Wanted: Students to participate in a user study

- Requirements:
  - Know how to use the Eclipse IDE
  - Knowledge in Java development
  - Knowledge of static analysis is not required, but it is a plus

- Time: 2-3 hours
- Interested? Contact Lisa Nguyen: lisa.nguyen@cased.de

Projects

Goal: Perform a security analysis of an open source project

Organization

- Group: 2 to 3 students
- Choose an open source software
- Choose whether to do a code analysis or penetration testing and the tools to use
- Send ½ page project proposal by Dec 4 and wait for confirmation
- Repost submission deadline March 1, 2016
- Work on your own—no advising
- No recommended size for the report

Projects

Report structure

- Description of the architecture
- Threat analysis
- Performed testing/ code analysis
- Review of the results

Grading criteria (20% of total score)

- Importance of the software
- Thorough threat analysis
- Discovered vulnerabilities
- Innovation
- Quality of the report

Research Activity

Goal: Address a research question related to one of the topics of the course

Paper size

- 5 pages for group of 2 students
- 7 pages for group of 3 students
- Paper Format: IEEE Conference Style (2 columns)

Organization

- Send ½ page project proposal by Dec 11 and wait for confirmation
  - Group members
  - Research problem and approach
- Submission deadline is March 20
- Work on your own—no advising

Lecture 6

Static Code Analysis

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20 November 2015

Fraunhofer SIT

TECHNISCHE UNIVERSITÄT DARMSTADT

SECURE SOFTWARE ENGINEERING GROUP

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Summary

- Introduction to static analysis
  - Static and dynamic analysis
  - Basics of static analysis
- Data-flow analysis
  - Intra-procedural analysis
  - Inter-procedural analysis
- Pointer analysis
  - Simple points-to analysis
  - Field-sensitive points-to analysis
- Taint analysis
  - Simple taint analysis
  - Taint analysis and alias information
- Static analysis in practice
  - Examples
  - In industry

Testing programs

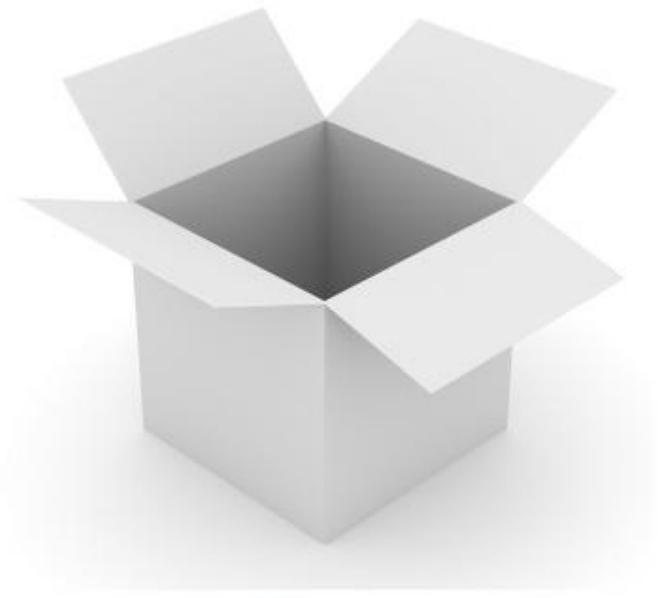
- Testing
  - Functional testing: make sure everything behaves as it should
  - Security testing: make sure nothing behaves as it shouldn‘t

- Methods
  - Static analysis (white box approach)
  - Dynamic analysis (black box approach)

Static analysis (white box approach)

- Inspect the source code and try to predict malicious behaviour
  - Requires extensive knowledge
    - Software skills: software engineering, language specifics
    - operating systems, databases, networking, etc.
    - Awareness: known vulnerabilities, latest attacks
  - Requires creativity
    - Imagining possible threats, crafting attacks

- Will report every possible scenario, even unlikely



- Best done with automated tools
  - HP Fortify, IBM AppScan, Coverity, etc.

Dynamic analysis (black box approach)

- Inspect the running program, without access to the source code
  - Passive: observing traffic
  - Active: Interacting with the program to find and confirm issues
    - Achieved with different levels of coverage (authenticated or not, different privileges, right to use social engineering, etc.)
    - Ex: Stress tests, penetration testing

- Can miss some issues (code coverage is not total)

- Can be automated
  - Burp, HP WebInspect, etc.
  - But automated tools cannot reason on very complex exploits yet.

Static and dynamic analysis

- Static analysis
  - Scans the whole code base
  - Reports lots of warnings
  - Finds coding issues (Dead code, null pointer dereference, hardcoded credentials, unchecked errors, API mishandling, etc.)

- Dynamic analysis
  - Does not cover the whole attack surface
  - Can miss vulnerabilities
  - Finds runtime and platform-specific issues (Environment configuration, unpatched versions, runtime privileges, issues in 3rd party programs, etc.)

- Both find common vulnerabilities
  - SQL injection, XSS, Buffer overflows, etc.

Basics of static analysis

- Does a program P satisfy the property Φ?
  - Is this variable a constant? -> Constant propagation
  - Is this code reachable? -> Dead code analysis
  - Can this pointer ever be null? -> Nullness analysis
  - Is this file closed at that statement? -> Typestate analysis

- Unfortunately, we cannot write a perfect analysis
  - Rice‘s theorem: For any non-trivial property of partial functions, no general and effective method can decide whether an algorithm computes a partial function with that property.

Basics of static analysis

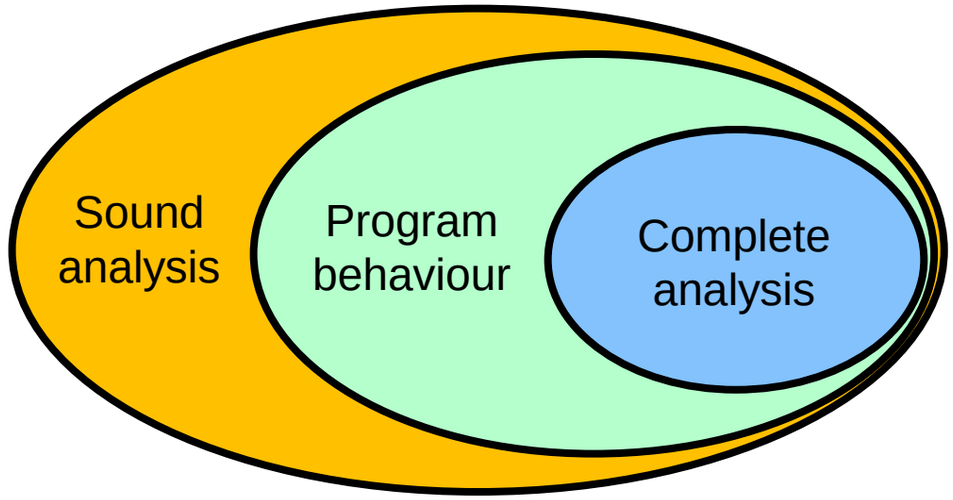
- Soundness:
  - The analysis over-approximates how the program behaves
  - It will report all violations of the property
  - But it will also report many false positives

