

Security Testing

Checking for what shouldn't happen

Azqa Nadeem

PhD Student @ Cyber Security Group

Agenda for today

- Part I
 - Latest security news
 - Security vulnerabilities in Java
 - Types of Security testing
 - SAST vs. DAST
- Part II
 - SAST under the hood
 - Pattern Matching
 - Control Flow Analysis
 - Data Flow Analysis
 - SAST Tools performance

Announcements

- Assignment 2 – Security module
- Exam questions

Agenda for today

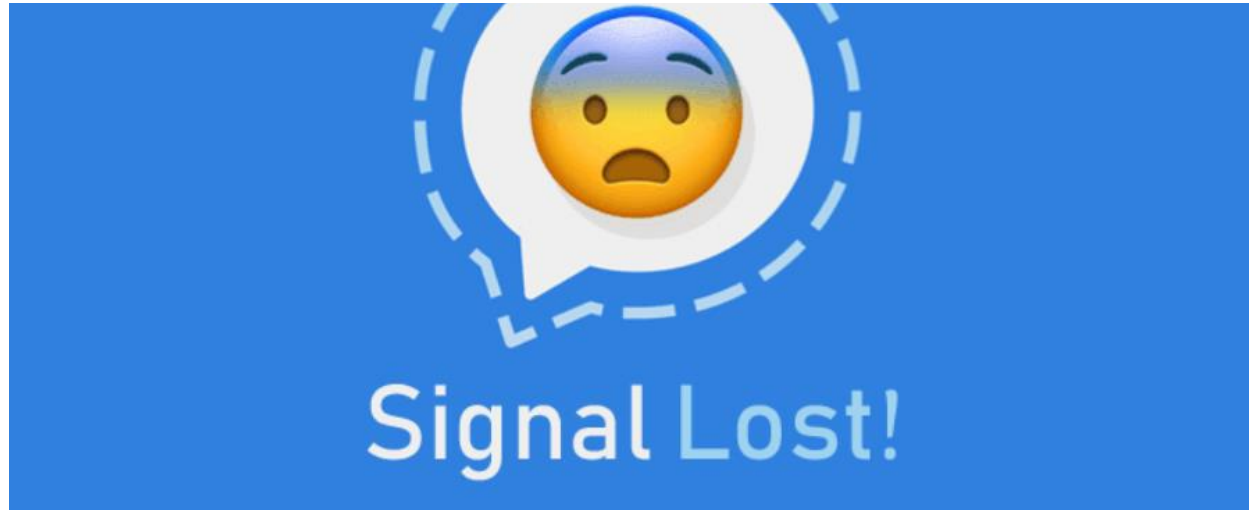
- **Part I**
 - Latest security news
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 - Control Flow Analysis
 - Data Flow Analysis
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Software testing
vs.
Security testing

Impact – Stolen chats

Another severe flaw in Signal desktop app lets hackers steal your chats in plaintext

📅 May 16, 2018 👤 Swati Khandelwal



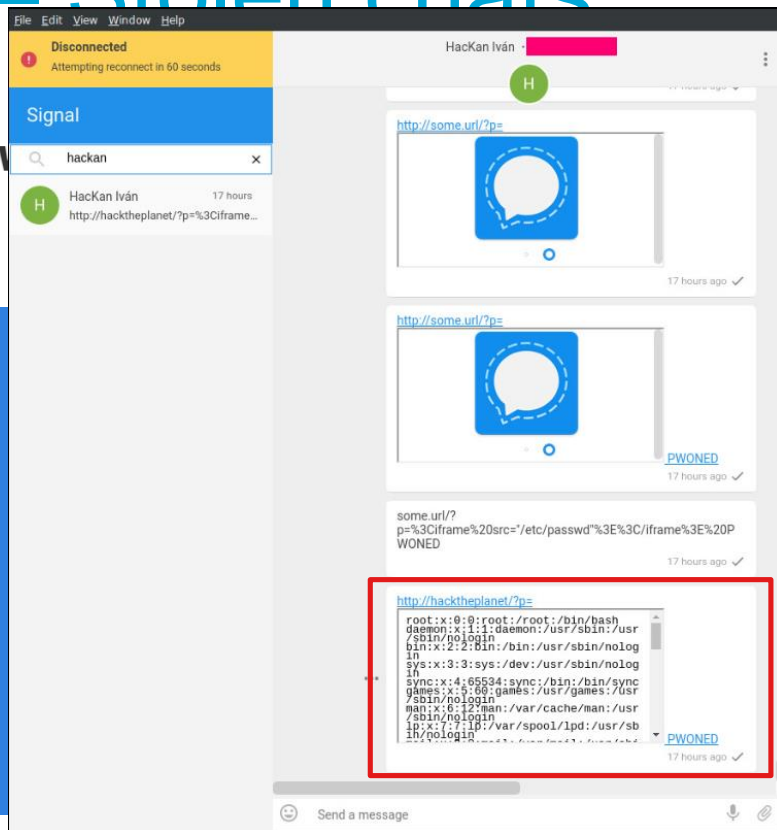
<https://ivan.barreraoro.com.ar/signal-desktop-html-tag-injection/>

Impact – Stolen chats

**Another severe flaw
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May 16, 2018 Swati Khandelwal

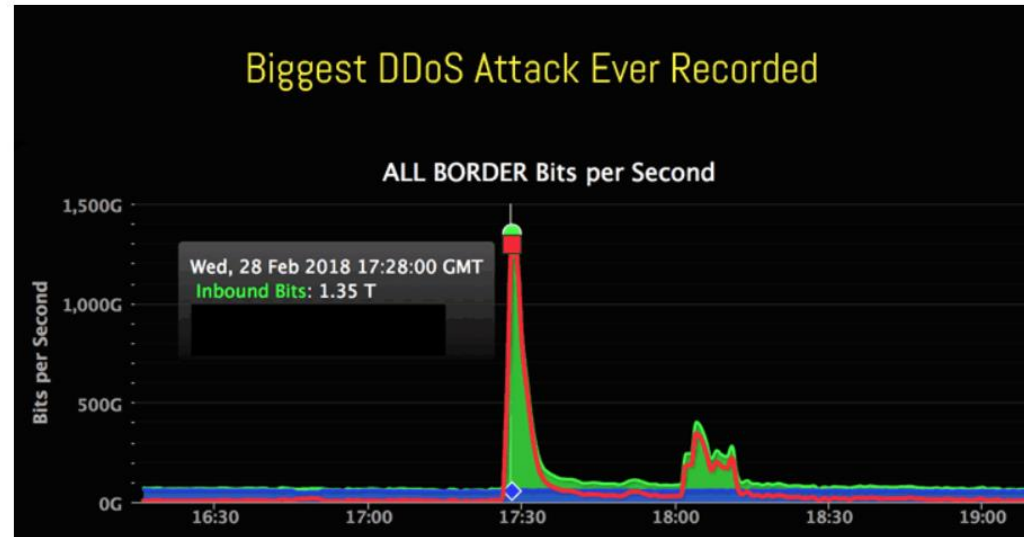
Read your chats



Impact – Github down

Biggest-Ever DDoS Attack (1.35 Tbs) Hits Github Website

March 02, 2018 Mohit Kumar



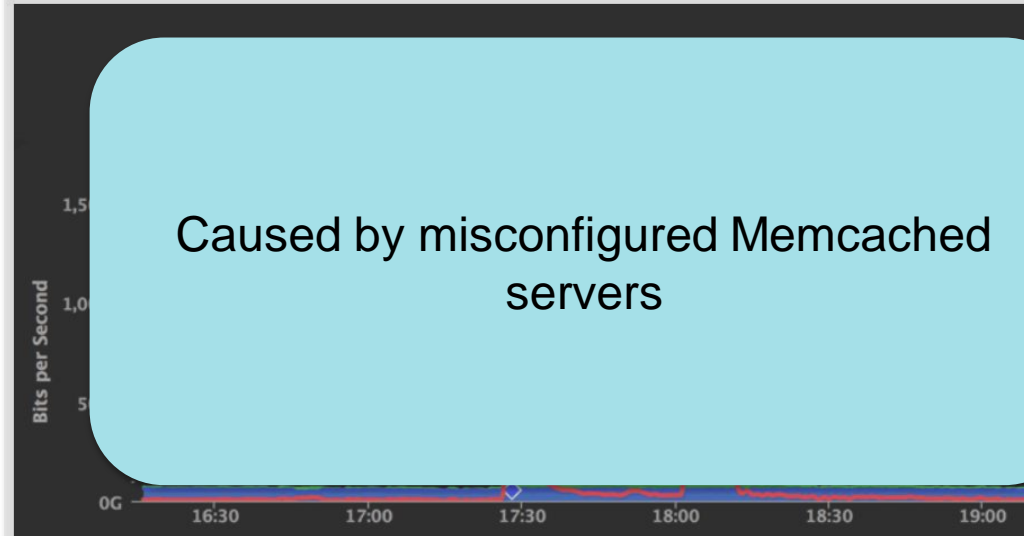
On Wednesday, February 28, 2018, GitHub's code hosting website hit with the largest-ever distributed denial of service (DDoS) attack that peaked at record 1.35 Tbps.

<https://thehackernews.com/2018/03/biggest-ddos-attack-github.html>

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Is Java Secure?

- Secure from memory corruption
- ... but not completely
- Potential targets
 - Java Virtual Machine
 - Libraries in native code



15 billion
devices run Java

Vulnerability databases

- OWASP Top Ten project
 - Awareness document
 - Web application security

OWASP Top 10 Application Security Risks - 2017

[A1:2017-Injection](#)

Injection flaws, such as SQL, NoSQL, OS, and LDAP injection, occur when untrusted data is sent to an interpretation or execution engine without proper authorization.

[A2:2017-Broken Authentication](#)

Application functions related to authentication and session management are often implemented incorrectly, leading to temporary or permanent compromise.

[A3:2017-Sensitive Data Exposure](#)

Many web applications and APIs do not properly protect sensitive data, such as financial information, PII, or other confidential information, without extra protection, such as encryption at rest or in transit, and redaction.

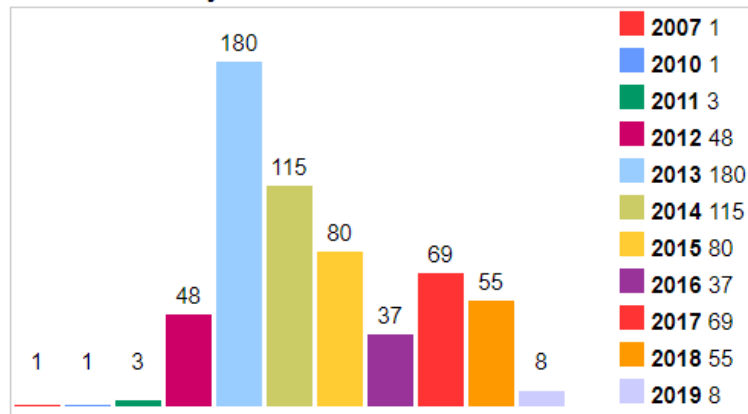
- NIST National Vulnerability Database
 - U.S govt. repository
 - General security flaws

Name

CVE-2019-9624	Webmin 1.900 allows remote attackers to execute arbitrary code via a crafted HTTP request.
CVE-2019-5312	An issue was discovered in weixin-java-tools v3.3.0. The application allows an attacker to bypass authentication and execute arbitrary code.
CVE-2019-3801	Cloud Foundry cf-deployment, versions prior to 7.9.0, contain a dependency, and inject malicious code into the component.
CVE-2019-2699	Vulnerability in the Java SE component of Oracle Java SE allows an attacker to access Java SE via multiple protocols to compromise Java SE. While the vulnerability applies to Java deployments, typically in client environments, the attack can be used to compromise Java SE and Availability impacts). CVSS Vector: (CVSS:3.0/AV:N/AC:L/AT:P/AU:N/C:N/I:N/H:N).
CVE-2019-2698	Vulnerability in the Java SE component of Oracle Java SE allows an attacker to access Java SE via multiple protocols to compromise Java SE. Successful attacks may allow an attacker to execute arbitrary code or access sensitive information in Java SE applications or sandboxed Java applets (in Java SE 8 and earlier versions, typically in servers, that load and run only in the Java sandbox). CVSS Vector: (CVSS:3.0/AV:N/AC:H/PR:N/UI:N/S:U/C:H/I:H/A:H).

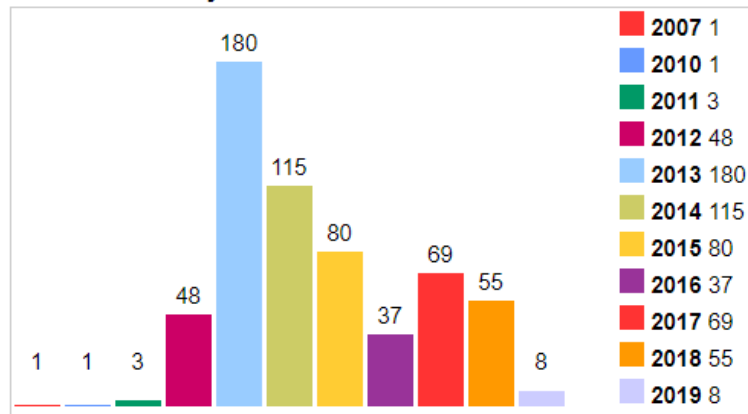
JRE vulnerabilities

Vulnerabilities By Year

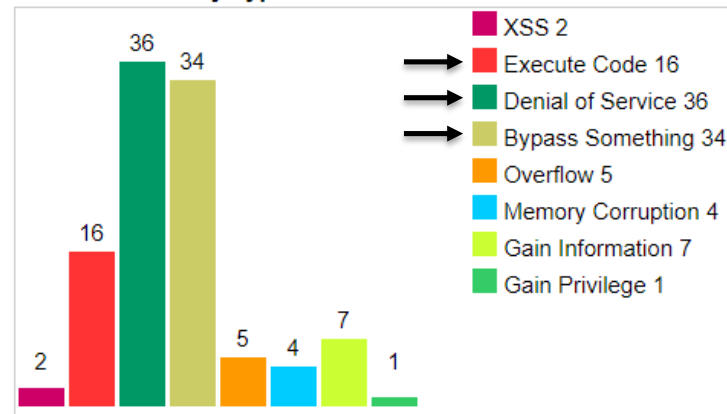


JRE vulnerabilities

Vulnerabilities By Year



Vulnerabilities By Type



Some Examples

What's wrong?

```
Socket socket = null;
BufferedReader readerBuffered = null;
InputStreamReader readerInputStream = null;

/* Read data using an outbound tcp connection */
socket = new Socket("host.example.org", 39544);

/* read input from socket */
readerInputStream = new InputStreamReader(socket.getInputStream(), "UTF-8");
readerBuffered = new BufferedReader(readerInputStream);

/* Read data using an outbound tcp connection */
String data = readerBuffered.readLine();

Class<?> tempClass = Class.forName(data); ←
Object tempClassObject = tempClass.newInstance();

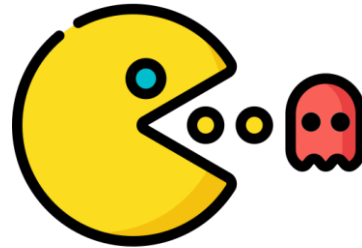
IO.writeLine(tempClassObject.toString()); /* Use tempClassObject in some way */
```

Code Injection vulnerability

- Execute code in unauthorized applications
- Victim to Update Attack

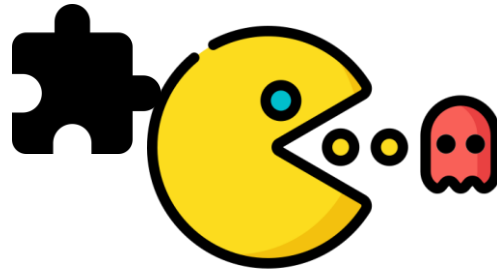
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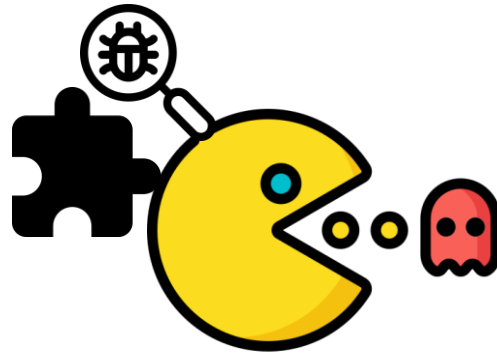
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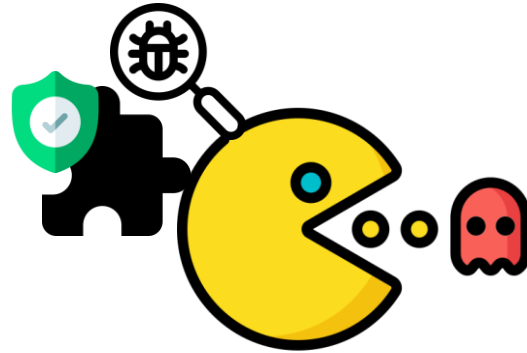
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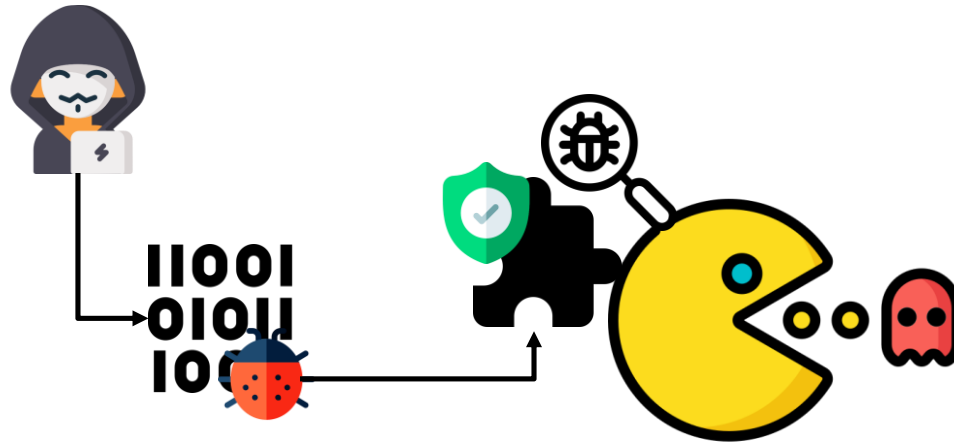
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Code Injection vulnerability

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- Top vulnerability in OWASP Top 10

Code Injection vulnerability

- Execute code in unauthorized applications
- Victim to Update Attack
- Top vulnerability in OWASP Top 10
- Tricky to fix
 - Stop adding plugins
 - Limit privileges

Type confusion vulnerability

WHEN JAVA THROWS YOU A LEMON, MAKE LIMENADE: SANDBOX ESCAPE BY TYPE CONFUSION

April 25, 2018 | Vincent Lee

Last week, Oracle released their quarterly [Critical Patch Update \(CPU\)](#). Seven of these bugs were submitted through the Zero Day Initiative (ZDI) program, and one of these bugs was quite reminiscent of the Java submissions in late 2012 and early 2013. The bug, [CVE-2018-2826 \(ZDI-18-307\)](#), is a sandbox escape vulnerability due to insufficient type checking discovered by XOR19. An attacker with low execution privileges may exploit this vulnerability to bypass the SecurityManager and escalate privileges.

