
# Software Engineering

## QA + Testing IV: Static Code Analysis

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# Learning Goals for Today

- Know the definition of static analysis.
- Explain the types of failures that static analysis targets.
- Differentiate between structural, control and data flow analyses

# Static Analysis

## Motivation

- Relevant errors may only occur on exceptional or hard to stimulate paths of a program
- Testing all possible paths through a program is impossible
- Wouldn't it be nice to have an analysis that checks if a property is true for ALL possible paths through a program?

## Static Analysis

A static analysis tool S analyzes the source code of a program P to determine whether it satisfies a property φ.

## Examples of Static Analysis

- P never accesses a variable that is null.
- P never uses inputs that are not validated.
- P never executes a division by zero.
- P will always close the DB connection.
- P will always return a value.

## Safety and Liveness Properties

- *Liveness*: "something good eventually happens."
- *Safety*: "something bad never happens."

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# Practical Static Analysis

**The Ultimate Property**

Does P always terminate?

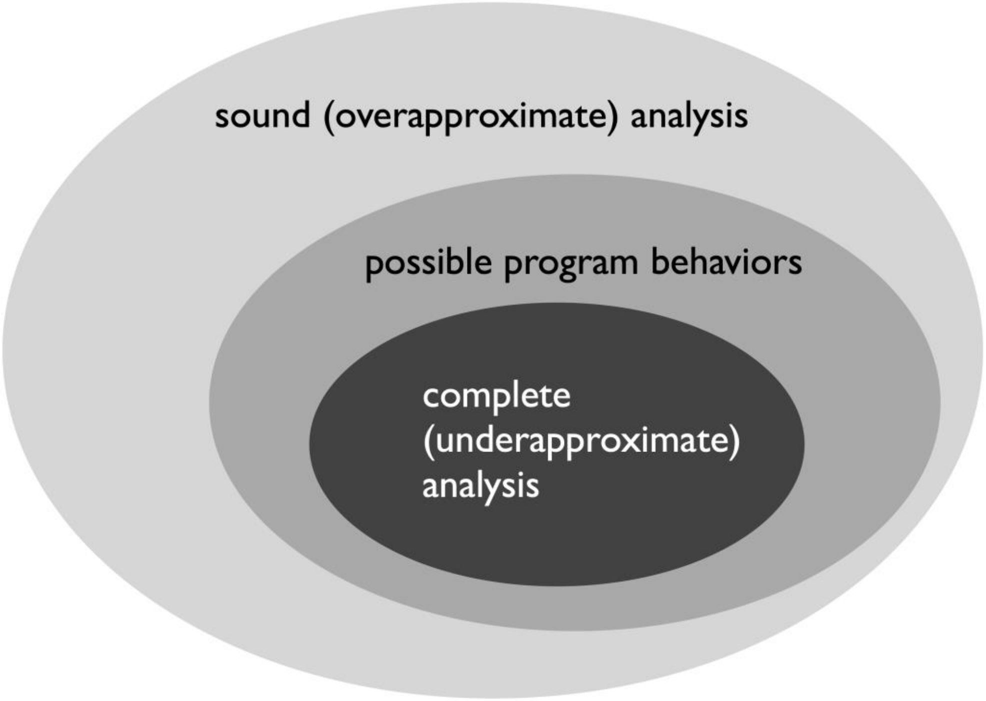
**Practical Static Analysis**

A static analysis tool S analyzes the source code of a program P to determine whether it satisfies a property φ, but it can be wrong in one of two ways:

- If S is **sound**, it will never miss any violations, but it may say that P violates φ even though it doesn't (resulting in **false positives**).
- If S is **complete**, it will never report false positives, but it may miss real violations of φ (resulting in **false negatives**).

**Rice's theorem**

For any nontrivial property φ, there is no general automated method to determine whether P satisfies φ. ☹

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# Concepts and Types of Static Analysis

## Basic Concepts of Static Analysis

**Abstraction**: The possible state space of a program (i.e., the possible values of its variables) is reduced.

**Programs as structures**: Code is represented by basic structures such as trees or graphs.

Static analysis **systematically** checks whether some property holds in an **abstraction** of the state space of a program.

## Types of Static Analysis

- Structural Analysis
- Control Flow Analysis
- Data Flow Analysis


# Structural Analysis

# Structural Analysis

## Abstraction: Abstract Syntax Tree (AST)

An **abstract syntax tree** (AST) is a data structure to represent the structure of a program.

It is a **tree representation** of the abstract syntactic structure of source code.

