Applied Static Analysis

Why Static Analysis?

Software Technology Group
Department of Computer Science
Technische Universität Darmstadt
Dr. Michael Eichberg

Questions that we may ask about a program:

- Will the variable `x` always contain the same value?
- Which objects can variable `x` points to?
- What is a lower/upper bound on the value of the integer variable `x`?
- Which methods are called by a method invocation?
- How much memory is required to execute the program?
- Will it throw a `NullPointerException`?
- Will it leak sensitive data? Will data from component `a` flow to component `b`?

Buggy C-Program:

```c
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
int main(int argc, const char * argv[]) {
    char *p, *q;
    p = NULL;
    printf("%s",p);
    q = (char *)malloc(100);
    p = q;
    free(q);
    *p = 'x';
    free(p);
    p = (char *)malloc(100);
    q = (char *)malloc(100);
    q = p;
    strcat(p,q);
}
```

What is Static Analysis?

A static analysis of a program is a *sound*, *finite*, and *approximate* calculation of the program's execution semantics which helps us to solve practical problems.

Purposes of Code Analyses

- Finding code smells.
- Quality assessments.
- Improving the quality of the code.
- Support debugging of code.
- Optimizing the code.

Not every analysis which does not execute the code is a *static analysis*!

Finding Programming Bugs

```
class X {
    private long scale;
    X(long scale) { this.scale = scale; }
    void adapt(BigDecimal d){
        d.setScale(this.scale);
    }
}
```

There is typically more than one way to find certain bugs and not all require (sophisticated) static analyses!

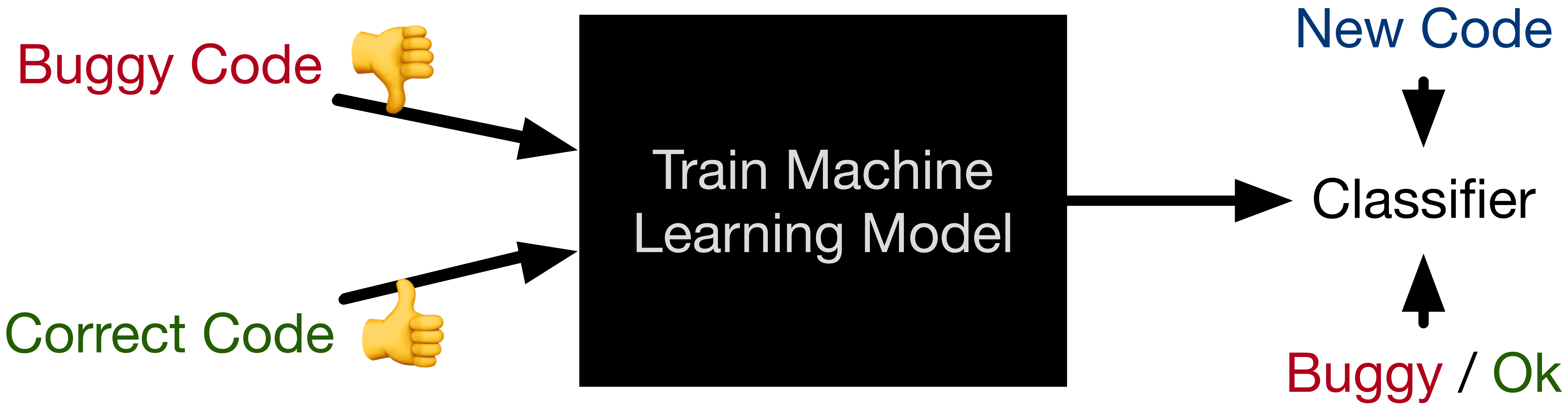
Finding Bugs Using Bug Patterns

```
import org.opalj.br._
import org.opalj.br.instructions.{INVOKEVIRTUAL,POP}
import org.opalj.bytecode.JRELibraryFolder
val p = analyses.Project(JRELibraryFolder) // <= analyze the code of the JRE
p.allMethodsWithBody.foreach{m =>
  m.body.get.collectPair{
    case (
        i @ INVOKEVIRTUAL(ObjectType("java/math/BigDecimal"),"setScale",_),
        POP
    ) => i
  }
  .foreach(i => println(m.toJava(i.toString)))
}
```

Finding Bugs Using Bug Patterns (Assessment)

- Advantages:
    - very fast and scale well to very large programs
    - (usually) simple to implement
- Disadvantages:
    - typically highly specialized to specific language constructs and APIs
    - requires some understanding how the issue typically manifests itself in the (binary) code
    - small variations in the code may escape the anaylsis
    - to cover a broader range of similar issues huge efforts are necessary

Finding Bugs Using Machine Learning



Finding Bugs Using Machine Learning

Guess the problem of the following JavaScript code snippet:

```
function setPoint(x, y) { ... }
var x_dim = 23;
var y_dim = 5;
setPoint(y_dim, x_dim);
```

Finding Bugs Using Machine Learning (Assessment)

- Finds bugs that are practically impossible to find using other approaches; hence, often complementary to classic static analyses and also bug pattern based analyses.
- Requires the analysis of a huge code base; it may be hard to find enough code examples for less frequently used APIs.

