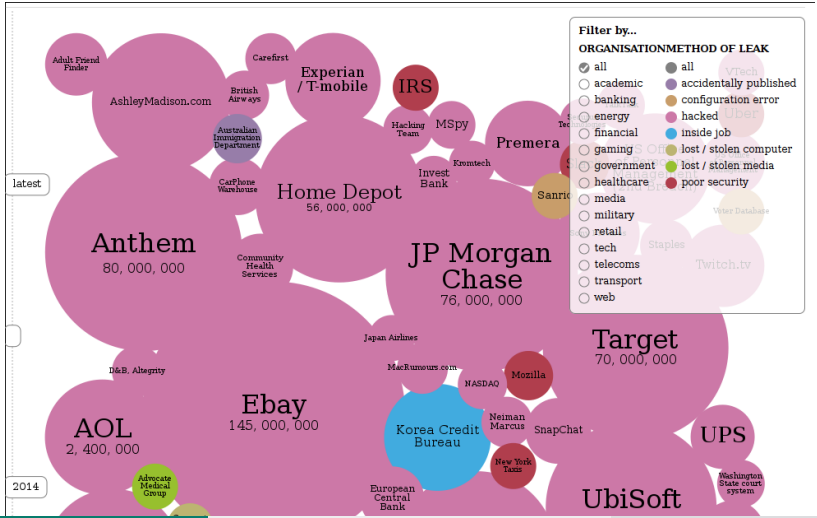
SAP SE

- Leader in Business Software
  - Cloud
  - Mobile
  - On premise
- Many different technologies and platforms, e.g.,
  - In-memory database and application server (HANA)
  - Netweaver for ABAP and Java
- More than 25 industries
- 63% of the world's transaction revenue touches an SAP system
- over 68 000 employees worldwide over 25 000 software developers
- Headquarters: Walldorf, Germany (close to Heidelberg)

Outline

Recent Data Breaches

http://www.informationisbeautiful.net/visualizations/worlds-biggest-data-breaches-hacks/



Costs of Data Breaches

TJX Company, Inc. (2007)	$250 million
Sony (2011)	$170 million
Heartland Payment Systems (2009)	$41 million

> A hack not only costs a company money, but also its **reputation** and the **trust** of its customers. It can take years and millions of dollars to repair the damage that a single computer hack inflicts.

(http://financialedge.investopedia.com/financial-edge/0711/Most-Costly-Computer-Hacks-Of-All-Time.aspx)

Has Sony been Hacked this Week?

http://hassonybeenhackedthisweek.com/

Time-line of the Sony Hack(s) (excerpt):

2011-04-20 Sony PSN goes down

2011-05-21 Sony BMG Greece: data 8300 users (**SQL Injection**)

2011-05-23 Sony Japanese database leaked (**SQL Injection**)

2011-05-24 Sony Canada: roughly 2,000 leaked (**SQL Injection**)

2011-06-05 Sony Pictures Russia (**SQL Injection**)

2011-06-06 Sony Portugal: **SQL injection**, iFrame injection and XSS

2011-06-20 20th breach within 2 months
177k email addresses were grabbed via a **SQL injection**

(http://hassonybeenhackedthisweek.com/history)

Consequences:

- account data of close to 100 million individuals exposed
- over 12 million credit and debit cards compromised
- more than 55 class-action lawsuits
- costs of $ 170 million only in 2011

A Bluffers Guide to SQL Injection (1/2)

- Assume an SQL Statement for *selecting all users with "**userName**" from table "**user**"*:

```
stmt = "SELECT␣*␣FROM␣‘users‘␣WHERE␣‘name‘␣=␣’" + userName + "’;"
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userName = "’ or ’1’=’1"
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```
stmt = "SELECT * FROM ‘users‘ WHERE ‘name‘ = ’’ or ’1’=’1’;"
```

- Which is equivalent to

```
stmt = "SELECT * FROM ‘users‘;"
```

selecting the information of **all users** stored in the table ‘users’!

A Bluffers Guide to SQL Injection (2/2)

```
void selectUser(HttpServletRequest req, HttpServletResponse resp)
     throws IOException {
  String userName = req.getParameter("fName"); // source

  String stmt     = "SELECT * FROM ‘users‘ WHERE ‘name‘ = ’"
                    + userName +"’;"
  SQL.exec(stmt); //sink
}
```

- Many vulnerabilities have similar causes:
  - cross-site-scripting (XSS), code-injection, buffer-overflows, . . .
- Root cause of a wide range of vulnerabilities
  - “bad” programming
  - mis-configuration
- **Warning:**
  - for preventing SQL injections, consider the use of prepared statements
  - do whitelisting (specify what is allowed) and *do not* blacklisting

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void selectUser(HttpServletRequest req, HttpServletResponse resp)
     throws IOException {
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         userName = Security.whitelistOnlyCharacters(userName); // sanitation
  String stmt     = "SELECT * FROM ‘users‘ WHERE ‘name‘ = ’"
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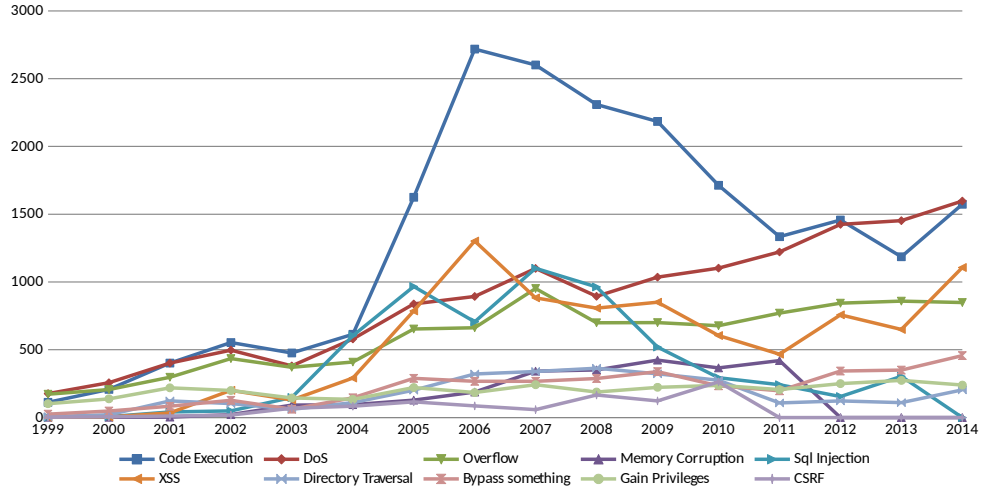
Vulnerability Distribution Since 1999



Security-critical (And Safety-critical) Systems Are Small, Right?

SAP®

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Aircraft:

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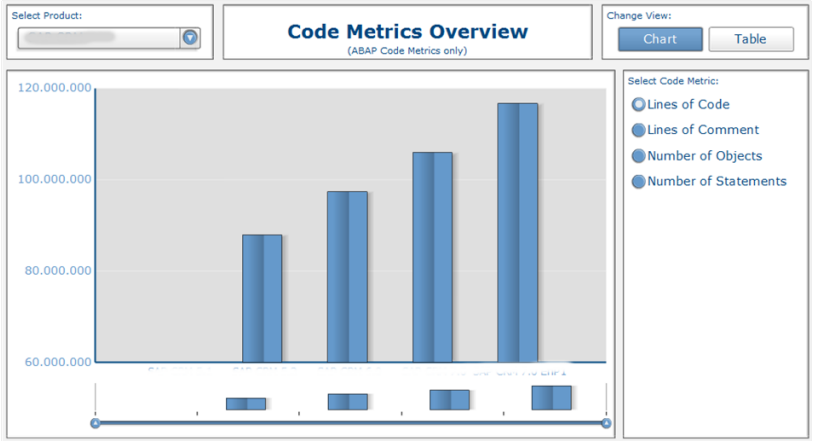
Enterprise System (SAP):

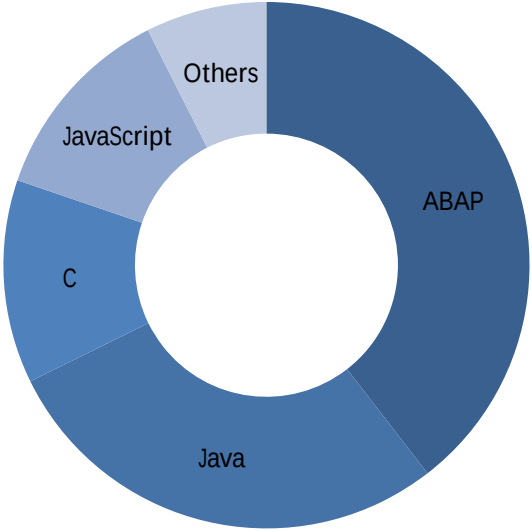
- ca. 500 000 000 LoC (without user interfaces)
- ca. 200 000 screens (user interface definitions)

Evolution of Source Code



- Increase in
  - code size
  - code complexity
  - number of products
  - product versions
  - used technologies (prog. languages, frameworks)

Languages Used at SAP



Outline

A Few Questions

1. You are responsible for quality assurance for a large scale IT system (> 10 000 000 LoC)
   - What do you have your team do?
   - Follow coding standards?
   - Test-driven Development?
   - Use Formal Methods?

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   - Does the distinction between **safety** versus **security** matter?
3. You are a researcher building code analysis tools.
   - How do you migrate them to large-scale applications?
   - What are the challenges in practise?
   - Would you invest in a high quality (sound???) analysis?
   - Would you invest a good integration into the development environment?

Pragmatic Static Analysis

The Coverity Experience

- Coverity: a tool for finding generic errors in C/C++ code
- Company goal: make money (and build a user community around the tool)
- Guiding principle: if it helps developers to avoid bugs, it's good
- **Focus on finding bugs/errors**, not proving their absence
- Embrace unsoundness (Focus on low hanging fruit)!

> Circa 2000, unsoundness was controversial in the research community, though it has since become almost a de facto tool bias for commercial products and many research projects.
>
> A few billion lines of code later, CACM, 2010.