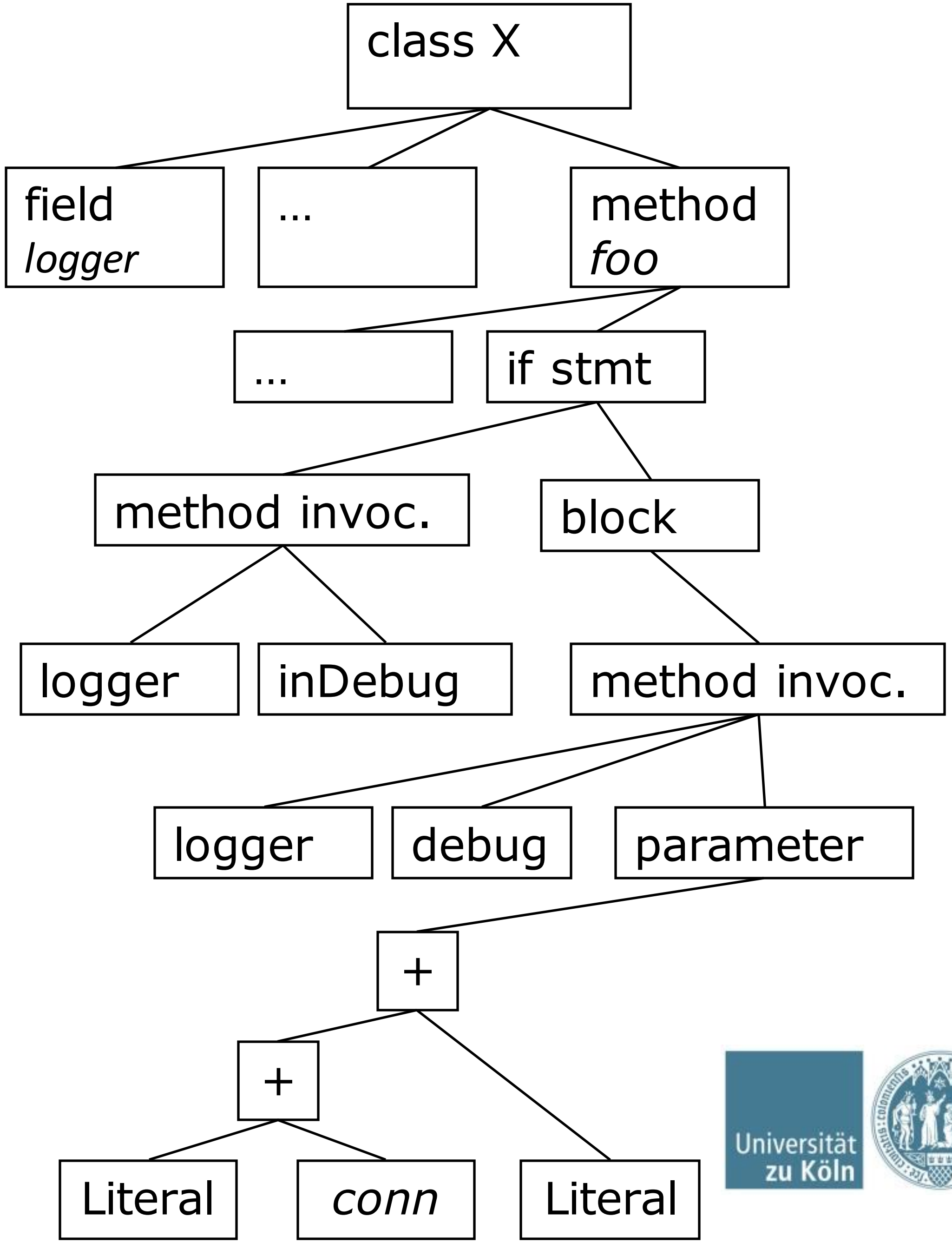
Each node of the tree denotes a construct occurring in the code.

The syntax is “abstract” in the sense that it does not represent every detail appearing in the real syntax, but rather just the **structural or content-related** details.

For instance, grouping parentheses are implicit in the tree structure, so these do not have to be represented as separate nodes. Likewise, a syntactic construct like an if-condition-then statement may be denoted by means of a single node with three branches.

# Abstract Syntax Tree

```
class X {
  Logger logger;
  …
  public void foo() {
    …
    if (logger.inDebug()) {
      logger.debug("We have " + conn +
                   "connections.");
    }
  }
}
```




**ASTs for Real Programs**

"Real" ASTs are way more detailed:

https://astexplorer.net

# Types of Structural Analysis

## Static Type Checking

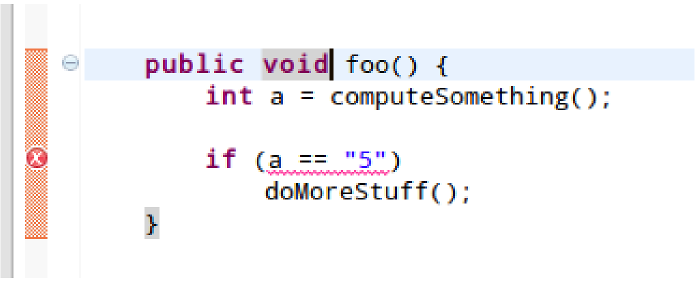
- The process of verifying and enforcing the **constraints of types**.
- **Static type checking** is the process of verifying the type safety of a program based on analysis of a program's text (source code)

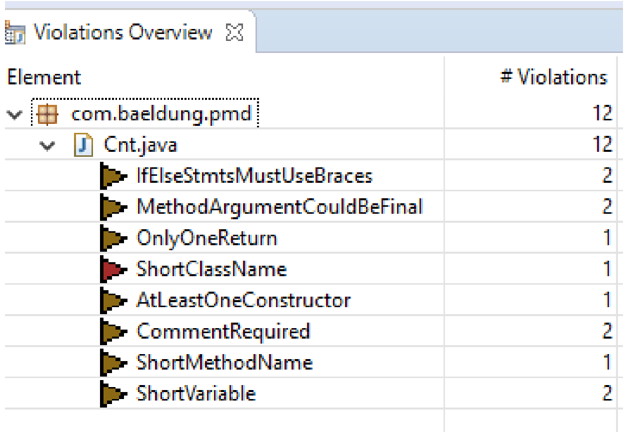
## Code Style Checks

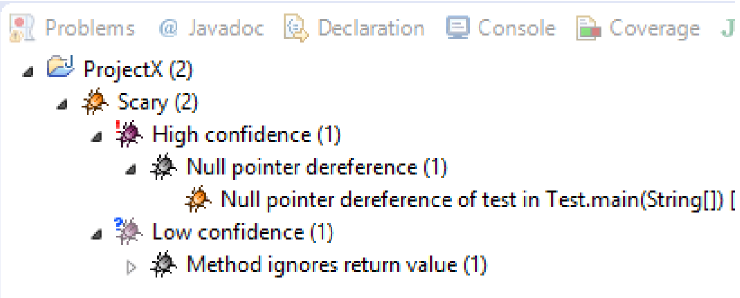
Analysis that check conformance to certain coding styles