- Completeness:
  - The analysis under-approximates how the program behaves
  - When it reports a violation of the property, it is guaranteed to be correct
  - But it will miss some violations

Basics of static analysis

- Example: A non field-sensitive analysis
  - The analysis manipulates base objects, but cannot model fields

```
a.f = getUserInput();
writeToDatabase(a.f);
writeToDatabase(a.g);
```



- A sound analysis:
  - Would over-approximate a.f to a, and consider a (and all its fields) dangerous
  - It would then report both a.f and a.g as dangerous database writes

- A complete analysis:
  - Would under-approximate a.f, and not consider anything dangerous
  - It would report neither a.f nor a.g

Basics of static analysis

- Precision:
  - In practice, no analysis is totally sound or totally complete. They try to model the program‘s behaviour with as much precision as possible

- In practice, the tradeoff is between precision and scalability
  - The more precision one wants to add, the more complex the program model is
  - Static analysis needs to model the whole code base

Data-flow analysis

- Data-flow analysis
  - Is a static analysis method
  - It iterates through program points and collects information about a property of the program until a fixed point is reached.

- Fixed point
  - For each program point, the collected information will not change anymore.

Data-flow analysis

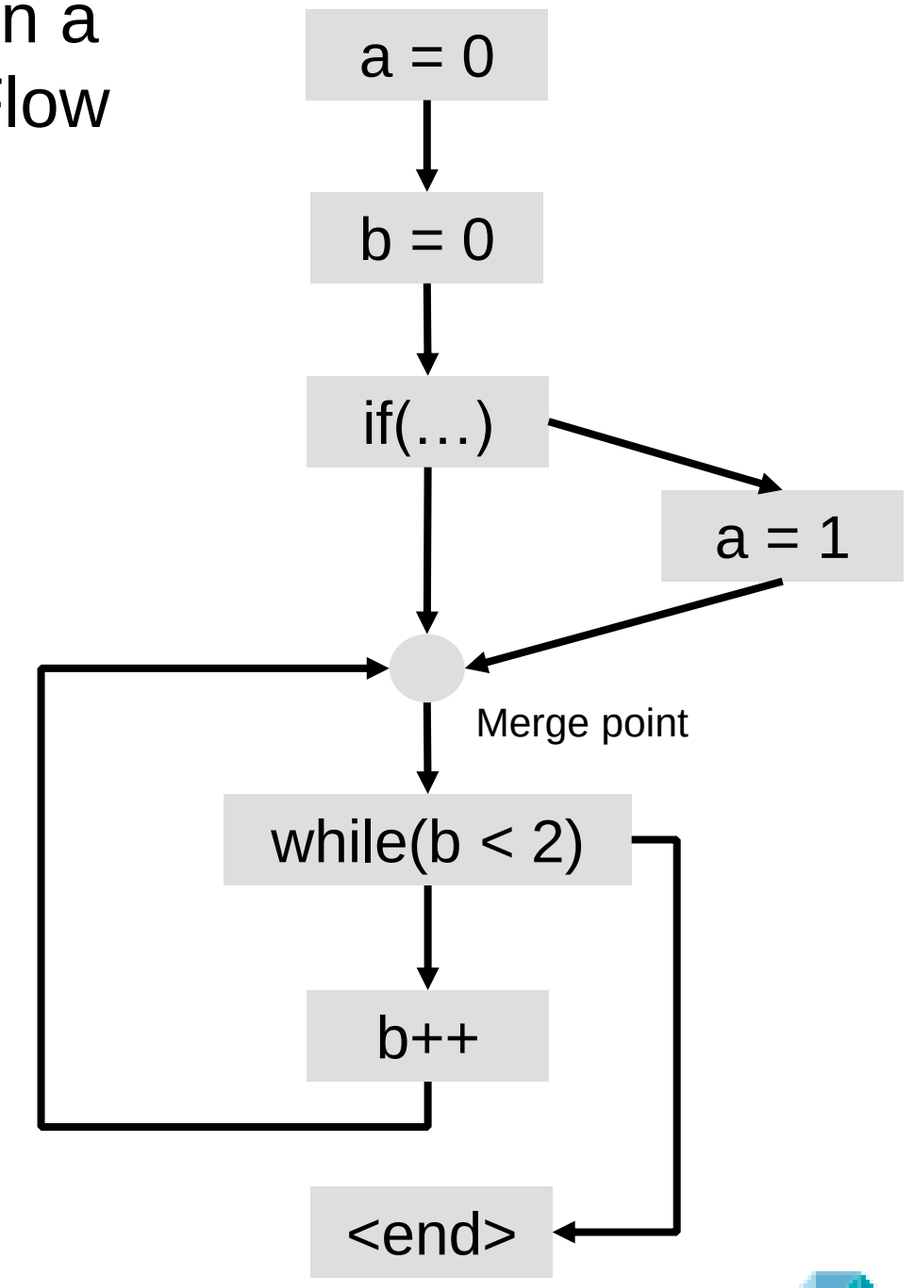
- Example: range analysis
  - Property: what are the values of the variables in this program?

```
int a = 0;
int b = 0;
if(...)
    a = 1;
while(b < 2){
    b++;
}
```

Intra-procedural analysis

- Intra-procedural analyses (within a method) operate on a Control Flow Graph (CFG)

```
int a = 0;
int b = 0;
if(...)
    a = 1;
while(b < 2){
    b++;
}
```



