软件分析

南京大学

计算机科学与技术系

程序设计语言与静态分析研究组

李樾 谭添

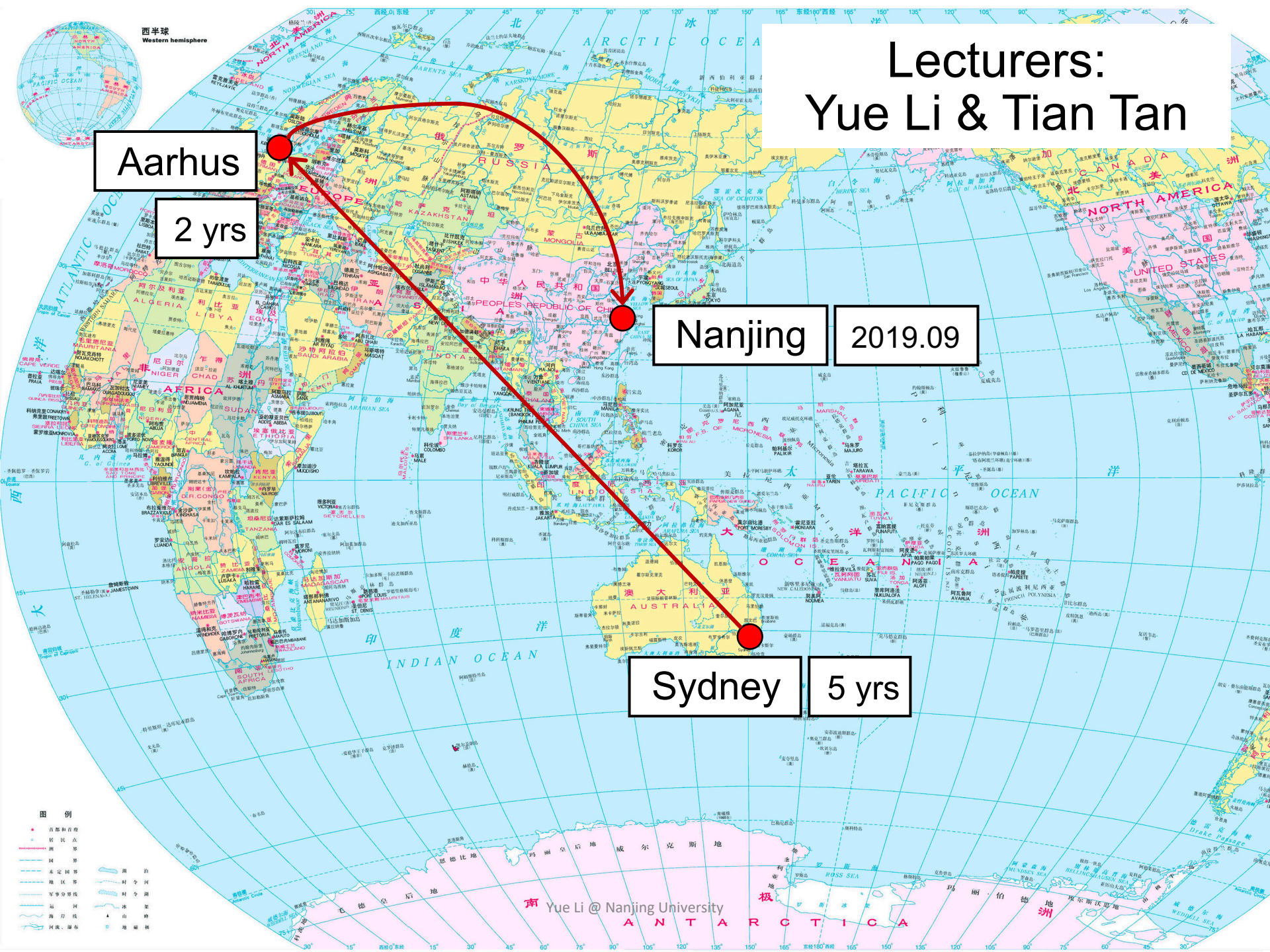
Static Program Analysis

Introduction

Nanjing University

Yue Li

Fall 2020


Lecturers:
Yue Li & Tian Tan
Aarhus
2 yrs
Nanjing
2019.09
Sydney
5 yrs
Yue Li @ Nanjing University

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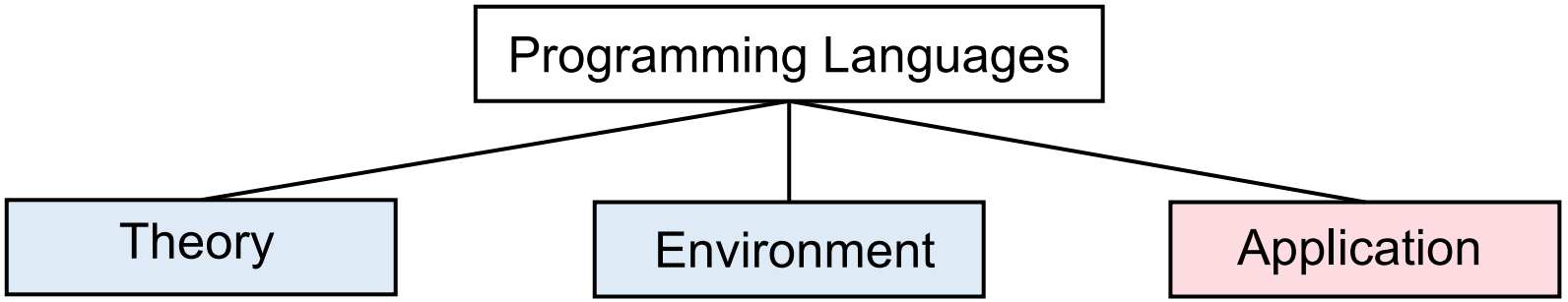
1. PL and Static Analysis
2. Why We Learn Static Analysis?
3. What is Static Analysis?
4. Static Analysis Features and Examples
5. Teaching Plan
6. Evaluation Criteria

Static Program Analysis (Static Analysis)

Programming Languages

Static Program Analysis (Static Analysis)

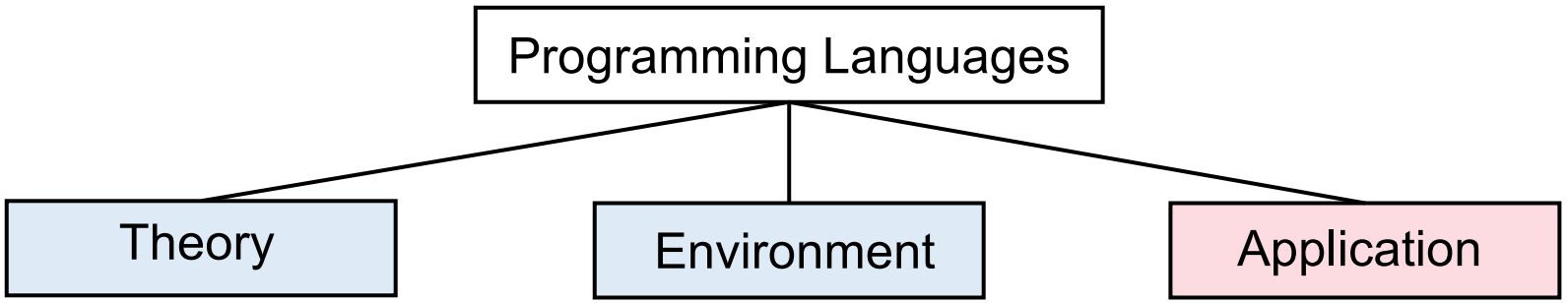


- Language design
- Type system
- Semantics and logics
- … …

- Compilers
- Runtime system
- … …

- Program analysis
- Program verification
- Program synthesis
- … …

Static Program Analysis (Static Analysis)



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Background: In the last decade, the language cores had few changes, but the programs became significantly larger and more complicated.

Challenge: How to ensure the reliability, security and other promises of large-scale and complex programs?

Why We Need Static Analysis?

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- Program Reliability

  Null pointer dereference, memory leak, etc.

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  Examples

- Program Understanding

  IDE call hierarchy, type indication, etc.

  Examples

Market of Static Analysis

Academia

Programming Languages

Software Engineering

Systems

Security

… …

Any directions that rely on programs

Industries

Market of Static Analysis

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Sec

… …

Any directions that rely on programs

Static analysis people are urgently needed !

Industries


ORACLE

Google

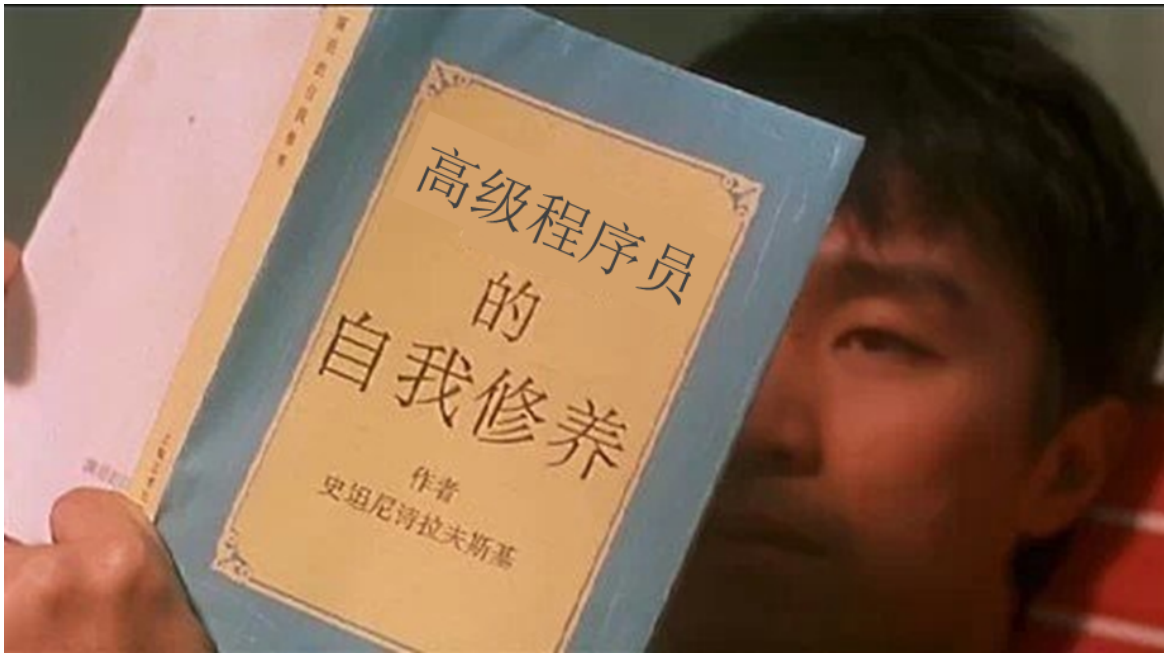
HUAWEI

Alibaba.com

前方中文预警

深入学习静态程序分析——附加值

- 更深入地理解编程语言的语法、语义（不枯燥）
- 自然而然地写出更可靠、更安全、更高效的程序



Static Analysis

Static analysis analyzes a program *P* to reason about its behaviors and determines whether it satisfies some properties before running *P*.