- Usability and simplicity are critical!

What We Want to Find

Programming Patterns That May Cause Security Vulnerabilities

Mainly two patterns

Local issues (no data-flow dependency), e.g.,

- Insecure functions

```
var x = Math.random();
```

- Secrets stored in the source code

```
var password = 'secret';
```

Data-flow related issues, e.g.,

- Cross-site Scripting (XSS)

```
var docref  = document.location.href;
var input = docref.substring(
            docref.indexOf("default=")+8);
var fake = function (x) {return x;}
var cleanse = function (x) {
               return 'hello world';}
document.write(fake(input));
document.write(cleanse(uinput));
```

- Secrets stored in the source code

```
        var foo = 'secret';
        var x = decrypt(foo,data);
```

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We trust our developers, i.e., we are focusing on finding "obvious" bugs. We do not need to do a sound verification.

What We Want to Find

Seven Pernicious Kingdoms: A Taxonomy of Software Security Errors (Tsipenyuk, Chess, and McGraw)

1. Input Validation and Representation
   Buffer overflows, command injection, . . .
2. API Abuse
   Dangerous functions, unchecked return values, . . .
3. Security Features
   Insecure randomness, password management, . . .
4. Time and State
   Deadlocks, race conditions, . . .
5. Errors
   Catching null pointer ex., empty catch blocks, . . .
6. Code Quality
   Double free, memory leak, . . .
7. Encapsulation
   Comparing classes by name, leftover debug code, . . .

* Environment: J2EE misconfigurations . . .

What We Can Expect to Find

	visible in the code	**visible only in the design**
generic defects	Static analysis sweet spot. Built-in rules make it easy for tools to find these without programmer guidance. *Example:* buffer overflows	Most likely to be found through architectural analysis. *Example:* the program executes code downloaded as an email attachement
context specific defects	Possible to find with static analysis, but customisation may be required. *Example:* mishandling of credit card information.	Requires both understanding of general security principles along with domain-specific expertise. *Example:* cryptographic keys kept in use for an unsafe duration.

The Core Technologies of Pragmatic Static Analysis

Pragmatic static analysis is based on

- successful developments from research community:
  - Type checking
  - Property checking (model-checking, SMT solving, etc.)
  - Abstract interpretation
  - . . .
- techniques from the software engineering community
  - Style Checking
  - Program comprehension
  - Security reviews
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Let's look at examples . . .

Type Checking

- The Java compiler will flag the following as an error. Is it?

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short s = 0;
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- How about this:

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Object [] objs = new String[1];
objs[0]        = new Object();
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What happens at runtime?

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What happens at runtime?

- Type checkers are useful
  - But may suffer from false positives/negatives
  - Identifying which computations are harmful is undecidable

Style Checkers

- Enforce more picker and more superficial rules than type checkers
- Some compiler can check these, e.g.,

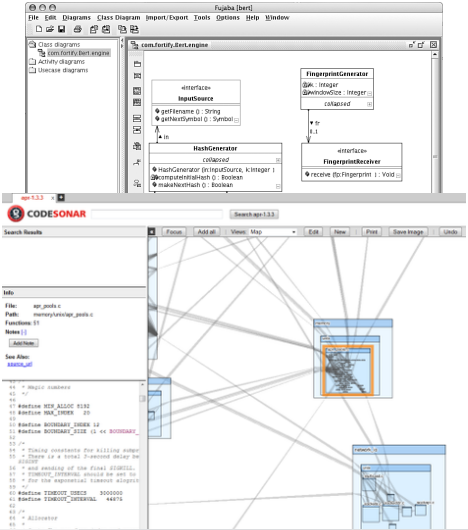
```
gcc -Wall enum.c
  enum.c:5: warning: enumeration value 'green'
                     not handled in switch
  enum.c:5: warning: enumeration value 'blue'
                     not handled in switch
```

- Or consider `x == 0` vs. `0 == x`
- Style checkers are often extensible, e.g.,
  - PMD (`https://pmd.github.io/`) for Java
  - JSHint (`http://jshint.com/`) for JavaScript
- Simple, but **very** successful in practice

```
typedef enum { red, green, blue } Color;
char* getColorString(Color c) {
  char* ret = NULL;
  switch (c) {
  case red:
       printf("red");
  }
  return ret;
 }
```

Program Understanding

- Tools can help with
  - Understanding large code bases
  - Reverse engineering abstractions
  - Finding declarations and uses
  - Analysing dependencies
  - . . .
- Useful for manual code/architectural reviews



Bug (Pattern) Finders

- Work with a fault model of typical mistakes

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```
Person person = aMap.get("bob");
if (person != null) {
person.updateAccessTime();
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String name = person.getName();
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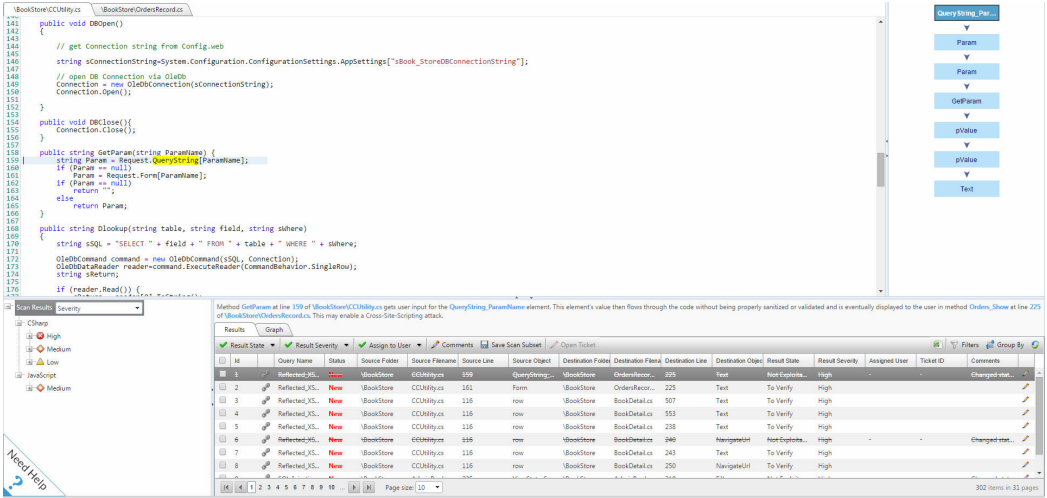
Ignored return values

- Findbugs (`http://findbugs.sourceforge.net/`) is a good example for Java

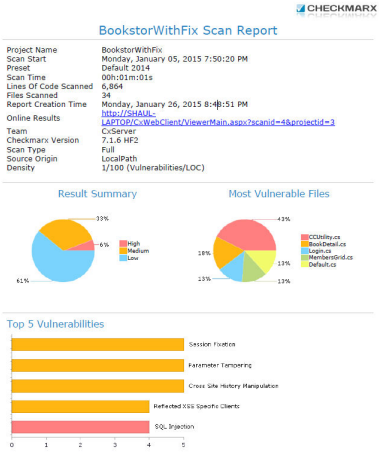
Sound Methods

- Software model checking
- All the nice methods Anders Møller introduced

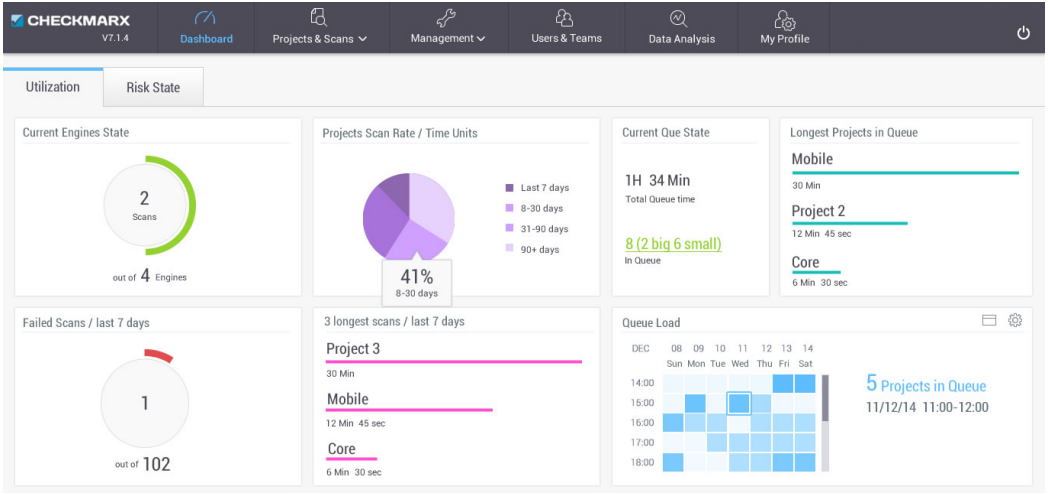
Checkmarx: Presentation of Scan Results



Checkmarx: Per Project Reporting



Checkmarx: Dashboard



HP WebInspect

Tool Demo!

Outline

Conclusion

There are a wide range of tools available that help developers to implement systems securely, safely, and reliably!

Next: How to apply them in a large organisation . . .

Part II

Applying Static (And Dynamic) Analysis At SAP

Outline

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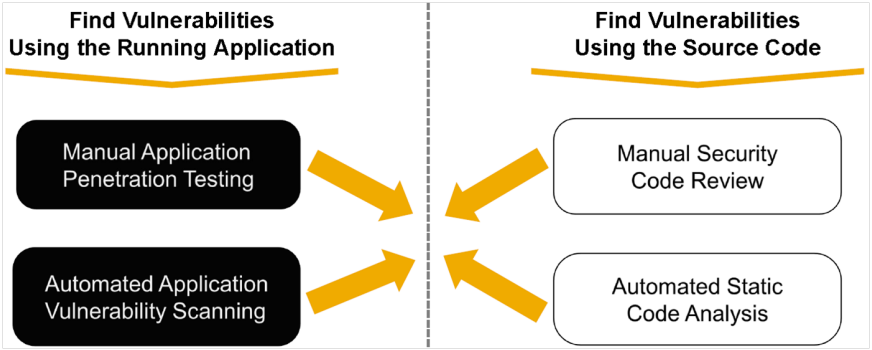
Finding Security Vulnerabilities

You are responsible for quality assurance for a large scale IT system (> 10 000 000 LoC)

- What do you have your team do?