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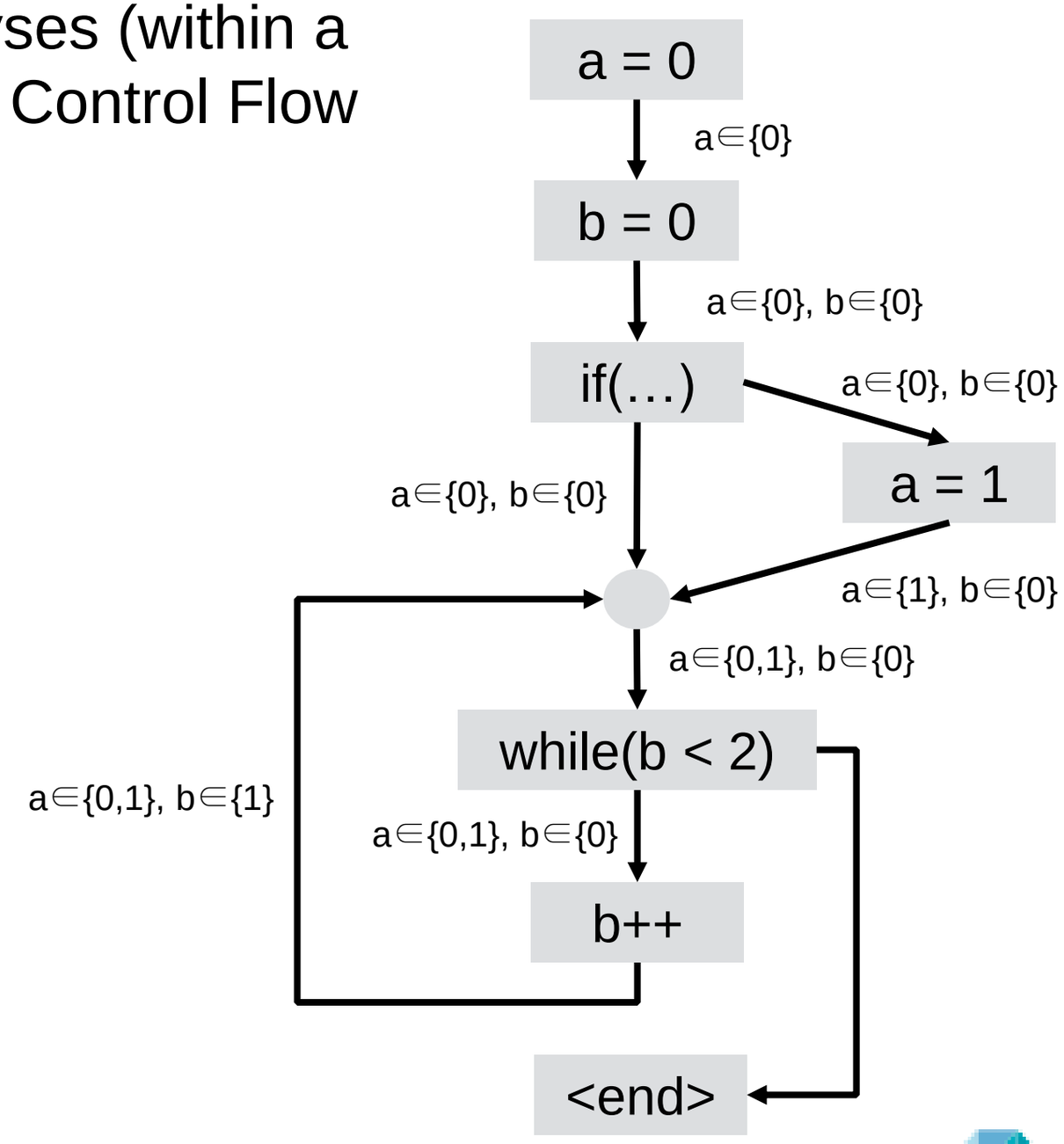

Intra-procedural analysis

- Intra-procedural analyses (within a method) operate on a Control Flow Graph (CFG)

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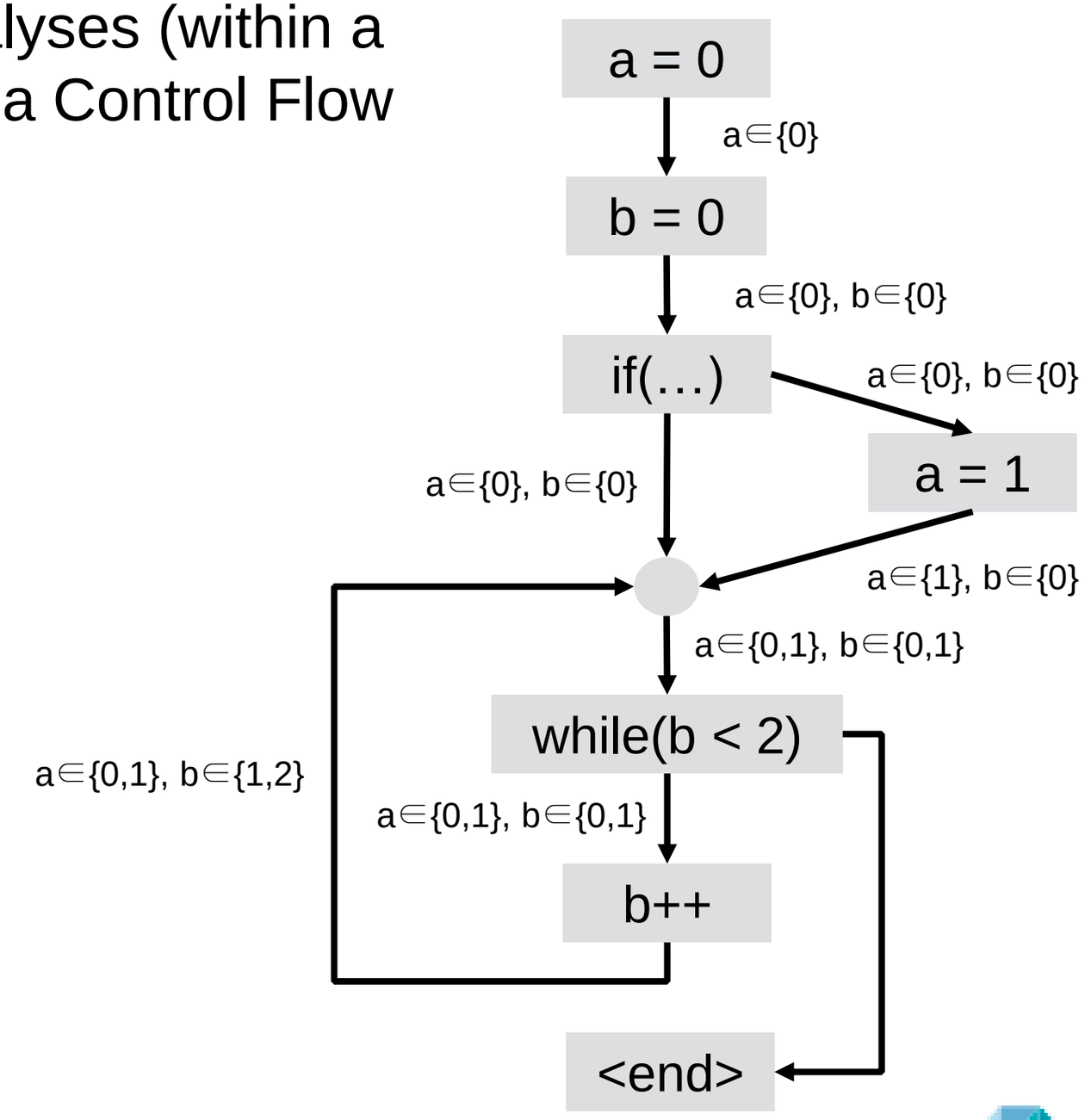