Type confusion vulnerability

```
class Cast1 extends Throwable{
    Object Lemon;
}

class Cast2 extends Throwable{
    Lime lime;
}

public static void handleEx(Cast2 e) {
    e.lime.makeLimenade();
}
```

Last week... bugs
were subn... was
quite remi... 2018-
2826 (ZDI... ng
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Bypassing Java Security Manager

- Exploit Type confusion vulnerability



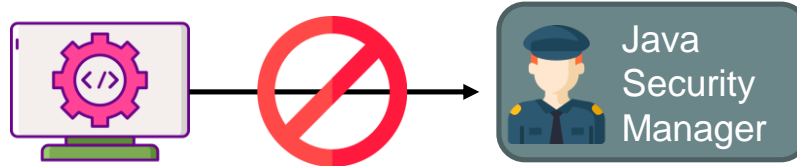
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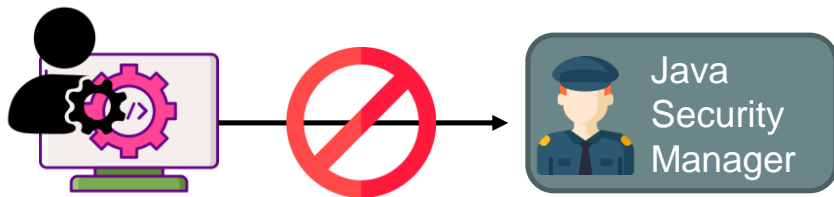
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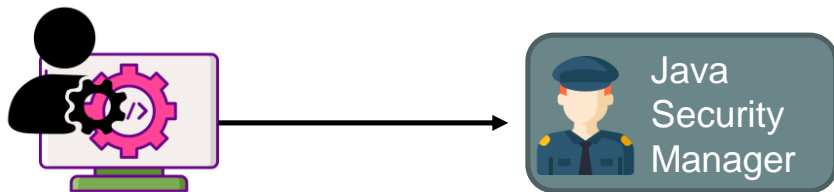
Bypassing Java Security Manager

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- Escalated privileges



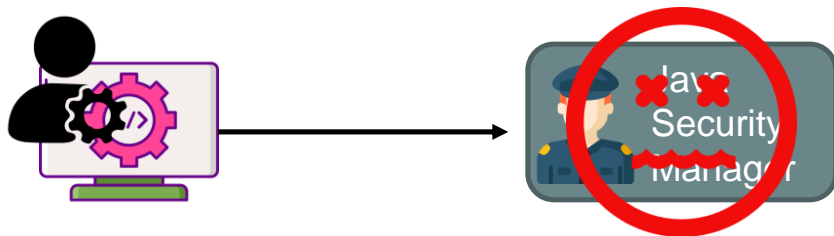
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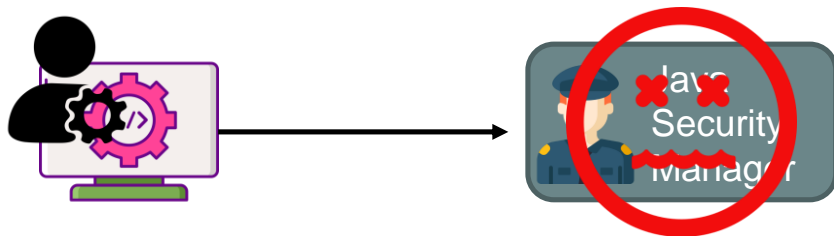
Bypassing Java Security Manager

- Exploit Type confusion vulnerability
- Escalated privileges
 - Set JSM to null



Bypassing Java Security Manager

- Vulnerable: Hibernate → Reflection helper
- Exploit Type confusion vulnerability
- Escalated privileges
 - Set JSM to null



Arbitrary Code Execution (ACE)

- Vulnerable: XStream → Converts XML to Object
- Deserialization vulnerability



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 - Via malicious input XML



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Remote Code Execution (RCE)



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Remote Code Execution (RCE)

- Spring Data Commons → DB connections
- Property binder vulnerability
 - Via specially crafted request parameters



Oracle April 2018 CPU: Most Java flaws can be remotely exploited

By News | April 18, 2018 | Alerts

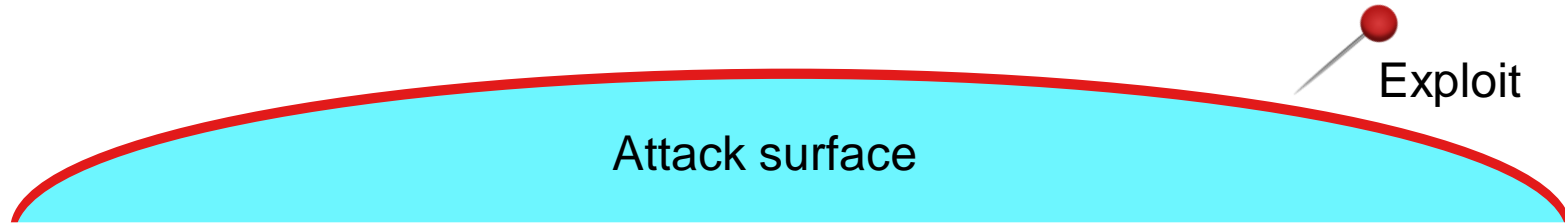
Half of the Java patches relate to Deserialization Flaws.

Customer Alert 20180418

Oracle Critical Patch Update April 2018 Released

<https://www.waratek.com/alert-oracle-guidance-cpu-april-2018/>

Why test for security?



- Security testing → Non-functional testing
- *Who's job is to test for security?*

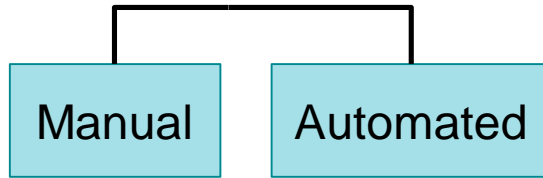


When to test for security?



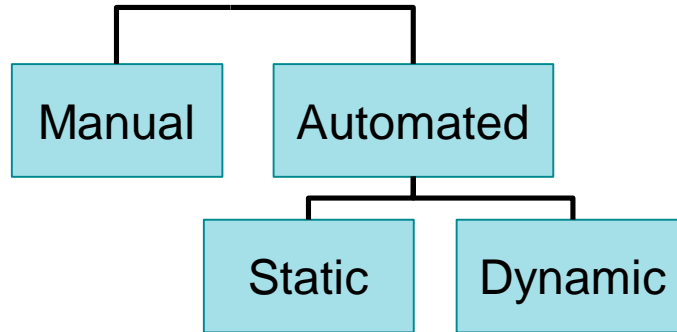
Classes of Security Testing

- Manual vs. Automated Testing



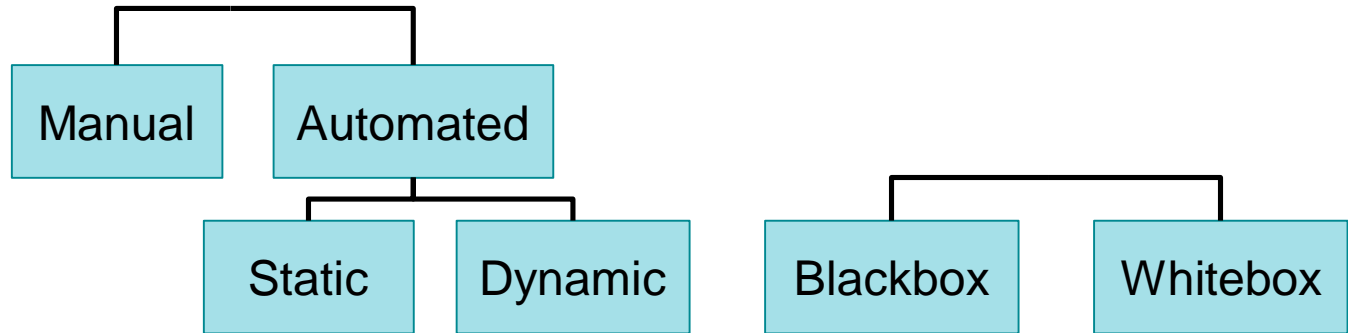
Classes of Security Testing

- Manual vs. Automated Testing
- Static vs. Dynamic Testing



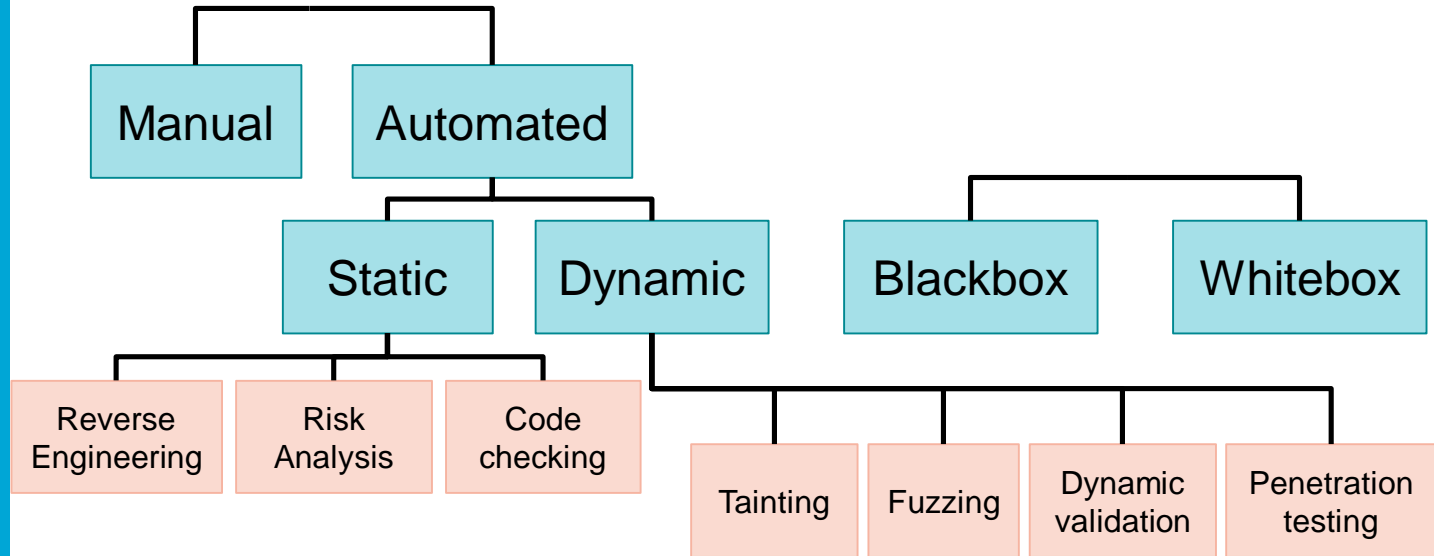
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- Manual vs. Automated Testing
- Static vs. Dynamic Testing
- Black vs. White box Testing



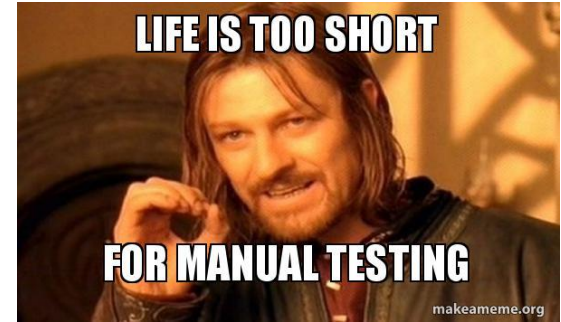
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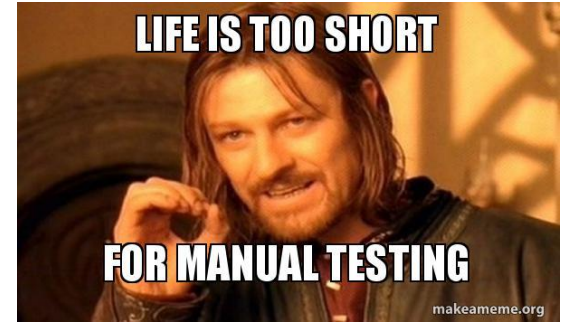
Manual vs. Automated Testing

- Manual
 - Code reviews
 - Efficient use of human expertise
 - Labour intensive



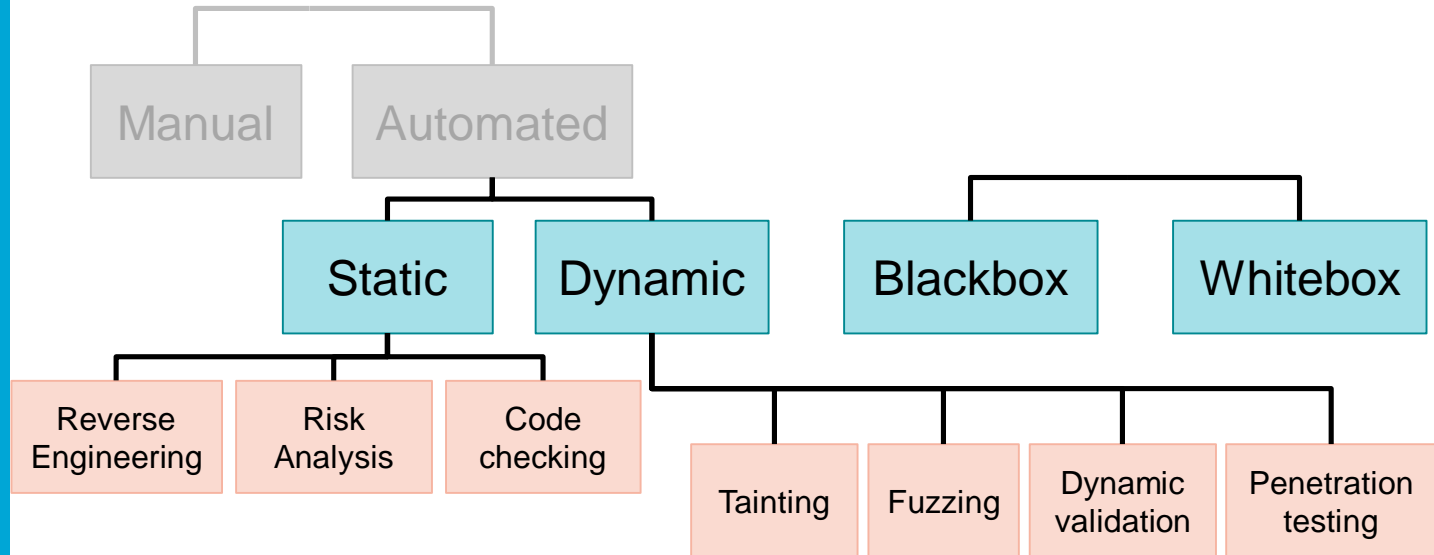
Manual vs. Automated Testing

- Manual
 - Code reviews
 - Efficient use of human expertise
 - Labour intensive
- Automated
 - Automated code checking
 - Can check MLOC in seconds
 - Incomparable to human expertise



Classes of Security Testing

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Static vs. Dynamic Testing

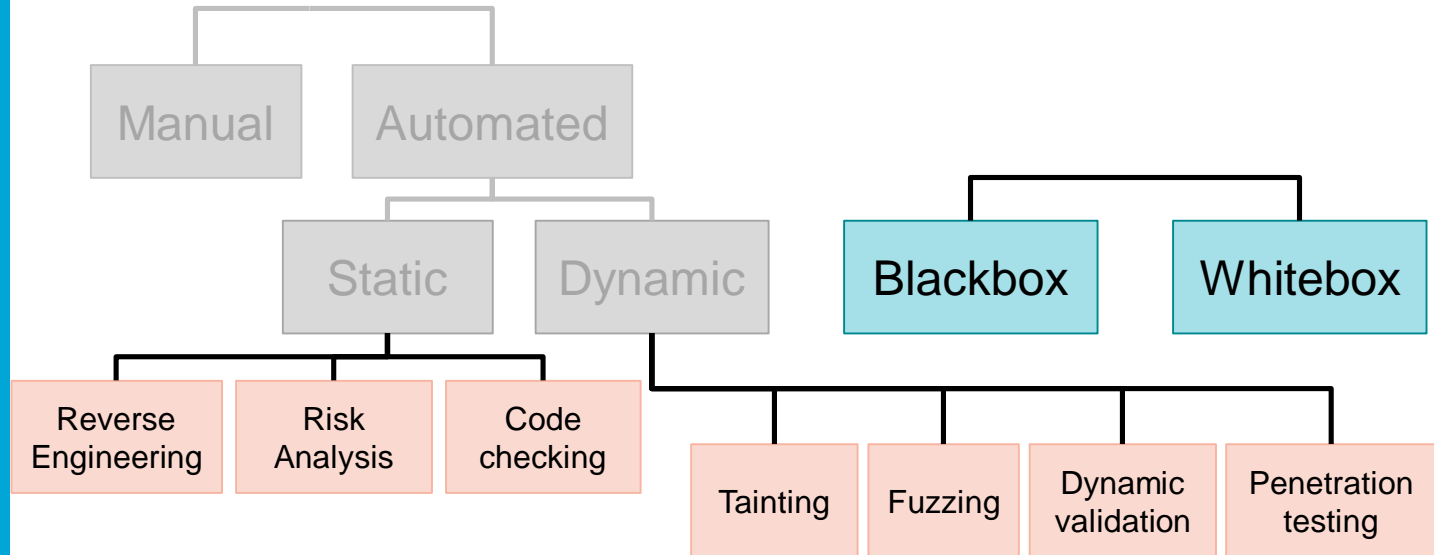
- (Automated) Static analysis
 - Code review by computers
 - Checks all possible code paths
 - Relatively easy to extract results
 - Limited capabilities

Static vs. Dynamic Testing

- (Automated) Static analysis
 - Code review by computers
 - Checks all possible code paths
 - Relatively easy to extract results
 - Limited capabilities
- Dynamic analysis
 - Execute code and observe behaviour
 - Checks functional code paths only
 - Much advanced analysis
 - Difficult to set up

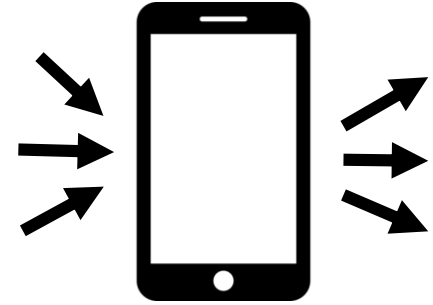
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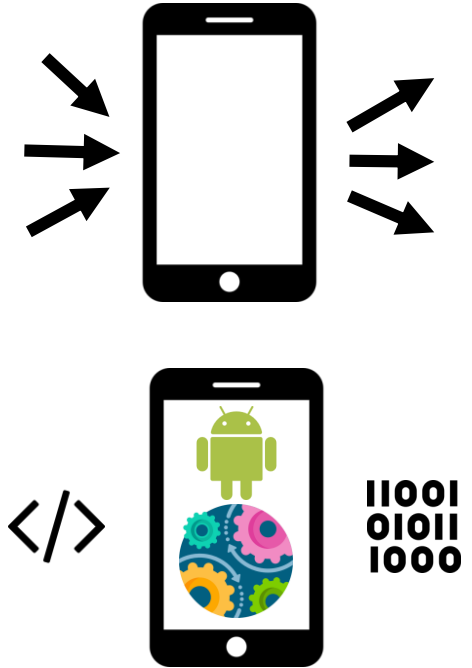
Black vs. White box Testing

- Black box
 - Unknown internal structure
 - Study Input → Output correlation
 - Generic technique
 - Requires end-to-end system
 - May miss components