## Bug Finding

Analysis that checks the code for typical bug patterns



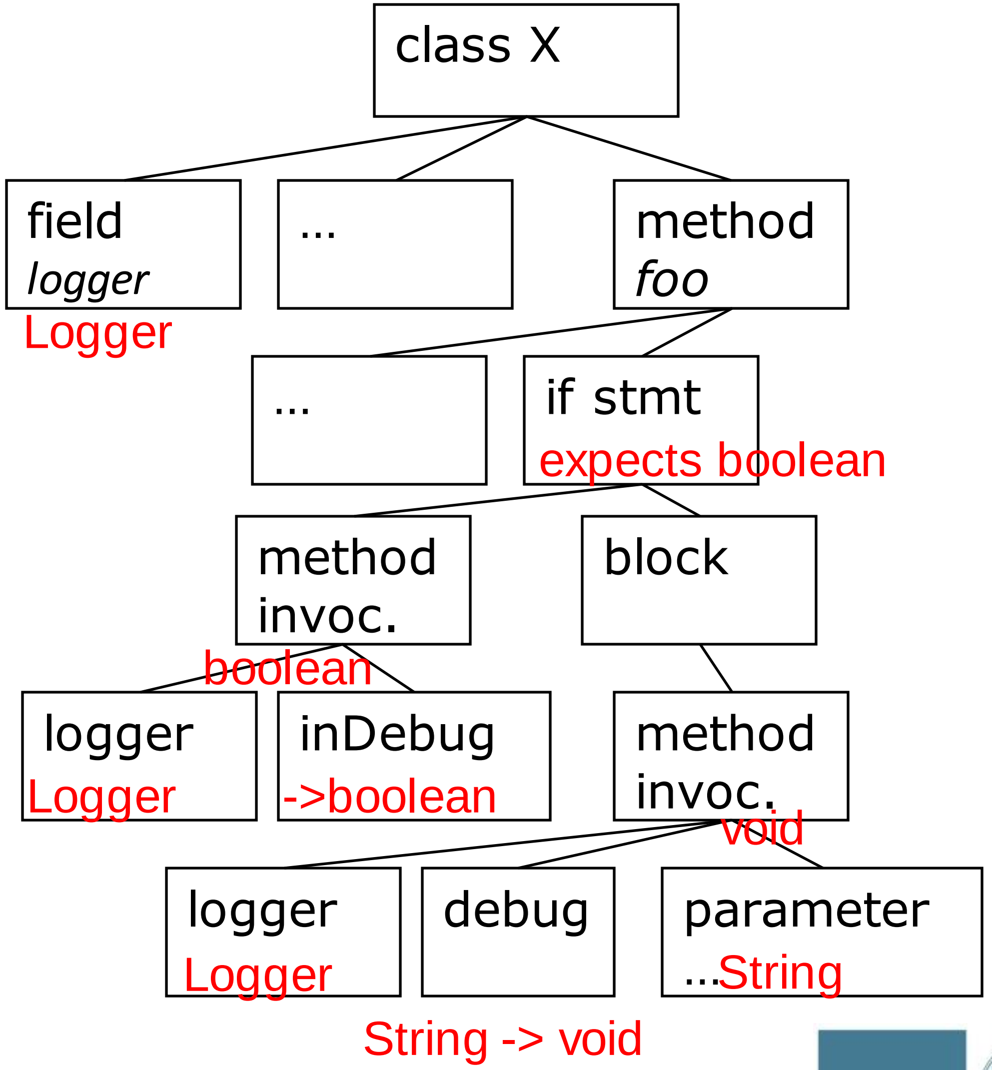



# Type Checking

```
class X {
  Logger logger;
  …
  public void foo() {
    …
    if (logger.inDebug()) {
      logger.debug("We have " + conn +
                   "connections.");
    }
  }
}

class Logger {
   boolean inDebug() {…}
   void debug(String msg) {…}
}
```