- Does *P* contain any private information leaks?
- Does *P* dereference any null pointers?
- Are all the cast operations in *P* safe?
- Can *v1* and *v2* in *P* point to the same memory location?
- Will certain *assert* statements in *P* fail?
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Unfortunately, by **Rice's Theorem**, there is no such approach to determine whether P satisfies such non-trivial properties, i.e., giving ***exact answer***: Yes or No

Rice's Theorem

"Any non-trivial property of the behavior of programs in a r.e. language is undecidable."

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Perfect static analysis

AND

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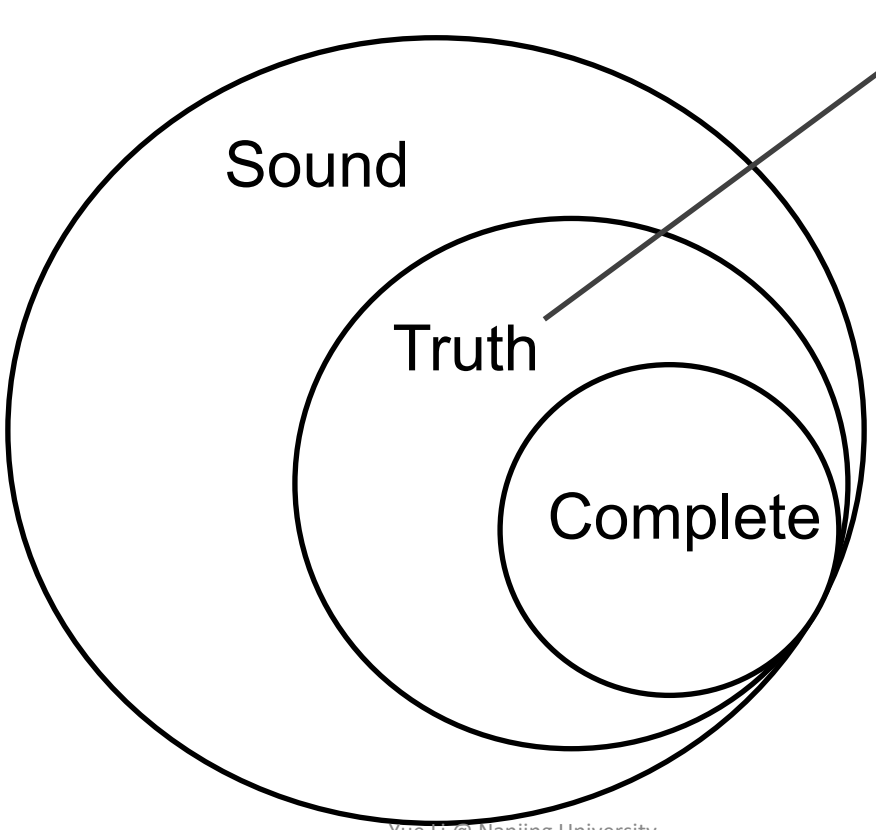

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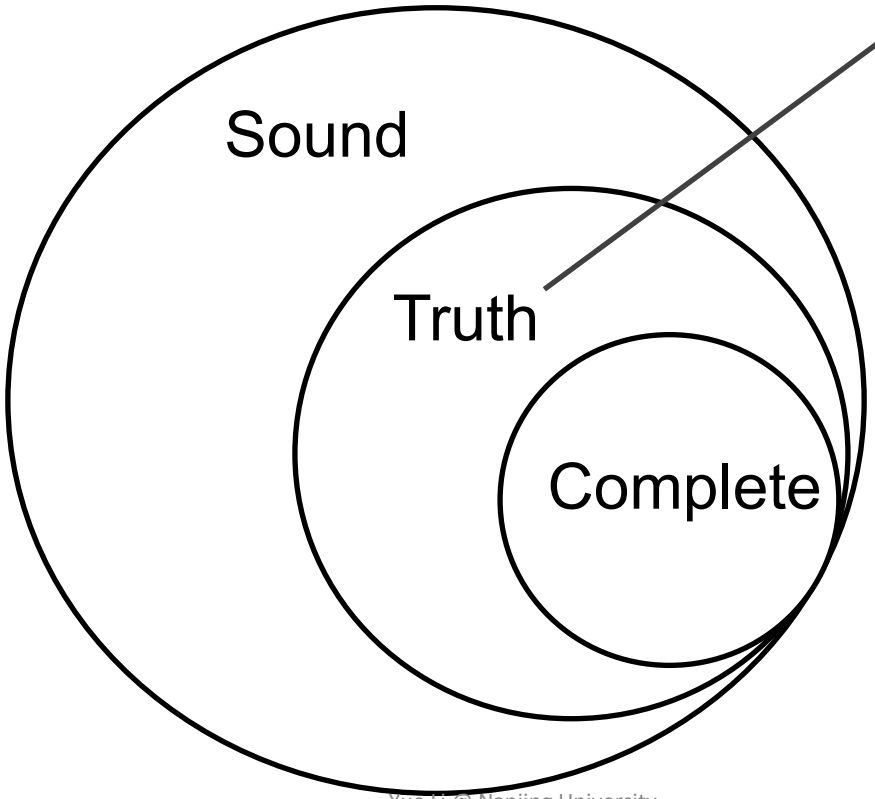

Sound & Complete

All possible true program behaviors

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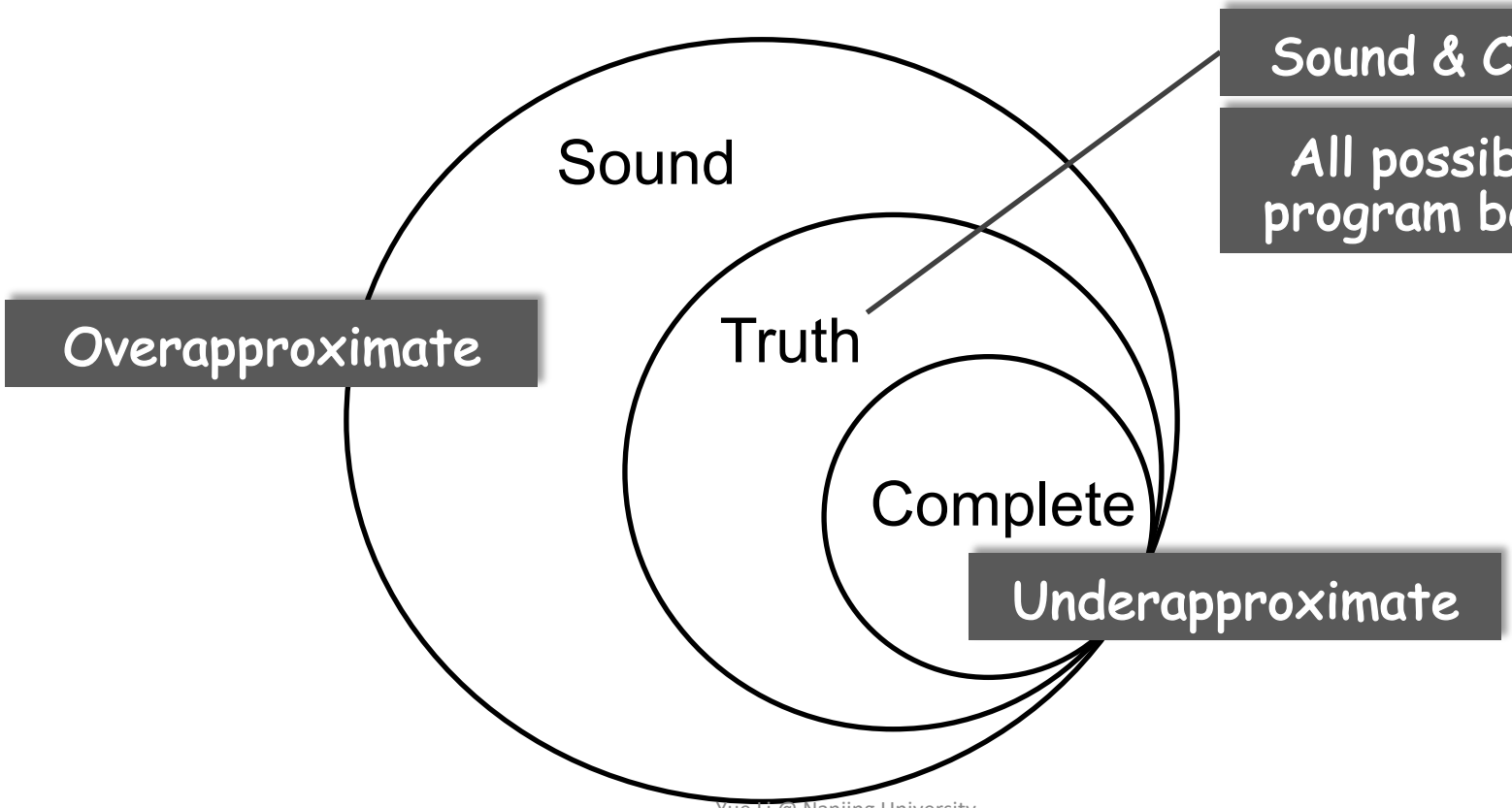

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Perfect static analysis

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Rice

Sound & Complete

All possible true am behaviors

Sound

NO perfect static analysis!

The end of story ???

Complete

Underapproximate

Perfect static analysis

Rice

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Useful static analysis

OR

- Compromise soundness (false negatives)
- Compromise completeness (false positives)

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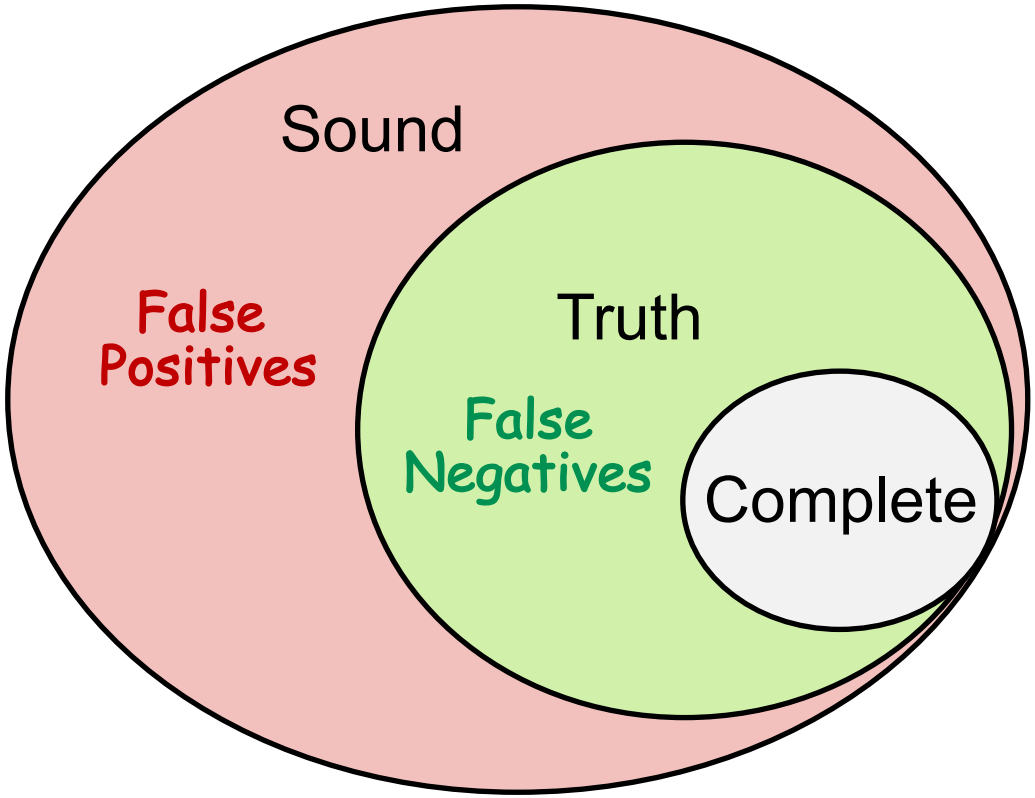