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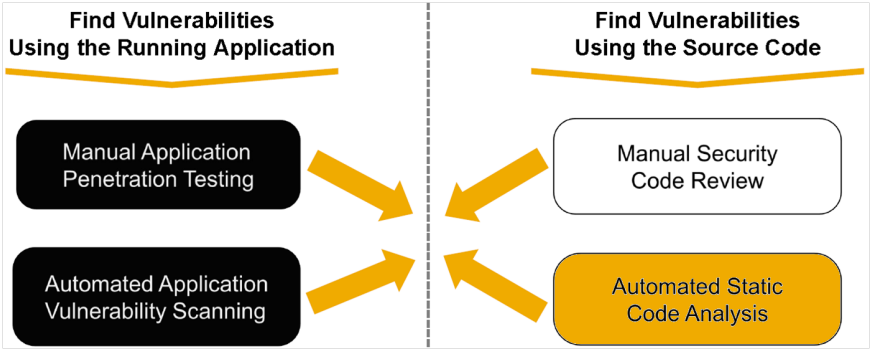

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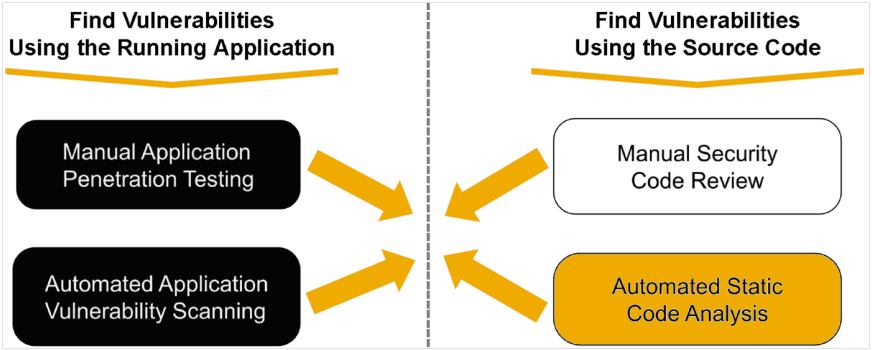
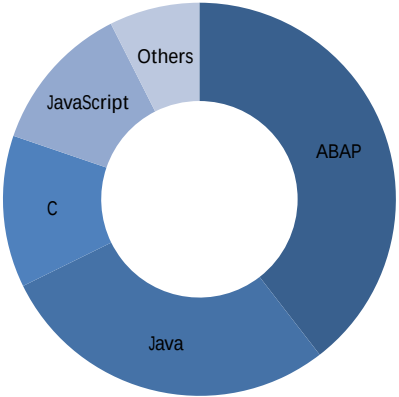


- Sounds easy, right?

In 2010: Static Analysis Becomes Mandatory



SAST tools used at SAP:

Language	Tool	Vendor
ABAP	CodeProfiler	Virtual Forge
Others	Fortify	HP

- Since 2010, mandatory for all SAP products
- Multiple billions lines analysed
- Constant improvement of tool configuration
- Further details:
  Deploying Static Application Security Testing on a Large Scale. In GI Sicherheit 2014. Lecture Notes in Informatics, 228, pages 91-101, GI, 2014.

So Everything is Secure Now, Right?

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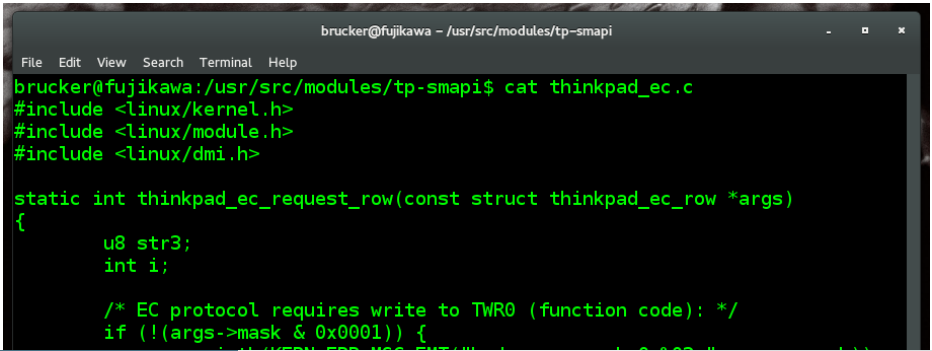

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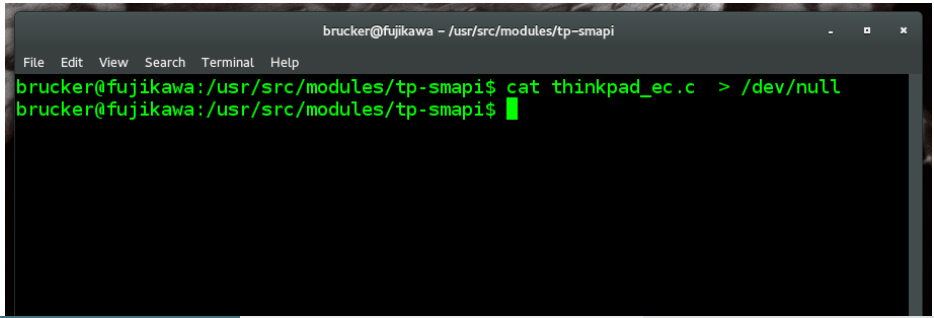
- The cat tool reports each line, that might contain a vulnerability:
- It supports also a mode that reports **no false positives**:



Outline

Moving to a De-Centralized Application Security Approach

How SAP's Application Development Approach Developed Over Time

- Governance & approvals
- De-centralized approach

- ~~One~~ Two SAST tools fit all
  - VF CodeProfiler
  - Fortify
- Blending of Security Testing Tools
  - SAST:
    SAP Netweaver CVA Add-on, Fortify,
    Synopsis Coverity, Checkmarx, Breakman
  - DAST:
    HP WebInspect, Quotium Seeker
  - Others:
    Burp Suite, OWASP ZAP, Codinomicon
    Fuzzer, BDD

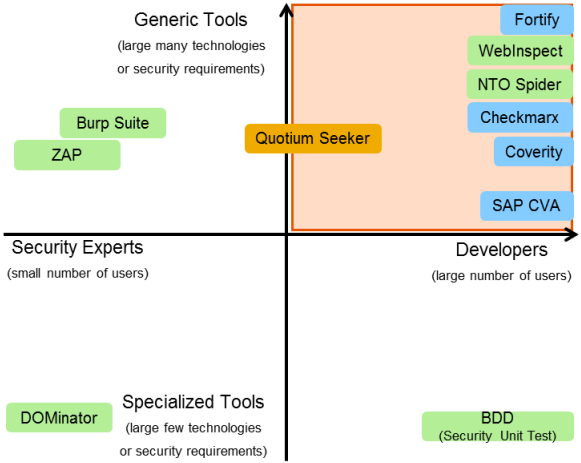
SAP Uses a De-centralised Secure Development Approach

- **Central security expert team** (S^2DL owner)
  - Organizes security trainings
  - Defines product standard “Security”
  - Defines risk and threat assessment methods
  - Defines security testing strategy
  - Selects and provides security testing tools
  - Validates products
  - Defines and executes response process
- **Local security experts**
  - Embedded into development teams
  - Organize local security activities
  - Support developers and architects
  - Support product owners (responsibles)
- **Development teams**
  - Select technologies
  - Select development model
  - Design and execute security testing plan
  - . . .

Focus of the Central Security Team: Security Testing for Developers

Security testing tools for developers, need to

- Be applicable from the start of development
- Automate the security knowledge
- Be deeply integrated into the dev. env., e.g.,
  - IDE (instant feedback)
  - Continuous integration
- Provide easy to understand fix recommendations
- Declare their “sweet spots”



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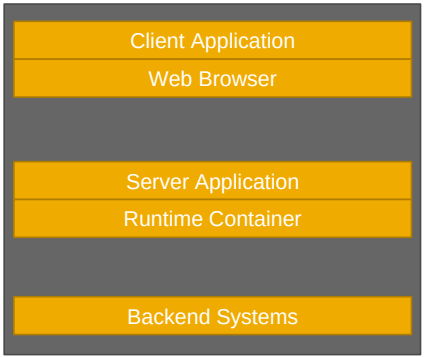
Combining Multiple Security Testing Methods and Tools



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  - Wasting effort that could be used more wisely elsewhere
  - Shipping insecure software
- Examples of SAST limitations
  - Not all programming languages supported
  - Covers not all layers of the software stack

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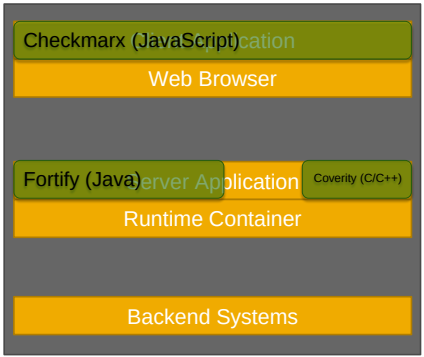

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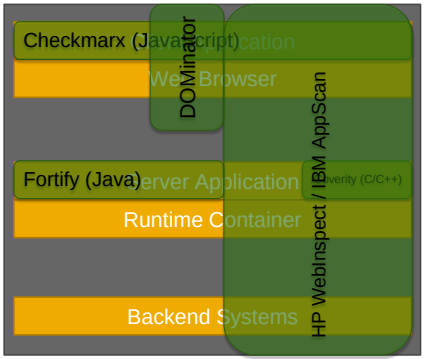