Finding Bugs by Mining Usage Patterns (Idea)

Is the following code buggy?

```
Iterator<?> it = ...
it.next();
while (it.hasNext()) {
    it.next();
    ...
}
```

Finding Bugs Using Generic Static Code Analysis

```
class com.sun.imageio.plugins.png.PNGMetadata{
    void mergeStandardTree(org.w3c.dom.Node) {
        [...]
        if (maxBits > 4 || maxBits < 8) {
            maxBits = 8;
        }
        if (maxBits > 8) {
            maxBits = 16;
        }
        [...]
    }
}
```

Finding Bugs Using Generic Static Code Analysis

```
class sun.font.StandardGlyphVector {
    public int getGlyphCharIndex(int ix) {
        if (ix < 0 && ix >= glyphs.length) {
            throw new IndexOutOfBoundsException("" + ix);
        }
    }
}
```

Finding Bugs Using Generic Static Code Analysis

```
class sun.tracing.MultiplexProviderFactory {
    public void uncheckedTrigger(Object[] args) {
        […]
        Method m = Probe.class.getMethod(
            "trigger",
            Class.forName("[java.lang.Object")
        );
        m.invoke(p, args);
    }
}
```

Finding Bugs Using Generic Static Code Analysis

```
class com.sun.corba.se.impl.naming.pcosnaming.NamingContextImpl {
    public static String nameToString(NameComponent[] name)
        [...]
        if (name != null || name.length > 0) {
            [...]
        }
        [...]
    }
}
```

Finding Bugs Using Static Code Analysis ?

```
private boolean ...isConsistent(
        String alg,
        String exemptionMechanism,
        Hashtable<String, Vector<String>> processedPermissions) {
    String thisExemptionMechanism = exemptionMechanism == null ? "none" : exemptionMechanism;
    if (processedPermissions == null) {
        processedPermissions = new Hashtable<String, Vector<String>>();
        Vector<String> exemptionMechanisms = new Vector<>(1);
        exemptionMechanisms.addElement(thisExemptionMechanism);
        processedPermissions.put(alg, exemptionMechanisms);
        return true;
    }
    […]
}
```

Finding Bugs Using (Highly) Specialized Static Analyses

Do you see the security issue?

```
Cipher c = Cipher.getInstance("DES/CBC/PKCS5PADDING")
```

(True|False) (Positives|Negatives)

- a <u>true positive</u> is the correct finding (of something relevant)
- a <u>false positive</u> is a finding that is incorrect (i.e., which can't be observed at runtime)
- a <u>true negative</u> is the correct finding of no issue.
- a <u>false negative</u> refers to those issues that are not reported.

Unguarded Access - True Positive ?

```
void printIt(String args[]) {
    if (args != null) {
        System.out.println("number of elements: " + args.length);
    }
    for (String arg : args) {
        System.out.println(arg);
    }
}
```

Implicitly Guarded Access

```
void printReverse(String args[]) {
    int argscount = 0;
    if (args != null) {
        argscount = args.length;
    }
    for (int i = argscount - 1; i >= 0; i--) {
        System.out.println(args[i]);
    }
}
```

Irrelevant True Positives

Let's assume that the following function is only called with `non-null` parameters.

```
private boolean isSmallEnough(Object i) {
    assert(i != null);
    Object o = " "+i;
    return o.length < 10;
}
```

Complex True Positives

The cast in line 5 will fail:

```
GeneralPath result = new GeneralPath(GeneralPath.WIND_NON_ZERO);
[…]
if (dx != 0 || dy != 0) {
    AffineTransform tx = AffineTransform.getTranslateInstance(dx, dy);
    result = (GeneralPath)tx.createTransformedShape(result);
}
```

Complex True Positives - Assessment

The sad reality:

[…] the general trend holds; a not-understood bug report is commonly labeled a false positive, rather than spurring the programmer to delve deeper. The result? We have completely abandoned some analyses that might generate difficult to understand reports. [^FindBugsInTheRealWorld]