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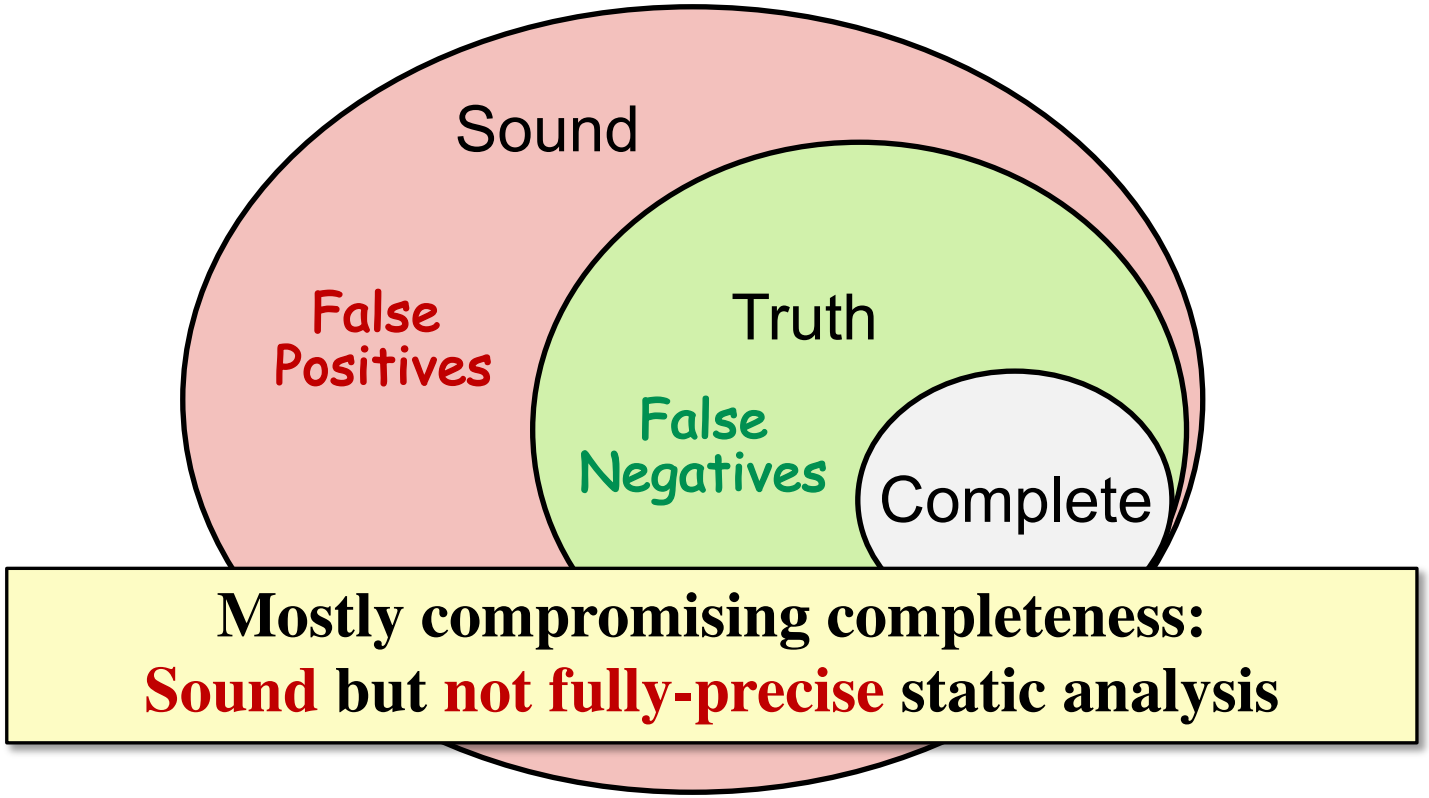

Mostly compromising completeness:
Sound but not fully-precise static analysis

Necessity of Soundness

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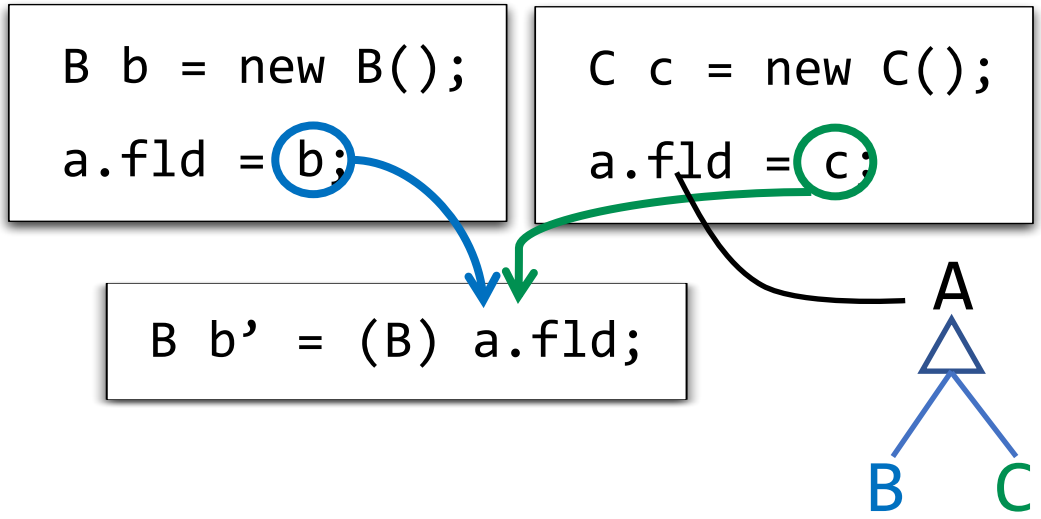
Unsound

"Safe Cast": wrong conclusion



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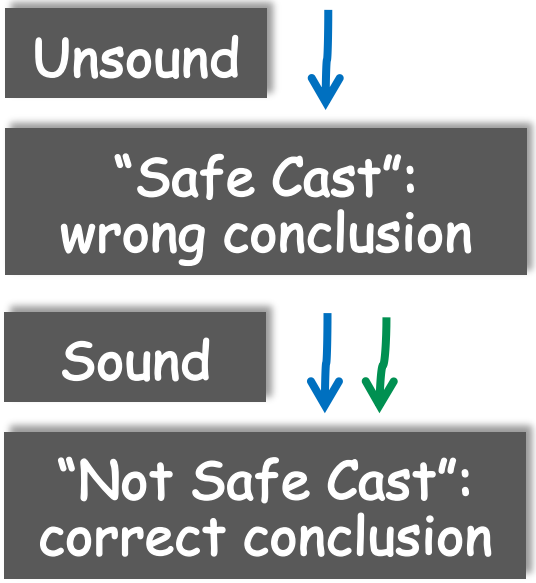

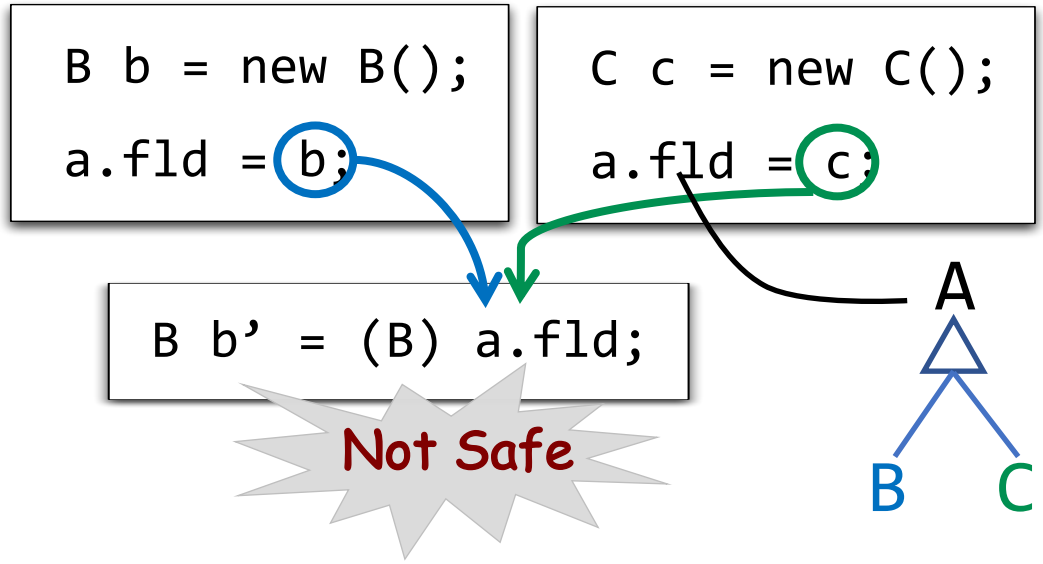

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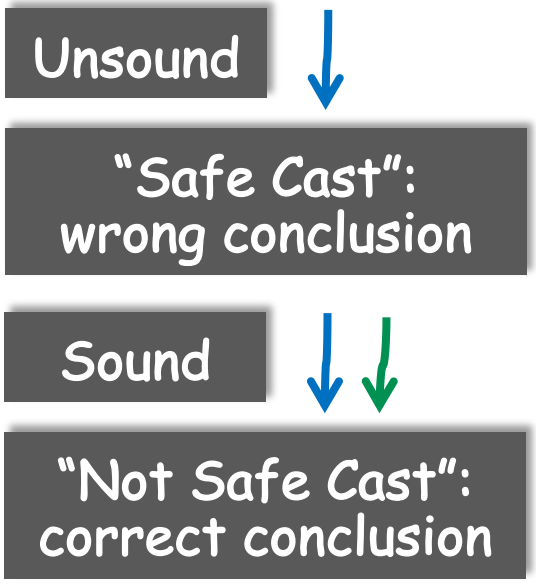

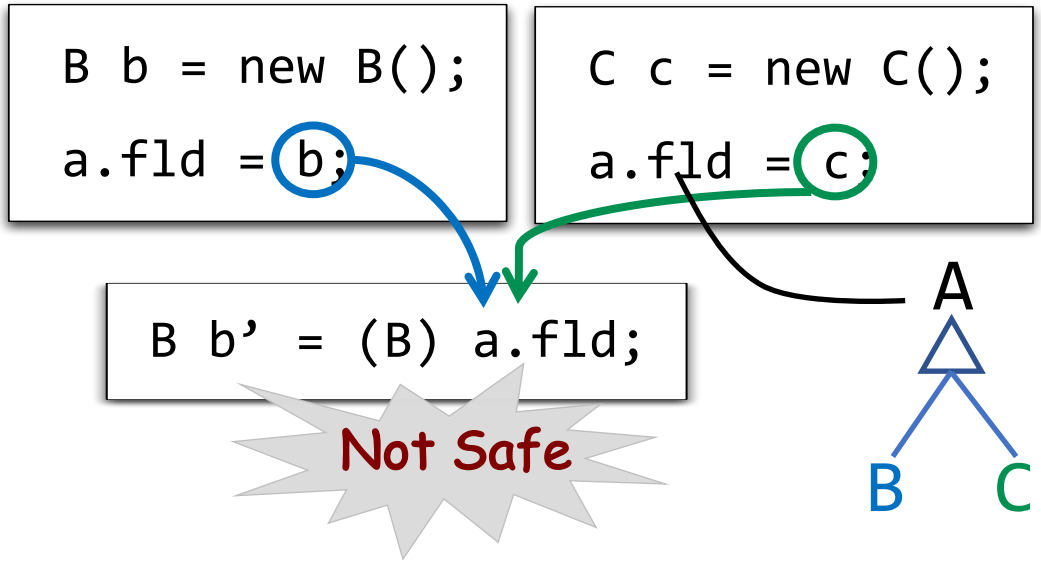

- Soundness is also preferable to other (static-analysis) applications for which soundness is not demanded, e.g., *bug detection*, as better soundness implies more bugs could be found.