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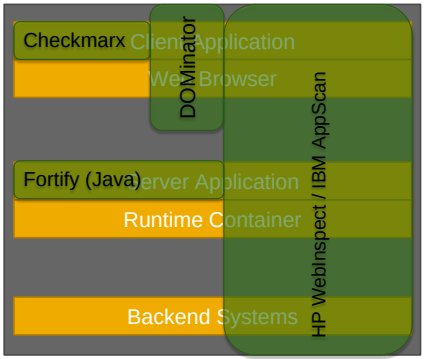

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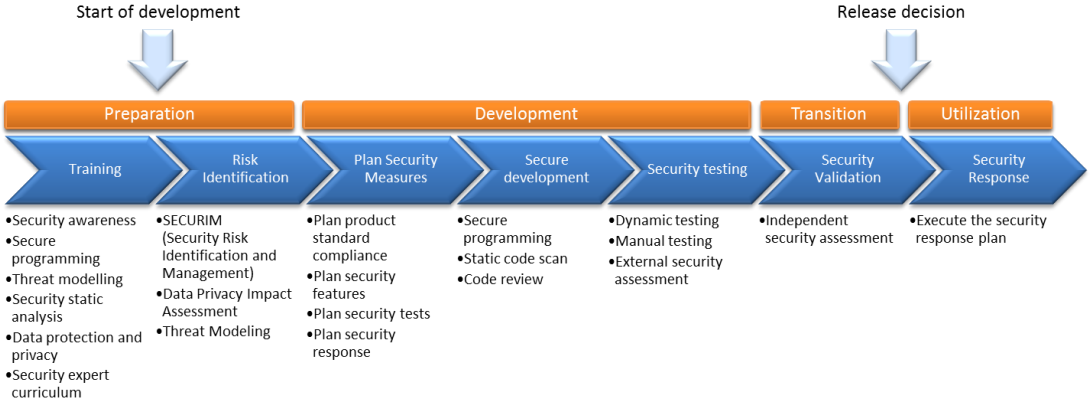
SAP' Secure Software Development Lifecycle (S^2DL)



Security Validation

- Acts as first customer
- Is not a replacement for security testing during development
- Security Validation
  - Check for “flaws” in the implementation of the S^2DL
  - Ideally, security validation finds:
  - No issues that can be fixed/detected earlier
  - Only issues that cannot be detect earlier
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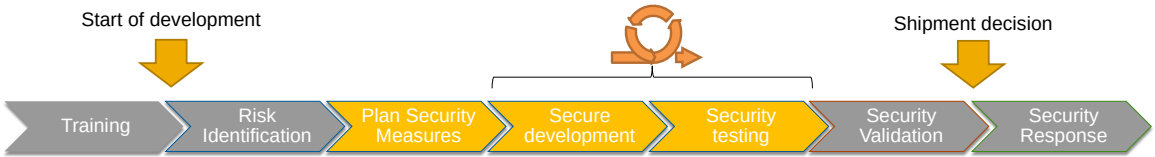
Penetration tests in productive environments are different:

- They test the actual configuration
- They test the productive environment (e.g., cloud/hosting)

SAST and DAST as Part of the S²DL

Security Testing Plan and Security Testing Report



A Risk-based Test Plan

- Combines multiple security testing methods, e.g., code scans, dynamic analysis, manual penetration testing or fuzzing
- Selects the most efficient test tools and test cases based on the risks and the technologies used in the project
- Re-adjusts priorities of test cases based on identified risks for the project
- Monitors false negative findings in the results of risk assessment

Outline

A Lethal Question

Assume you implemented all this, which

- costs a zillion of dollars license fees each year and
- results in a significant portion of your developers working on improving security **instead of new features/products**.

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Now your boss enters your office and asks only one question:

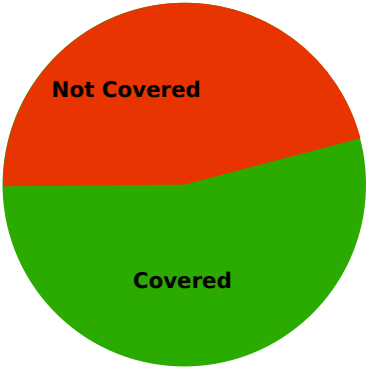
- Can you justify these costs/efforts?

Not answering is not an option:

- you might be fired
- the security program will be killed

How to Measure Success (and Identify White Spots)

- Analyze the vulnerabilities reported by
  - Security Validation
  - External security researchers
- Vulnerability not detected by currently used methods
  - Improve tool configuration
  - Introduce new tools
- Vulnerability detected by our security testing tools
  - Vulnerability in older software release
  - Analyze reason for missing vulnerability



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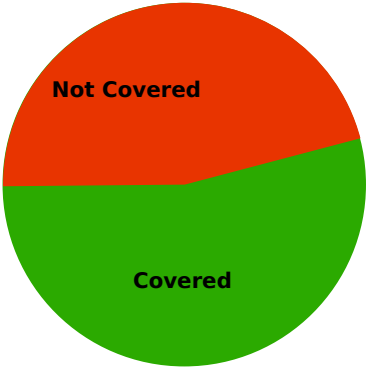

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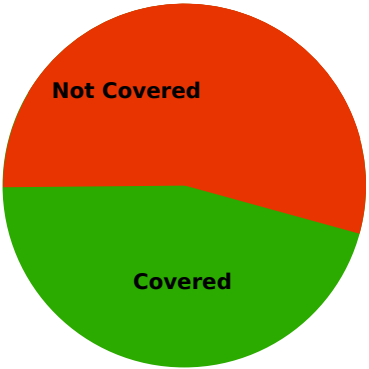

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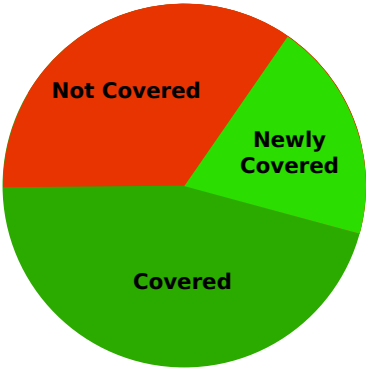

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Outline

Key Success Factors

- A holistic security awareness program for
  - Developers
  - Managers

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> Developer awareness is even more important!

Listen to Your Developers And Make Their Life Easy!

We are often talking about a lack of security awareness and, by that, forget the problem of lacking development awareness.

- Building a secure system more difficult than finding a successful attack.
- Do not expect your developers to become penetration testers (or security experts)!

Often, organisations make it hard for developers to apply their security testing skills!

- Don't ask developers to do security testing, if their work contract doesn't allow for it
- Budget application security activities centrally (in particular, in a decentralised model)

Recommendations for Selecting Security Testing Tools

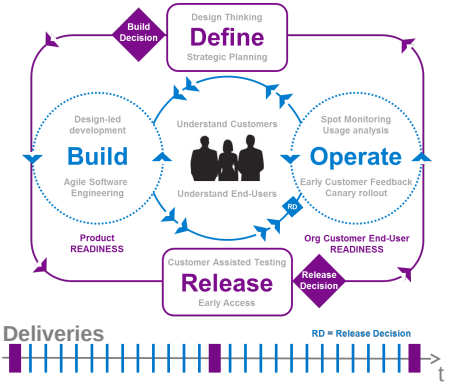
Select tools that are

- easy to integrate into your development process and tools
  - central scan infrastructure
  - source code upload, CLI, Jenkins, github, . . .
- easy to use by developers
  - easy to understand descriptions of findings
  - actionable fix recommendations
- easy to adapt to your security policies and prioritisation
  - report issues that are relevant for you
  - focus developers effort on the issues that are critical for you
- allow for tracking your success
  - tool internal reporting
  - interfaces to your own reporting infrastructure

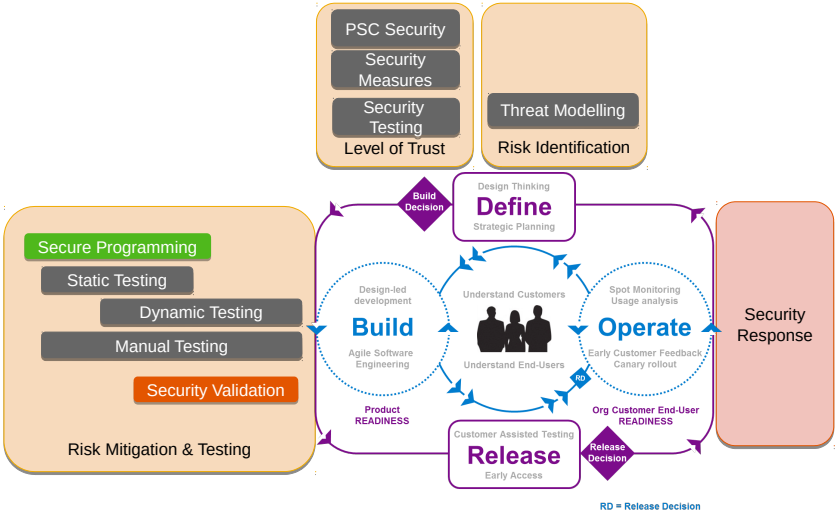
Outline

Agile Development

- What is agile for you?
  SCRUM, Continuous Delivery, DevOps, SCRUM, Cloud development, . . .
- Cloud/agile development lifecycle



Secure Agile Development



Secure Agile Development and SecDevOps

Open (Research) Questions

- Social aspects
  - Does the SecDevOps model increase security awareness?
    (Developers and their managers are also responsible for operational risks)
  - Does this impact the willingness to take (security) risks and/or the risk assessment?
- Process and organisational aspects
  - What services should be offered centrally?
  - How to ensure a certain level of security across all products?
  - How to ensure a certain level of security across the end-to-end supply chain?
- Technical and fundamental aspects
  - How do we need to adapt development support
  - How do we need to adapt threat modelling or risk assessment methods
  - How do we need to adapt security testing techniques
- The big challenge in practice:
  Products are often offered in the cloud (SaaS) and on premise

From Dynamic to Static and Back Again

Observations

Let’s have a look on memory corruption analysis

- until 1995: random testing, simple fuzzing
- 1995-2005: the decade of runtime analysis (dynamic testing)
- 2005-2015: the decade of static analysis
- 2015-????: dynamic approaches and combined techniques are getting popular

(dates are rough estimates)

There are (at least) two reasons why people are looking again at dynamic approaches:

- People are not happy with false-positive e rates of static approaches
  (Warning: dynamic approaches are not false-positive free either)
- DevOps pushes dynamic approaches to development,
  as operations uses pre-dominantly dynamic testing

From Dynamic to Static and Back Again

A few thoughts (not final conclusions yet)

- On the long-run, people will not be happy with (simple) DAST solutions
  - IAST (concolic testing) is a logical next step
  - Improved coverage and increased test case complexity (lowering false-negative rate)
  - Grey-box attack validation (lowering false-positive rate)
- My feeling:
  Runtime protection is hyped, but hard to sell to traditional software companies (e.g., SAP)
  - requires a close collaboration of development and operations (close to DevOps)
  - Why not use runtime-technology (e.g., end-to-end tainting) for security testing during development
    - improves results of manual or automated dynamic tests
    - compute advanced dynamic test cases or rule out false positives

    Test systems
    - are not as performance critical as production systems
    - are less risky to change (runtime environments, instrumentation, etc.)