# Code Style Checks

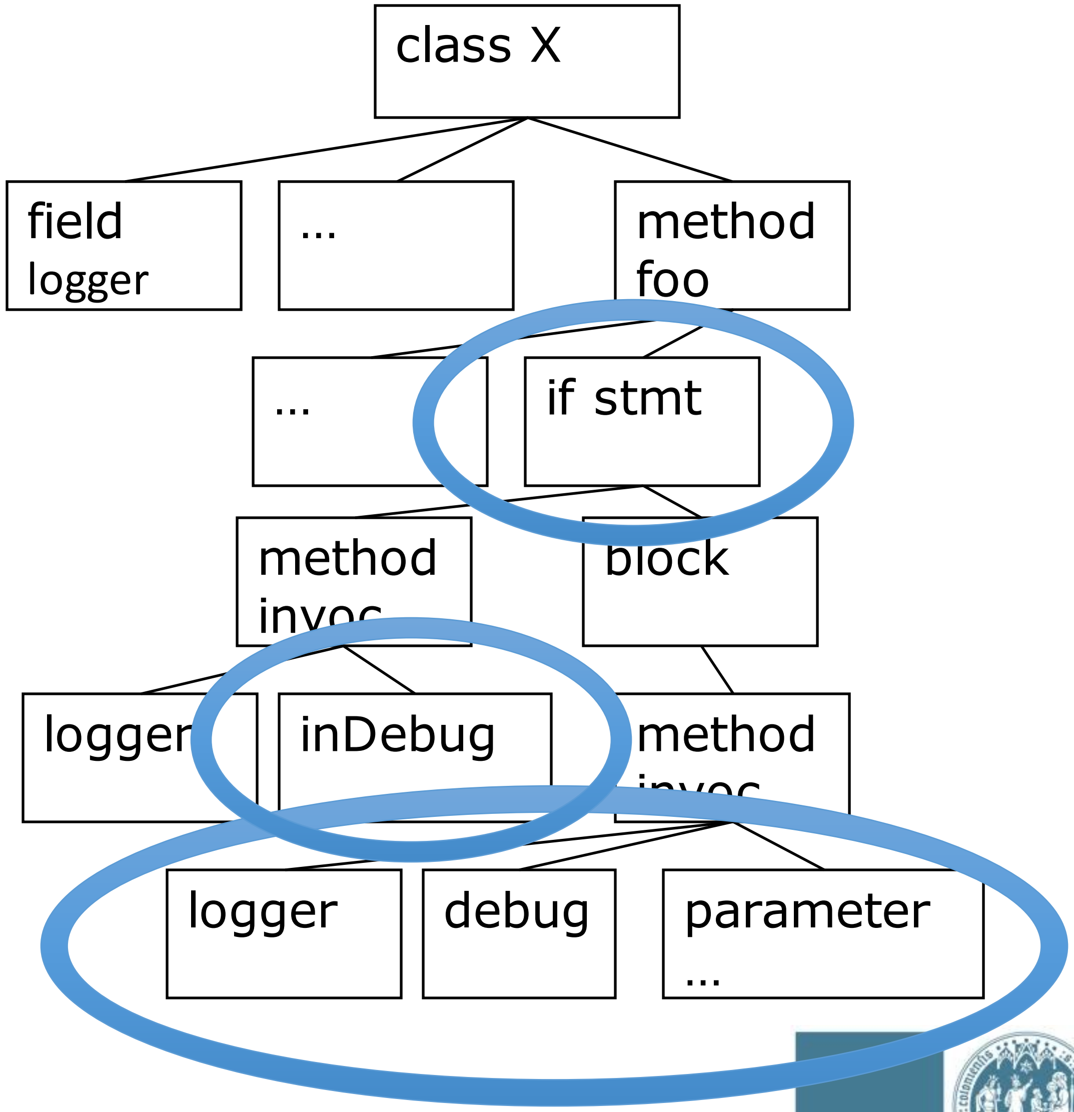
**AST Walker**

A check that traverses the AST to find violations of rules or properties

**Example**

No string shall be logged outside of `Logger.inDebug()` check.

- Look for `Logger.debug()` calls
- Check if these are children of an `if (Logger.inDebug())` node



# Bug Finding

## AST Walker

Bug finding works like Code Style Checks. An AST walker searches for bug patterns.

```java
public Boolean decide() {
    if (computeSomething()==3)
        return Boolean.TRUE;
    if (computeSomething()==4)
        return false;
    return null;
}
```

Problem | Javadoc | Declarati | Search | Console | Coverag | History | Bug Info | Bug Expl

A.java: 69

Navigation

**Bug**: FBTest.decide() has Boolean return type and returns explicit null

A method that returns either Boolean.TRUE, Boolean.FALSE or null is an accident waiting to happen. This method can be invoked as though it returned a value of type boolean, and the compiler will insert automatic unboxing of the Boolean value. If a null value is returned, this will result in a NullPointerException.

**Confidence**: Normal, **Rank**: Troubling (14)
**Pattern**: NP_BOOLEAN_RETURN_NULL
**Type**: NP, **Category**: BAD_PRACTICE (Bad practice)

# Structural Analysis Summary

| Structural Analysis |
| --- |
| • Analysis of token streams (text) or code structures.<br>• Suitable for finding patterns.<br>• Checks local and structural properties that are independent from any execution path. |

| Tools for Java |
| --- |
| Checkstyle: Checks coding style and conventions |
| PMD: Identifies bad practices<br>• Complicated statements<br>• Inefficient code<br>• … |
| Findbugs: Specialized on bug patterns |

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# Control Flow Analysis

# Control Flow Analysis

**Idea**

Analysis of **all possible executions** via paths in a **control flow graph**

- Checking specific properties at each **program point**.
- Including exception handling, function calls, etc.

**Abstraction**

- Definition of an **abstract domain** that considers **only** the values/states relevant to the property
- Testing the abstract state instead of any concrete values in all possible paths of the program

# Propagate state through the CFG

**Program Points**

Every edge in a control flow graph denotes a *program point*.

Program points characterize the possible conditions that hold **before entering** and **after leaving** a node in the CFG.

**Control Flow Analysis**

For every node in the CFG:

- Evaluate the state before entering the node
- What is the possible state after leaving the node (apply the transfer function)?

Iterate over all successor nodes in the CFG until no program point's state changes anymore.

**Result: A state in every program point**

# Example: Check if DB connection is always closed after executing a method

**Abstraction**

- 3 abstract states of interest: `open`, `closed`, `maybe-open`
- Raise a warning if at the end of a method, the state is not `closed`.

**Transfer function**

Transfer functions specify how to evaluate program expressions on abstract values.

**Transfer function for example**

`openDBconn()` changes state to `open`

`closeDBconn()` changes state to `closed`

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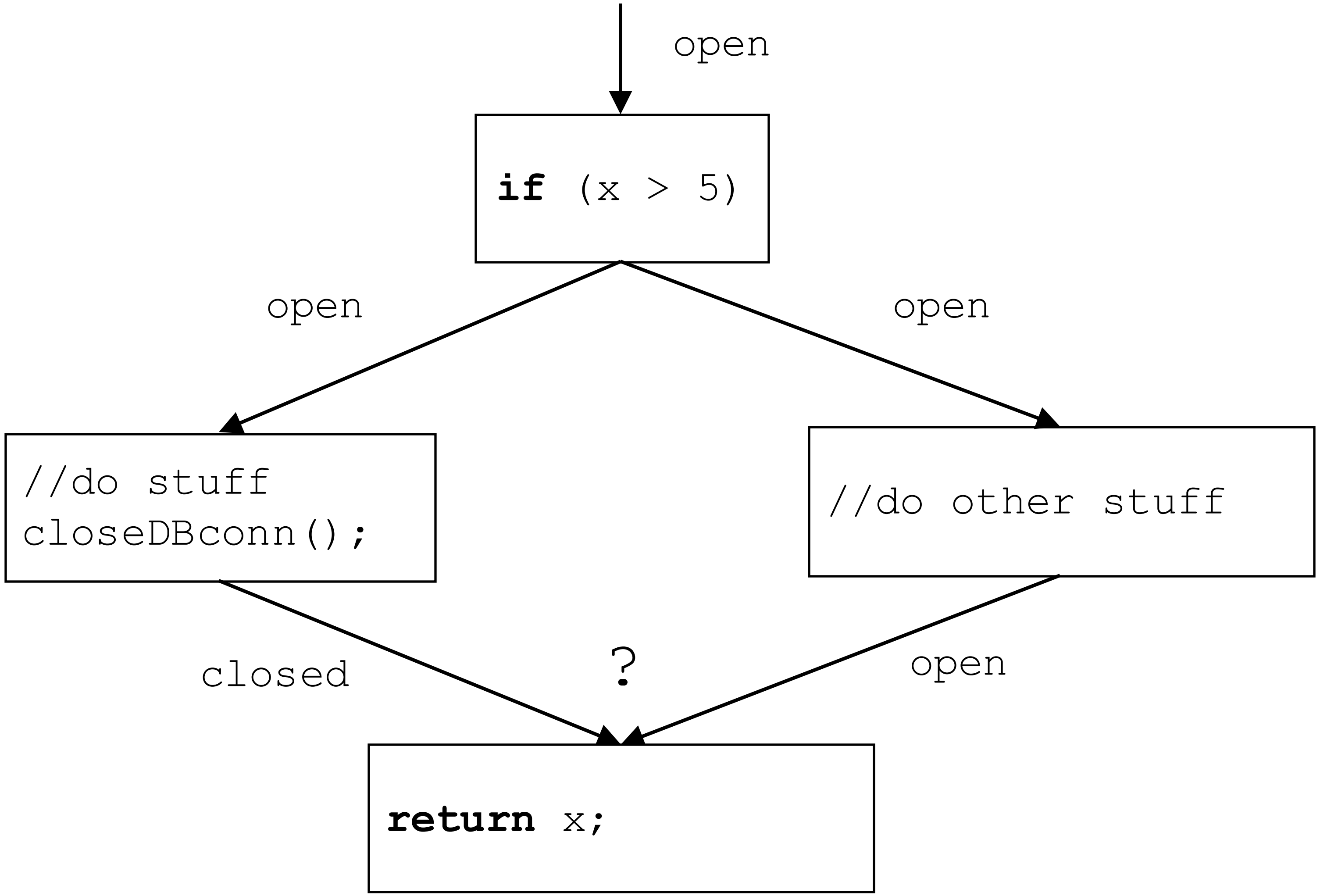
# What if control flow merges?