Static Analysis — Bird's Eye View

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    if(input)
       x = 1;
    else
       x = 0;
→ x = ?
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Static Analysis: ensure (or get close to) soundness, while making good trade-offs between analysis precision and analysis speed.

For most static analyses
(may analysis)

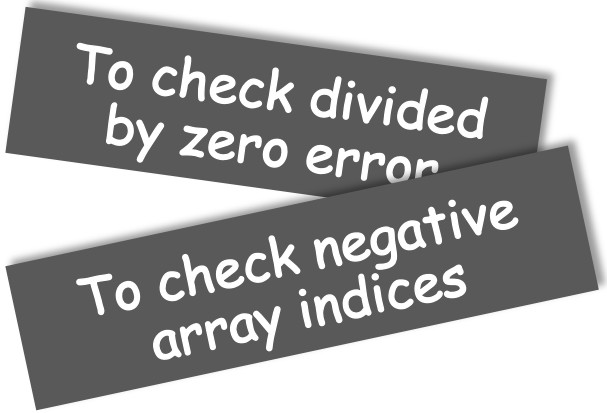
Two Words to Conclude Static Analysis

Abstraction + **Over-approximation**

Static Analysis — An Example

Determine the sign (+, -, or 0) of all the variables of a given program.

- Abstraction
- Over-approximation
  - Transfer functions
  - Control flows



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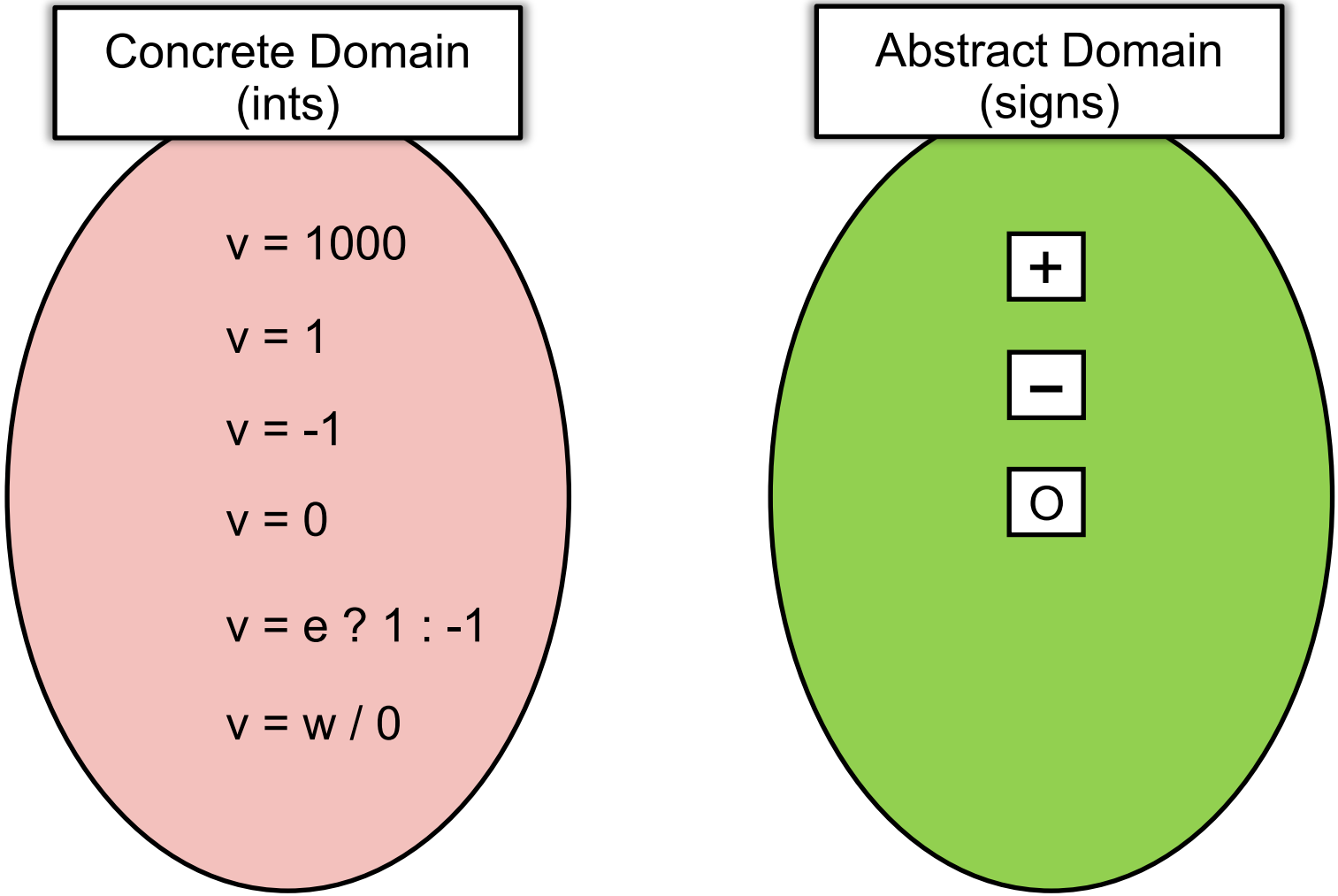

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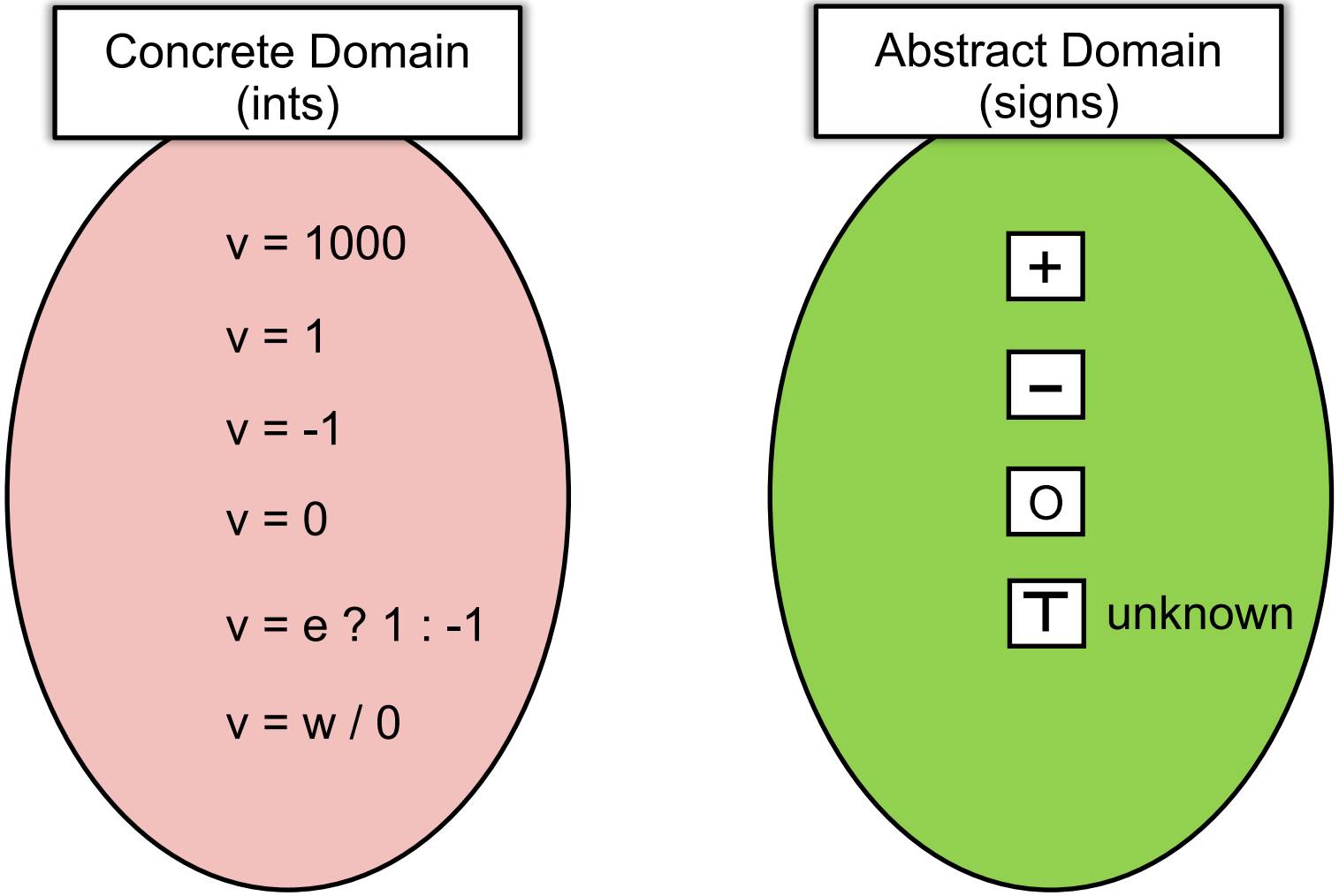