Outline

Conclusion

- Secure software development is a
  - prerequisite for the secure and compliant operation
  - minimises the risk of operating and maintaining IT systems
- Developers are your most important ally
  - Make life easy for them
- SAST, DAST (or IAST), and runtime technologies are friends: they complement each other

Part III

Problems in Practise
(And Pragmatic Mitigation Strategies)

Outline

10 Why is Static Analysis Hard (Vendor Perspective)?

11 Why is Static Analysis Hard (User Perspective)?

Outline

Why is Static Analysis Hard (Vendor Perspective)?

Theory

- **Problem:**
  Many properties are undecidable
  (recall the nice explanation during the lecture of Anders Møller)
- **Consequence:**
  - Tools **over-approximate**: might result in false positives
  - Tools **under-approximate**: might result in false negatives

Why is Static Analysis Hard (Vendor Perspective)?

Practice: Getting And Understanding The Source Files

Where is the code?

- **Problem:** Home-grown build environments (build tools, code repositories, etc.)

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- **Solution:** Relaxed parsing, ignoring unknown constructs

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Practice: Change Management

Ever changing source languages (and compilers/development environments)

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- **Solution:**
  - (Static) fix recommendations pointing to standard recommendations
  - Computing bet fix locations

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- Estimating the risk of not fixing security issues is hard
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- Dynamic programming paradigms and languages
  - JavaScript, Ruby, etc.
- Lack of standardized regression test suites
  - Different tools
  - Different versions of the same tool

Outline

Pragmatics: False Positives (Unwanted Findings)

An informal definition:

- If a static analysis tools reports a finding, this finding
  - can be exploitable **(true positive)**
  - cannot be exploitable **(false positive)**
- If a static analysis tools does not reports a finding,
  - the code is secure **(true negative)**
  - the code contains a vulnerability **(false negative)**

Let us take the view point of a

- **Developer:** “I want a tool with zero false positives!”
  False positives create unnecessary effort
- **Security expert:** “I want a tool with zero false negatives!”
  False negatives increase the overall security risk

False Negatives

Reasons and Recommendations (Examples)

- *Fundamental:* under-approximation of the tool (method), e.g.,
  - missing language features (might intercept data flow analysis)
  - missing support for complete syntax (parsing errors)

  Report to tool vendor
- *Configuration:* lacking knowledge of insecure frameworks, e.g.,
  - insecure sinks (output) and sources (input)

  Improve configuration
- *Unknown security threats:* For us, e.g.,
  - XML verb tampering

  Develop new analysis for tool (might require support from tool vendor)

False Positives

Reasons and Recommendations (Examples)

- *Fundamental:* over-approximation of the tool (method), e.g.,
  - pointer analysis
  - call stack
  - control-flow analysis

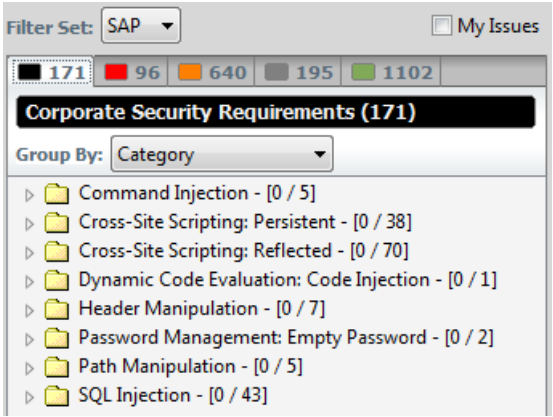
  Report to tool vendor
- *Configuration:* lacking knowledge of security framework, e.g.,
  - sanitation functions
  - secure APIs

  Improve configuration
- *Mitigated by attack surface:* strictly speaking a true finding, e.g,
  - No external communication due to firewall
  - SQL injections in a database admin tool

  Should be fixed.
  In practice often mitigated during audit, or local analysis configuration

Prioritisation of Findings

A Pragmatic Solution for Too Many Findings



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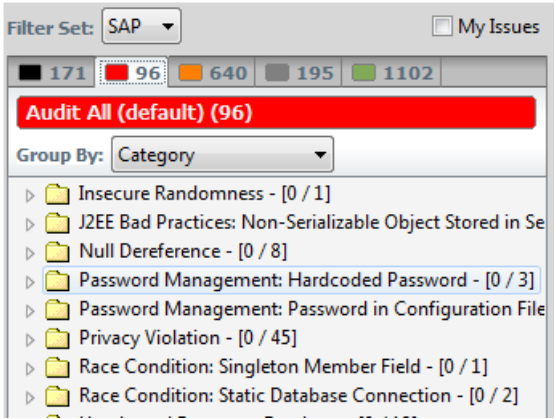

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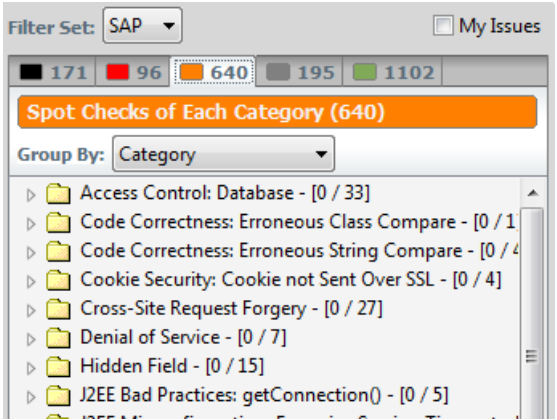

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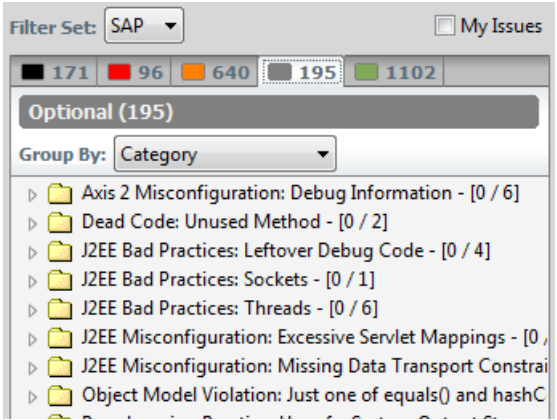
Prioritisation of Findings

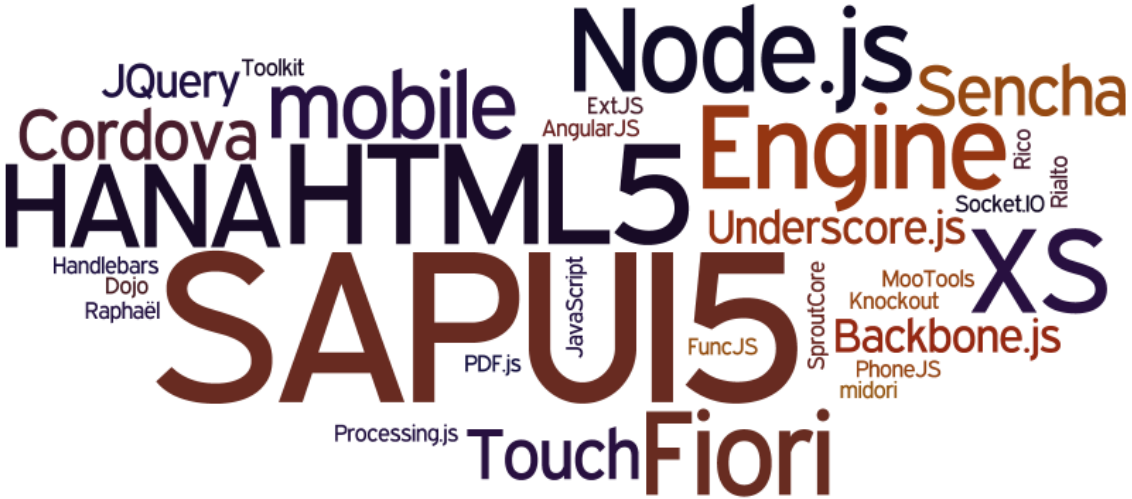
A Pragmatic Solution for Too Many Findings



- What needs to be audited
- What needs to be fixed
  - as security issue (response effort)
  - quality issue
- Different rules for
  - old code
  - new code

Outline

SAP Development Experienced a Change in 2012/2013



In 2012: Rumours Began to Spread

> The existing solution does not work for JavaScript!

It looks like the existing solution

- reports less issues per line of code (compared to Java, C/C++, . . .)
- has some noise checks

We need to make ourselves aware that

- scanning JavaScript is easy (compared to Java, C/C++)
- fewer reported issues allow for a more diligent audit

Food for thought:

- **many issues** being report (*without* careful review) might result in a **false sense of security**
- due to low effort, it might still be valuable (**good cost-benefit ratio**)

In 2012: We Asked Ourselves

- Is SCA is useful for JavaScript?
- Are there better SCA Tools available?
- Can we use the tools more effectively and efficiently?