**Join function**

Join functions specify how to assess the state when the two control flows merge.

Usually, the merge must be resolved to include all possible preconditions.

**Join function for example**

Join(`open`, `open`) → `open`

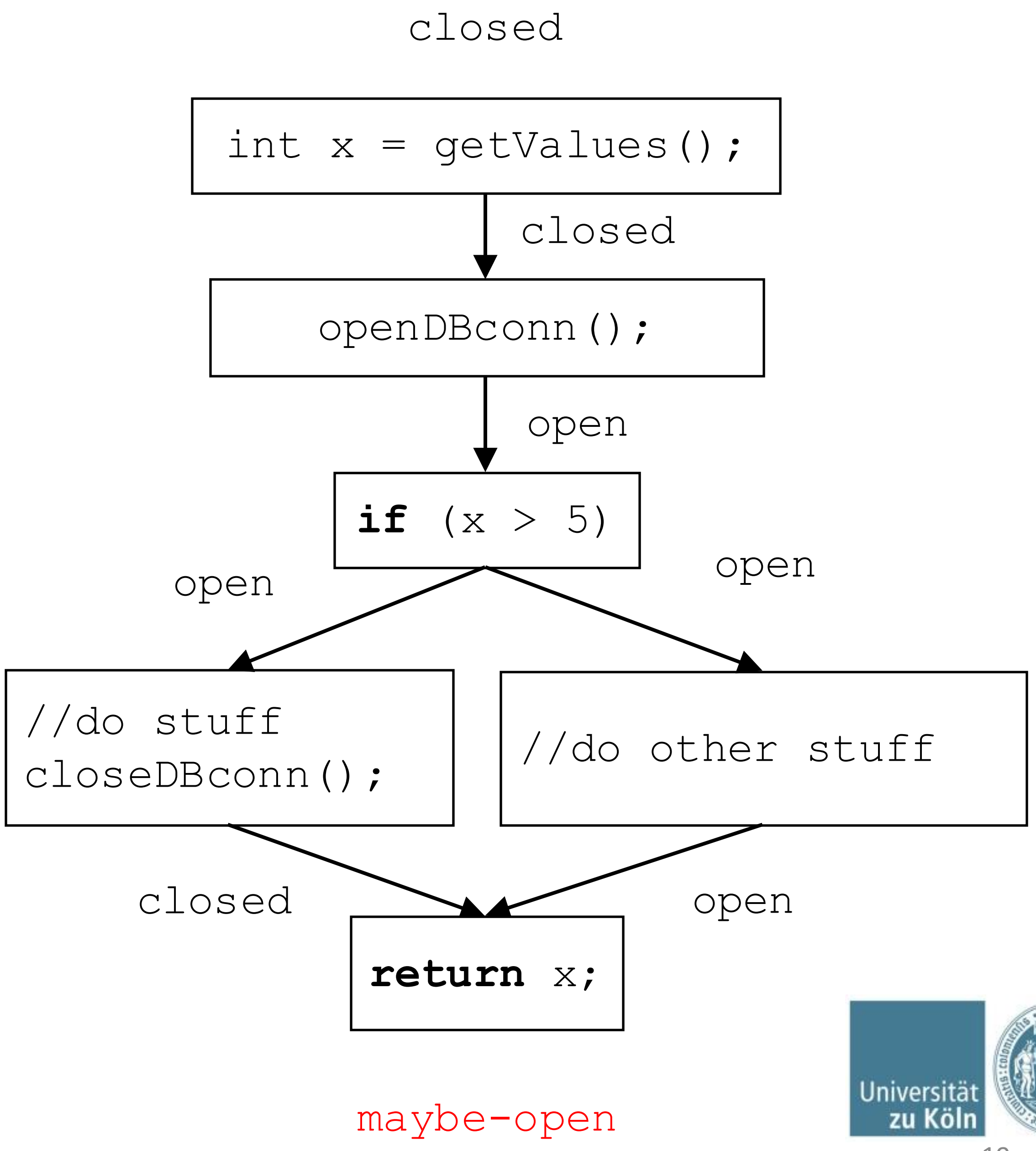
Join(`closed`, `closed`) → `closed`

Join(`open`, `closed`)
→ `maybe-open`

Join(`maybe-open`, `*`)
→ `maybe-open`

# Iterate over the CFG

```
int foo() {
  int x = getValue();
  openDBconn();
  if (x > 5){
    //do stuff
    closeDBconn();
  }
  else{
    // do other stuff
  }
  return x;
}
```




# Data Flow Analysis

# Data Flow Analysis

## Data Flow vs. Control Flow Analysis

**Data flow:** Tracks and manipulates abstract values for a program's variables

**Control Flow:** Tracks and manipulates the global state of a function.

The analysis itself works similar for both types, except for that, in DFA, a state for each variable must be maintained.