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}
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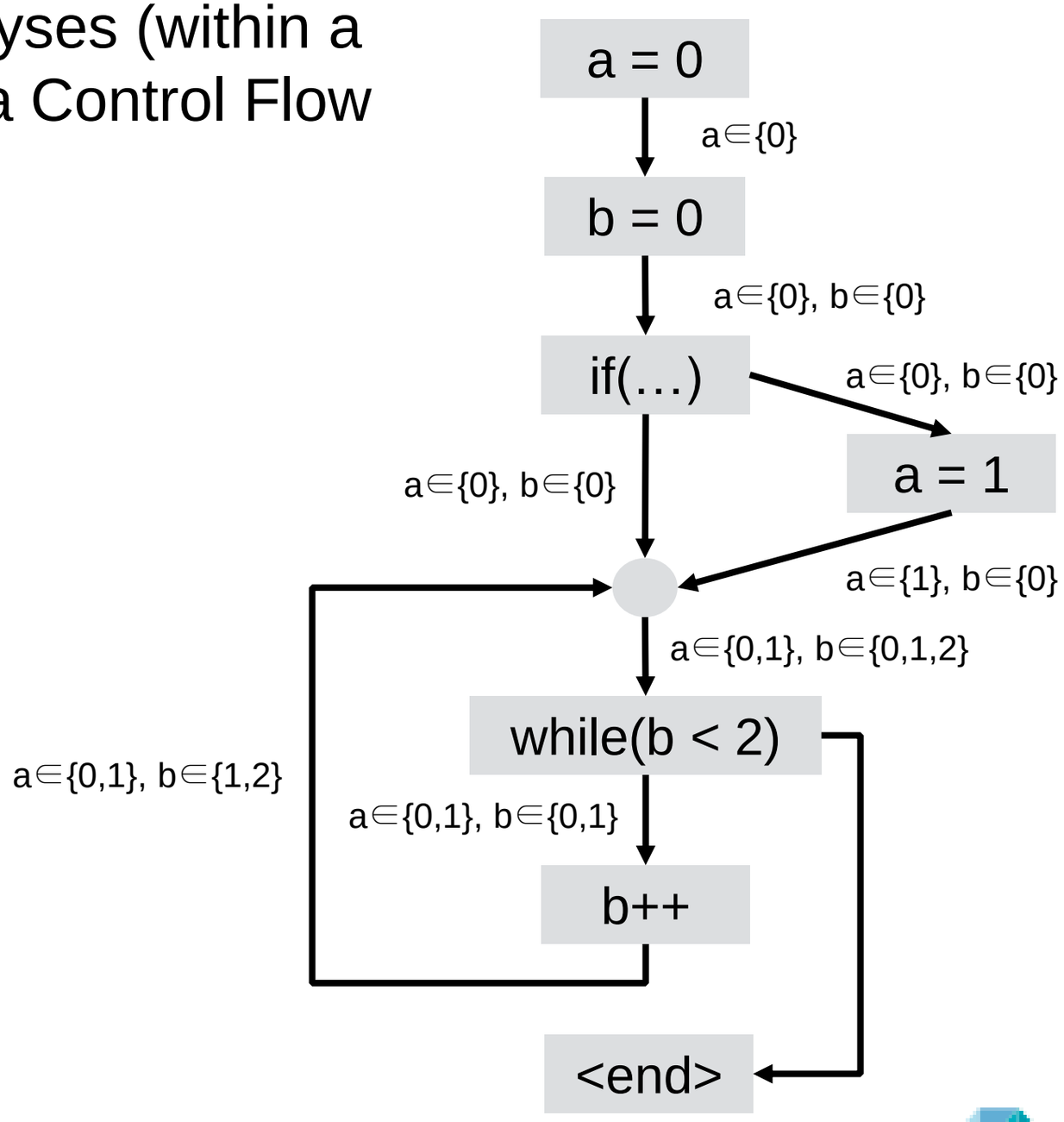


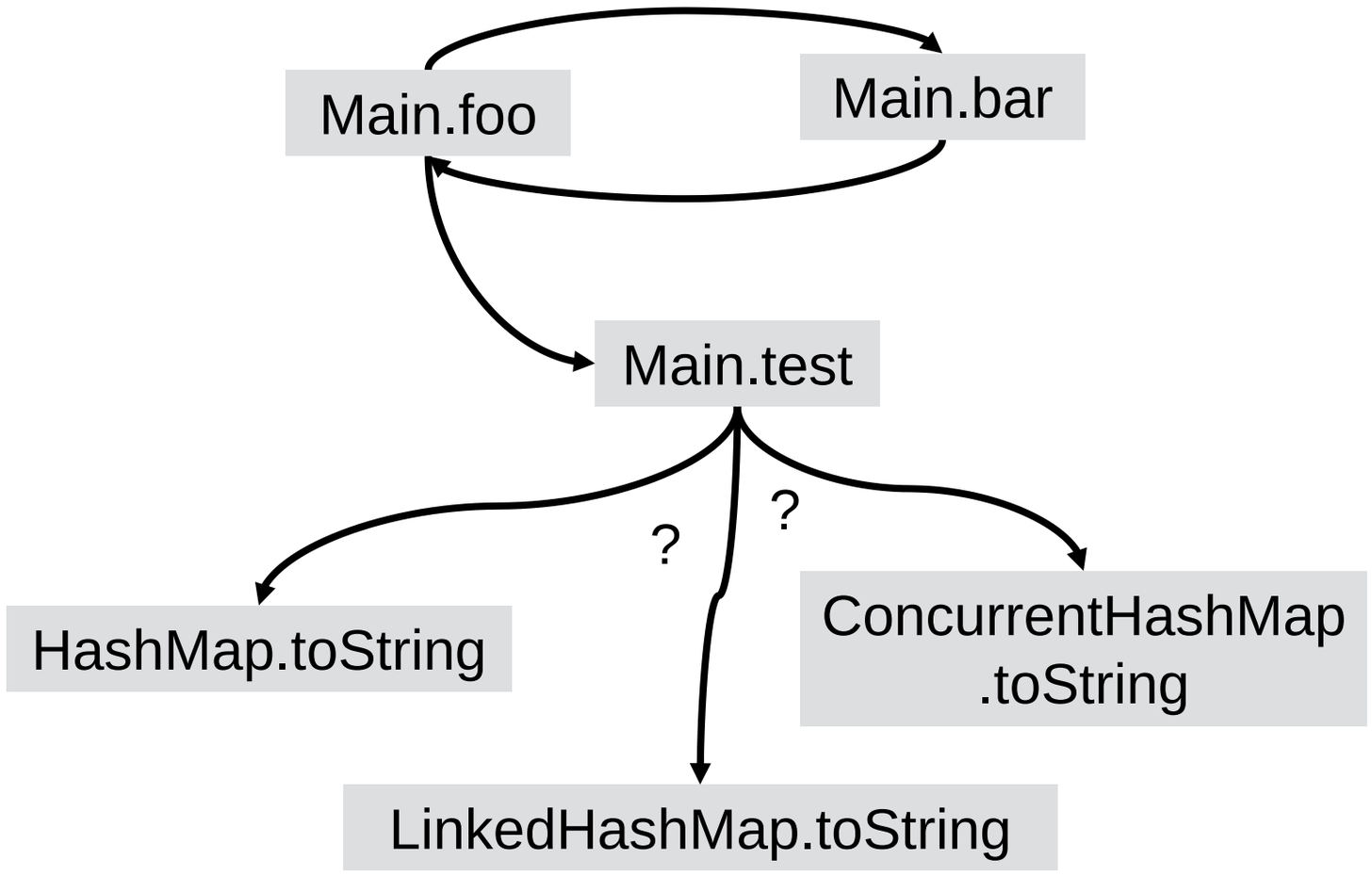
Inter-procedural analysis

- The call-graph‘s precision influences the analysis‘ workload and precision

```
public foo(){
    ...
    bar();
    test(new HashMap());
    ...
}

public bar(){
    foo();
    ...
}

public test(Map m){
    m.toString();
}
```