In 2012: We Asked Ourselves

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  Yes: Serious flaws are found and fixed!
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  Checkmarx, Fortify, IBM AppScan Source Edition
- Can we use the tools more effectively and efficiently?

In 2012: We Asked Ourselves

- Is SCA is useful for JavaScript?
  Yes: Serious flaws are found and fixed!
- Are there better SCA Tools available?
  Checkmarx, Fortify, IBM AppScan Source Edition
- Can we use the tools more effectively and efficiently?
  Most likely, **yes**

In 2013: What Tools Were Available

Our market study revealed three classes of tools:

- Scale-able analyzers with a broad security scope
  - Fortify
  - Checkmarx
  - IBM AppScan Source Edition
- Light-weight analyzers
  - JSPrime (focused on DOM-based XSS)
  - JSLint (very useful, focused on coding styles)
  - HSInt (early stage, extensible JSLint)
  - YASCA (simple grep)
  - . . .
- Research prototypes
  - TAJS (scalability – jQuery?)
  - . . .

In 2013: Evaluation

We evaluated in detail:

- Fortify
- Checkmarx
- IBM AppScan Source Edition

For all tools, we used

- most sensitive “default” configuration
  (no SAP template/filters)
- the same evaluation targets
  - library of JavaScript “challenges” (self-made)
  - three (fourth ongoing) SAP applications of different size
    (including one with server-side JavaScript using the XS Engine)
  - detailed comparison for
    - XSS-variants
    - All findings of the two topmost priorities (high)

Evaluation Approach For Direct Tool Comparisons

Assume we want to compare tool (configuration) *A* and *B*:

1. Analyse same test target with both tools (configurations)
2. For all findings (or well-defined subset, e.g., one vulnerability type):
   1. Ignore all findings reported by both tools (configurations)
      (Regardless if you use *A* or *B*, you need to cope with these findings)
   2. Analyse all findings only reported by *A*
      - True positives of *A* are *false negatives* for *B*
   3. Analyse all findings only reported by *B*
      - True positives of *B* are *false negatives* for *A*
3. Compare the number of false/true positives for both tools
   (how to weight — depends on your actual efforts . . .)

In 2013: A First Evaluation Result

> No tool is perfect (for us) in its default configuration

- For real SAP Applications,
  - there is no clear winner in the category “JavaScript semantics”
  - interesting difference in terms of available checks (categories)
- Important follow-up:
  How can we adapt the tools to our needs?
  - We tried to write custom checks/rules for two test cases
    - an eval-example
    - an SQL-injection example

  Only one tool (partially) successful

Generalised Evaluation and Roll-out Approach

1. Identify need
2. Market research
3. For a larger set of candidates:
   Limited evaluation by central security team based on
   - artificial test cases
   - one or two selected SAP applications
4. For a smaller set of candidates:
   Proof-of-Concept (pilot) with SAP development team and vendor
5. In case of success (roll-out decision):
   - Ramp-up projects on a per project/team basis
   - Adaption to SAP technologies
   - Integration into SAP build systems, IDEs, reporting, ...

Note, step 1) and 2) are sometimes replaced by vendor marketing ...

Outline

Insight: Changing/Improving Tool Configurations

Fortify

- Report all occurrences where the first argument to `system` can be influenced by an attacker (input not sanitised)

```
<?xml version="1.0" encoding="UTF-8"?>
<DataflowSinkRule formatVersion="3.2" language="cpp">
  <MetaInfo>
    <Group name="package">C Core</Group>
  </MetaInfo>
  <RuleID>AA212456-92CD-48E0-A5D5-E74CC26A276F</RuleID>
  <VulnKingdom>Input Validation and Representation</VulnKingdom>
  <VulnCategory>Command Injection</VulnCategory>
  <DefaultSeverity>4.0</DefaultSeverity>
  <Description ref="desc.dataflow.cpp.command_injection"/>
  ...
```

Insight: Changing/Improving Tool Configurations

Fortify

- Report all occurrences where the first argument to `system` can be influenced by an attacker (input not sanitised)

```
...
<Sink>
  <InArguments>0</InArguments>
  <Conditional>
    <Not>
      <TaintFlagSet taintFlag="VALIDATED_COMMAND_INJECTION"/>
    </Not>
  </Conditional>
</Sink>
<FunctionIdentifier>
  <FunctionName>
    <Value>system</Value>
  </FunctionName>
</FunctionIdentifier>
</DataflowSinkRule>
```

Insight: Changing/Improving Tool Configurations

Checkmarx

- Report all occurrences where the first argument to `system` can be influenced by an attacker (input not sanitised)

```
CxList inputs          = Find_Inputs();
CxList validSanitation = getSanitizers()
CxList SystemCalls     = All.FindByShortName("system")
CxList output = All.GetParameters(SystemCalls, 0));

result = outputs.InfluencedByAndNotSanitized(inputs, validSanitation);
```

Outline

- Conclusion
  - Static analysis is a challenging problem both theoretically and pragmatically
- Recommendations for users
  - Adapt the tools to your needs!
  - Provide clear guidelines which findings are important to your organisation!
  - Choose your tools carefully
  - Scan daily (or at least weakly)

Part IV

Outlook

Outline

JavaScript: Binding and External Functions

```
var docref  = document.location.href
var input  = docref.substring(docref.indexOf("default=")+8);
var fake = function (x) {return x;}
var cleanse = function (x) {return 'hello world';}

var uinput = unknown(input); // unknown is nowhere defined
document.write(uinput); // secure!?

var finput = fake(input);
document.write(finput);  // not secure

var cinput = cleanse(input);
document.write(cinput); // secure

var extfinput = extfake(input);  // defined externally (part of scan)
document.write(extfinput);  // not secure

var extcinput = extcleanse(input); defined externally (part of scan)
document.write(extcinput); // secure

var nobodyKnows = toCleanOrNotToCleanse(input); multiply defined (underspecified)
document.write(nobodyKnows); // not secure!?
```

Functions as First-Class Objects

```
var href = document.location.href;
var unsafeInput = href.substring(href.indexOf("default=")+8) // unsafe input
var safeInput = "1+2";                                      // safe input

// aliasing eval
var exec = eval;
var doit = exec;

var func_eval1     = function (x) {eval(x);};
var func_eval2     = function (x,y) {eVaL(y);};

var func_eval_eval = function (x) {func_eval1(x);};
var func_doit      = function (x) {doit(x);};
var func_exec      = function (x) {exec(y);};
var run            = func_eval1;
var inject_code    = func_exec;
```

CSRF Prevention

```
var request = {
        headers : {
                "X-Requested-With" : "XMLHttpRequest",
                "Content-Type" : "application/atom+xml",
                "X-CSRF-Token" : "Fetch"
        },
};
if (Appcc.CSRFToken)
        var request = {
                headers : {
                        "X-Requested-With" : "XMLHttpRequest",
                        "Content-Type" : "application/atom+xml",
                        "X-CSRF-Token" : Appcc.CSRFToken
                },
        };
else  var request = {
                headers : {
                        "X-Requested-With" : "XMLHttpRequest",
                        "Content-Type" : "application/atom+xml",
                        "X-CSRF-Token" : "etch"
                },
        };
var response = this.oServiceManager.read(request, this, this.batch, this.busy);
```

Prototype-based Inheritance

```
var vl = new sap.ui.commons.layout.VerticalLayout();
sap.ui.core.Control.extend("foobar.Label", {
    metadata : {
        properties : {
            "text" : "string"
        }
    },
    renderer : function(oRm, oControl) {
        oRm.write("<span>XSSLabel:␣");
        oRm.write(oControl.getText());
        oRm.write("</span>");
    }
});
var p = jQuery.sap.getUriParameters().get("xss");
vl.addContent(new foobar.Label({text:p}));
return vl;
```

Outline

What is a Hybrid App?

Native, HTML5, or hybrid

Native apps
Java \ Swift \ C#

- Developed for a specific platform
- All features available

Web apps
HTML5 and JS

- Hosted on server, all platforms
- No access to device features

Platform-specific

Platform-independent

What is a Hybrid App?

Native, HTML5, or hybrid

Native apps
Java \ Swift \ C#

- Developed for a specific platform
- All features available

Hybrid apps
HTML5, JS, and native

- Build once, run everywhere
- Access to device features through plugins

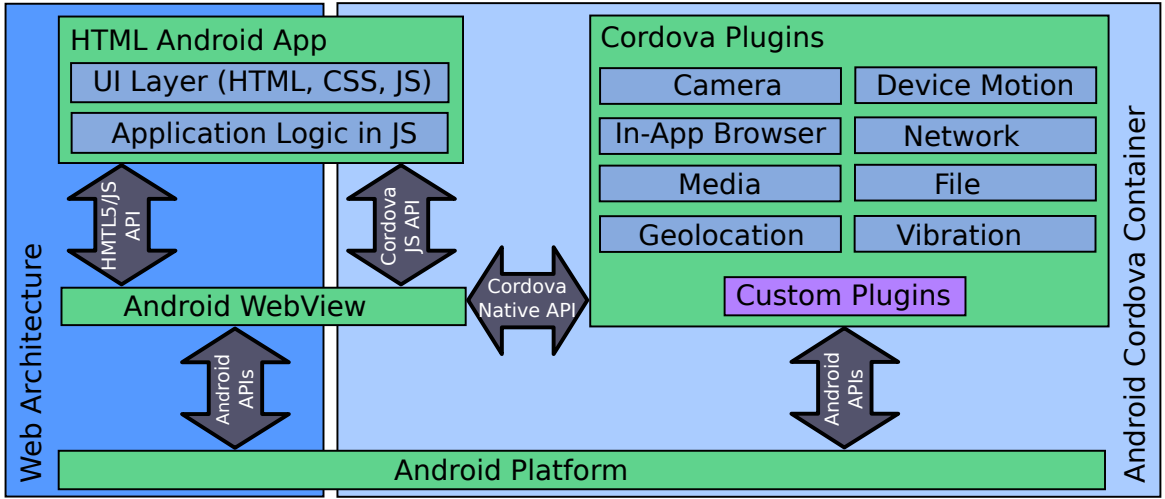
Web apps
HTML5 and JS

- Hosted on server, all platforms
- No access to device features

Platform-specific

Platform-independent

The architecture of Apache Cordova



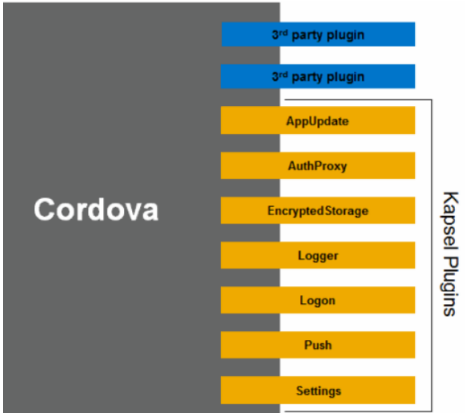
Example: Get Contacts

```
function showPhoneNumber(name) {
        var successCallback = function(contact) {
                alert("Phone number: " + contacts.phone);
        }
        exec(successCallback, null, "ContactsPlugin", "find",
                [{"name" : name}]);
}
```

```
class ContactsPlugin extends CordovaPlugin {
        boolean execute(String action, CordovaArgs args, CallbackContext callbackContext) {
                if ("find".equals(action)) {
                        String name = args.get(0).name;
                        find(name, callbackContext);
                } else if ("create".equals(action)) ...
        }
        void find(String name, CallbackContext callbackContext) {
                Contact contact = query("SELECT ... where name=" + name);
                callbackContext.success(contact);
        }
}
```