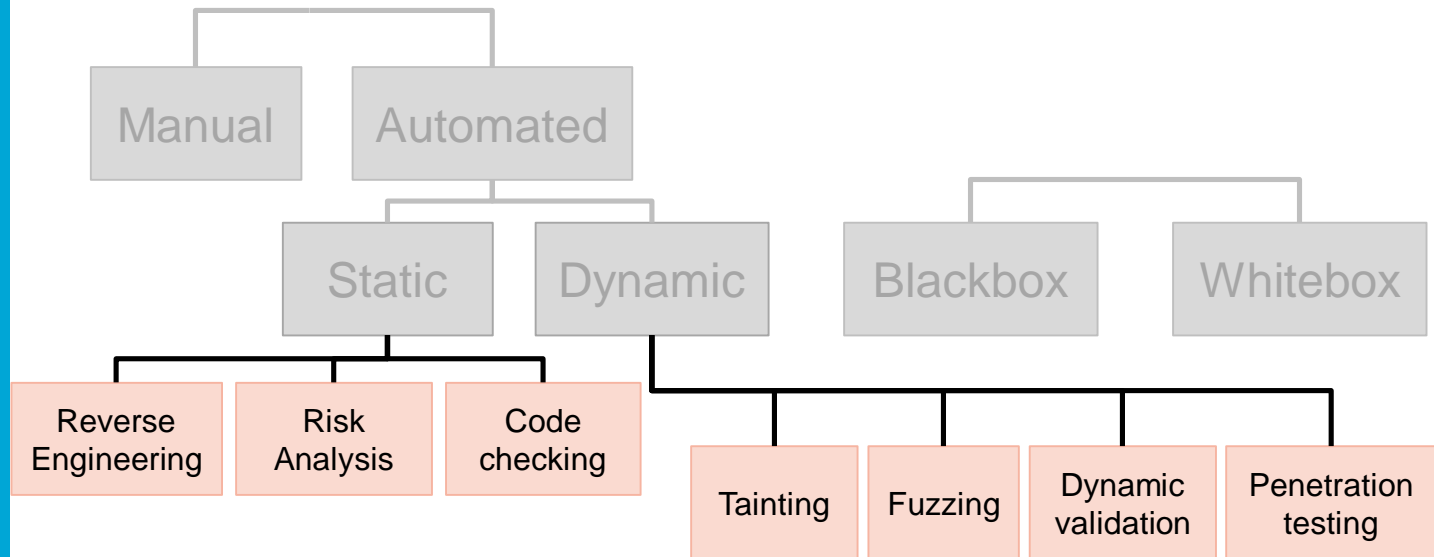
Black vs. White box Testing

- Black box
 - Unknown internal structure
 - Study Input → Output correlation
 - Generic technique
 - Requires end-to-end system
 - May miss components
- White box
 - Known internal structure
 - Analysis of internal structure
 - GUI not necessarily required
 - Thorough testing and debugging
 - Time consuming



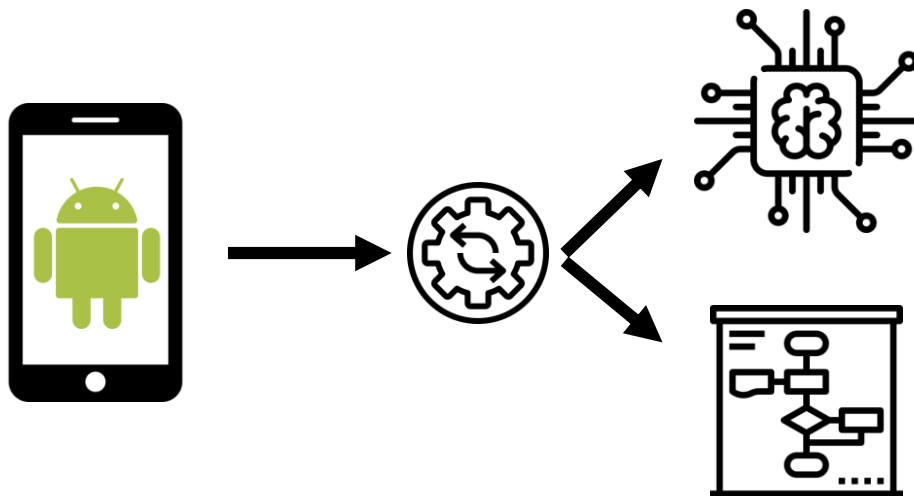
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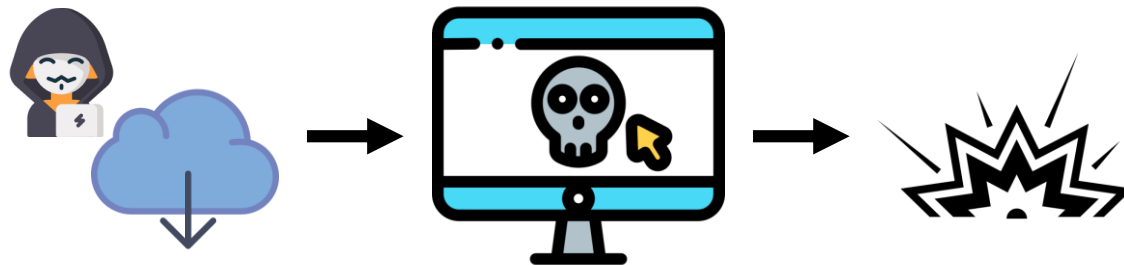
Static Application Security Testing

- Reverse engineering (System level)
 - Disassemble application to extract internal structure
 - Black box to White box
 - Useful for gaining information



Static Application Security Testing

- Reverse engineering (System level)
- Risk-based testing (Business level)
 - Model worst case scenarios
 - Threat modelling for test case generation



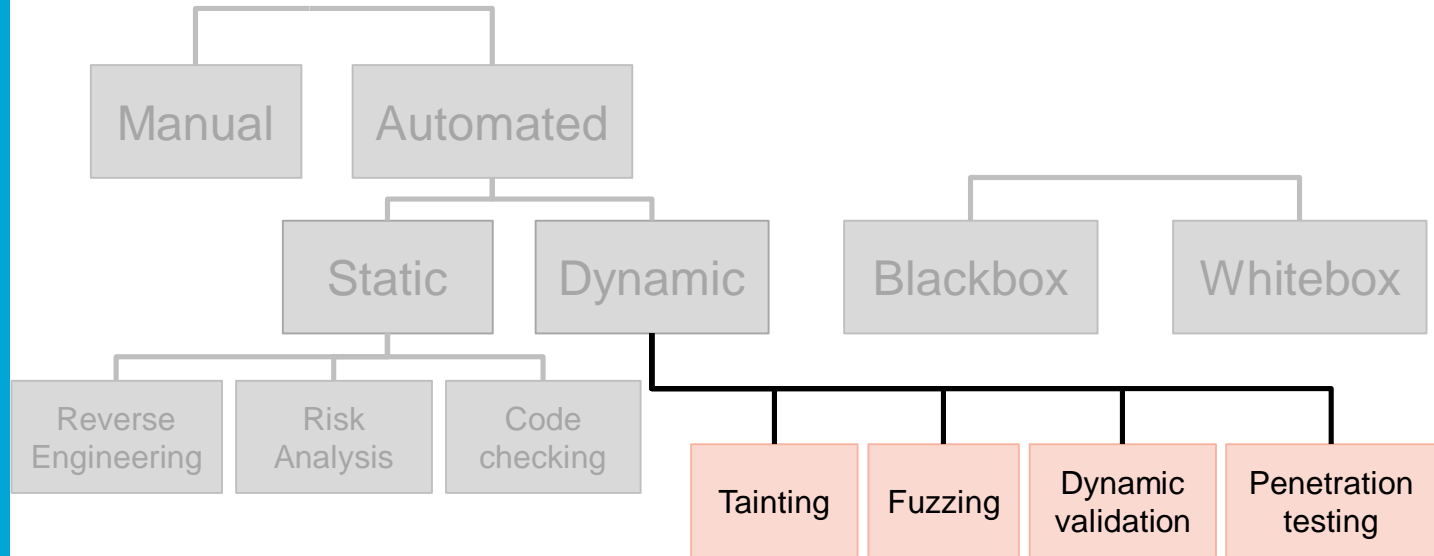
Static Application Security Testing

- Reverse engineering (System level)
- Risk-based testing (Business level)
- Static code checker (Unit level)
 - Checks for rule violations via code structure
 - Parsers, Control Flow graphs, Data flow analysis
 - Identifies bad coding practices, potential security issues, etc.



Classes of Security Testing

- Manual vs. Automated Testing
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Dynamic Application Security Testing

- Taint analysis
 - Tracking variable values controlled by user
- Fuzzing
 - Bombard with garbage data to cause crashes
- Dynamic validation
 - Functional testing based on requirements
- Penetration testing
 - End-to-end black box testing

Topic for next lecture

Summary Part I

- Java vulnerabilities have large attack surfaces
- Crucial to adapt Secure SDLC
- Threat modelling can drive test case generation
- Static analysis checks code without executing it
- Dynamic analysis executes code and observes behavior

Quiz Time!

Which type of testing aims to convert a black box system to white box?

Reverse Engineering

Quiz Time!

Which vulnerability allows a remote attacker to change which instruction will be executed next?

Remote Code Execution

Quiz Time!

Why is Java safe from buffer overflows?

It's not!

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- **Part II**
 - **SAST under the hood**
 - **Pattern Matching**
 - **Control Flow Analysis**
 - **Data Flow Analysis**
 - **SAST Tools performance**

Why doesn't the perfect static analysis tool exist?

Static Analysis

- Soundness
- Completeness

Static Analysis

- Soundness
 - No missed vulnerability (0 FNs)
 - No alarm \rightarrow no vulnerability exists
- Completeness



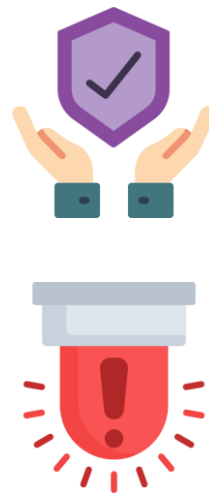
Static Analysis

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 - No false alarms (0 FPs)
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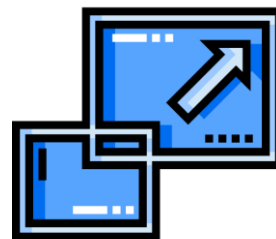
Static Analysis

- Soundness
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- Ideally: \uparrow Soundness + \uparrow Completeness
- Reality: Compromise on FPs or FNs

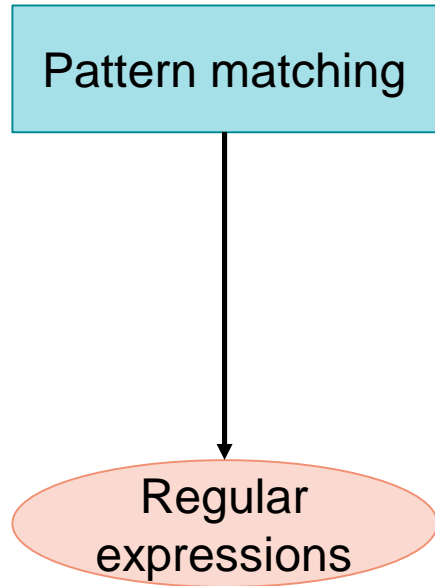


Usable SAST Tools

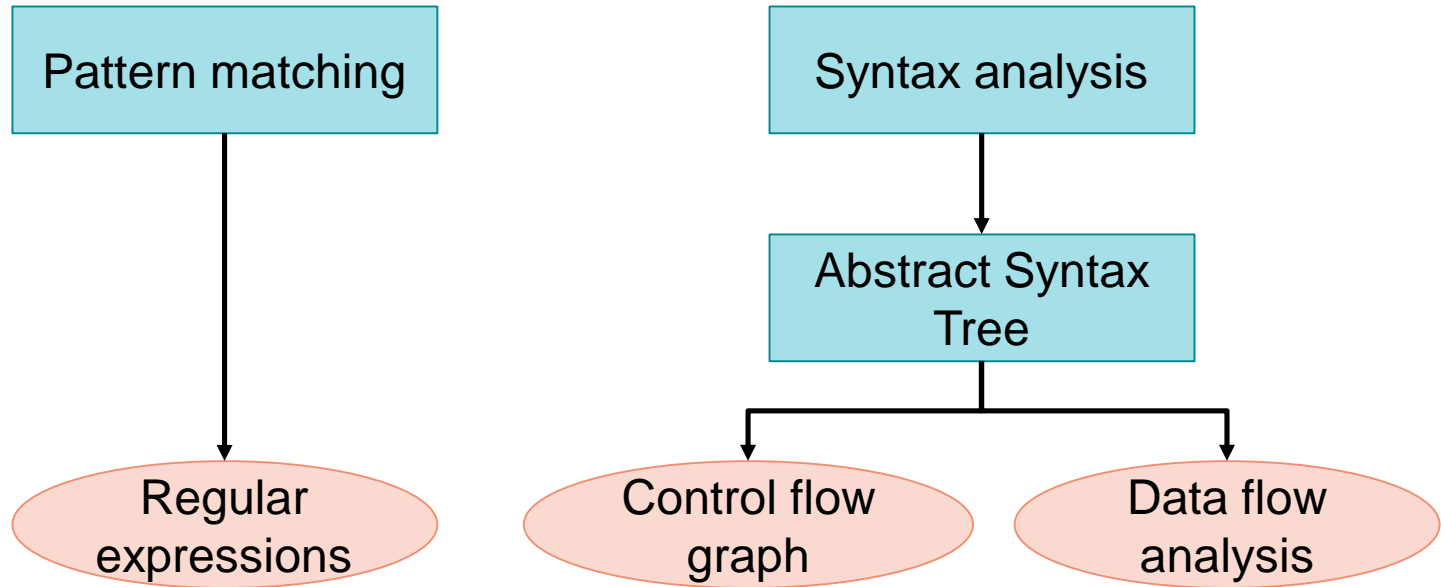
- ↓ FPs vs. ↓ FNs
- ↑ Interpretability
- ↑ Scalability



SAST under the hood



SAST under the hood

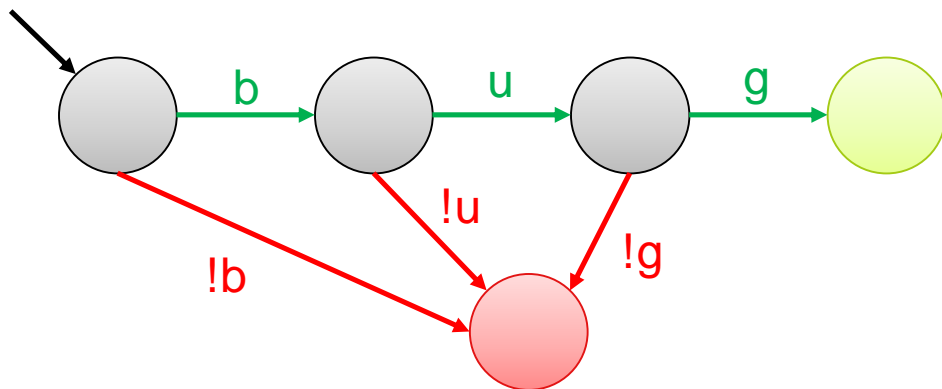


Pattern Matching

- Look for predefined patterns in code
 - Regular Expressions
 - Finite State Automata

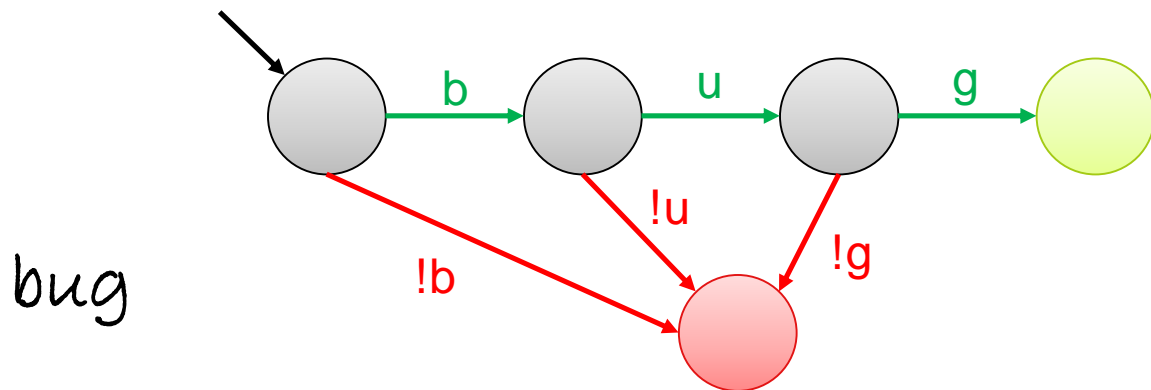
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- Look for predefined patterns in code
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- *Find all instances of “bug”*