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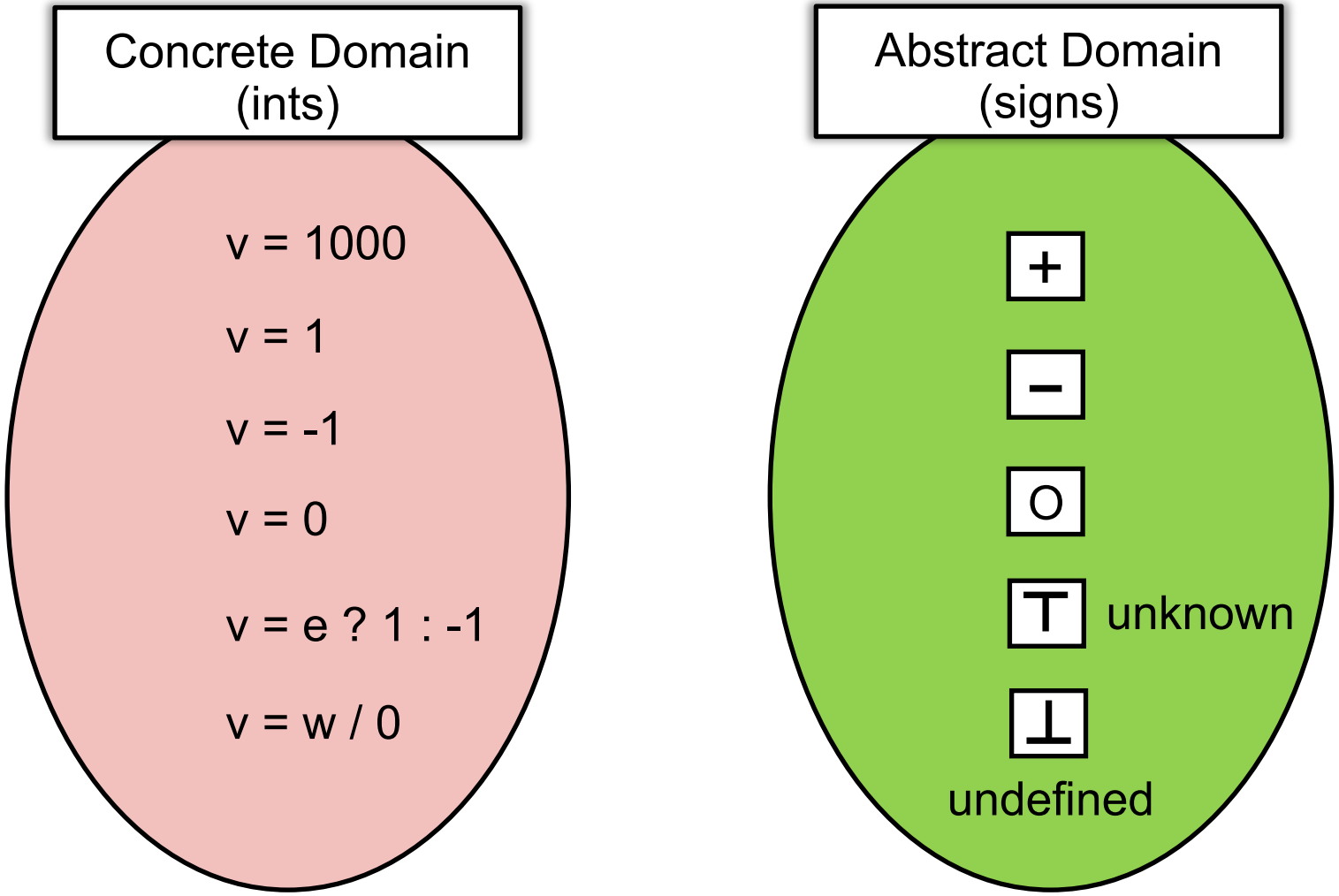

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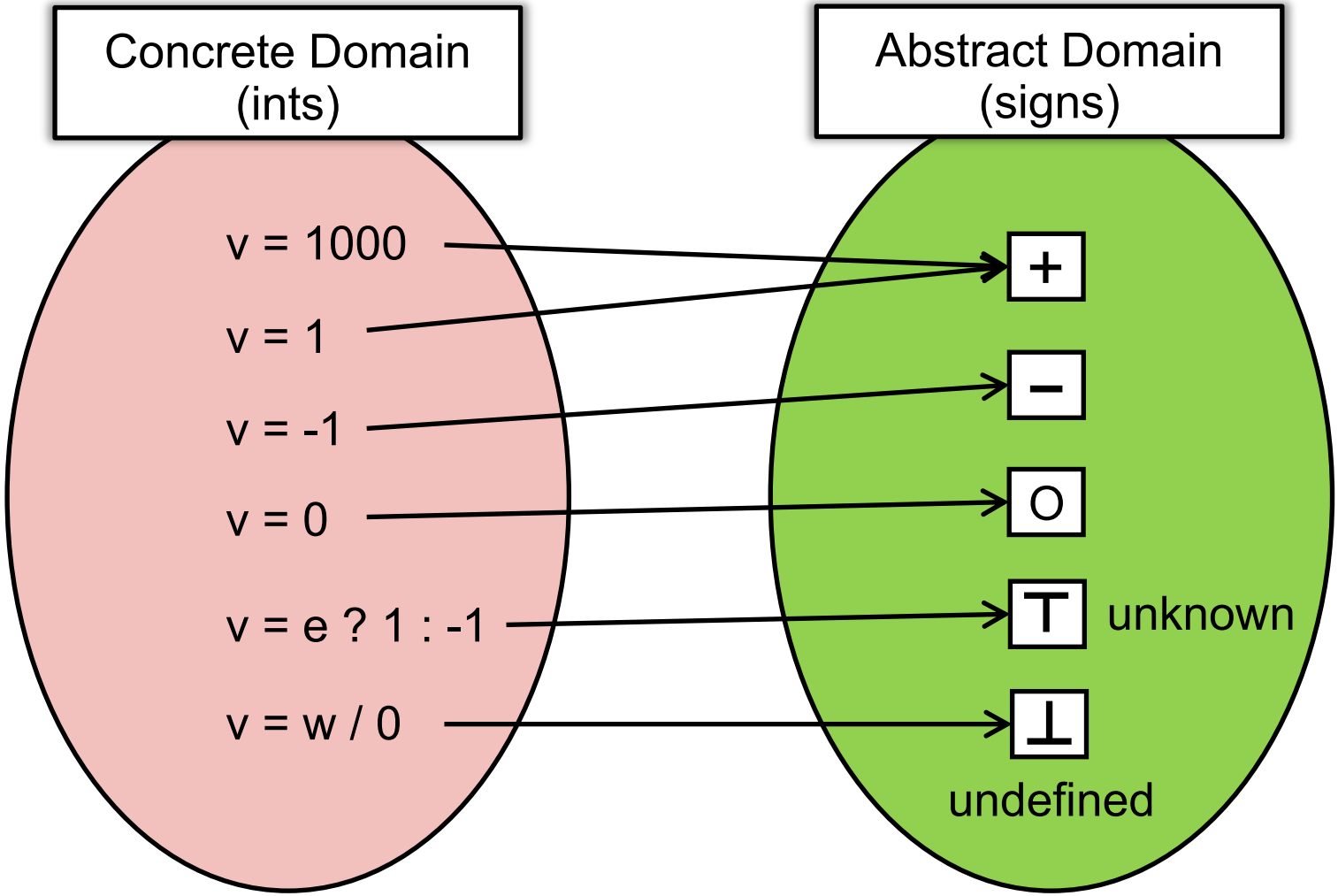

Over-approximation: Transfer Functions

- In static analysis, transfer functions define how to evaluate different program statements on abstract values.
- Transfer functions are defined according to “analysis problem” and the “semantics” of different program statements.

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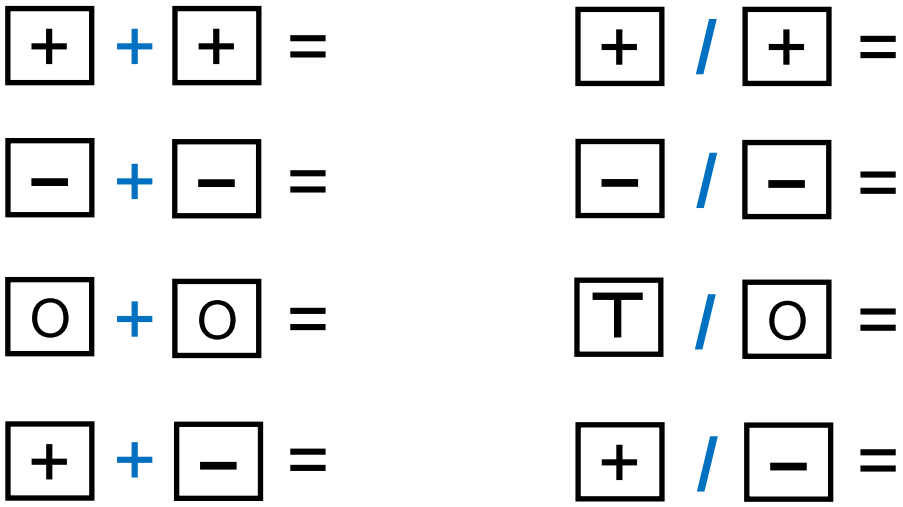

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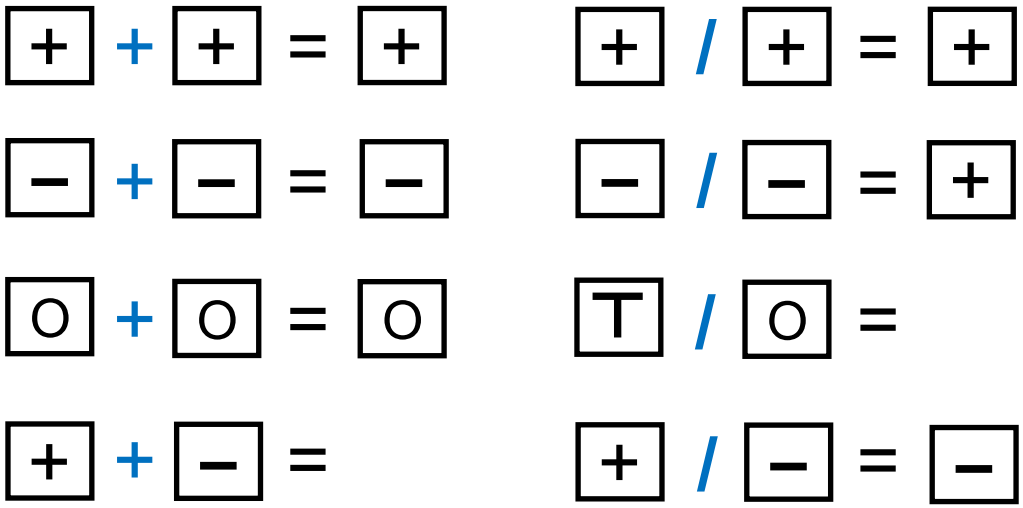

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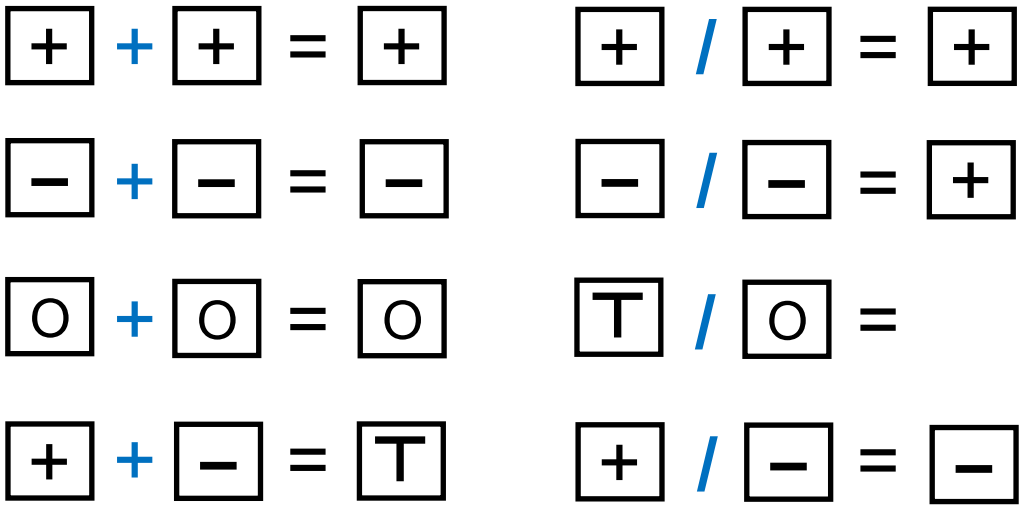