Pointer analysis

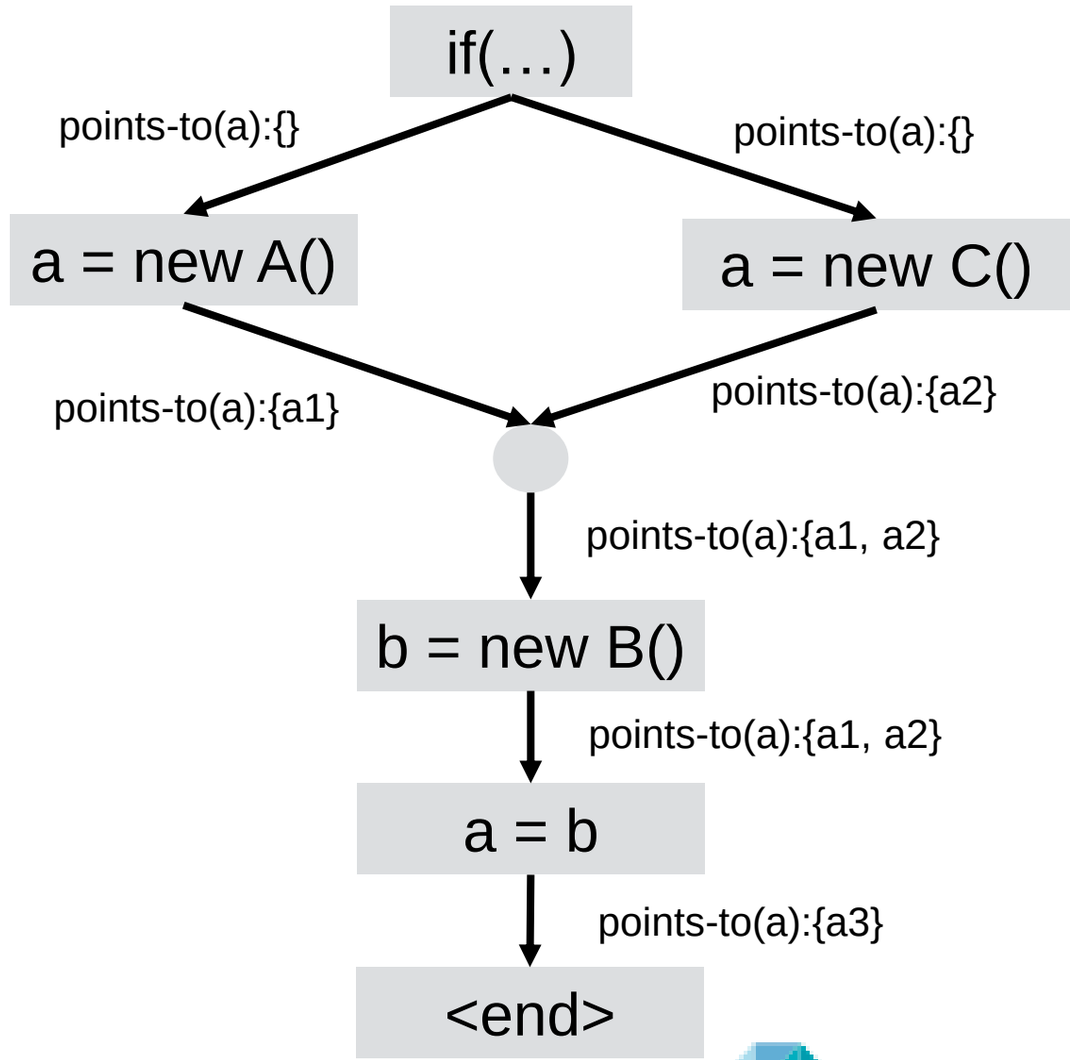
- Reasons about allocation sites / memory locations

- Two types of pointer analysis
  - Points-to analysis
    - Where are the allocation sites of a?
    - points-to(a) = {a1, a2}
  - Alias analysis
    - Do a and b refer to the same object?
    - alias(a,b) = true/false

Simple points-to analysis

- Property: what is the points-to set of a in this program?

```
        if(...)
a1:         a = new A();
        else
a2:         a = new C();
a3:     b = new B();
        a = b;
```