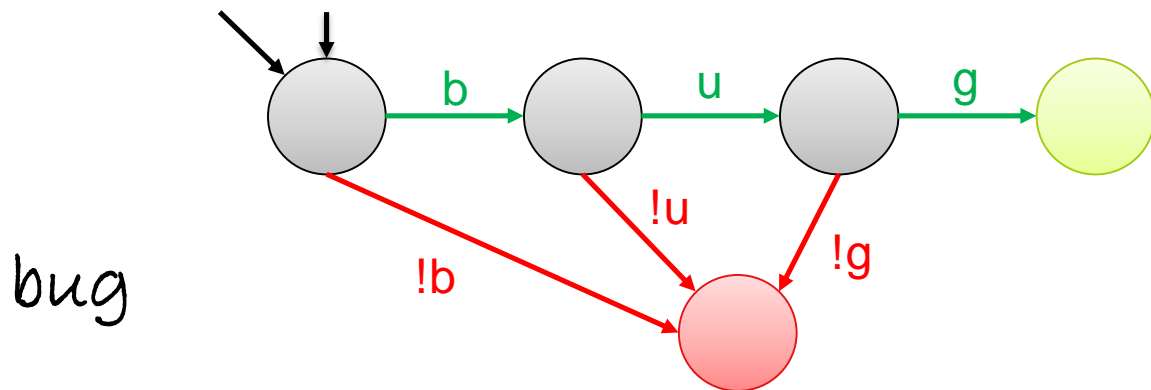
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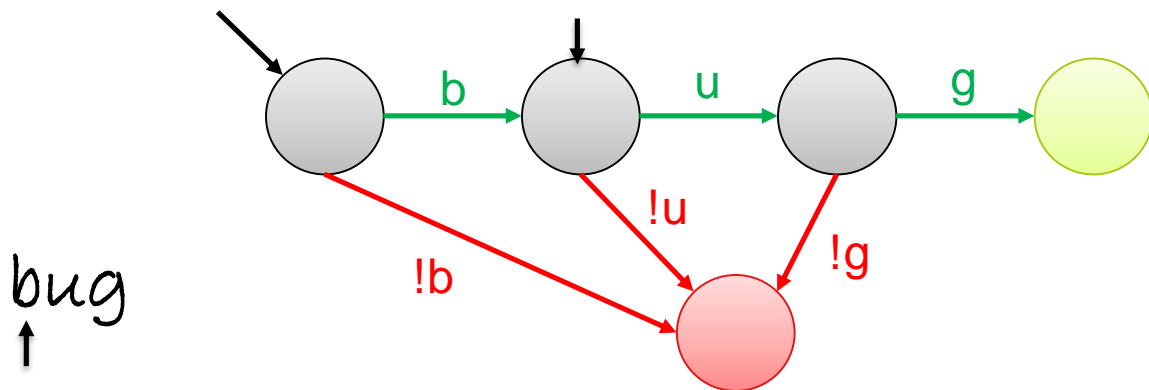
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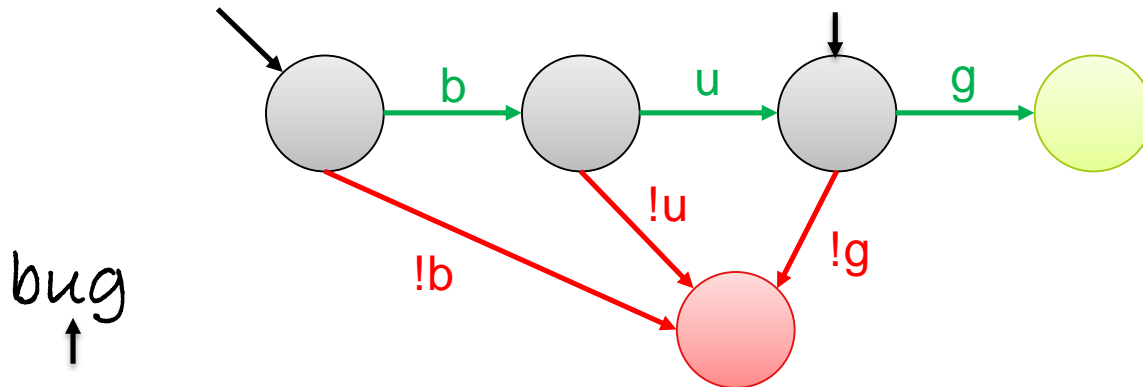
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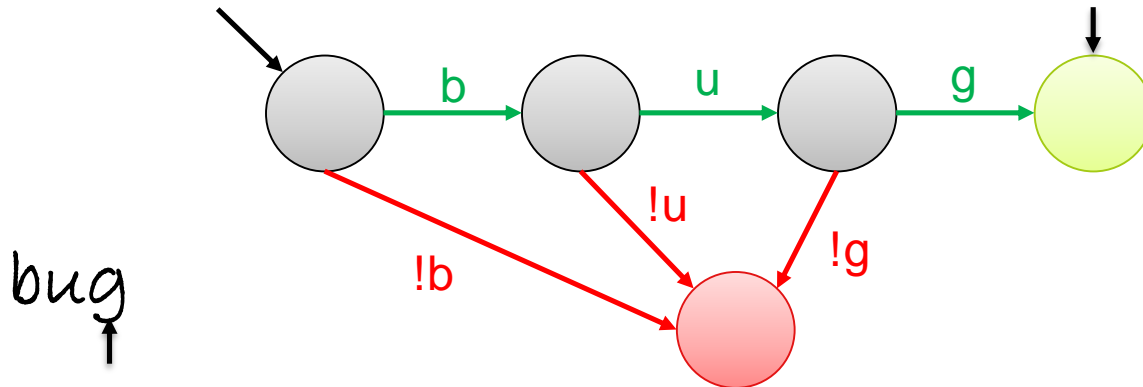
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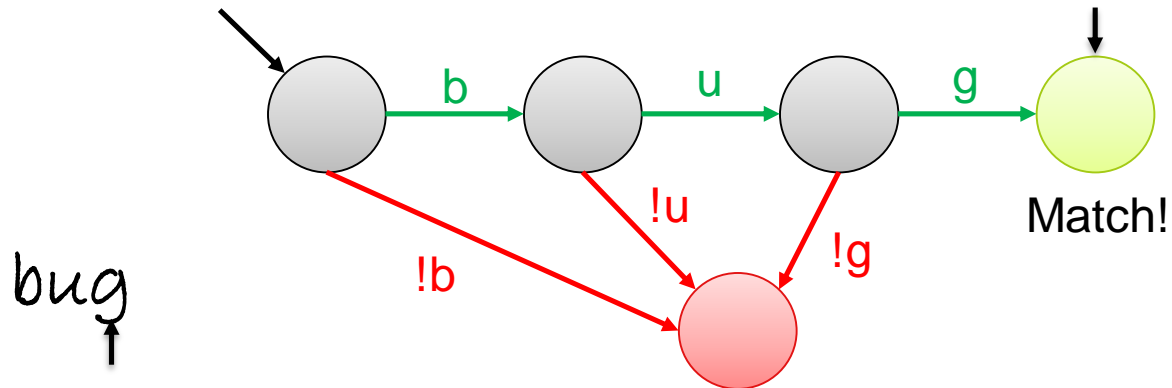
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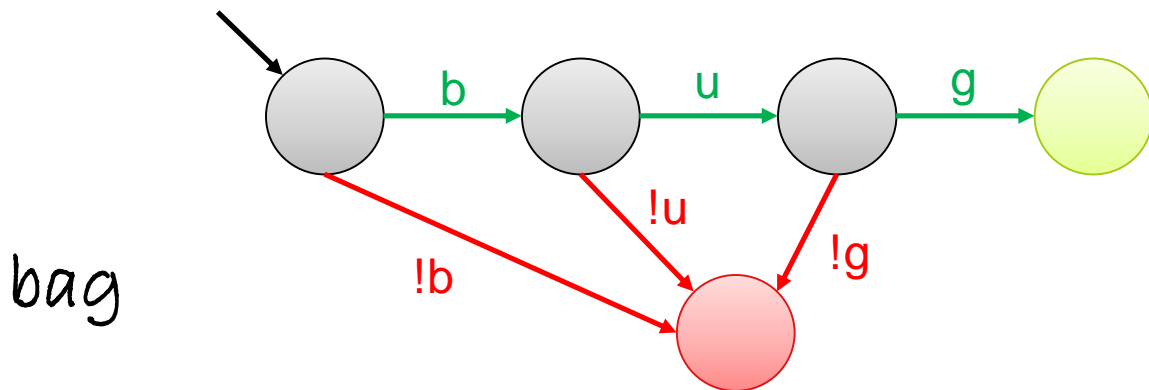
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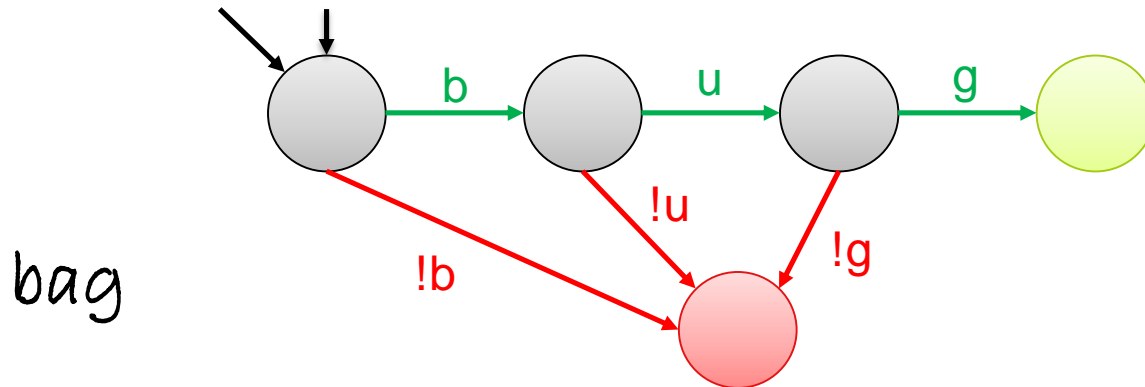
Pattern Matching via Regex

- Look for predefined patterns in code
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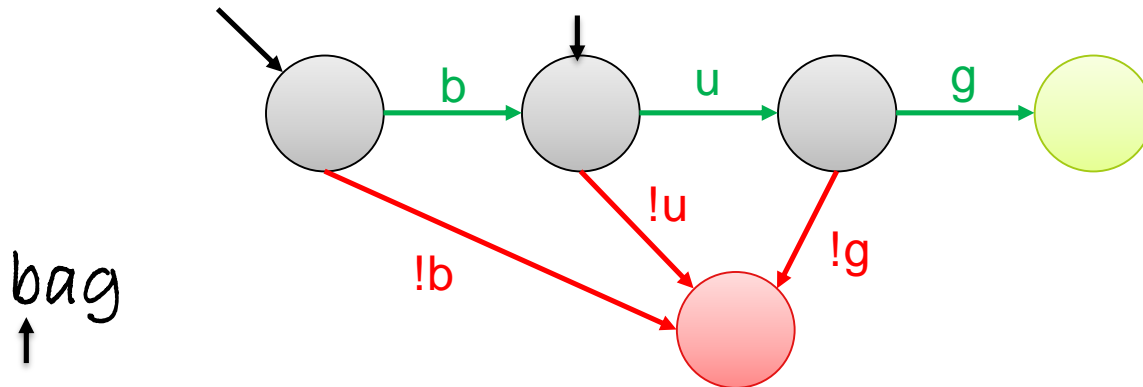
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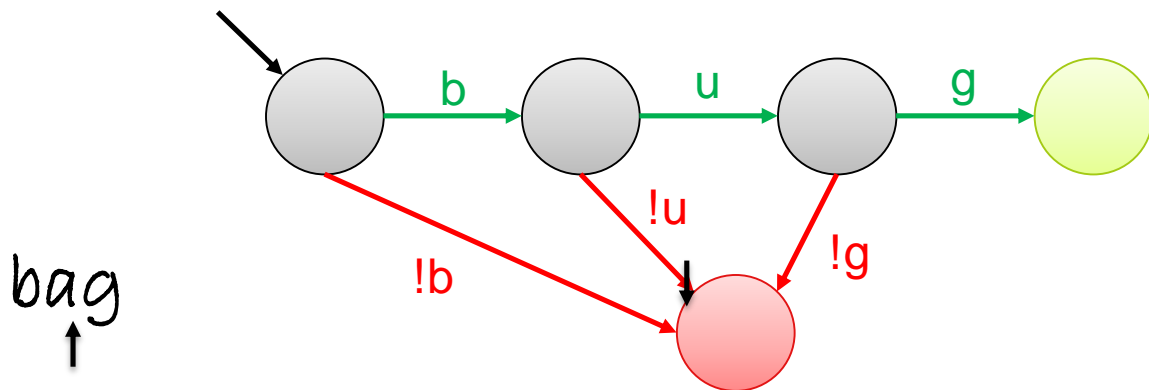
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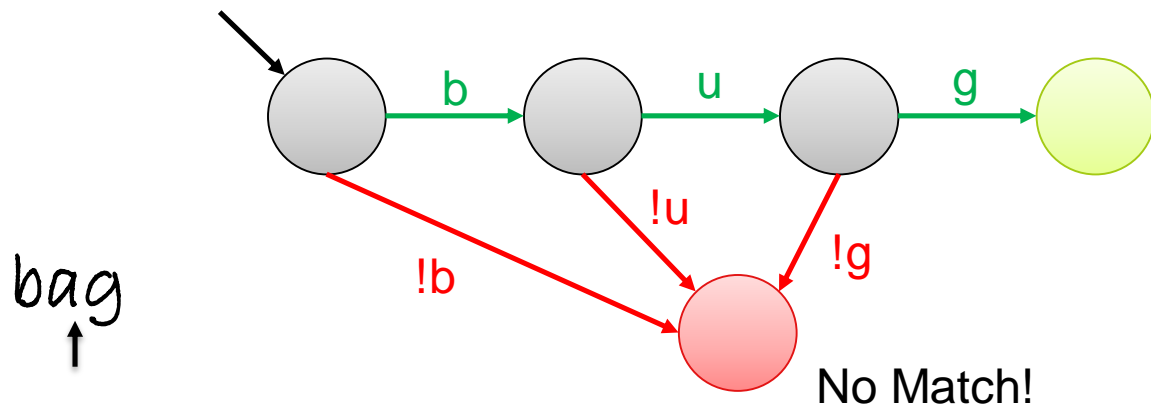
Pattern Matching via Regex

- Look for predefined patterns in code
 - Regular Expressions
 - Finite State Automata
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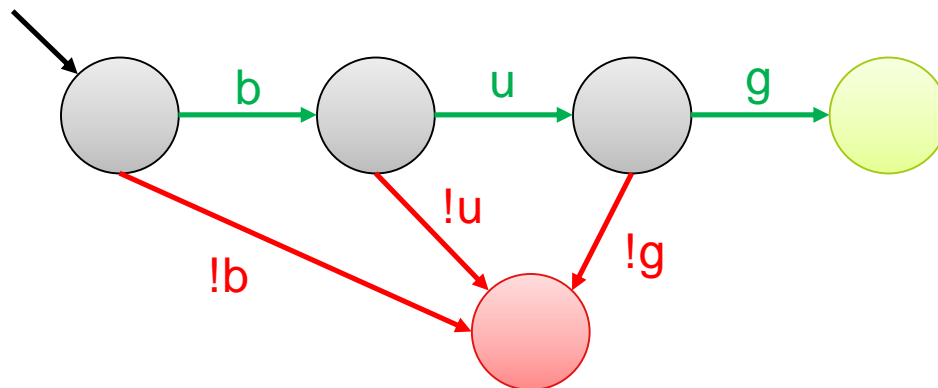
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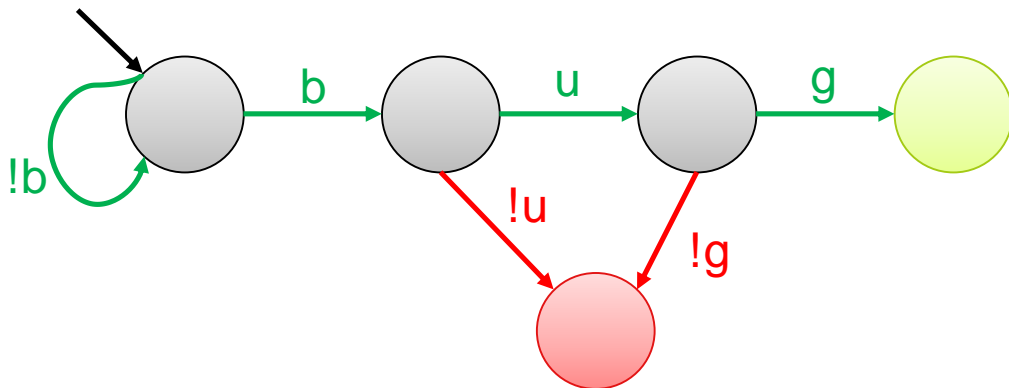
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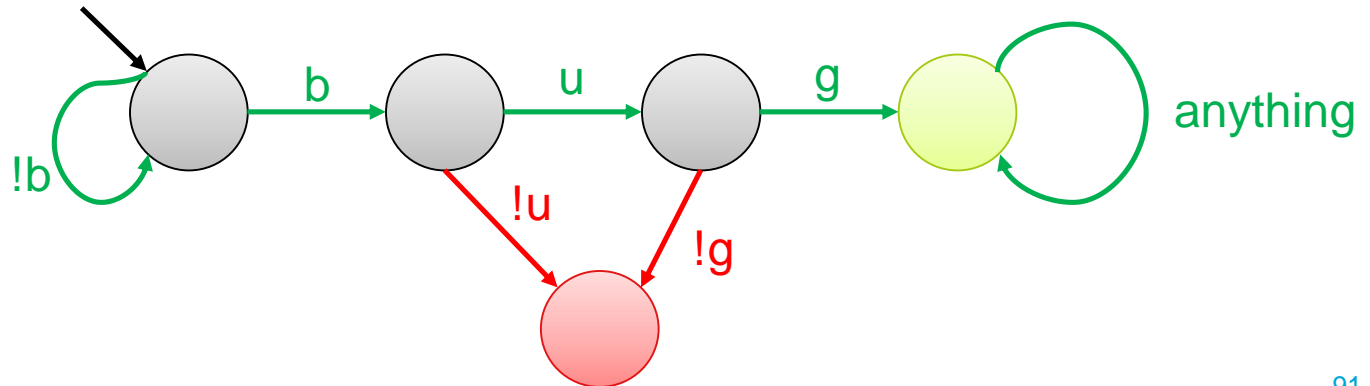
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Pattern Matching via Regex

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Pattern Matching via Regex

- Finds low hanging fruit
 - Misconfigurations (port 22 open for everyone)
 - Bad imports (System.io.*)
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```

Syntactic Analysis

- Performed via Parsers



- Tokens → Hierarchical data structures
 - Parse Tree – Concrete representation
 - Abstract Syntax Tree – Abstract representation

Abstract Syntax Tree (AST)

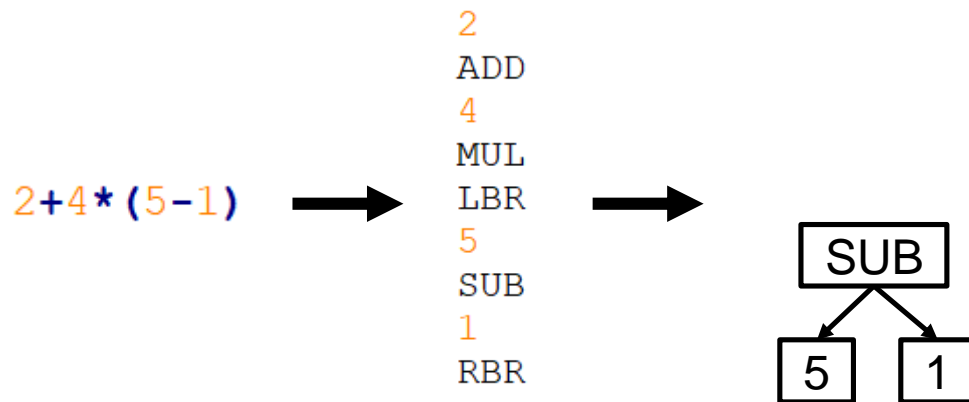
2+4*(5-1)

Abstract Syntax Tree (AST)

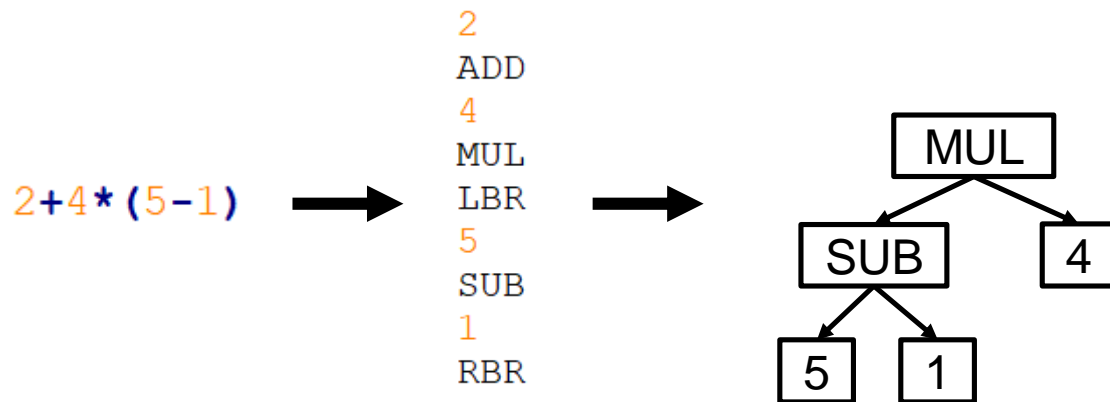
$2 + 4 * (5 - 1)$ \rightarrow

```
2
ADD
4
MUL
LBR
5
SUB
1
RBR
```