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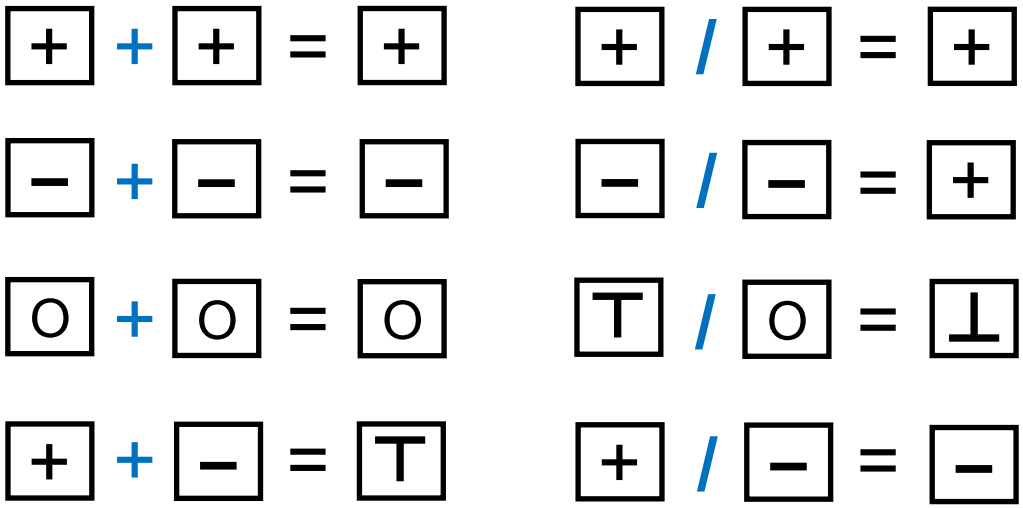

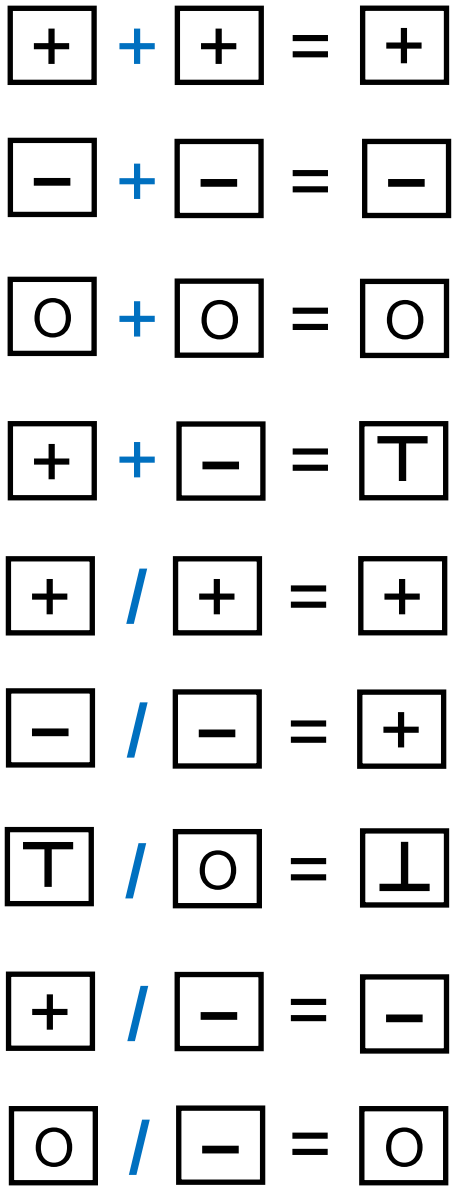
+ + + = +
− + − = −
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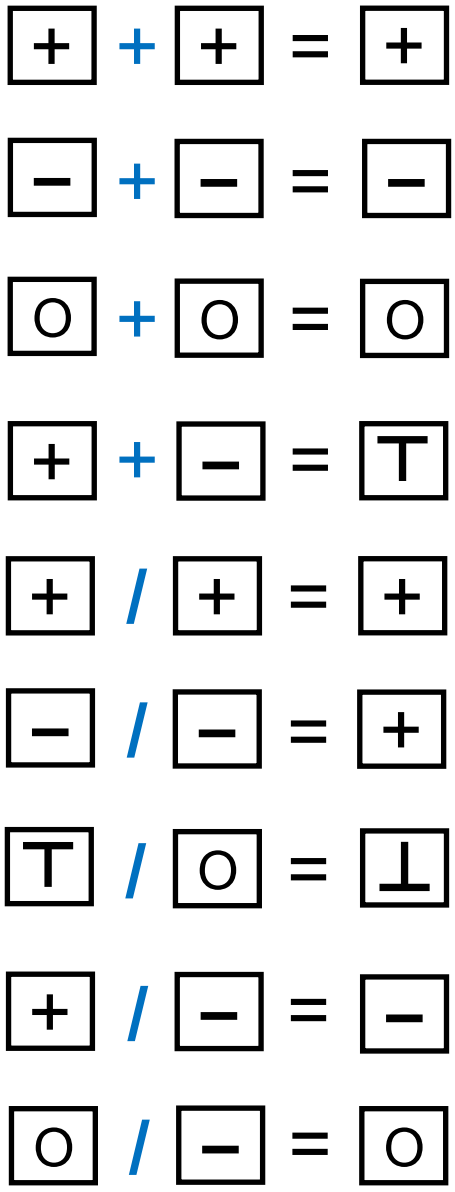


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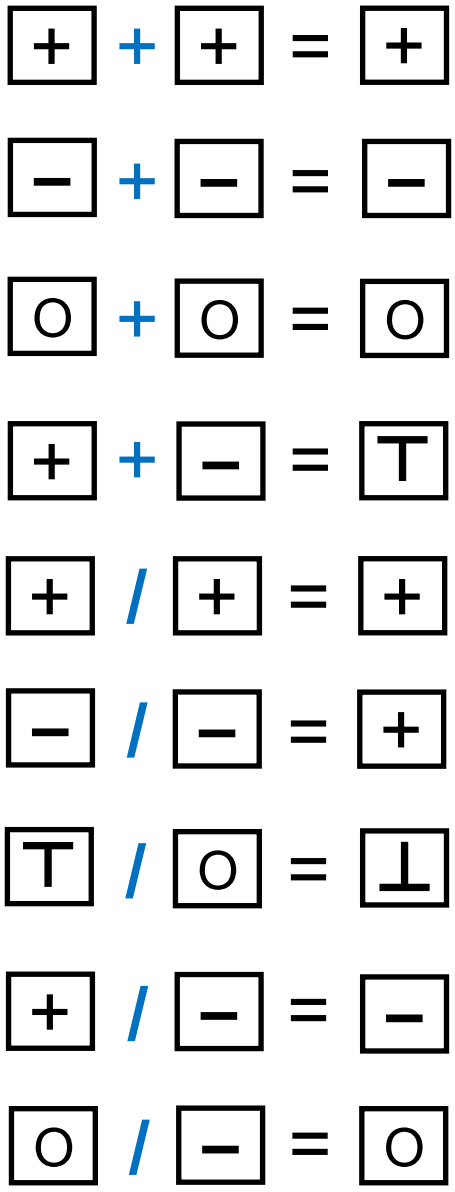


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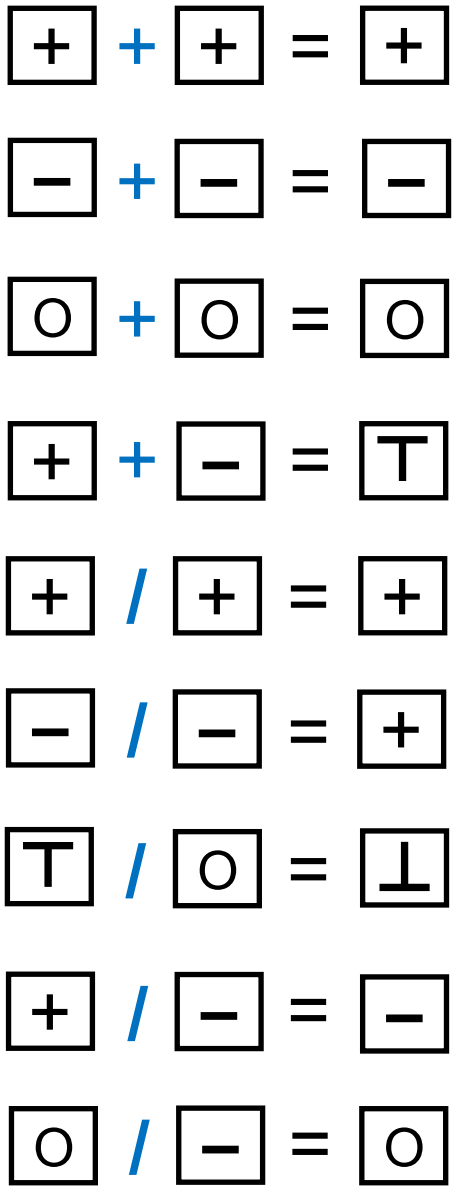


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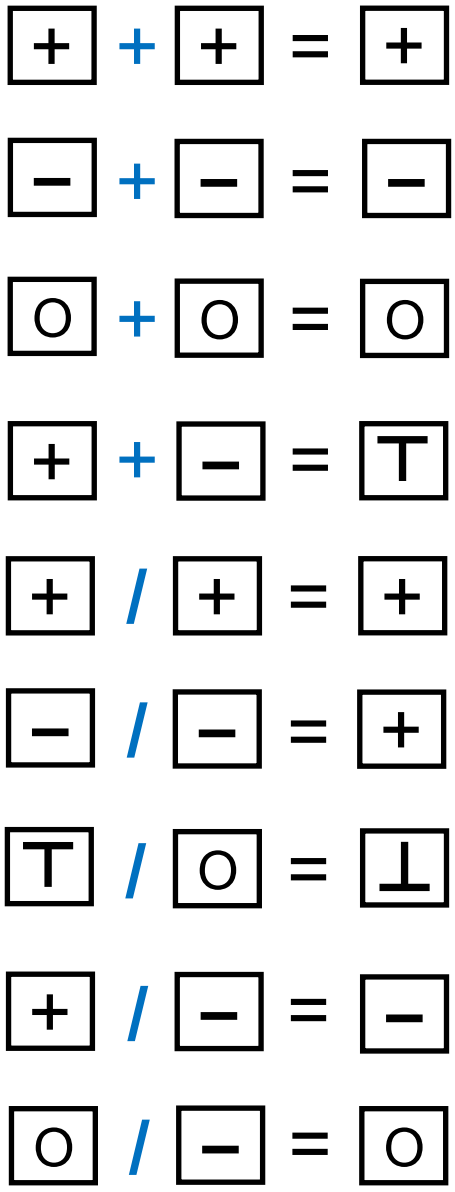