Soundiness

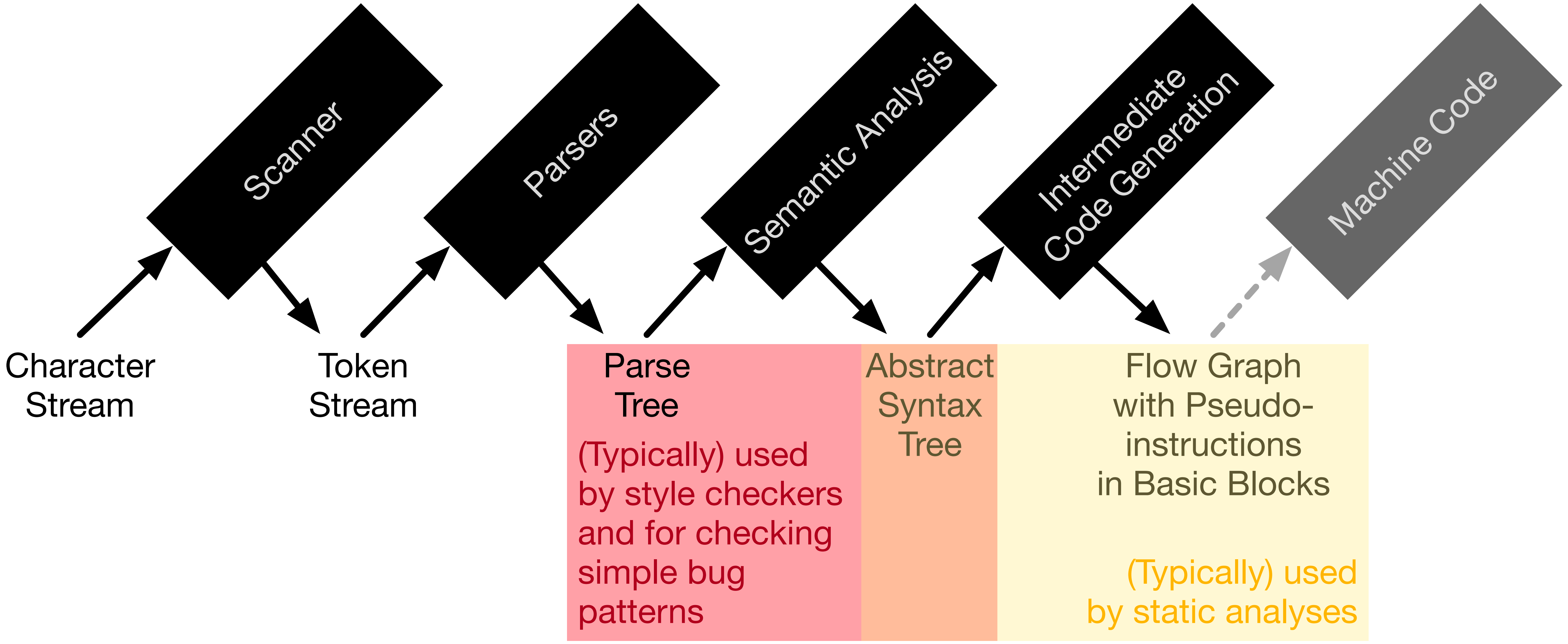
[…] in practice, soundness is commonly eschewed: we [the authors] are not aware of a single realistic whole-programa analysis tool […] that does not purposely make unsound choices.
[…]
Soundness is not even necessary for most modern analysis applications, however, as many clients can tolerate unsoundness. [^Soundiness]

Soundiness - Java

Common features that are often not soundly handled in Java:

- Reflection (*often mentioned in research papers*)
- Native methods (*often mentioned in research papers*)
- Dynamic Class Loading / Class Loaders (*sometimes mentioned in research papers*
- (De)Serialization (*often not considered at all*)
- Special System Hooks (e.g., `shutdownHooks`)

Compilers and Static Analyses


Scanner
Parsers
Semantic Analysis
Intermediate Code Generation
Machine Code
Character Stream
Token Stream
Parse Tree
(Typically) used by style checkers and for checking simple bug patterns
Abstract Syntax Tree
Flow Graph with Pseudo-instructions in Basic Blocks
(Typically) used by static analyses

Compilers and Static Analyses

Source Code:

```
i = j + 1;
```

Tokens:

```
Ident(i) WS Assign WS Ident(j) WS Operator(+) WS Const(1) Semicolon
```

AST with annotations:

```
AssignmentStatement(
    target     = Var(name=i,type=Int),
    expression = AddExpression(
                     type  = Int,
                     left  = Var(name=j,type=Int),
                     right = Const(1)))
```