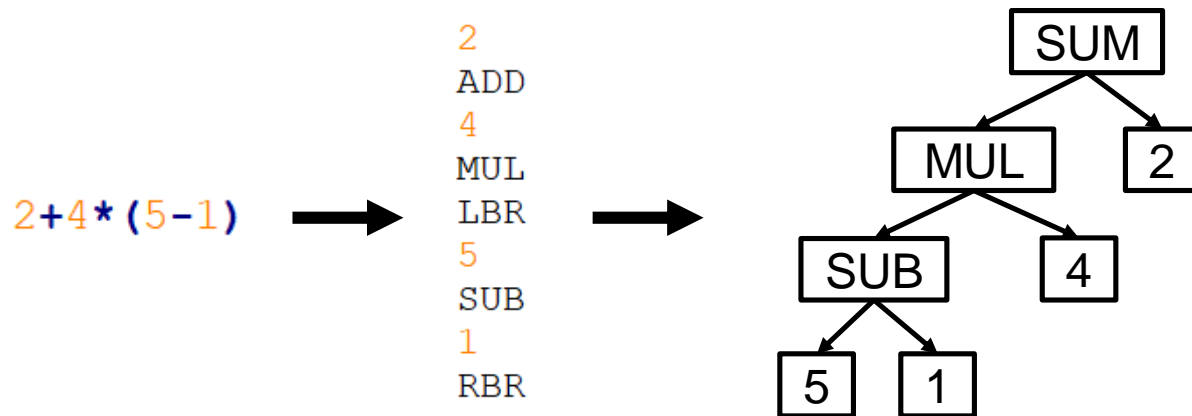
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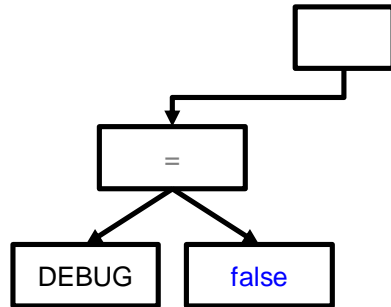
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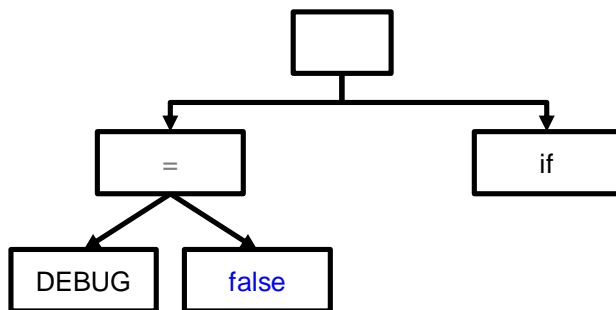
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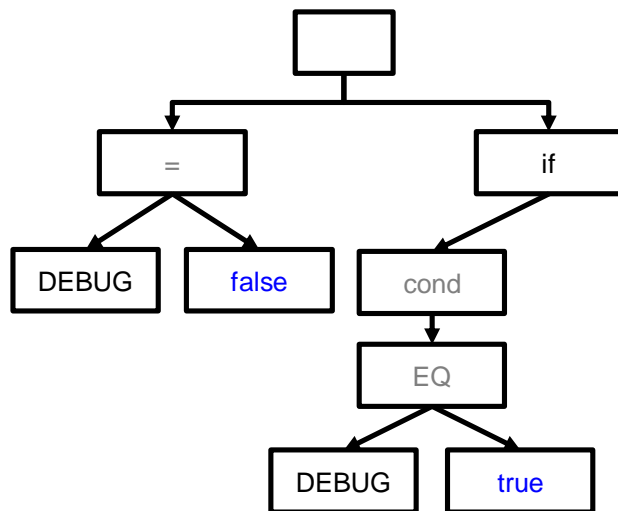
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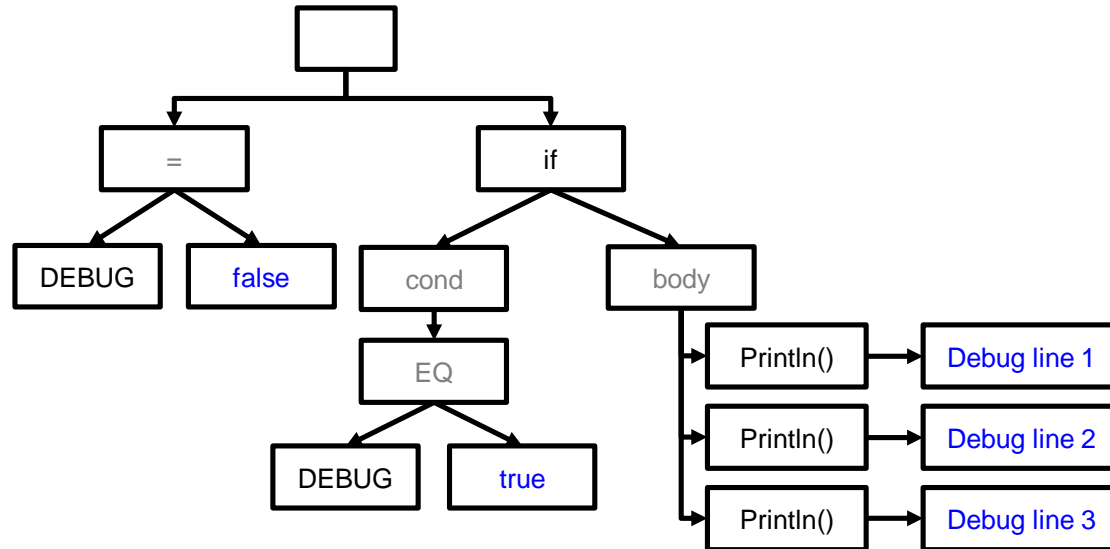
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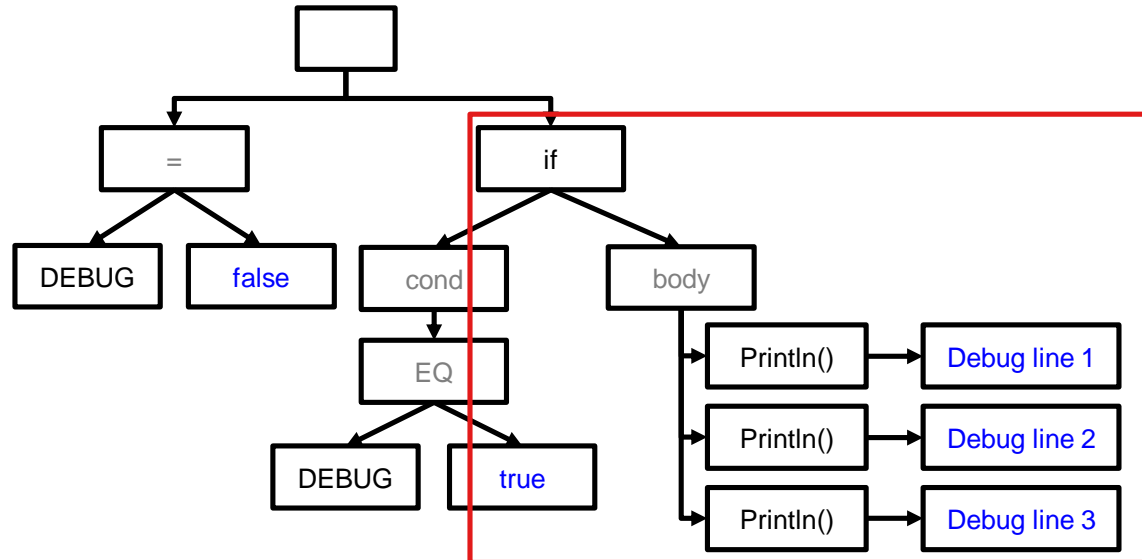
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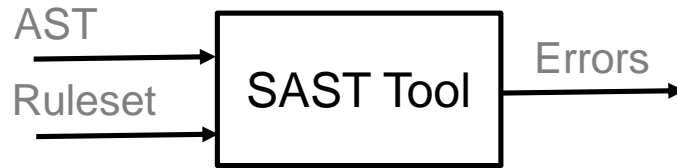
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Syntactic Analysis via AST

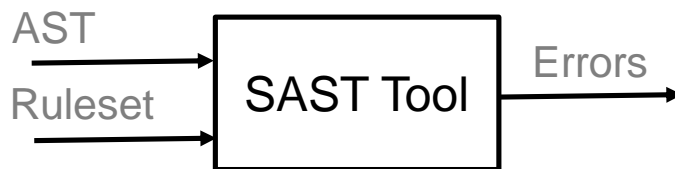


Syntactic Analysis via AST



Rule # 1: Allow 3 methods

Syntactic Analysis via AST

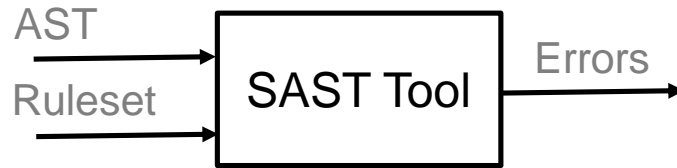


Rule # 1: Allow 3 methods

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public class test {  
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    public void xyz() {...}  
    public void blah() {...}  
    public int akw() {...}  
}
```

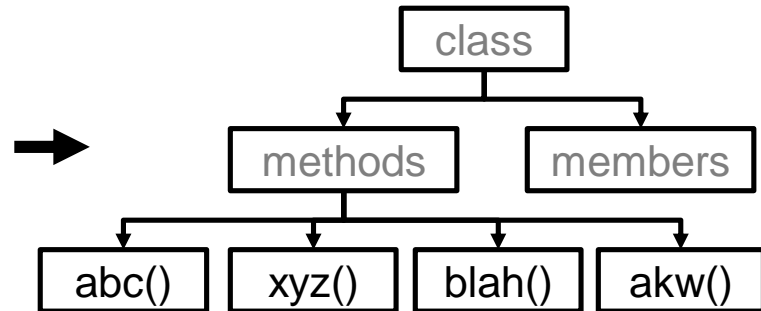


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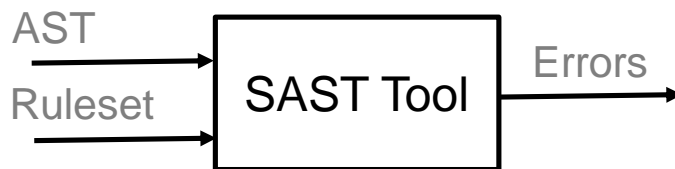


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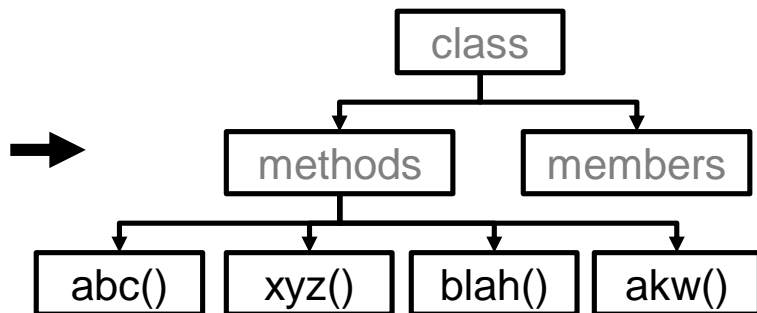


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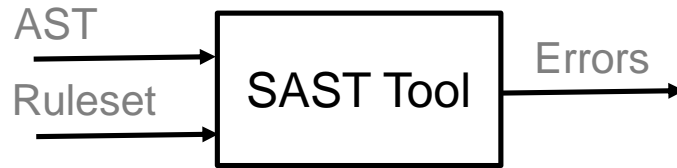
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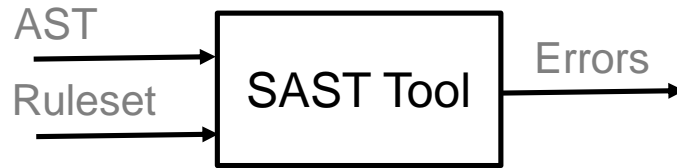
Error: Too many methods!

Syntactic Analysis via AST



Rule # 2: `printf(format_string, args_to_print)`

Syntactic Analysis via AST

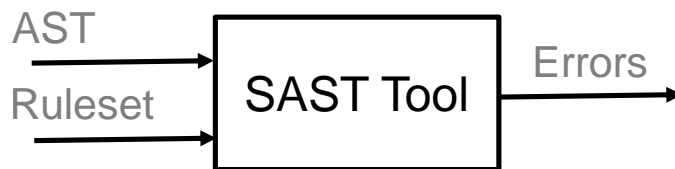


Rule # 2: `printf(format_string, args_to_print)`