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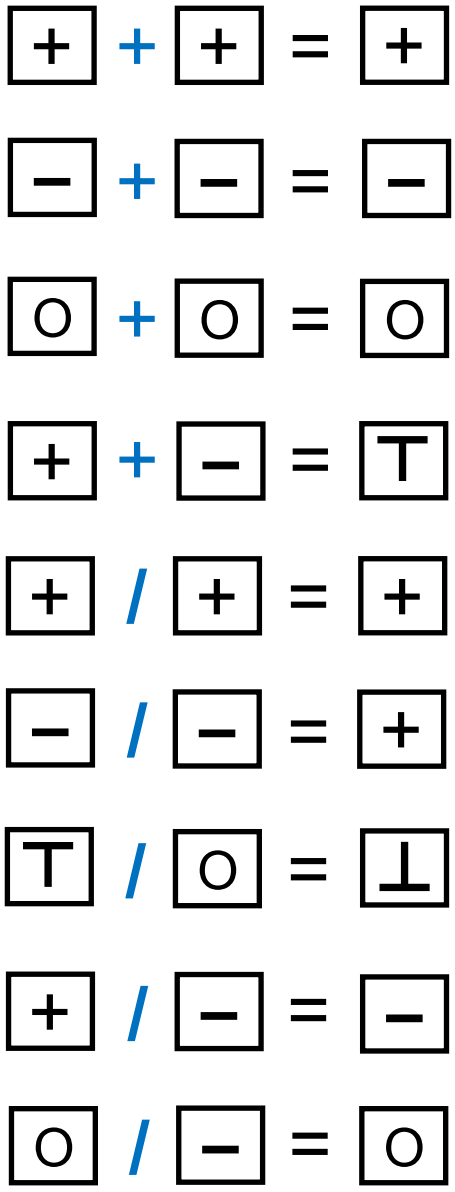


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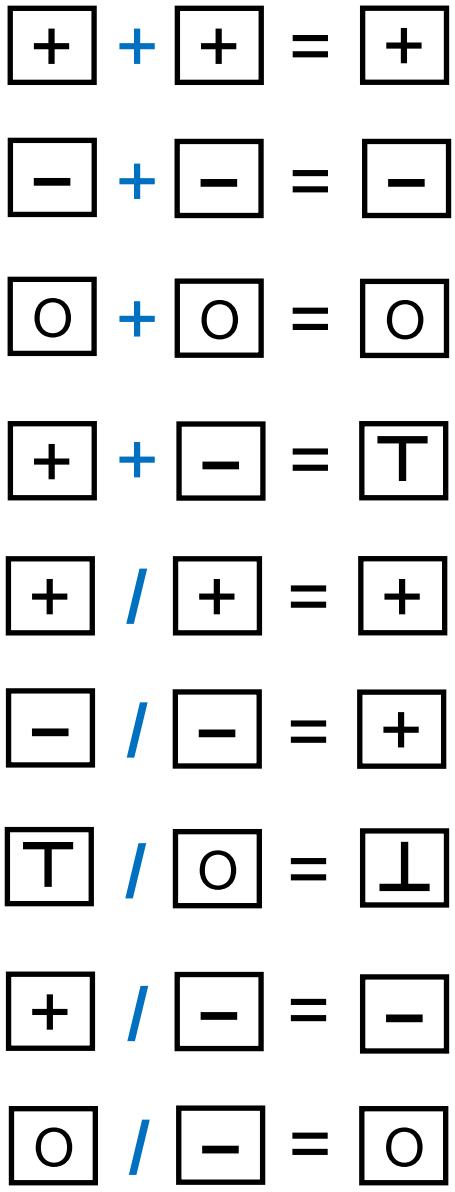


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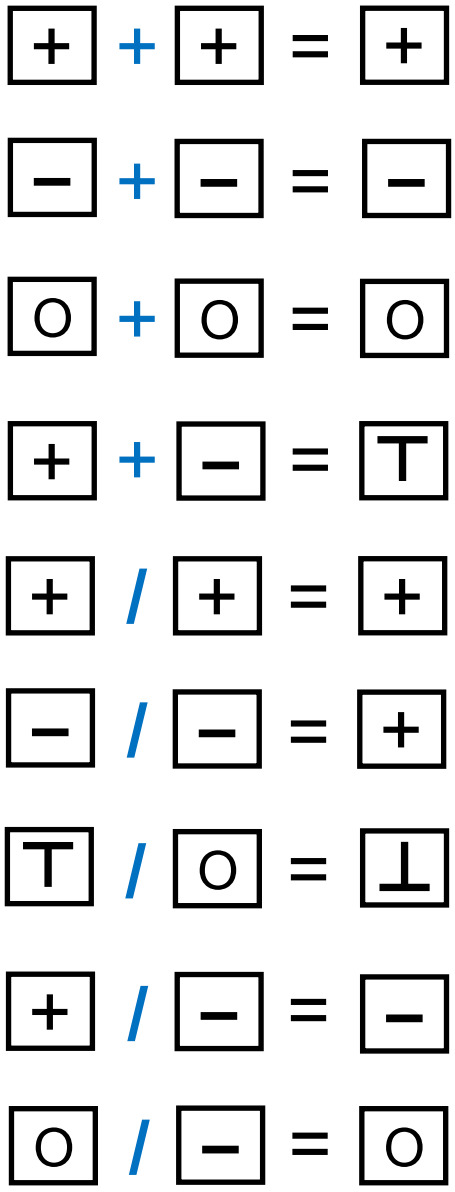


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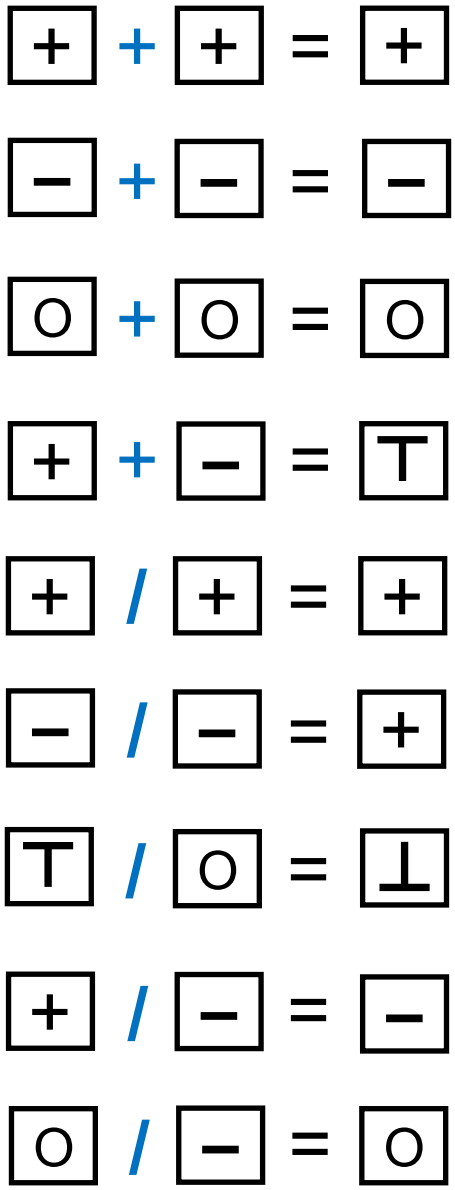


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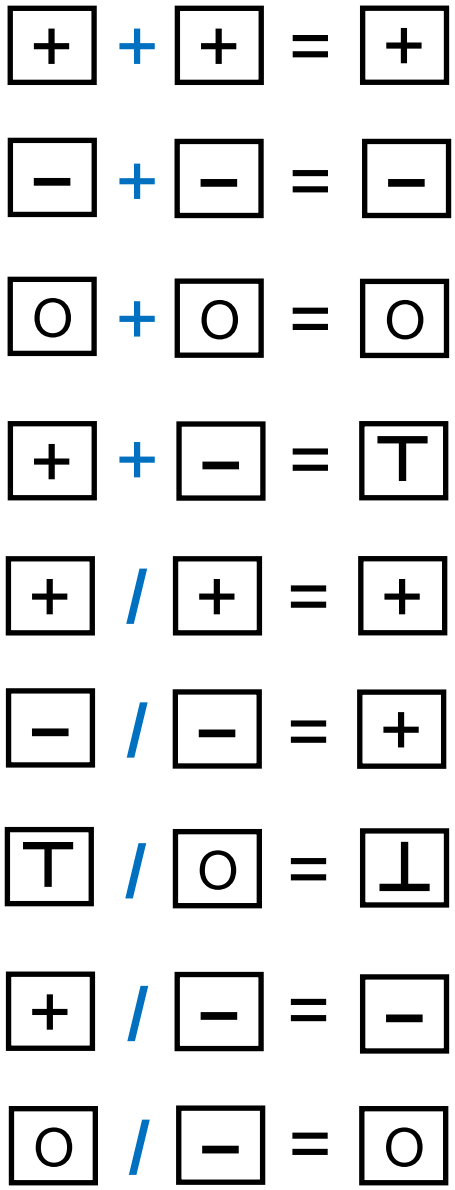
```

Divided by zero

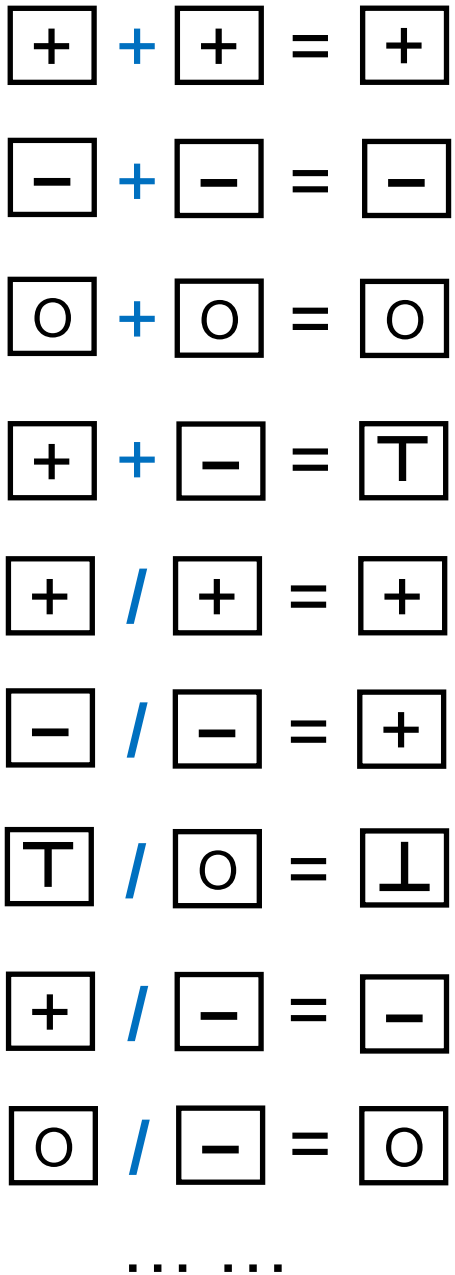



```
x = 10;
y = -1;
z = 0;
a = x + y;
b = z / y;
1 c = a / b;
2 p = arr[y];
3 q = arr[a];
```