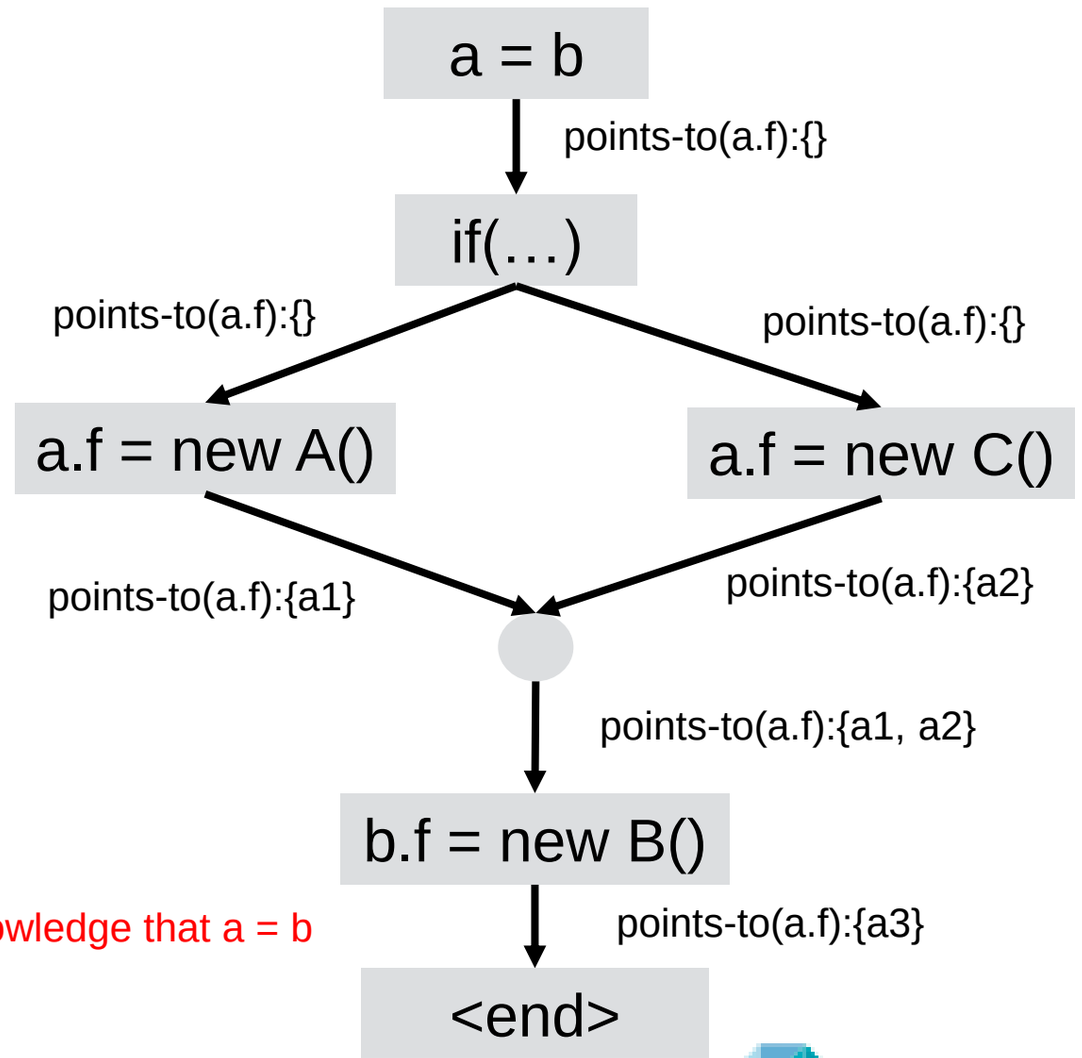
Simple points-to analysis

- More precision?
  - Field sensitivity:
    - In some languages, the analysis needs to model object fields as well.

Points-to analysis with access paths

- Property: what is the points-to set of a.f in this program?

```
        a = b;
        if(...)
a1:         a.f = new A();
        else
a2:         a.f = new C();
a3:     b.f = new B();
```



Must have knowledge that a = b

Pointer analysis

- As soon as field-sensitivity is introduced, pointer analysis becomes trickier
  - Loops, recursion, function returns, field writes, etc. can potentially create/kill an allocation.

- This is also true for any kind of precision introduced in the analysis.

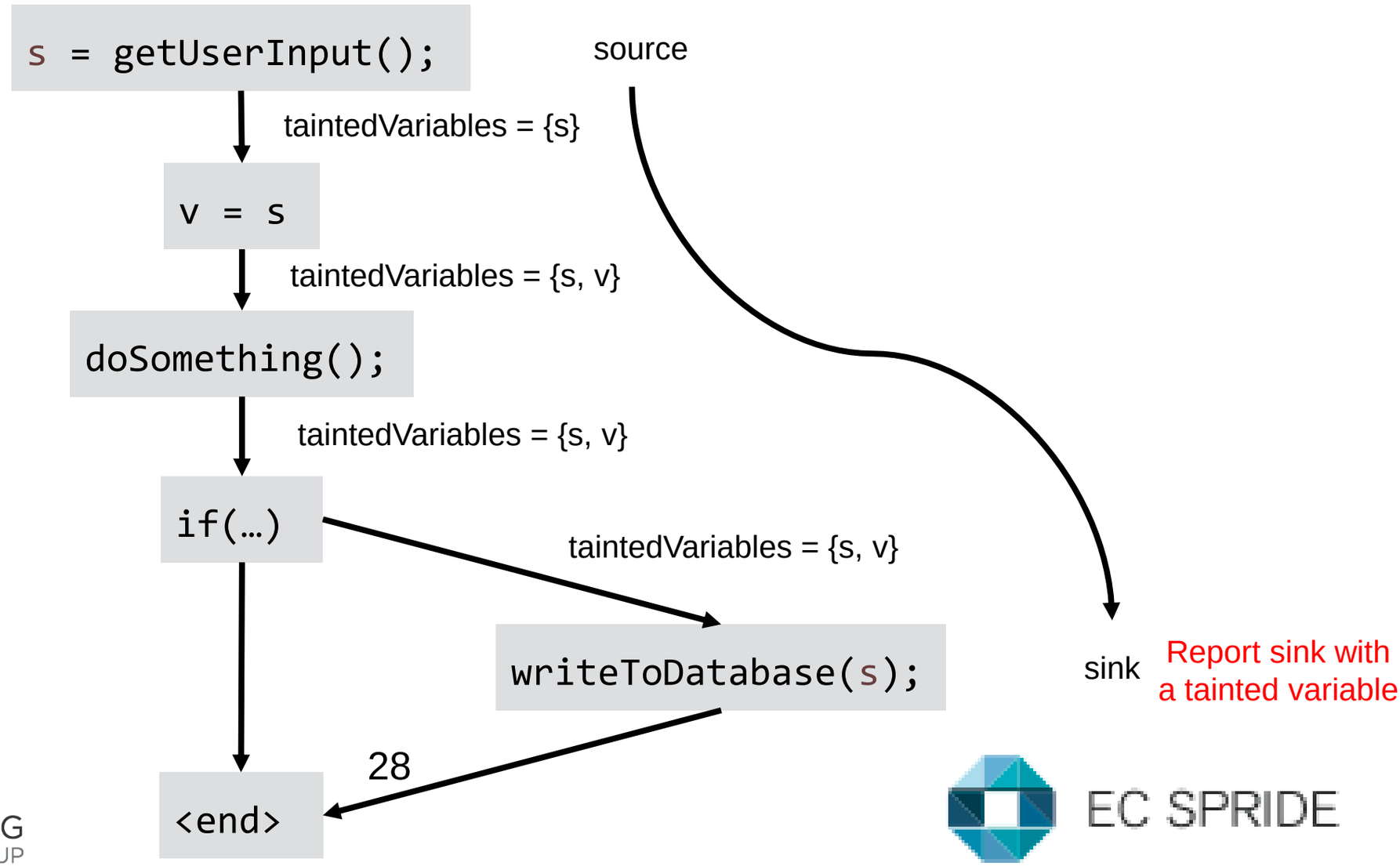
Pointer analysis

- Pointer analyses are often used for:
  - Call-graph construction
  - Type information
  - Strong/weak updates
  - Other client analyses. Ex: taint analysis

- The precision of a pointer analysis directly influences the precision and workload of its client analysis.