```
x = "Hello World!";  
printf(x);
```

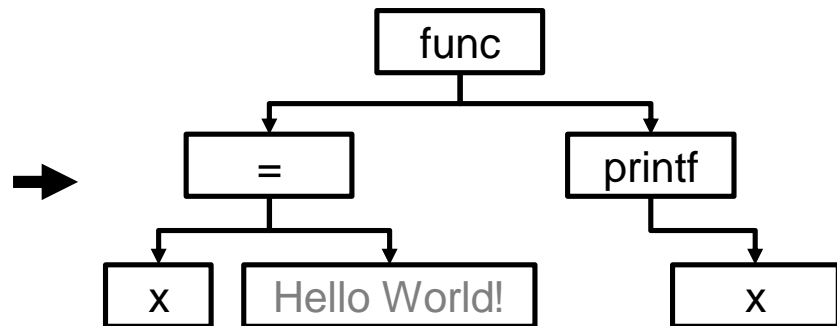


Syntactic Analysis via AST

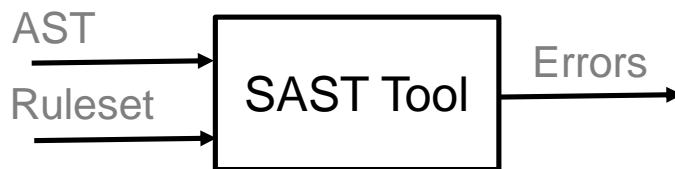


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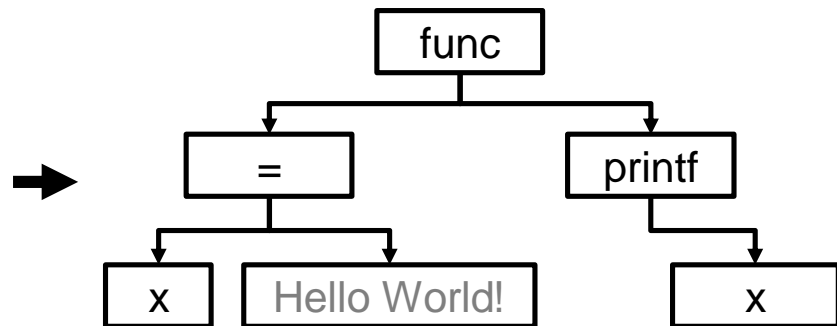


Syntactic Analysis via AST



Rule # 2: printf(format_string, args_to_print)

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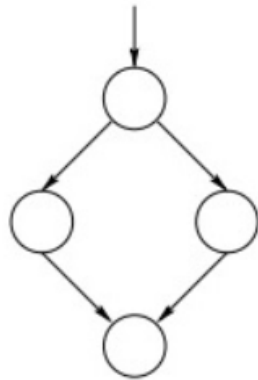
Error: Missing param!

Control Flow Graphs

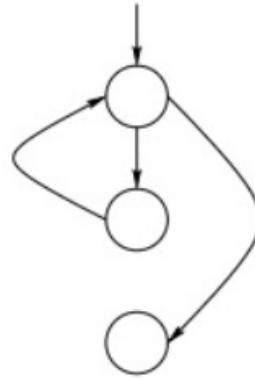
- Shows all execution paths a program *might* take
- Trace execution without executing program
- Nodes → Basic blocks
- Transitions → Control transfers

Control Flow Graphs

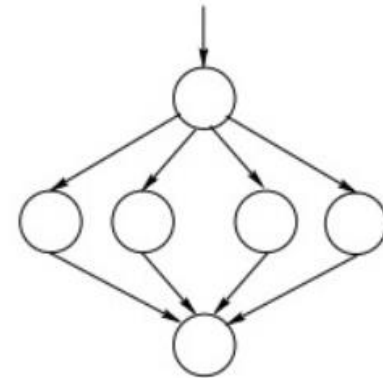
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If-then-else



while



case

Control Flow Graphs

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    int i = 0;  
    int next = -1;  
    int a = 0;  
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    while (i <= n) {  
        printf(" %d ", a);  
  
        next = a + b;  
        a = b;  
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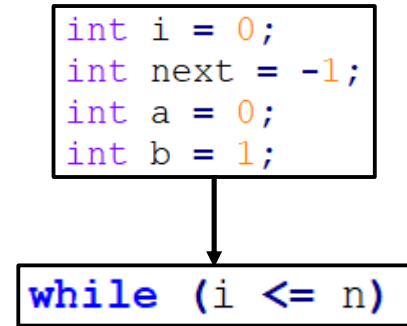

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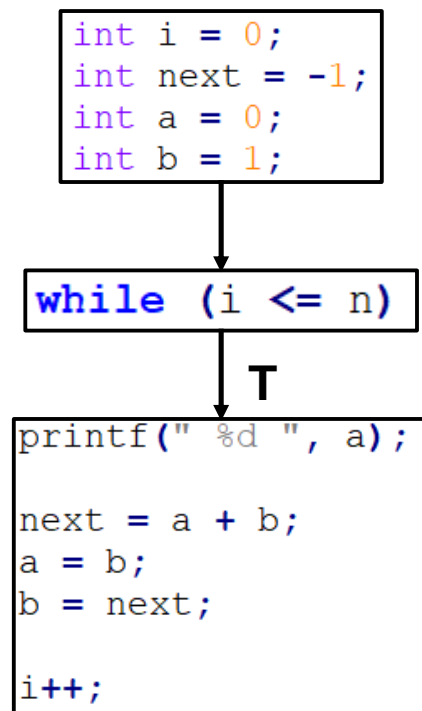
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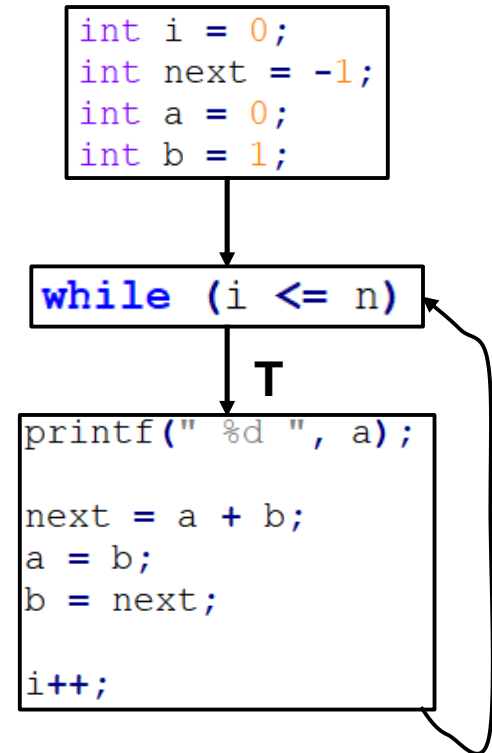
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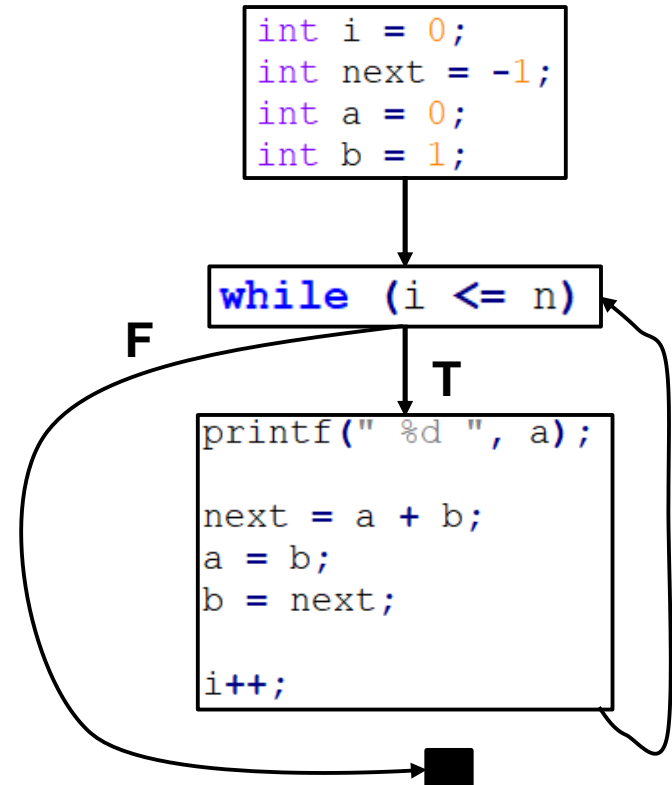
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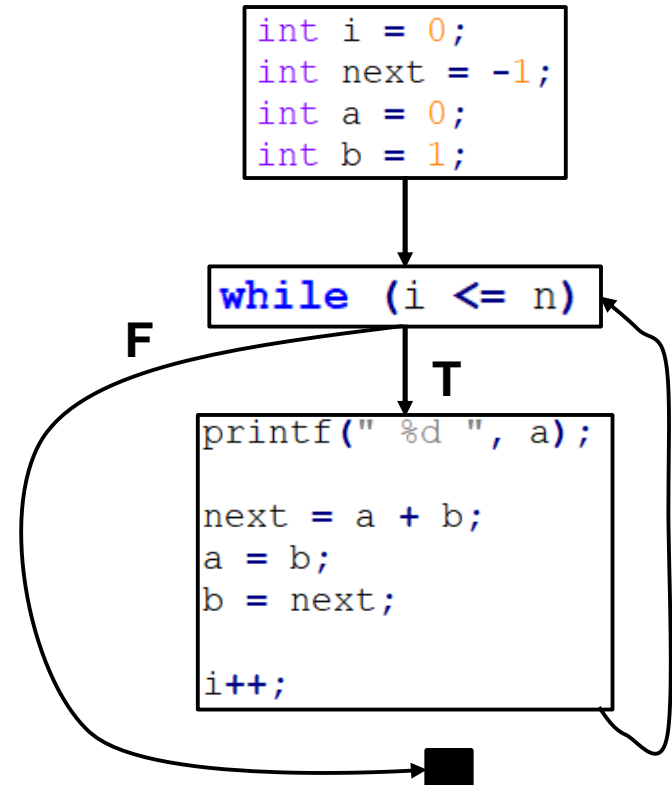


Control Flow Graphs

`n=?`

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```

Only traces control

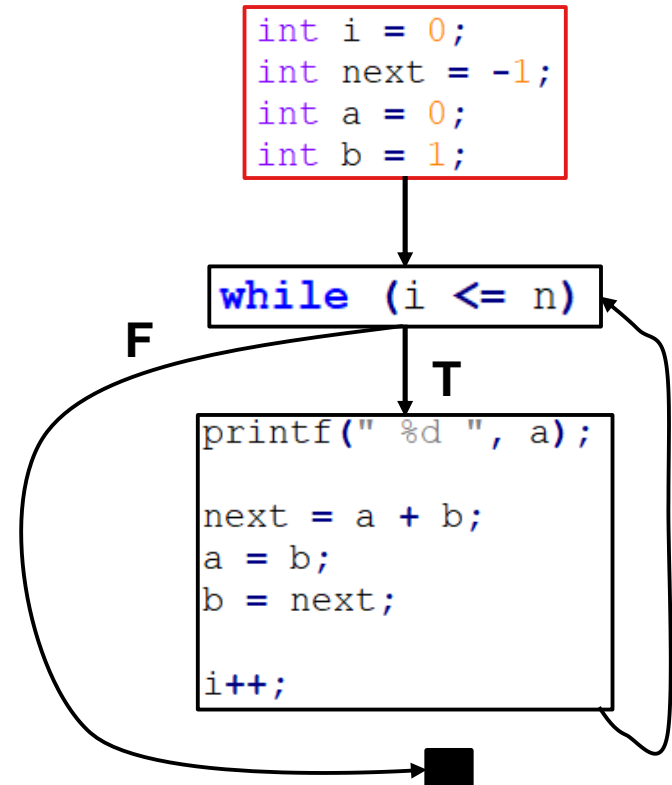


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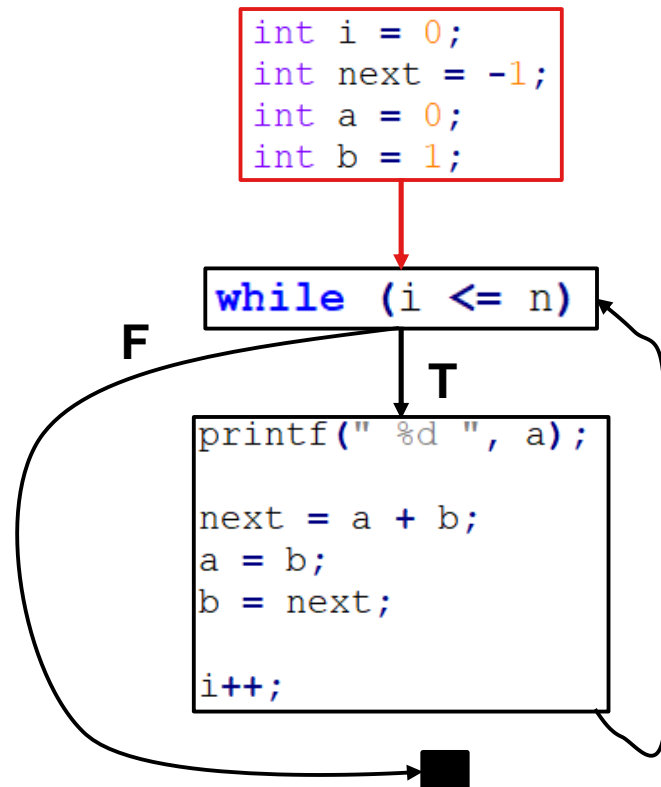


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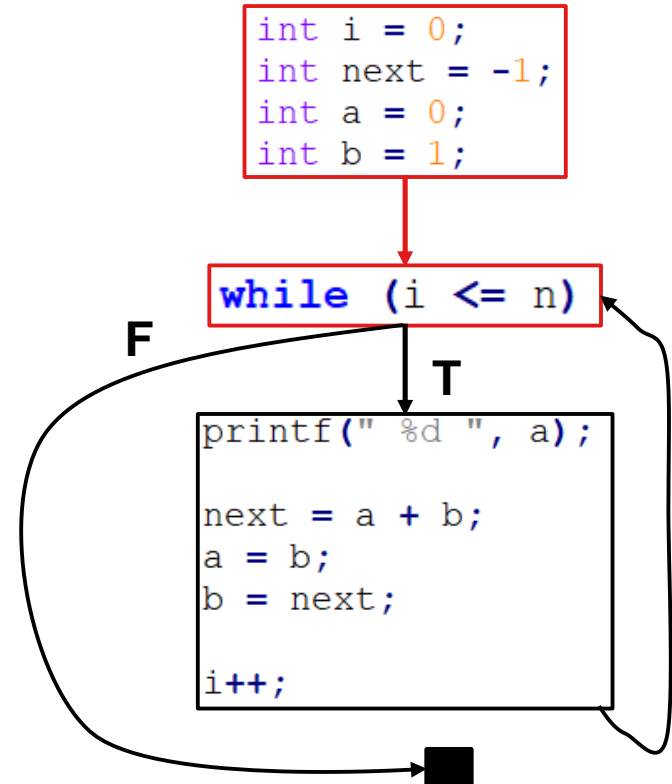


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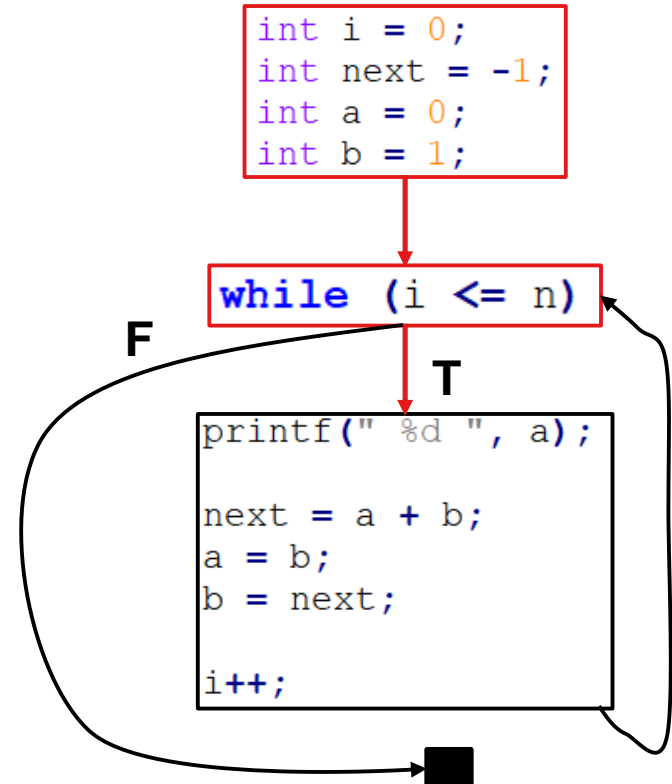


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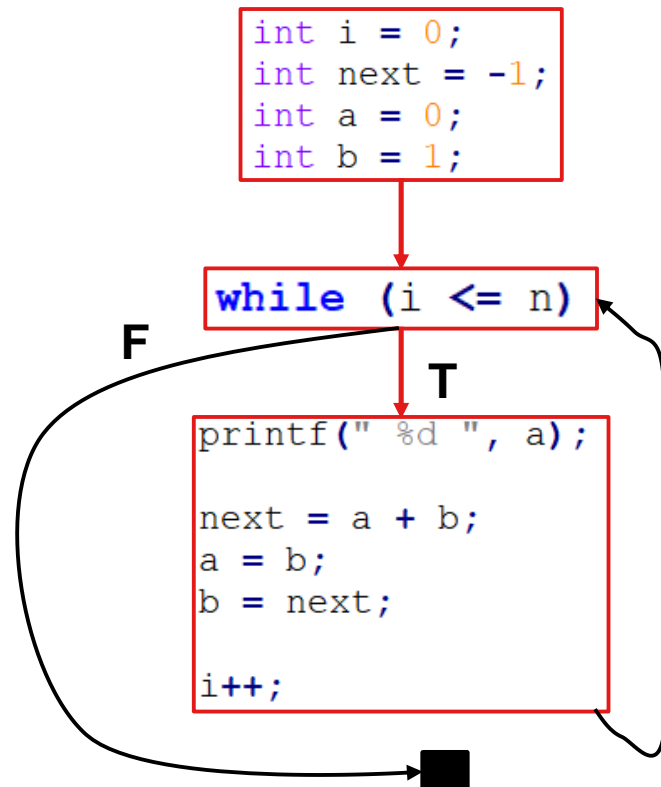


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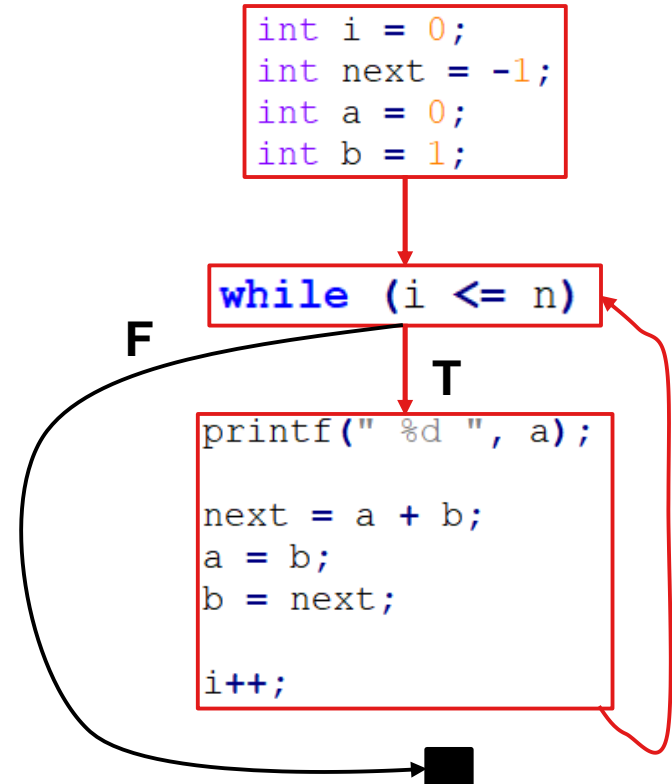


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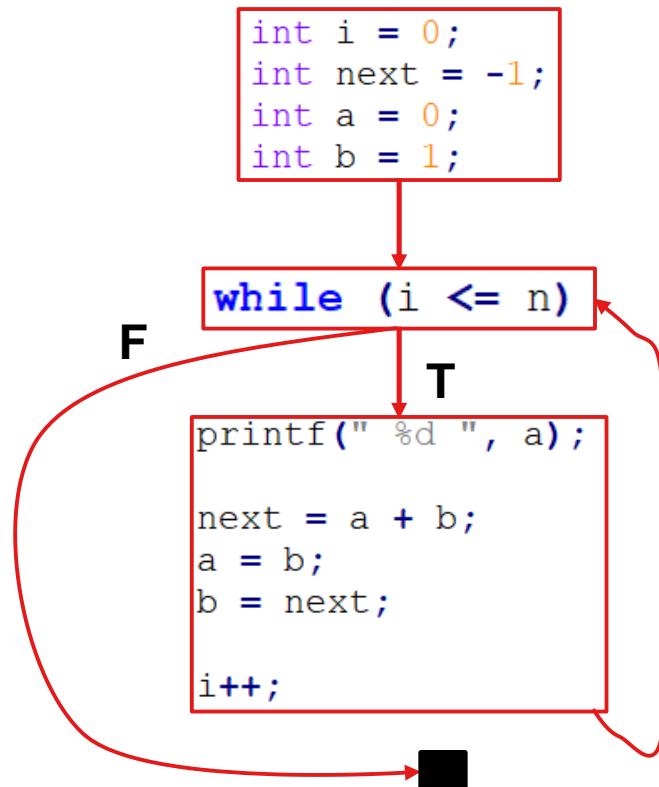


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Data Flow Analysis

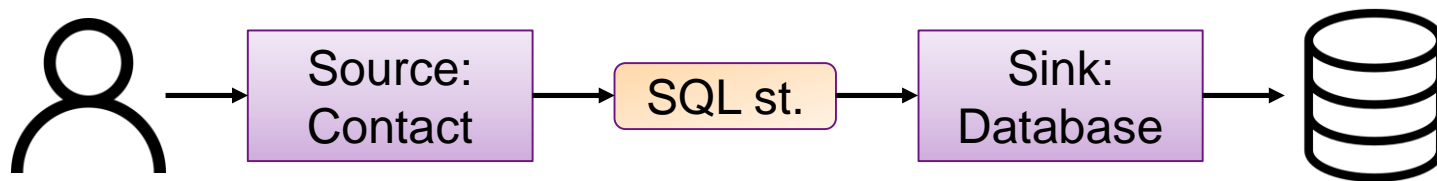
- Tracks data values throughout program
- Shows all values variables *might* have
- User controlled variable (Source) → Tainted
- Rest (Sink) → Untainted

Data Flow Analysis

- Prove that
 - No untainted data is expected
 - No tainted data is used

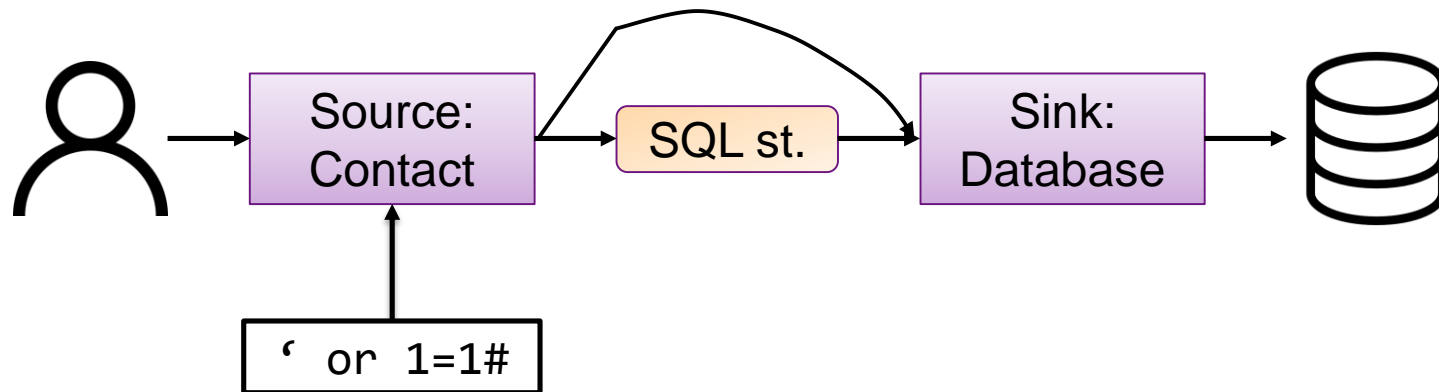
Data Flow Analysis

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Data Flow Analysis

- Prove that
 - No untainted data is expected
 - No tainted data is used



Source/Sink Clash

```
/* uses badsource and badsink */
public void bad(HttpServletRequest request, HttpServletResponse response)
    throws Throwable
{
    String data;

    /* POTENTIAL FLAW: Read data from a
     * querystring using getParameter
     */
    data = request.getParameter("name");

    if (data != null)
    {
        /* POTENTIAL FLAW: Display of data in web page
         * after using replaceAll() to remove script
         * tags, which will still allow XSS with strings
         * like <scr<script>ipt> (CWE 182: Collapse
         * of Data into Unsafe Value)
         */
        response.getWriter().println("<br>bad(): data = "
            + data.replaceAll("<script>", ""));
    }
}
```

data is tainted →

println() expects untainted →

Data Flow Analysis

- Reaching definitions
 - Top-down approach
 - Possible values of a variable