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# Example: Zero-Detection

**Problem**

Given a program P, determine which variables may be 0.

**Selecting an appropriate abstraction**

Instead of evaluating all possible values/states of a program, we select an appropriate abstraction for numbers:

- We represent all non-zero numbers by the label `NZ`
- We represent 0 by the label `Z`
- We represent all potentially 0 numbers by the label `MZ` (maybe zero)

**Why is this problem interesting?**

- Check for division by 0
- Check for empty arrays
- Check for error codes
- …

# Example: Zero detection

**Working with the abstraction**

```
x = 5 // label(x) = NZ
z = -5 // label(z) = NZ
p = 0 // label(p) = Z
x = b ? 1 : 0 // label(x) = MZ
y = y * 0 // label(x) = Z
```

**Transfer function for example**

- NZ + NZ = MZ
- Z + Z = Z
- Z * NZ = Z
- NZ * NZ = NZ
- …

**concrete**

```
a = 5;
b = -3;
c = a * b;
d = 0;
e = c * d;
f = 10 / e;
```

**abstract**

```
a = NZ;
b = NZ;
c = NZ;
d = Z;
e = Z;
f = NZ;
```

**Join function for example**

- Join(Z, Z) → Z
- Join(NZ, NZ) → NZ
- Join(Z, NZ) → MZ
- Join(MZ, *) → MZ

← Division by zero indicated by the NZ label

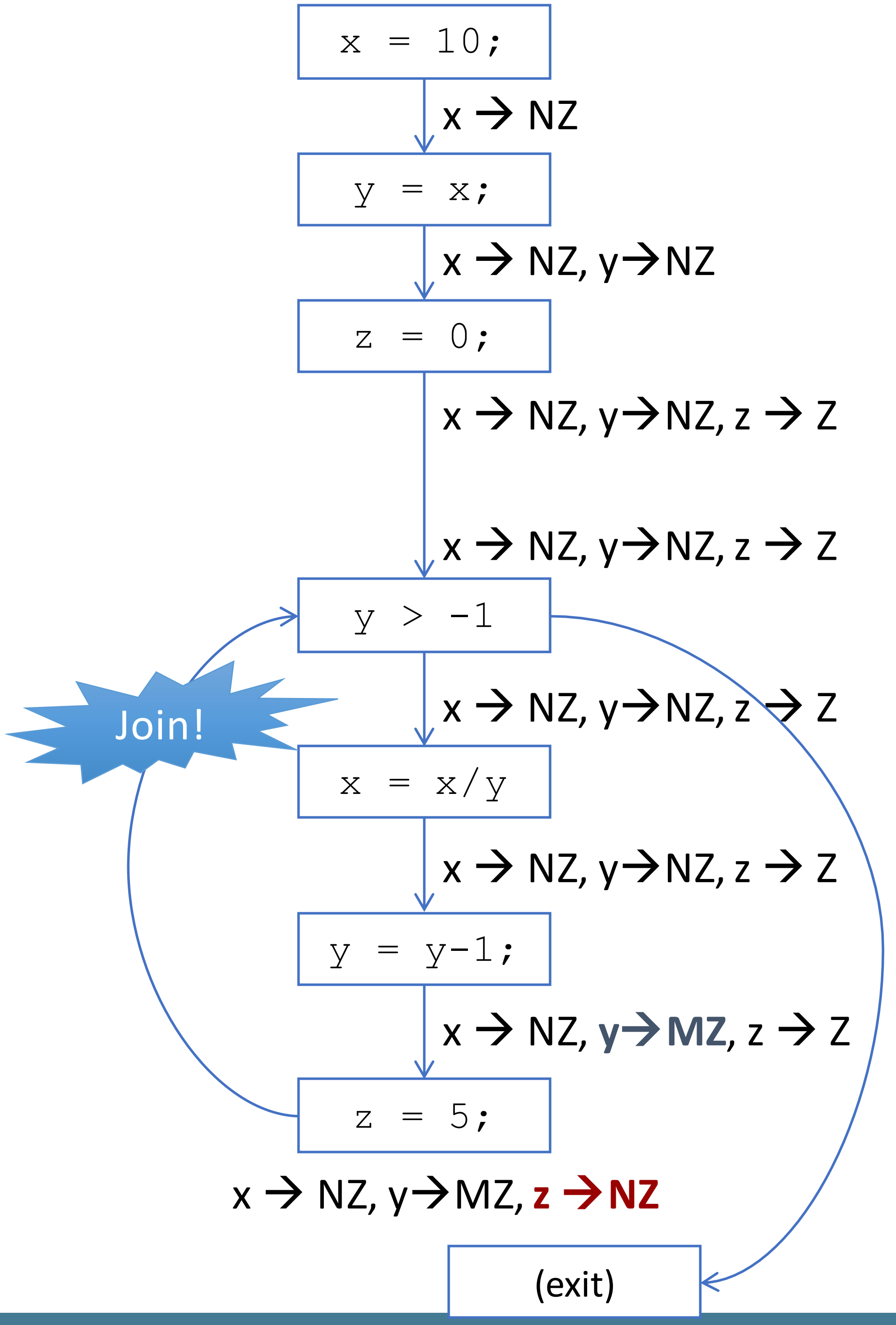
## Join Function

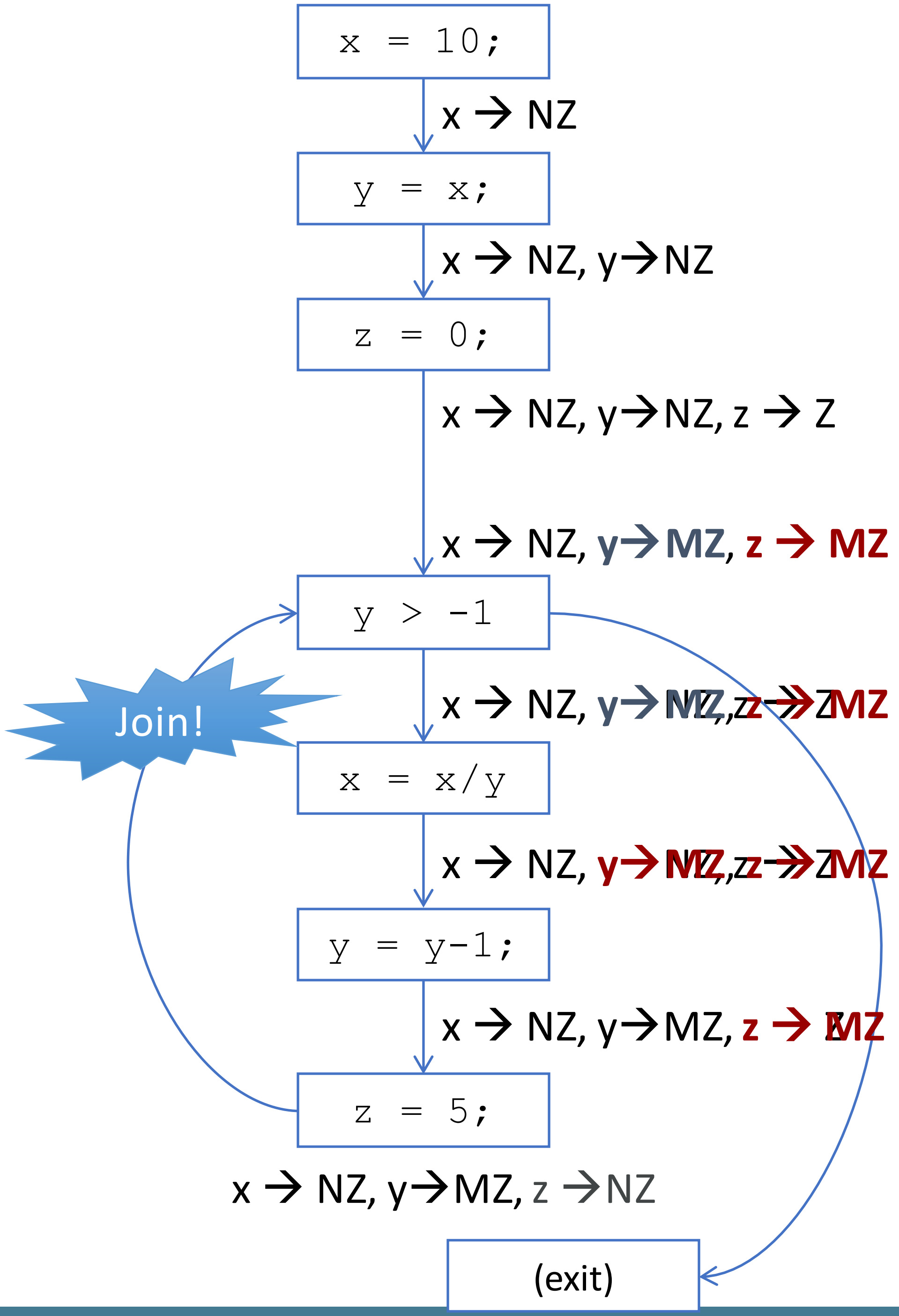
x: Join(NZ, NZ) → NZ

y: Join(MZ, NZ) → MZ

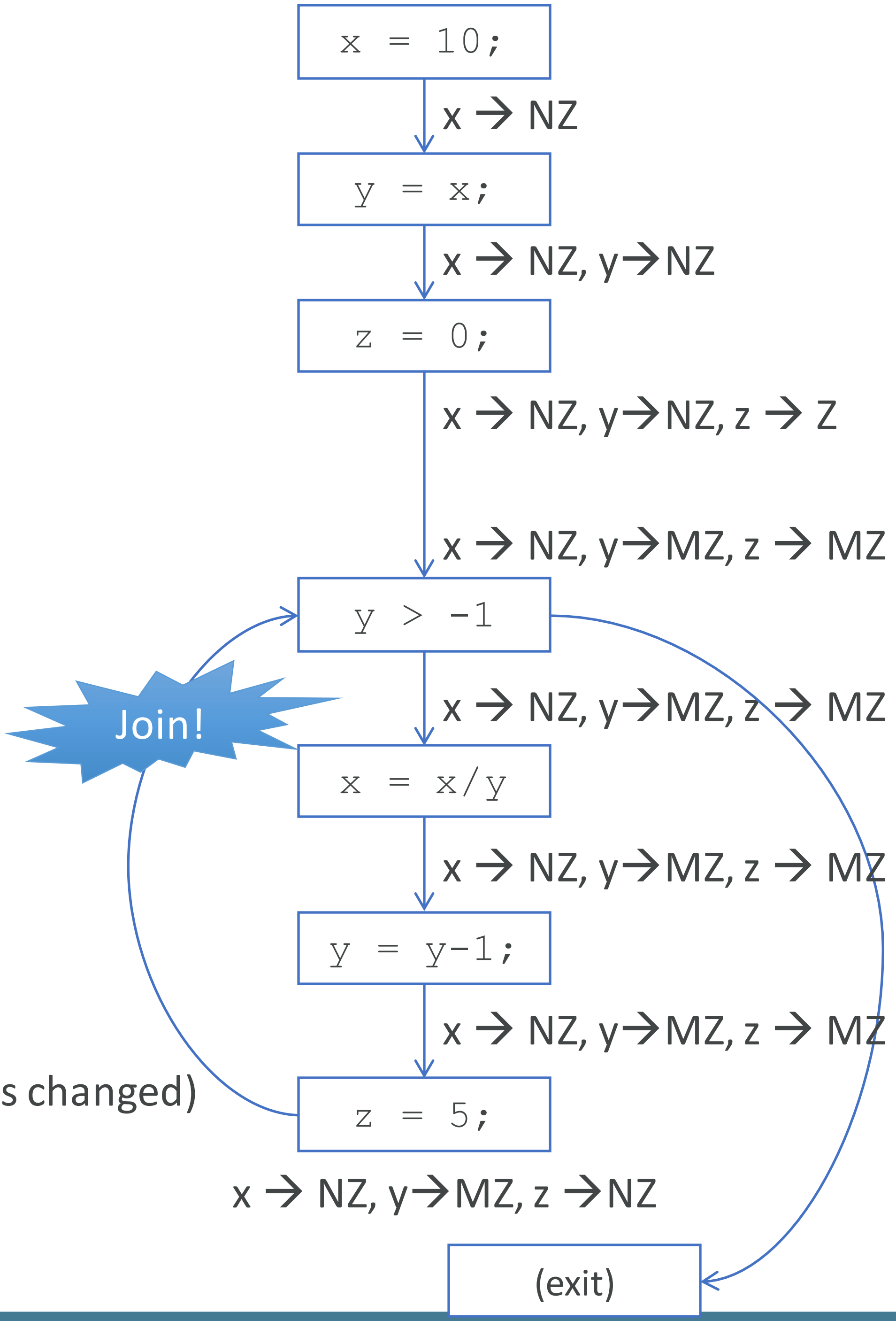
z: Join(NZ, Z) → MZ

```
x = 10;
y = x;
z = 0;
while (y > -1) {
   x = x/y;
   y = y-1;
   z = 5;
}
```