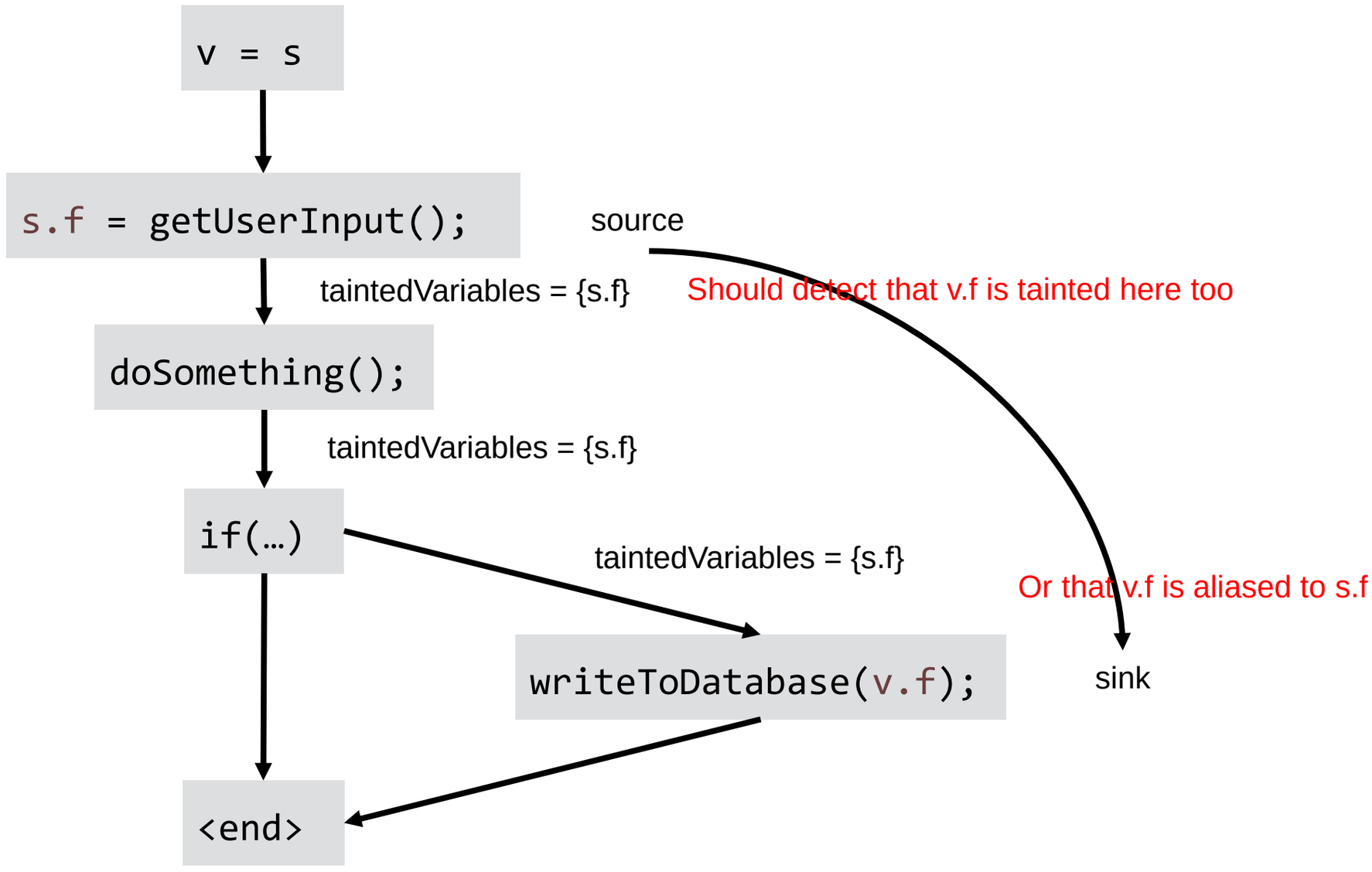
Taint analysis

- Is used to find privacy leaks
  - Matches sources and sinks to find paths of unsanitized data
  - Finds: uses of unvalidated inputs and leaks of private information to the outside world



Taint analysis and alias information

- Alias information can be used to enhance the precision of the analysis



Taint analysis

- To be as precise as possible, an analysis should take various information into account
  - Alias information
  - Language-specific information (ex: Android lifecycle modelling)
  - Analysis-specific information
    - Model sources and sinks (for a taint analysis)
    - Flow, path, context sensitivity
  - Etc.

Example 1

```
protected void processRequest(HttpServletRequest request, HttpServletResponse response) throws
ServletException, IOException {
        try {
            String studentId = request.getParameter("studId");
            Connection conn = null;
            try {
                Class.forName(driver).newInstance();
                conn = DriverManager.getConnection(url + dbName, userName, password);

                Statement st = conn.createStatement();
                String query = 'SELECT * FROM  Students where studId='' + studentId + ''';
                out.println('Query : ' + query);
                System.out.printf(query);
                ResultSet res = st.executeQuery(query);

                PrintWriter out = response.getWriter();
                while (res.next()) {
                    String s = res.getString('classes');
                    out.println('\t\t' + s);
                }
                conn.close();

            } catch (Exception e) {
                e.printStackTrace();
            }
        } finally {
            out.close();
        }
    }
```

studentId

studentId, query

SQL Injection
Can be found with taint analysis

Example 2

```
int main(void) {
    char buff[15];
    printf("\n Enter the password : \n");
    gets(buff);

    if(strcmp(buff, getPassword())) {
        printf ("\n Wrong Password \n");
    } else {
        printf ("\n Correct Password \n");
        // doRootStuff();
    }
    return 0;
}
```

Buffer overflow
Can be detected with a taint analysis
but it alone will not be enough
(Will yield some false positives)

Example 3

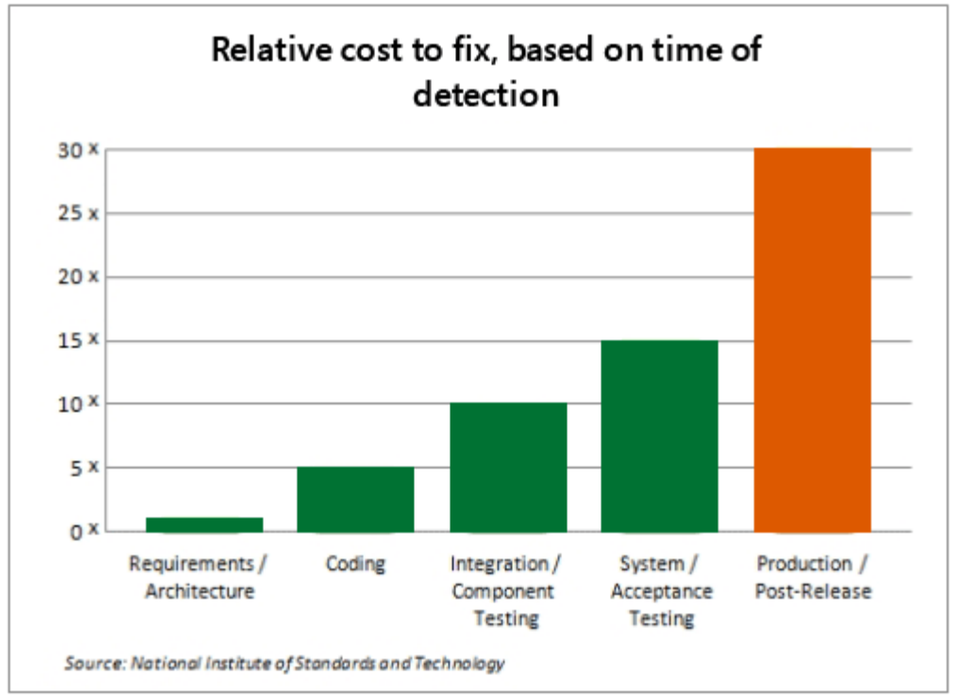
```
private A getNewHandler() {
    A a = null;                          nullVariables = {a}
    try {
a1:     a = new A();                     nullVariables = {}
    } catch (Exception e) {
        e.printStackTrace();             nullVariables = {a}
    }
    return a.getHandler();               nullVariables = {a}      points-to{a} = {a1, null}
}
```