```
int b = 0;  
int c = 1;
```

```
for(int a = 0; a < 3; a++) {  
    if (a > 1)  
        b = 10;  
    else  
        c = b;  
}  
return b, c;
```



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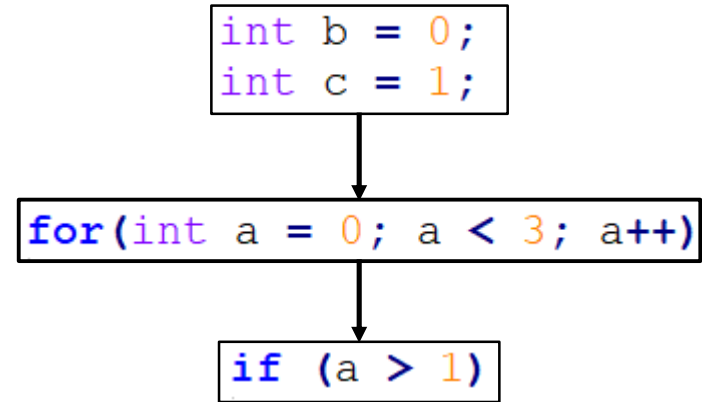
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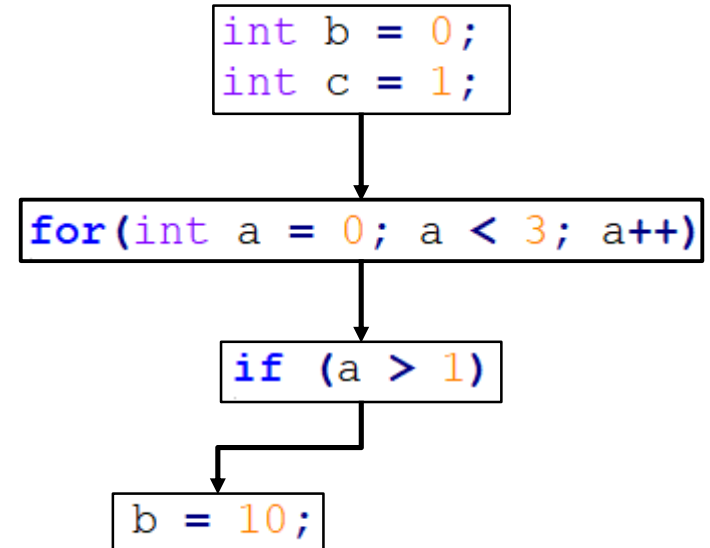


Data Flow Analysis

- Reaching definitions
 - Top-down approach
 - Possible values of a variable

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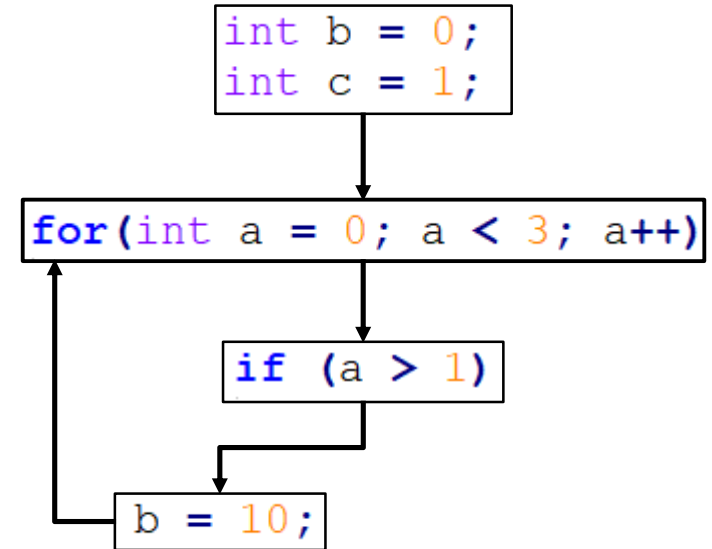


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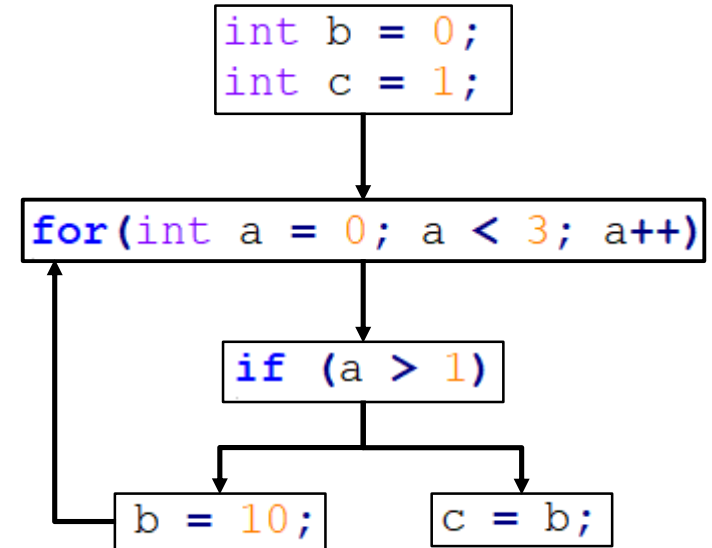


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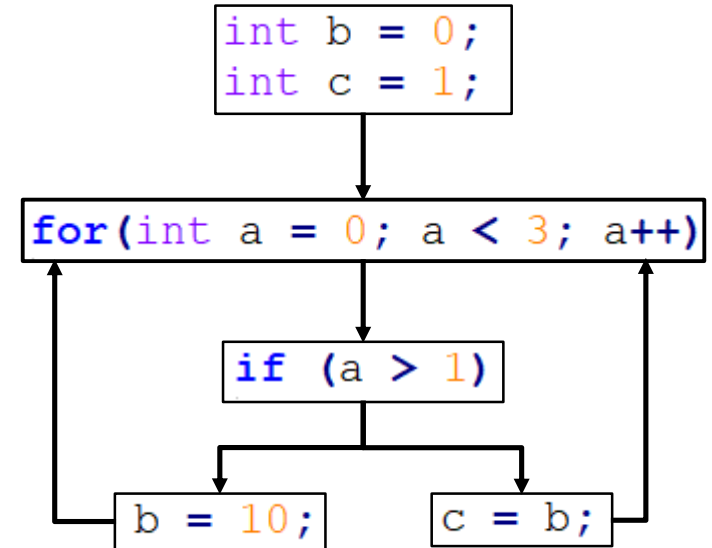


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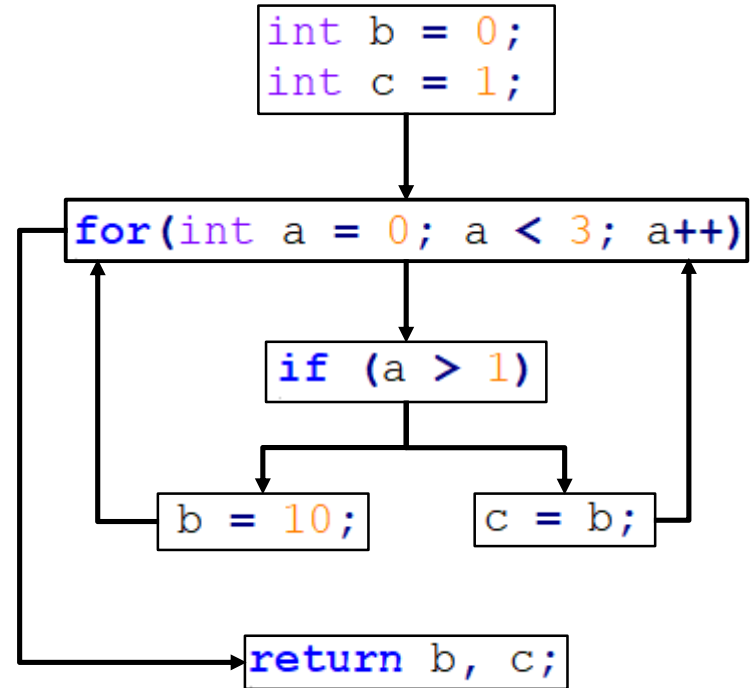


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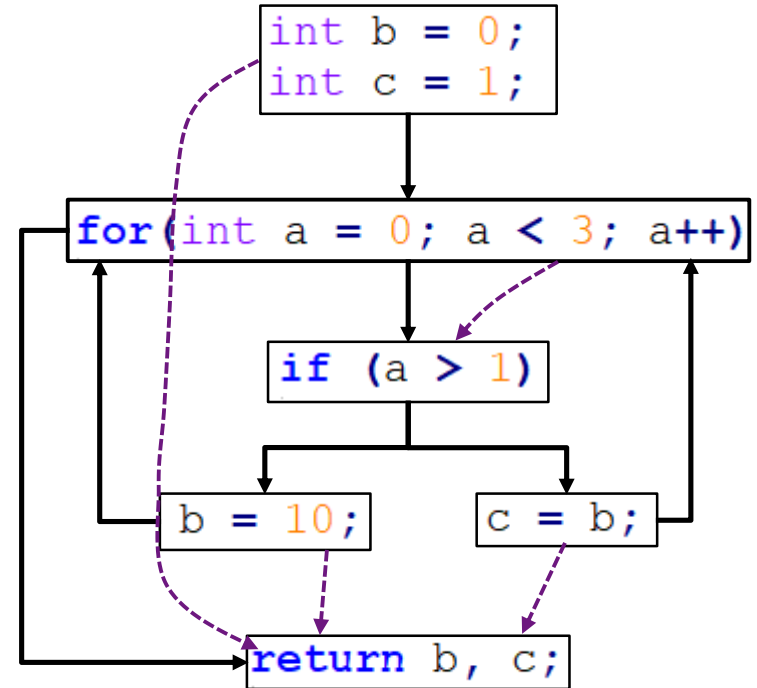


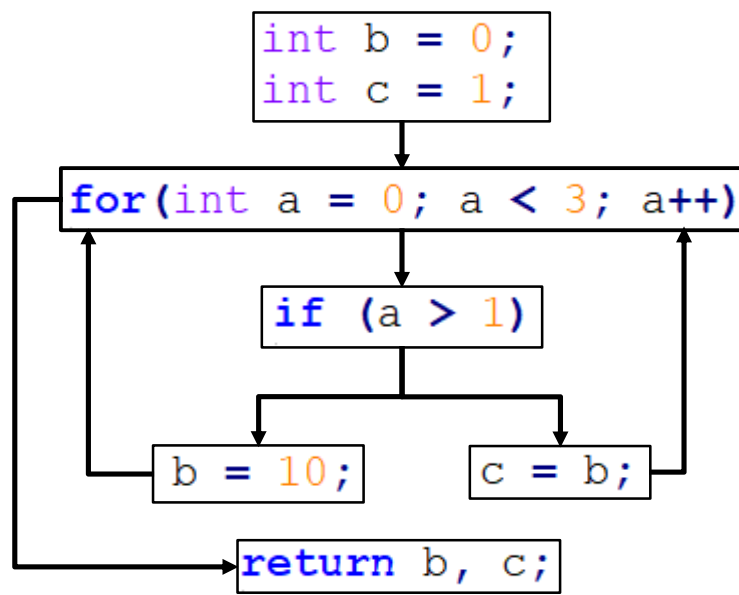
Data Flow Analysis

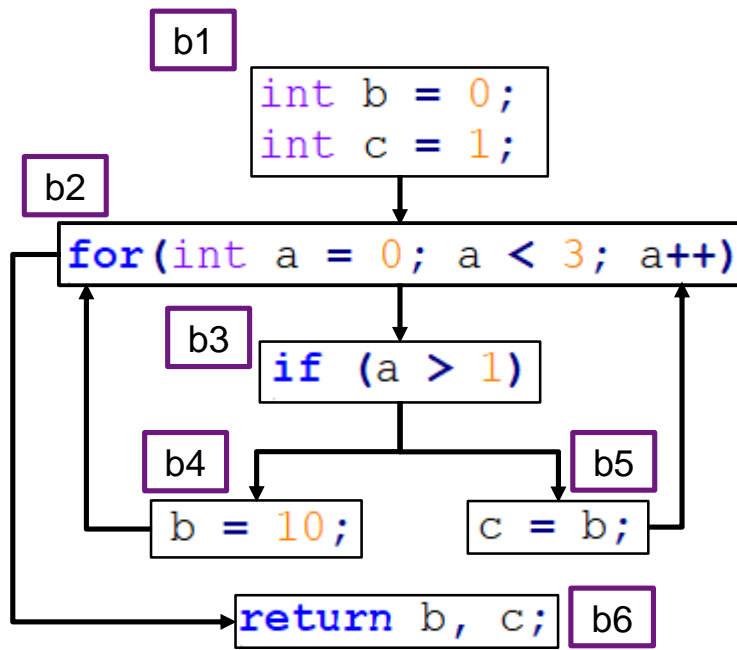
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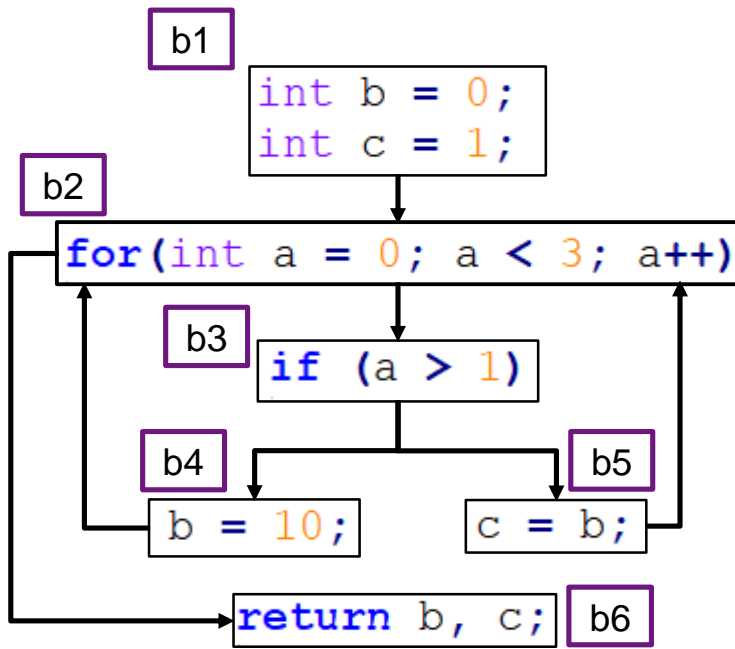
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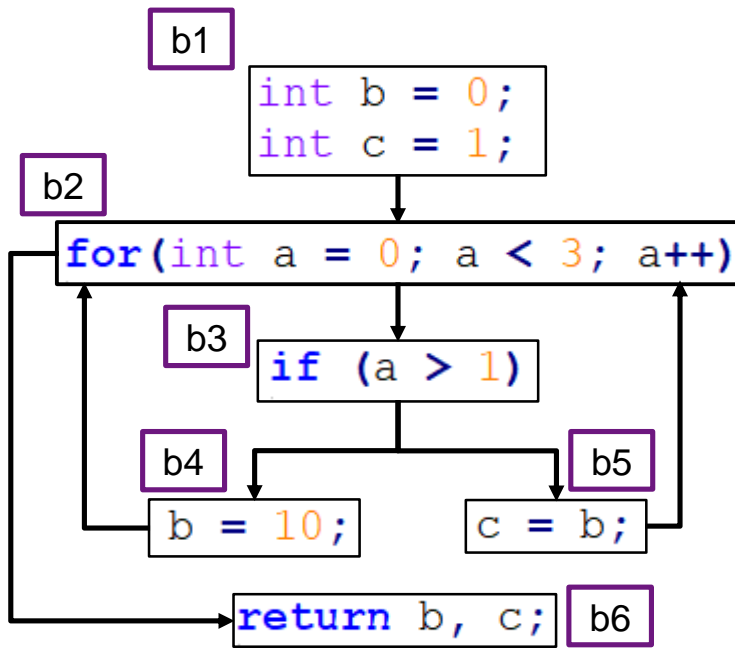




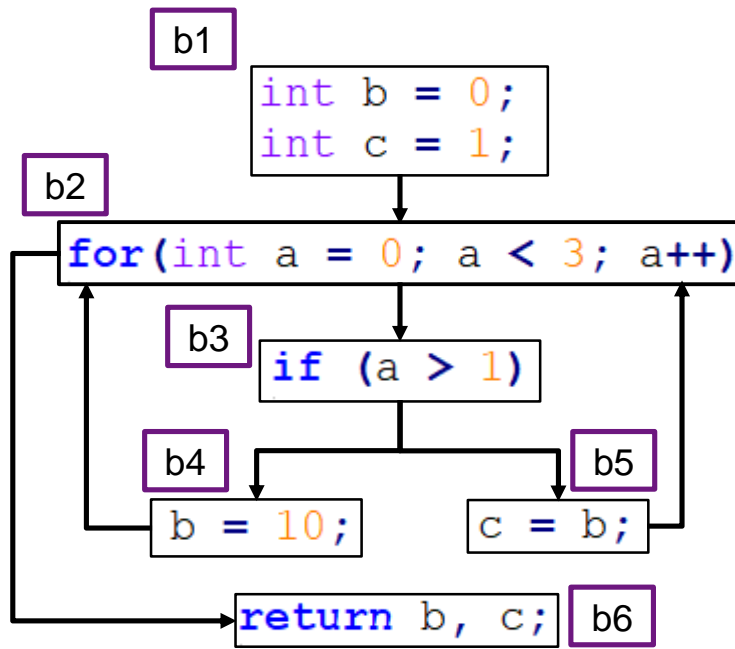




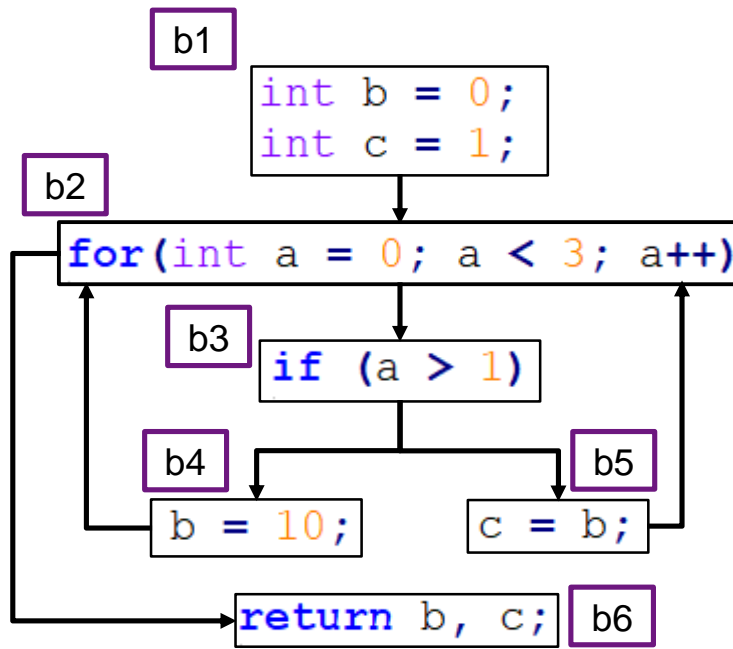
	a	b	c
b1			
b2			
b3			
b4			
b5			
b6			



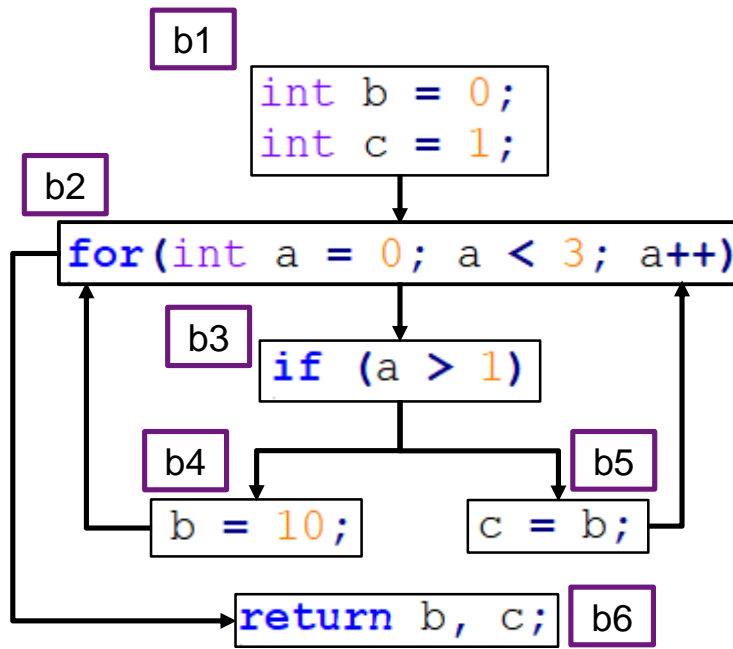
	a	b	c
b1	-	0	1
b2			
b3			
b4			
b5			
b6			



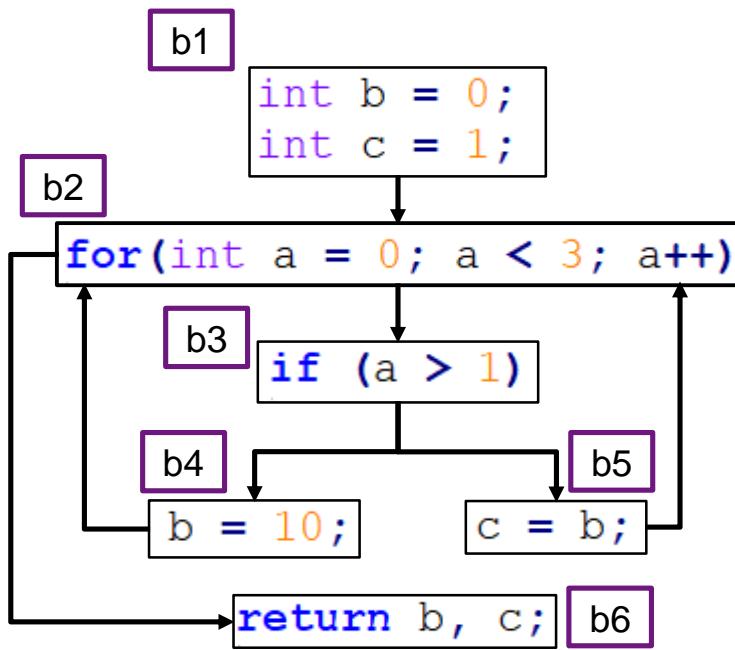
	a	b	c
b1	-	0	1
b2	0, a++	-	-
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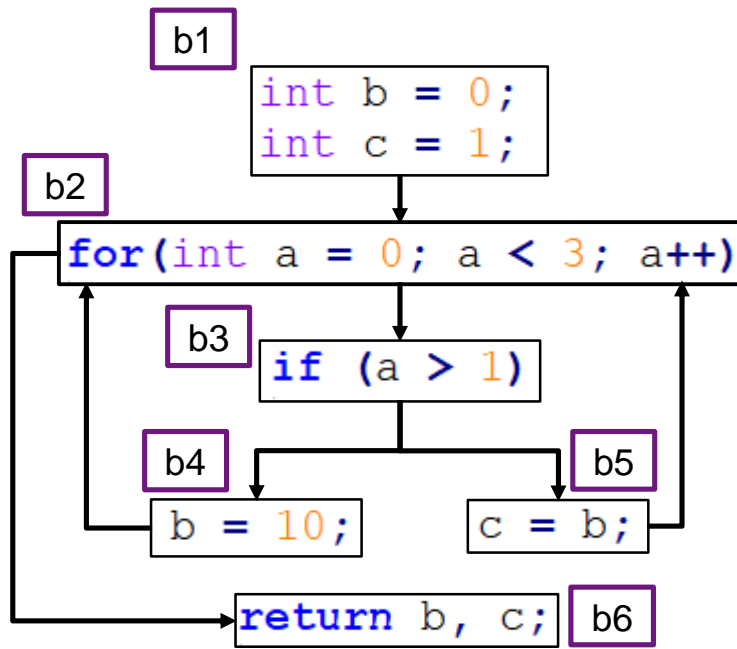
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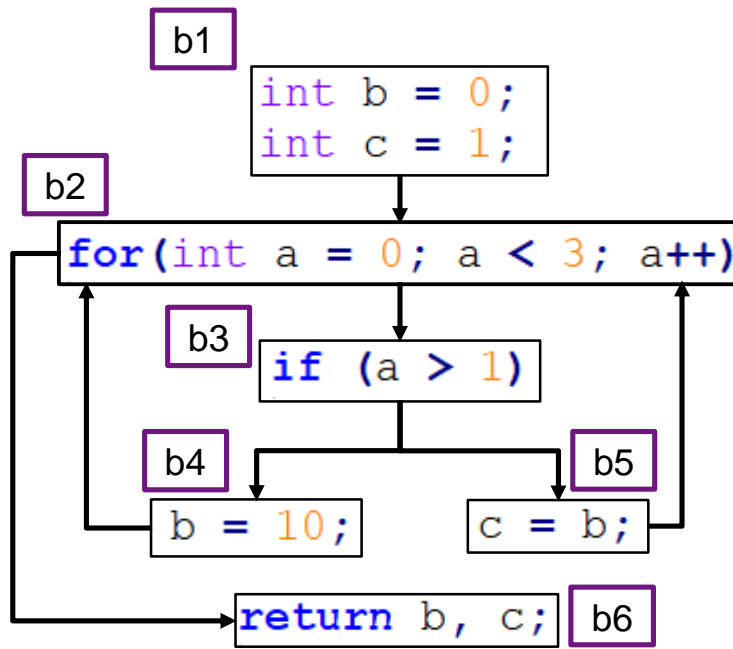
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b6			

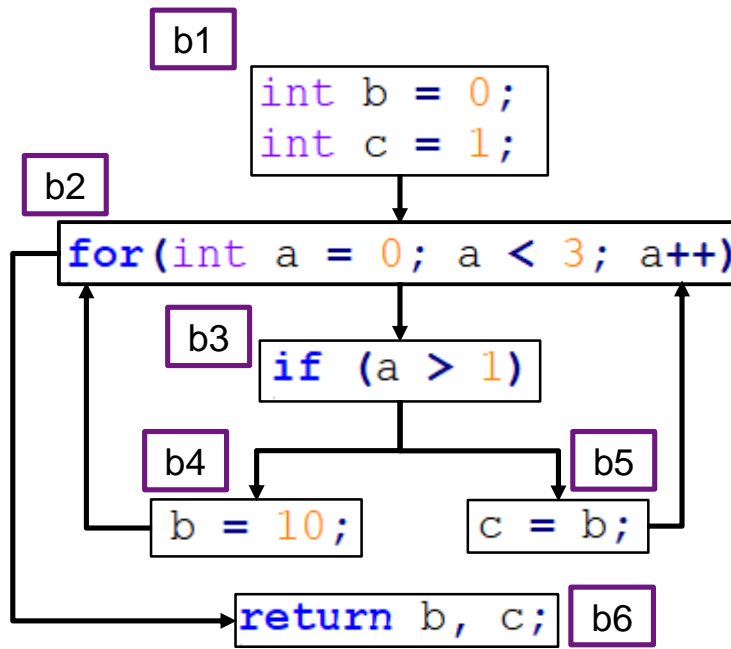


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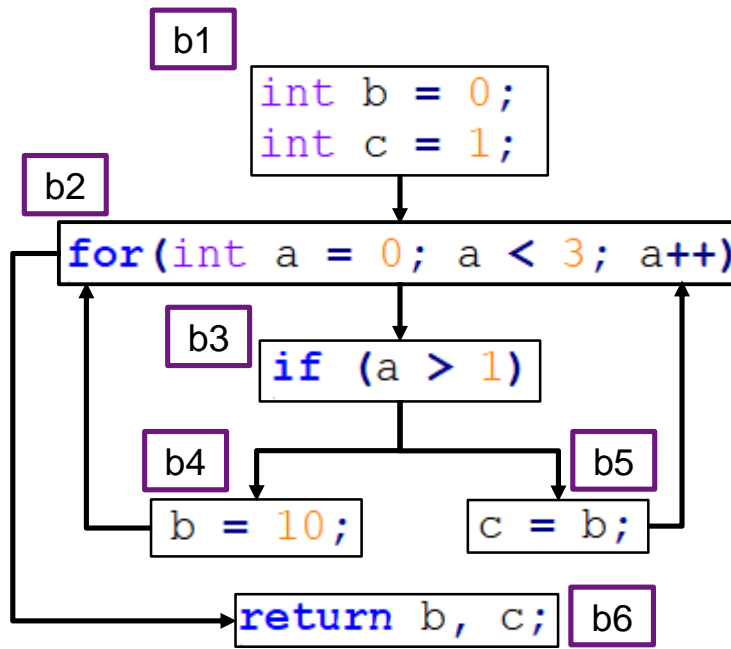
Data Flow Analysis



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Data Flow Analysis

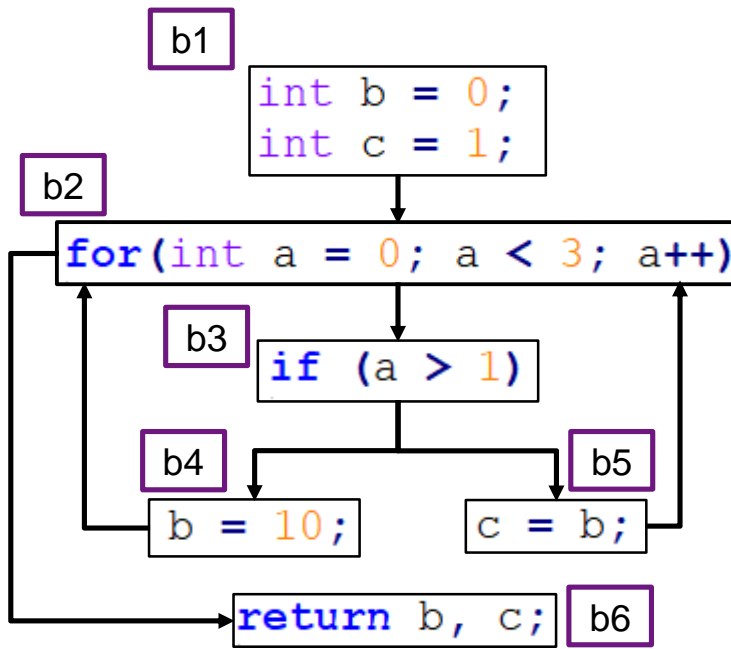
$a = \{0, 1, 2, 3, \dots\}$



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Data Flow Analysis

$a = \{0, 1, 2, 3, \dots\}$
 $b = \{0, 10\}$



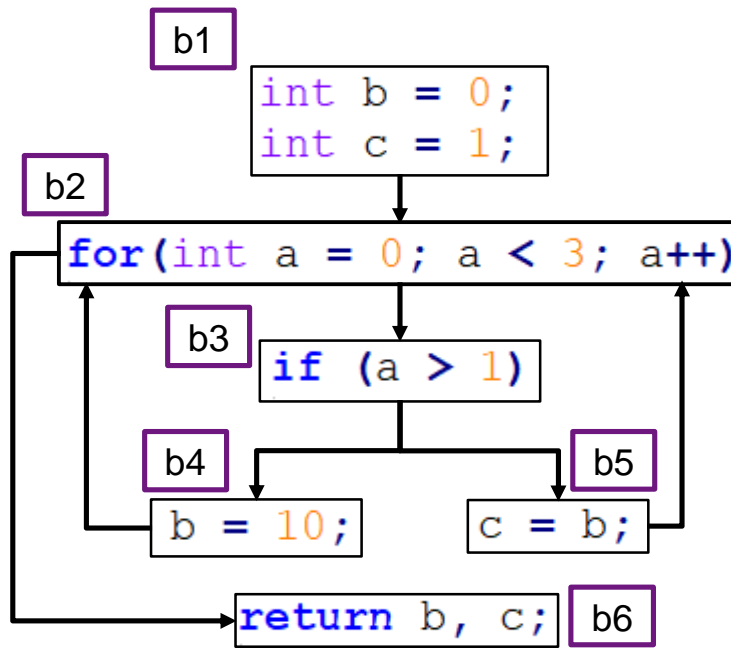
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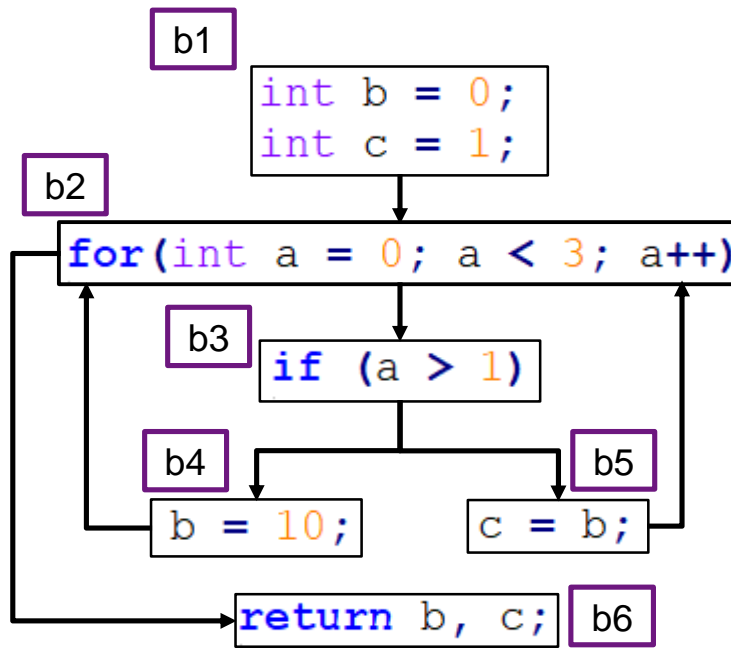
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$a = \{0, 1, 2, 3, \dots\}$

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$a = \{0, 1, 2, 3, \dots\}$

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*Sound but
imprecise*

Data Flow Analysis in Security

- Source/Sink clash

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- Control and Data flow analysis
 - Type confusion vulnerability
 - Use-after-free vulnerability
- *Denial of Service??*
- *Crashes??*

Static Analysis Tools

- Open source
 -  Pmd
 -  checkstyle
 -  SpotBugs
 -  FindSecBugs
- Proprietary
 -  Coverity
 -  CheckMarx

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 - Full fledged platform for static analysis and exposure management

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- SAST platform for defects and security vulnerabilities



- Full fledged platform for static analysis and exposure management

SAST Tools Performance

- Telenor Digital wants to incorporate security into SDLC
- Investigate developer perceptions of SAST tools