From Apache Cordova to SAP Kapsel (Fiori/Kapsel Browser)

- Based on Apache Cordova (FOSS Framework)
- Apache Cordova plus plugins for
  - Encrypted Storage
  - Authentication
  - Logging
  - . . .
- Enterprise features
  - Single sign-on
  - Application management (SMP)
  - Mobile Device Management (MDM)
- SAP UI5 (JavaScript framework for UIs)



Why is it hard to ensure the security of hybrid apps

Web technologies (i.e., JavaScript)

- lack of typing, higher order functions, asynchronous programming models
- highly dynamic (e.g., eval(...), dynamic loading)
- ...

Large Libraries and Modules

- large ($\approx$ 100kLOC) third party (FOSS, proprietary) libraries
- both native (Java) and JavaScript
- complex core framework
- ...

Cross-Language-Analysis

- many data-flows across language boundaries
- datatype conversion
- not only for accessing sensors (e,g, session plugin requires $>$ 10 language switches)
- ...

Exploiting the JavaScript to Java Bridge (CVE-2013-4710)

- We can expose Java methods in JavaScript

```
foo.addJavascriptInterface(new FileUtils(), "FUtil");
```

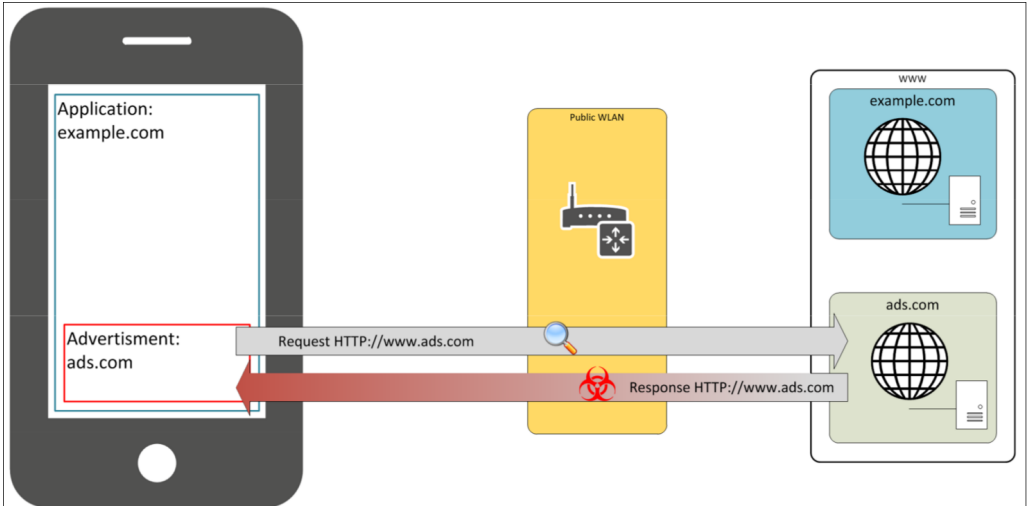
- And use them in JavaScript easily

```
<script type="text/javascript">// <![CDATA[
filename = '/data/data/com.livingsocial.www/' + id +'_cache.txt';
FUtil.write(filename, data, false);
// ]]></script>
```

- Which might expose much more than expected

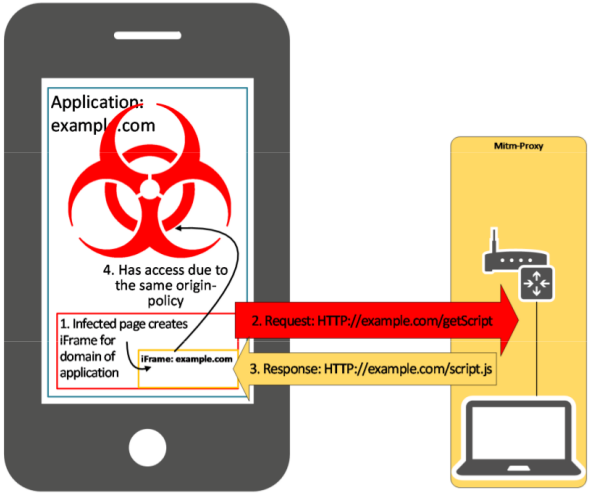
```
function execute(cmd){
   return
   window._cordovaNative.getClass().forName('java.lang.Runtime').
                  getMethod('getRuntime',null).invoke(null,null).exec(cmd);
}
```

Never, really never, use http without SSL



Thanks to Jens Heider from Fraunhofer SIT.

Never, really never, use http without SSL



Thanks to Jens Heider from Fraunhofer SIT.

What did we learn from this

There are many subtle things to consider:

- always use http**s** and **validate** certificates
- dynamically loaded code from third parties can be dangerous (even if “iframed”)
- in Cordova apps, XSS attackers can be very powerful
- ship only the plugins that you need (unused plugins can still be exploited)
- if you need only limited functionality, secure the plugin in the native/Java code
- Did you know that

```
<application android:debuggable="true" />
```

  disables certificates checks in WebViews!

Outline

How to help the developer?

We want to find bugs in Cordova apps

- Idea: Static program analysis, build a call graph of the Cordova app
- But how to find cross-language calls?

Four heuristics that model the Cordova framework:

- ConvertModules
- ReplaceCordovaExec
- FilterJavaCallSites
- FilterJSFrameworks

Based on examination of real Cordova apps
Exploit frequent coding patterns to improve precision

ConvertModules

```
define("com.foo.contacts", function(require, exports, module) {
        exports.find = function(successCallback, name) {
                exec(successCallback, null, "ContactsPlugin", "find",
                        [{"name" : name}]);
        }
});
...
var successCallback = function(contact) {
        alert("Phone␣number:␣" + contacts.phone);
}
plugins.contacts.find(successCallback, "Peter");
```

Problem:

- Not all callback functions are defined within the plugin
- Difficult to track callback functions from app code

Solution:

- Substitute dynamic mechanism with unique, global variable

ConvertModules

```
define("com.foo.contacts", function(require, exports, module) {
        @plugins.contacts.find@ = function(successCallback, name) {
                exec(successCallback, null, "ContactsPlugin", "find",
                        [{"name" : name}]);
        }
});
...
var successCallback = function(contact) {
        alert("Phone␣number:␣" + contacts.phone);
}
plugins.contacts.find(successCallback, "Peter");
```

Problem:

- Not all callback functions are defined within the plugin
- Difficult to track callback functions from app code

Solution:

- Substitute dynamic mechanism with unique, global variable

ConvertModules: results

- Most useful for
  - small plugins
  - more precise analysis
- Allowed finding of callback functions in app code
- Less errors due to less ambiguity of dynamic mechanism

ReplaceCordovaExec

```
function showPhoneNumber(name) {
        var successCallback = function(contact) {
                alert("Phone number: "+contacts.phone);
        }




        exec(successCallback, null, "ContactsPlugin", "find",
                [{"name" : name}]);
}
```

Problem:

- Callback call sites are hard to find
- No context-sensitivity

Solution:

- Stub the exec method

ReplaceCordovaExec

```
function showPhoneNumber(name) {
        var successCallback = function(contact) {
                alert("Phone number: "+contacts.phone);
        }
        function stub1(succ, fail) {
                succ(null);
                fail(null);
        }
        stub1(successCallback, null, "ContactsPlugin", "find",
                [{"name" : name}]);
}
```

Problem:

- Callback call sites are hard to find
- No context-sensitivity

Solution:

- Stub the exec method

ReplaceCordovaExec: Results

- Neccessary to find any Java to JavaScript calls
- Most apps use exec to communicate, only some bypass it
- Inexpensive way to get context-sensitivity where it is needed the most

FilterJavaCallSites

```
class ContactsPlugin extends CordovaPlugin {
        boolean execute(String action, CordovaArgs args, CallbackContext callbackContext) {
                if ("find".equals(action)) {
                        String name = args.get(0).name;
                        find(name, callbackContext);
                } else if ("create".equals(action)) ...
        }
        void find(String name, CallbackContext callbackContext) {
                Contact contact = query("SELECT␣...␣where␣name=" + name);
                callbackContext.success(contact);
        }
}
```

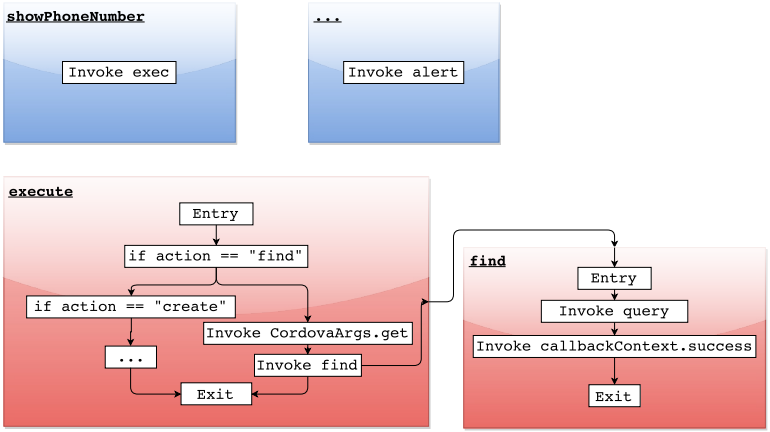
Problem:

- How to determine the targets of the `callbackContext` calls?
- Can we use the pattern of the `action` usage?