```
x = +
y = −
z = 0
a = ⊤
b = 0
c = ⊥
p = ⊥
q = ⊥
```

Divided by zero

negative array index

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y = −
z = O
a = T
b = O
c = ⊥
p = ⊥
q = ⊥
```
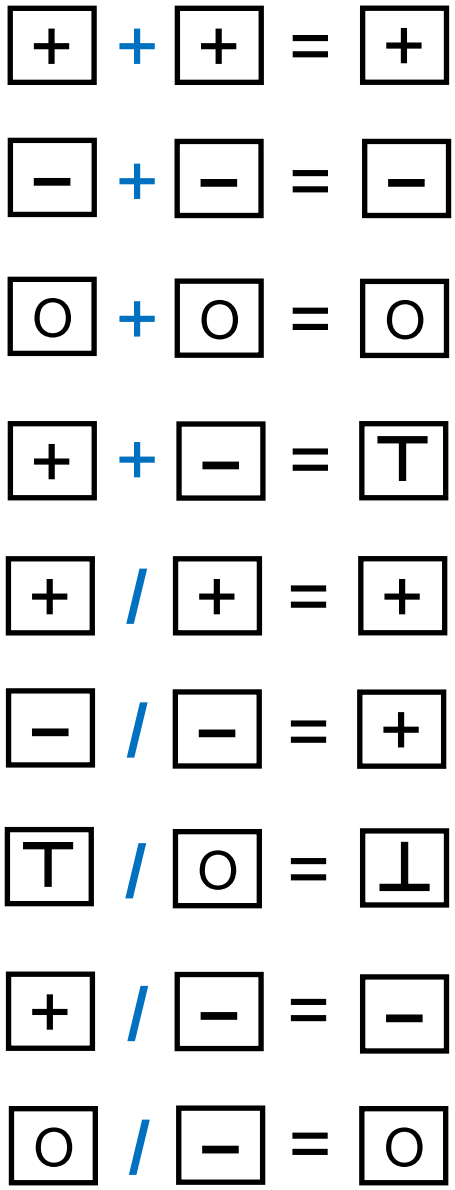

Divided by zero

negative array index

1 2 Static analysis is useful

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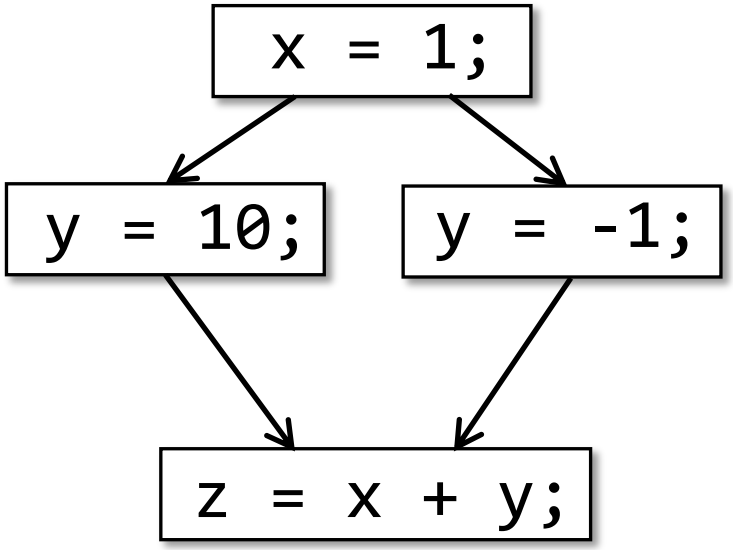
1 2 Static analysis is useful

3 But (over-approximated) static analysis produces false positives

Over-approximation: Control Flows

```
x = 1;
if(input)
  y = 10;
else
  y = -1;
z = x + y;
```



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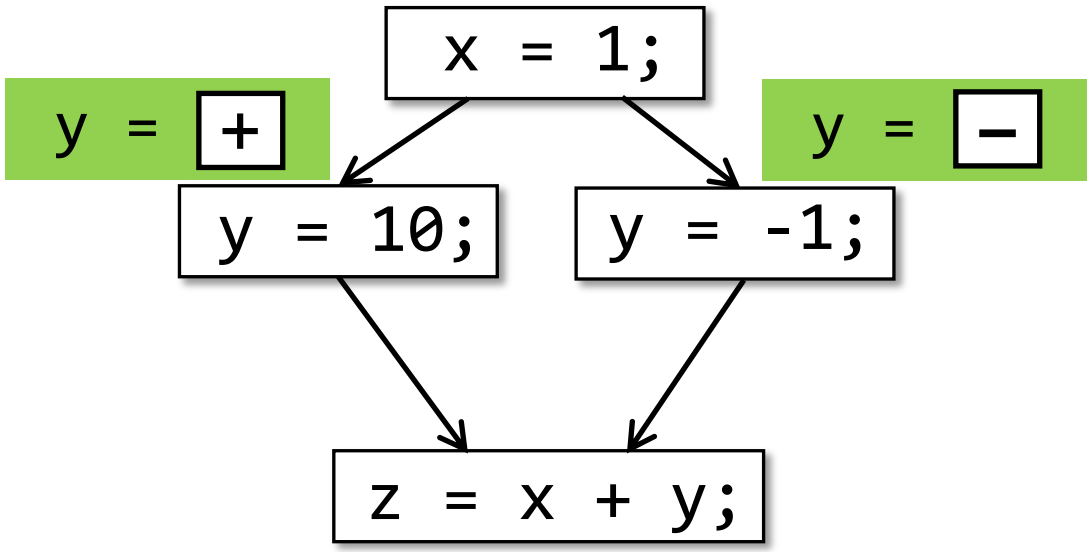

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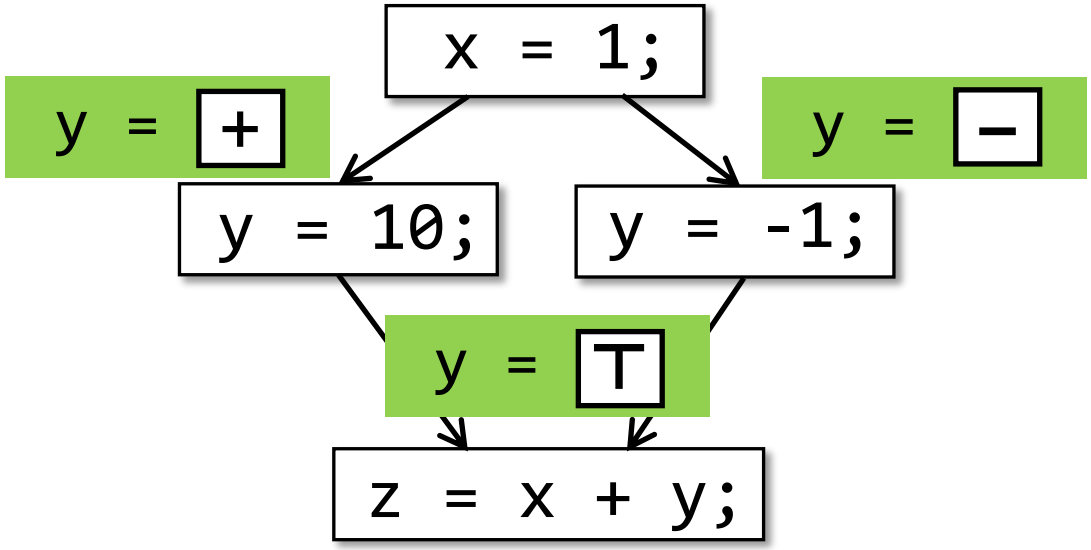

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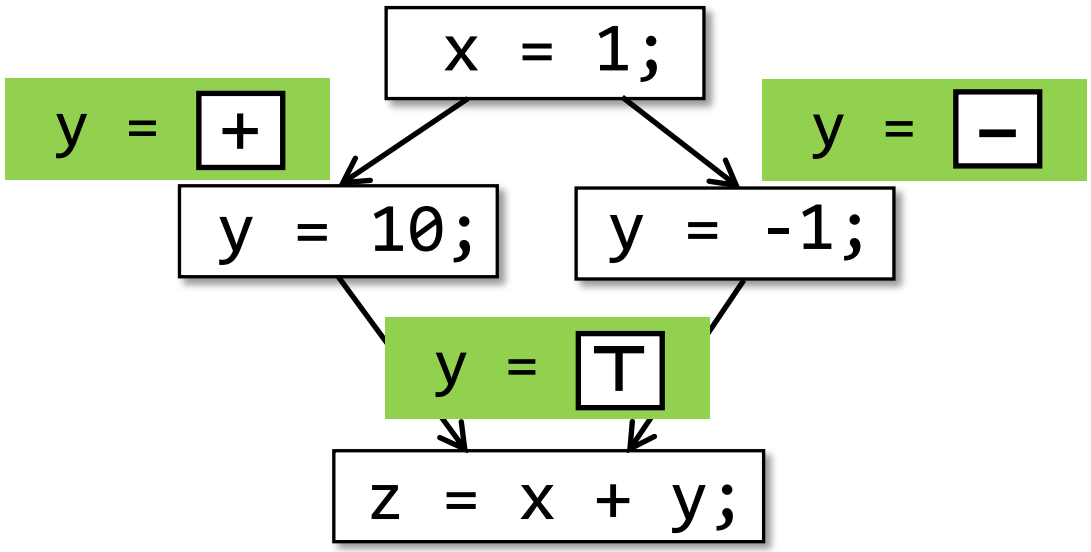

As it's impossible to enumerate all paths in practice, flow merging (as a way of over-approximation) is taken for granted in most static analyses.

Teaching Plan (Tentative)

1. Introduction
2. Intermediate Representation
3. Data Flow Analysis – Applications (I)
4. Data Flow Analysis – Applications (II)
5. Data Flow Analysis – Foundations (I)
6. Data Flow Analysis – Foundations (II)
7. Inter-procedural Analysis
8. Pointer Analysis
9. Pointer Analysis – Foundations (I)
10. Pointer Analysis – Foundations (II)
11. Context Sensitivity (I)
12. Context Sensitivity (II)
13. Static Analysis for Security
14. Datalog-Based Static Analysis
15. CFL-Reachability and IFDS
16. Soundness and Soundiness
17. Abstract Interpretation/Summary

Evaluation Criteria

- Coding Assignments 50%
- Final Exam 50%

Coding Assignments (Tentative)

- Assignment 1: Constant Propagation (CP, 10 points)
  - Statically compute and propagate constant values in program
  - Intra-procedural analysis

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  - Based on constant propagation, detect dead code in program
  - b =true; if (b) { … } else { /* dead code */ }

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- Assignment 5: Context-Sensitive Pointer Analysis (CSPTA, 6 points)
  - Build a call graph via C.S. pointer analysis (more precise than PTA)
  - Enable more precise inter-procedural constant propagation

The X You Need To Understand in This Lecture

- What are the differences between static analysis and (dynamic) testing?
- Understand soundness, completeness, false negatives, and false positives.
- Why soundness is ~~usually~~ required by static analysis?
- How to understand abstraction and over-approximation?

Our PASCAL Research Group @Nanjing University

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Programming LAnguages and StatiC AnaLysis Group

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The **PASCAL Research Group** is affiliated with Institute of Computer Software and Department of Computer Science and Technology at Nanjing University. We develop effective static program analysis techniques and tools for solving the problems in programming languages, software engineering, system and security.

News

October 15, 2019
Yue Li and Tian Tan start the **PASCAL Research Group** at Nanjing University!

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Undergraduate, 2018 —


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Undergraduate, 2017 —


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Season 2


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Yue Li
谭 添
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