Myths and Facts About Static Application Security Testing Tools: An Action Research at Telenor Digital

Tosin Daniel Oyetoan^{1(✉)}, Bisera Milosheska², Mari Grini²,
and Daniela Soares Cruzes¹

¹ Department of Software Engineering, Safety and Security,
SINTEF Digital, Trondheim, Norway

{tosin.oyetoan,danielac}@sintef.no

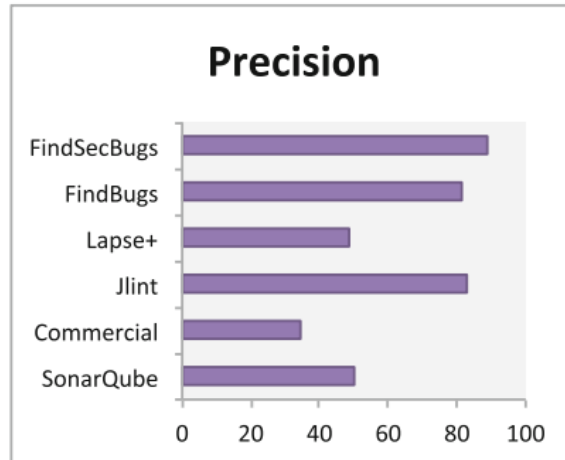
² Telenor Digital, Oslo, Norway

{bisera.milosheska,mari}@telenordigital.com

Abstract. It is claimed that integrating agile and security in practice is challenging. There is the notion that security is a heavy process, requires

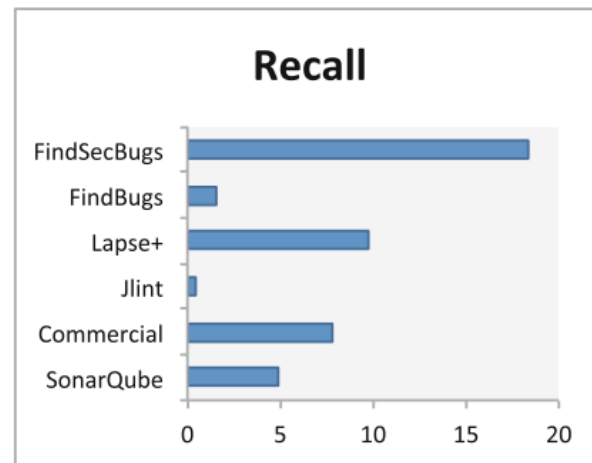
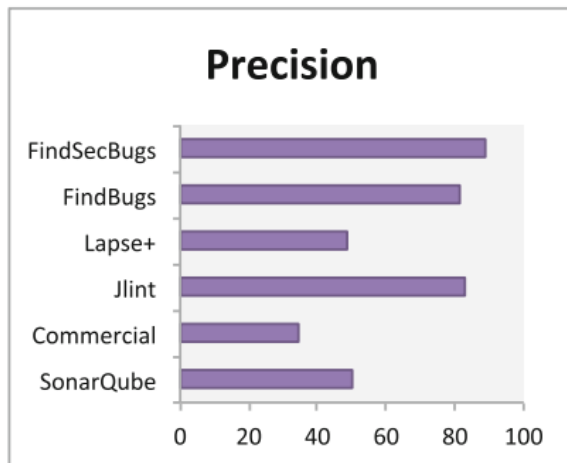
SAST Tools Performance

- Using Juliet Test Suite – 24,000 test cases
- **Precision** – Ability to guess correct type of flaw



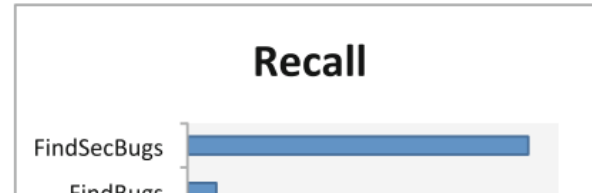
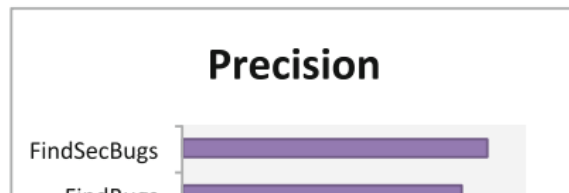
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Malicious Logic: Only Commercial tool and FindSecBugs detected weaknesses under this category. The highest detection rate is 4.17% by FindSecBugs while commercial tool only detected 1.23% of the weaknesses.

SAST Dev Perceptions

- *“ . . . Making the things actually work, that usually is the worst thing. The hassle-factor is not to be underestimated. . . ”*
- *“ . . . At least from my experience with the Sonar tool is that it sometimes complains about issues that are not really issues...”*
- *“ . . . And of course in itself is not productive, nobody gives you a hug after fixing SonarQube reports...”*

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- *“ . . . And of course in itself is not productive, nobody gives you a hug after fixing SonarQube reports...”*
- Using one SAST tool is not enough
- Low capability of SAST tools in general.
- Commercial tool not an exception

Summary Part II

- Perfect static analysis is not possible
- Pattern matching can find limited but easy to find problems
- ASTs make code structure analysis easy
- Control and Data FGs are better at finding security vulnerabilities
- Current SAST Tools are
 - Useful
 - Difficult to integrate
 - Limited in capabilities

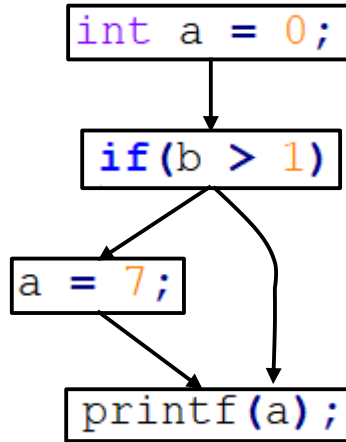
Additional Material

- <https://www.theserverside.com/feature/Stay-ahead-of-Java-security-issues-like-SQL-and-LDAP-injections>
- <https://www.upguard.com/articles/top-10-java-vulnerabilities-and-how-to-fix-them>
- https://en.wikipedia.org/wiki/Static_program_analysis
- <https://youtu.be/Heor8BVa4A0>
- <https://youtu.be/7KCMK-LY-WM>
- Aktas, Kursat, and Sevil Sen. "UpDroid: Updated Android Malware and Its Familial Classification." *Nordic Conference on Secure IT Systems*. Springer, Cham, 2018.

Time for questions

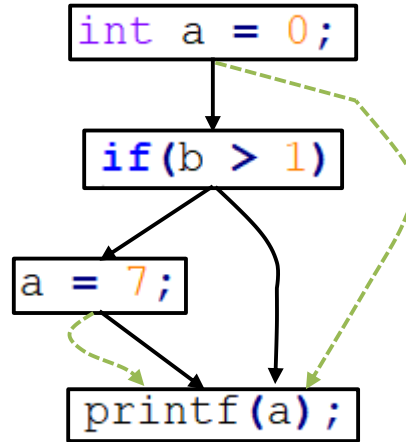


Data Flow Analysis



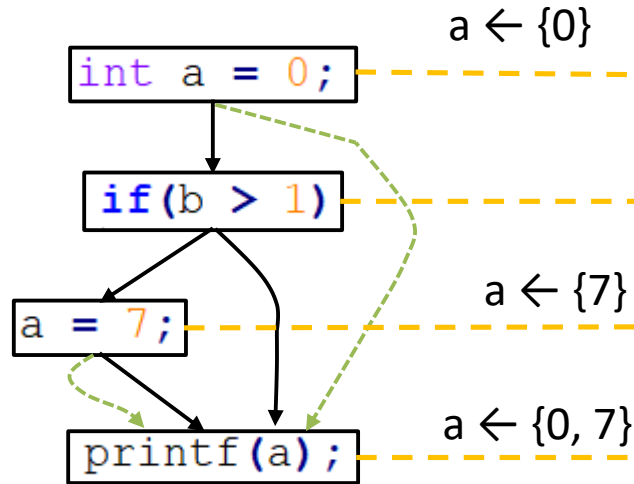
→ Control

Data Flow Analysis



→ Control
→ Data

Data Flow Analysis



→ Control
→ Data

Overflow vulnerability

- This vulnerability allows remote attackers to execute arbitrary code on vulnerable installations of Oracle Java. The user must visit a malicious page or open a malicious file to exploit this vulnerability.
- The flaw exists within the handling of image data. The issue lies in insufficient validation of supplied image data inside the native function `readImage()`. An attacker can leverage this vulnerability to execute arbitrary code under the context of the current process.