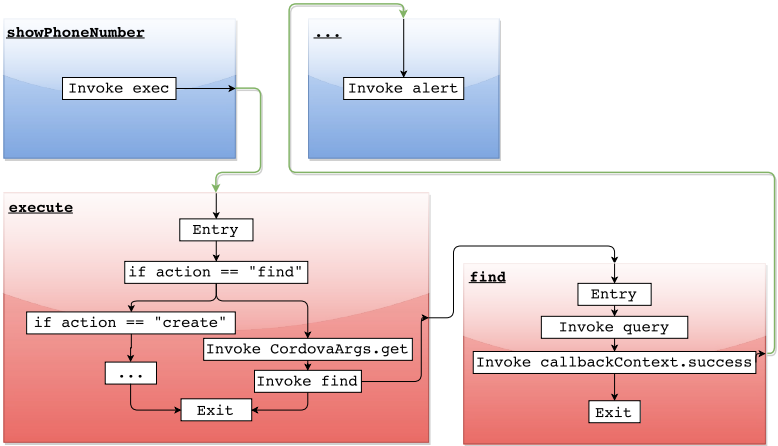
Solution:

- Determine which `callbackContext` calls are reachable

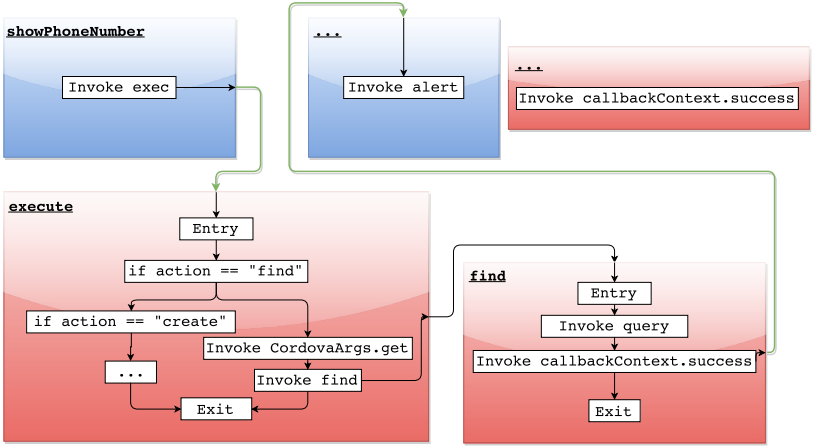
FilterJavaCallSites: details



FilterJavaCallSites: details



FilterJavaCallSites: details



FilterJavaCallSites: results

- Developers all use `action` variable similarly
- Therefore: Many incorrect edges avoided
- But: A few calls from Java to JavaScript are missed now
- Some store the `callbackContext` and call asynchronously

Outline

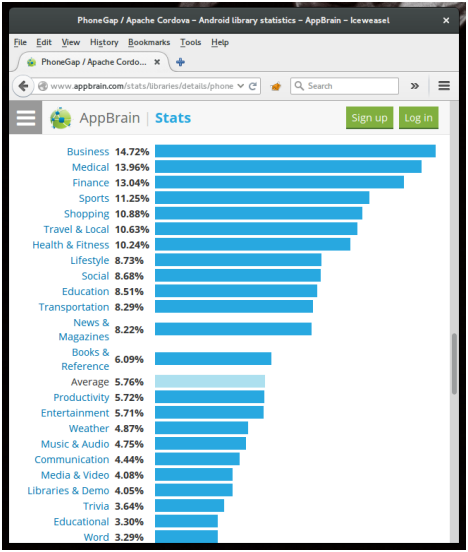
What we where interested in

Main goals:

- Understand the use of Cordova
- Learn requirements for Cordova security testing tools

Looking for answers for questions like

- How many apps are using Cordova?
- How is Cordova used by app developers?
- Are cross-language calls common or not?



What we did

Selection of apps

- all apps that ship Cordova from Google's Top 1000:
  - 100 apps ship Cordova plugins
  - only 50 actually use Cordova (5%)
- three selected apps from SAP (using SAP Kapsel)
- one artificial test app (to test our tool)

Development of a static analysis tool

- analysing Android apps (`*.apk` files)
- specialised in data-flows from Java to JavaScript and vice versa
- based on WALA
- in addition: list used plugins

Manual analysis of 8 apps (including one from SAP)

- to understand the use of Cordova
- to assess the quality of our automated analysis

What we have learned: plugin use

Plugins are used for

- accessing device information
- showing native dialog boxes and splash screens
- accessing network information
- accessing the file storage
- accessing the camera
- . . .

Plugin	
device	52%
inappbrowser	50%
dialogs	40%
splashscreen	36%
network-information	28%
file	28%
console	24%
camera	22%
statusbar	22%
PushPlugin	22%

What we have learned: app size and cross-language calls

App size:

- mobile apps are not always small
- SAP apps seem to be larger than the average

Cross-language calls:

- calls from Java to JS: very common
- calls from JS to Java: surprisingly uncommon

App	Category	Java2JS	JS2Java	JS [kLoC]	Java [kLoC]
sap_{01}	Finance	2	12	35.5	17.0
sap_{02}	Business	20814	39	345.3	53.5
sap_{03}	Business	9531	75	572.3	135.8
app_{01}	Finance	9	13	26.3	17.8
app_{02}	Finance	2	10	11.2	16.8
app_{03}	Social	2349	31	4.6	103.7
app_{04}	Business	1	6	37.5	16.8
app_{05}	Finance	6	26	20.0	44.8
app_{06}	Finance	693	70	30.4	24.3
app_{07}	Travel & Local	3430	43	129.0	304.0
app_{08}	Entertainment	14220	67	36.7	23.0
app_{09}	Lifestyle	51553	89	36.3	44.7
app_{10}	Finance	8	36	43.7	18.4
app_{11}	Business	0	0	14.0	438.9
⋮	⋮	⋮	⋮	⋮	⋮

Recall and Precision

Excerpt

- Recall:

$$\frac{\textit{Correctly reported calls}}{\textit{All reported calls}}$$

- Precision:

$$\frac{\textit{Correctly reported calls}}{\textit{Calls actually present}}$$

App	kLoC	kNodes	Plugins	Recall	Precision	Calls
app_{01}	43	9	5	33%	75%	17
app_{02}	27	8	4	100%	66%	13
app_{03}	106	18	8	1%	93%	61
app_{04}	53	14	3	100%	100%	7
app_{05}	64	10	7	33%	66%	29
app_{06}	53	8	12	35%	97%	316
app_{08}	58	14	11			
app_{20}	68	10	15			
app_{22}	20	9	3			
app_{25}	161	59	2			
app_{37}	280	65	18			
app_{38}	77	56	6			
app_{45}	18	7	4			
sap_{01}	52	19	6	100%	66%	15
sap_{02}	398	15	17			
sap_{03}	708	118	15			
dvhma	17	7	4	100%	100%	15

What we have learned: exceptional behaviours

Cordova use:

- no HTML/JS in the app
- no use of Cordova

Plugin use:

- often callbacks are not used (missing error handling)
- plugins are modified
- plugins might use JNI

Outline

Recommendations: The (hopefully) obvious parts (1/2)

Cordova apps are **Web applications**:

- do secure JavaScript programming
- content security policy, same origin policy
- . . .

Warning: the WebView sandbox is not as strong as on desktop Web browsers

Cordova apps are **native/Java apps**:

- do secure Java/Objective-C/. . . programming
- do not trust validations done in the JavaScript part of the plugin
- . . .

Recommendations: The (hopefully) obvious parts (2/2)

Cordova apps are **mobile applications**:

- permissions
- ...

Cordova apps are **cordova applications**:

- plugin whitelisting
- read the Cordova security guide:
  `https://cordova.apache.org/docs/en/5.4.0/guide/appdev/security/index.html`

Recommendation: Use the latest framework version

Frameworks (and the underlying OS) can have vulnerabilities:

- use the latest version of Cordova (SAP Kapsel)
- monitor for public know vulnerabilities (e.g., CVEs)

Framework vulnerabilities can be severe:

- Java code execution via JavaScript: CVE-2013-4710
  Avoid Cordova on Android below 4.1 & use AddJavaScriptInterface annotation
- (incomplete) overview: `https://www.cvedetails.com/vulnerability-list/vendor_id-45/product_id-27153/Apache-Cordova.html`

Summary

- Hybrid mobile apps are getting more popular
  - they are recommended at SAP
  - everything running in the Kapsel/Fiori Browser is a hybrid app
- Securing hybrid apps is a challenge and requires expertise in
  - Web application security
  - native/Java security
  - mobile security
  - Cordova/SAP Kapsel security
- Check the Cordova security guide:
  `https://cordova.apache.org/docs/en/5.4.0/guide/appdev/security/index.html`

Part V

Conclusions

Conclusion

Static and dynamic security testing approaches are an important means for improving software security.

From an industrial perspective

- They can be rolled out to 25 000 developers, but it is not easy
- Still problems that need to be solved
  - On the management/organizational level
  - On the technical level

From an academic (researcher) perspective

- While here is a wealth of literature, there are still many open questions
- Interesting area
  - crossing the boundary between verification and falsification
  - combining dynamic and static approaches
  - security and software/language engineering (“secure by construction”)

Thank you for your attention!

Any questions or remarks?

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