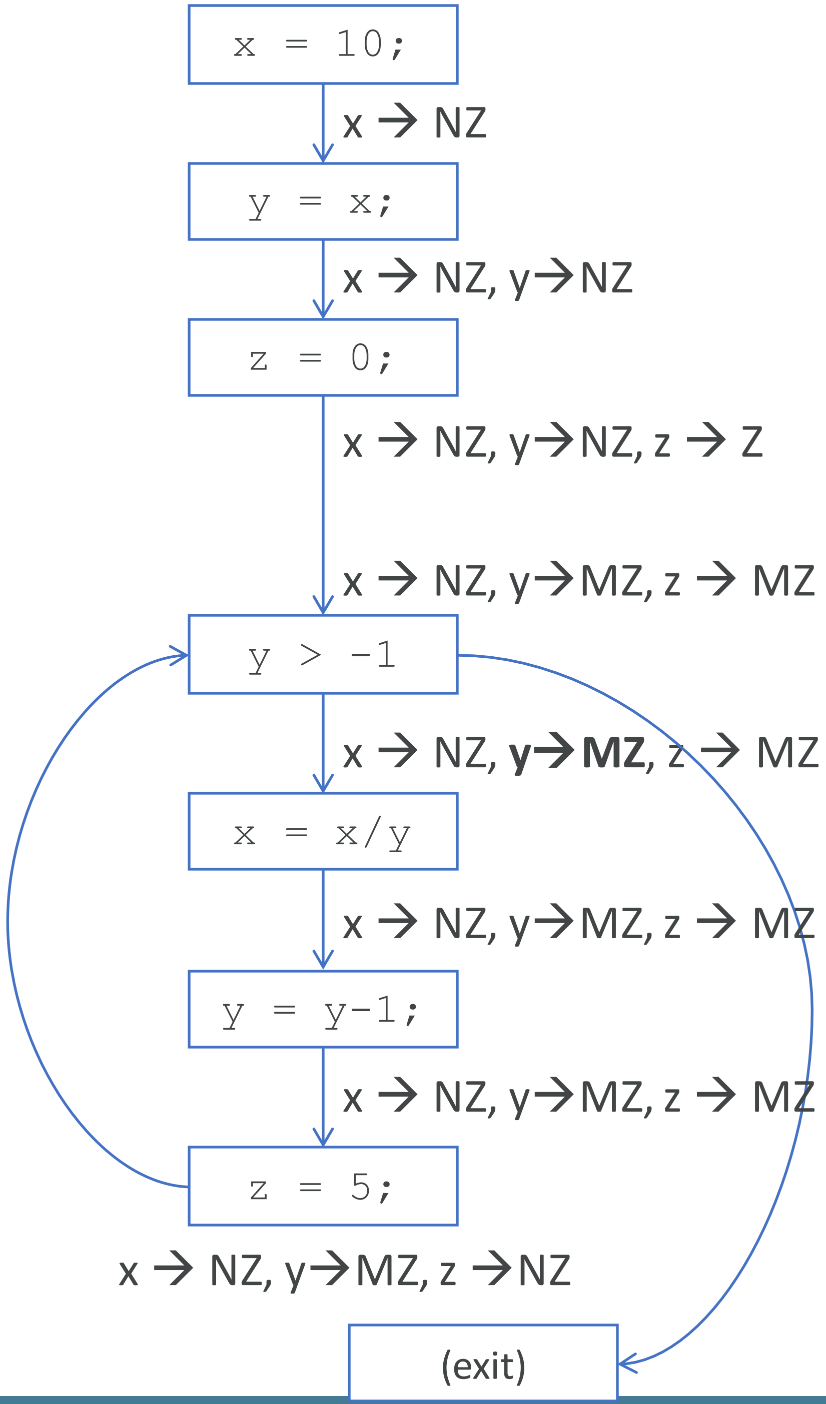



(end of iteration 2)




(end of iteration 3; nothing has changed)

Warning! Possible division by zero error!



# Static Code Analysis

| Summary |
|---|
| • Static analysis: systematic automated analysis of the code, without executing the program<br>  • Structural analysis: looking for patterns in code<br>  • Control Flow Analysis: Analyze all possible paths (global property)<br>  • Data Flow Analysis: Analyzing possible (abstract) values of variables on all paths<br>• All static analyses are *unsound* or *incomplete* or both |

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