Null pointer dereference
Can be detected with nullness analysis
Or points-to information

Static analysis in practice

- What is it used for?
  - Compilers (optimization, type checking, etc.)
  - Bug and vulnerability finding
  - Formal verification
- For bug finding
  - Increase in companies‘ use of the tools
    - Find bugs earlier in the software development lifecycle
    - Run on nightly builds
    - Relatively fast
    - Less expensive than manual audits
  - HP Forfify, IBM Appscan, FindBugs…

https://en.wikipedia.org/wiki/List_of_tools_for_static_code_analysis



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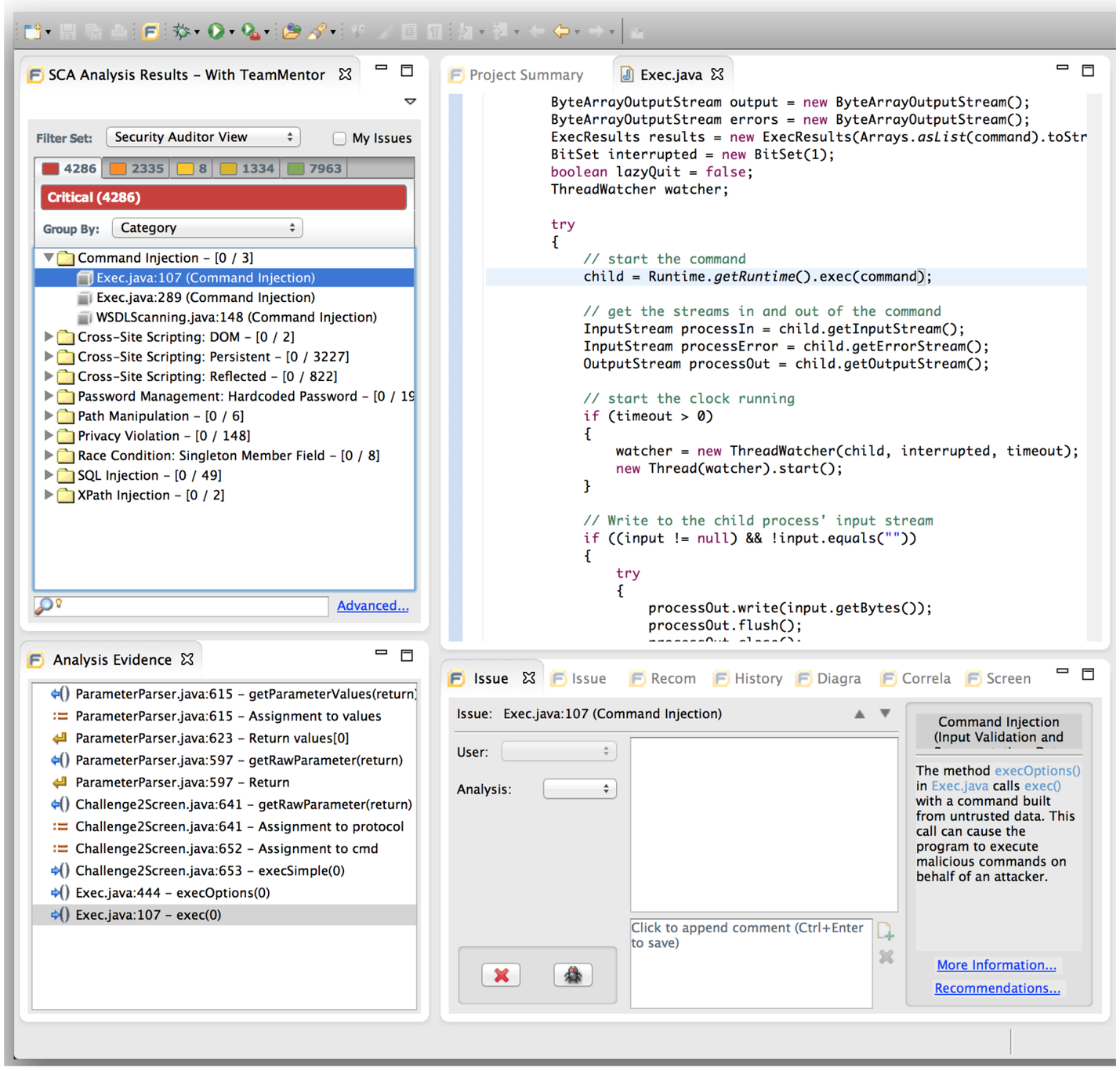
Static analysis in practice

- Developer feedback:
  - Takes hours to run
  - Has false positives and false negatives
  - Warnings are hard to understand and to fix
  - Developers are not trained enough to configure and use the tool to its full potential



https://www.securityinnovation.com/training/application-security/knowledgebase/team-mentor-plugins.html

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Static analysis in practice

- Developer feedback:
  - Takes hours to run
    - Tradeoff between precision and performance. Good results take time to compute.
  - Has false positives and false negatives
    - Achieving perfect soundness and completeness is not possible, although many efforts are made to improve this
  - Warnings are hard to understand and to fix
  - Developers are not trained enough to configure and use the tool to its full potential

Just-in-Time analysis

- Design an analysis that ensures:
  - Responsiveness
  - Precision
  - Fix easiness

- Demo

References and further reading

- IT Security Engineering, Prof. Philippe Janson, EPF Lausanne, 2012
- Designing Code Analyses for Large Software Systems, Prof. Eric Bodden, TU Darmstadt, 2015
- Mobile Application Security Through Static and Dynamic Analysis, Nguyen Quang Do, 2014
- DART: Demand-drive Flow, Field and Context-sensitive Points-to Analysis, Späth et al., 2015
- FlowDroid: Precise Context, Flow, Field, Object-sensitive and Lifecycle-aware Taint Analysis for Android Apps, Arzt et al.
- Toward a Just-in-Time Static Analysis, Nguyen Quang Do et al., 2015
- Data Flow Analysis: Theory and practice (Khedker et al.)
- Principles of Program Analysis (Flemming et al.)
- Precise Interprocedural Dataflow Analysis via Graph Reachability, Reps et al., 1995
- https://www.owasp.org/index.php/Static_Code_Analysis