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

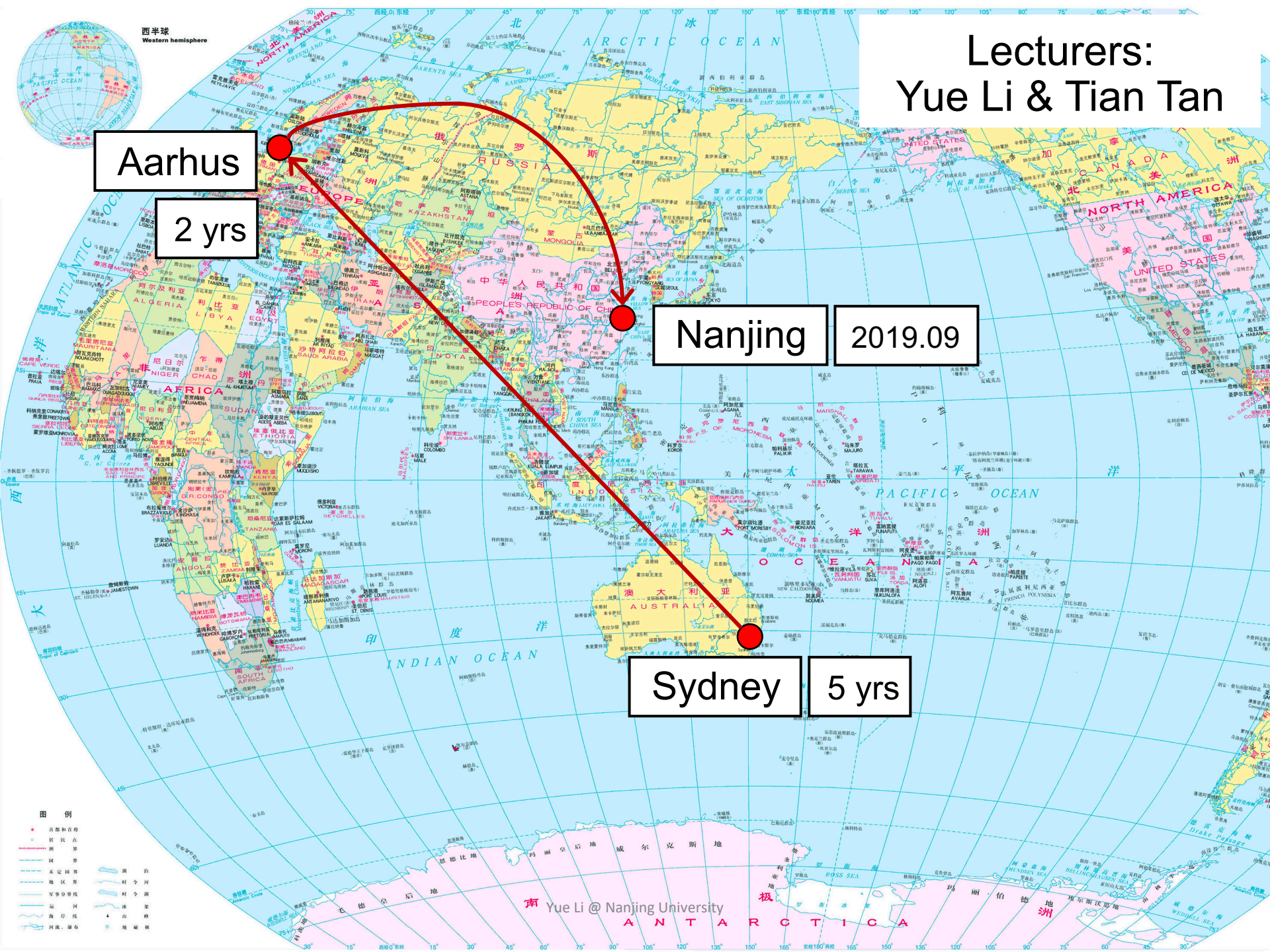
Static Program Analysis

Introduction

Nanjing University

Yue Li

Fall 2023


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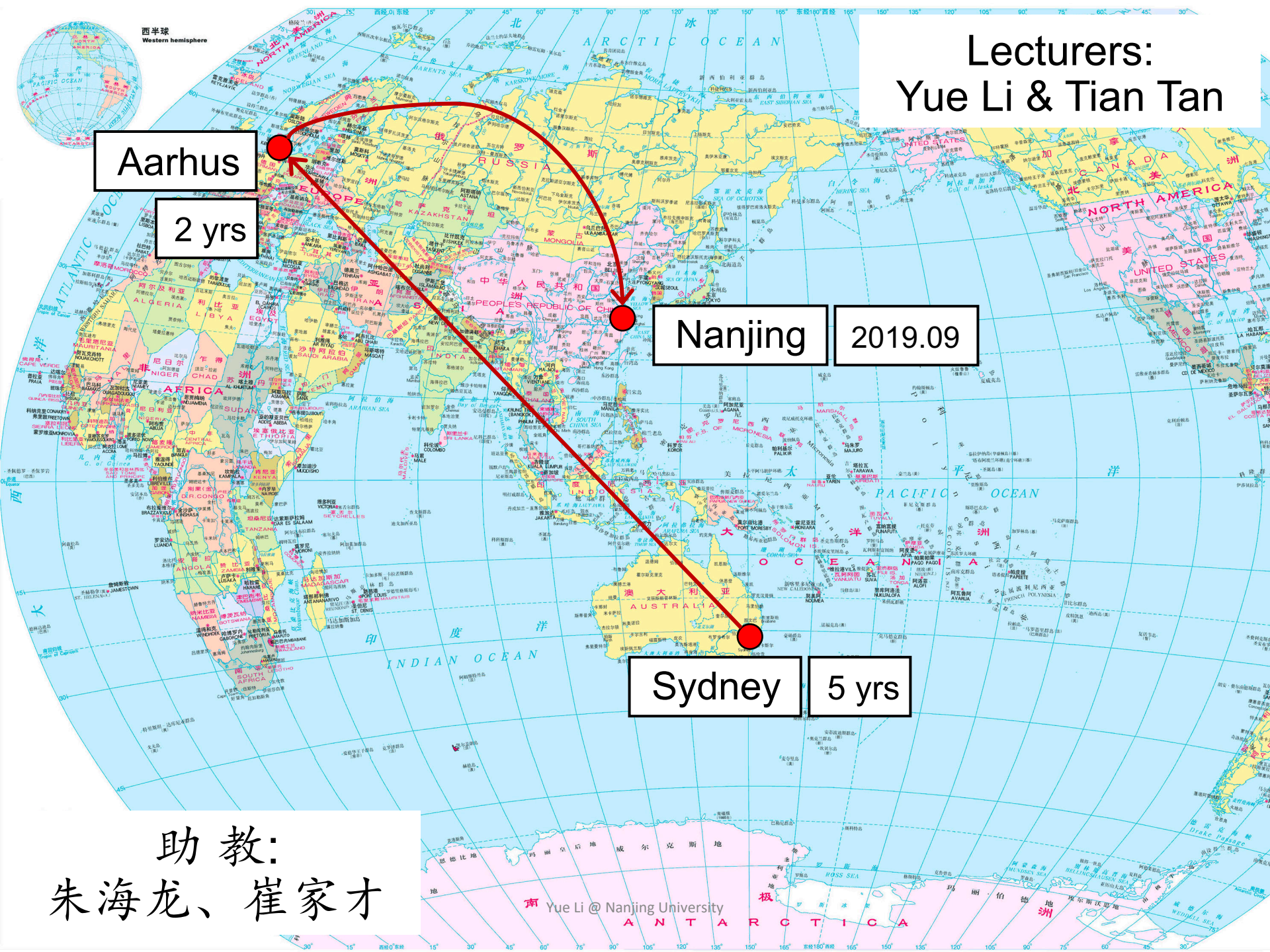
Yue Li @ Nanjing University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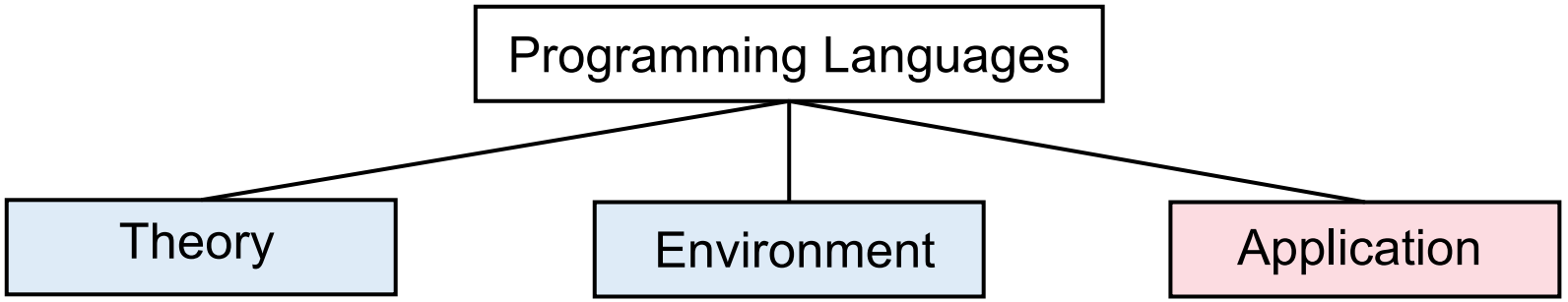
Contents

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)

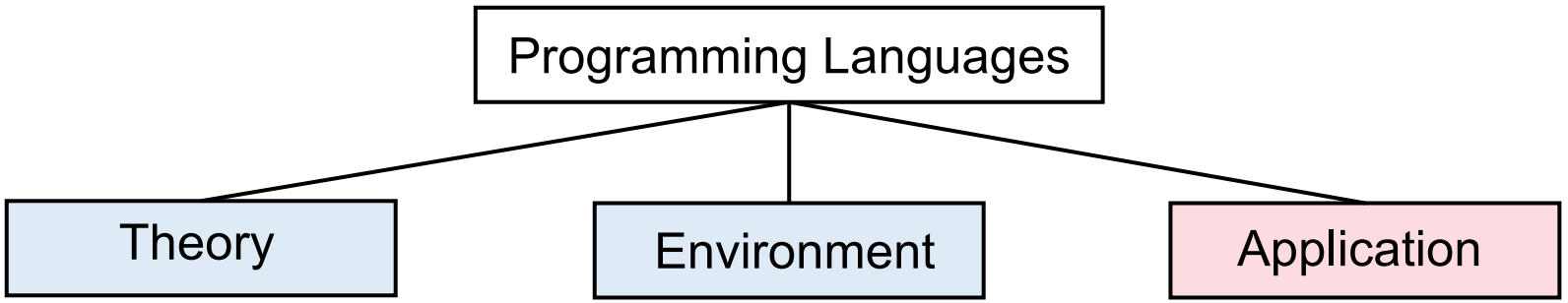


- Language design
- Type system
- Semantics and logics
- … …

- 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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  Dead code elimination, code motion, etc.

  Examples

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- Program Security

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- Compiler Optimization

  Dead code elimination, code motion, etc.

  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

Academia

Programming Languages

Software Engineering

Systems

Securit

… …

Any directions that rely on programs

Static analysis people are urgently needed !

Industries

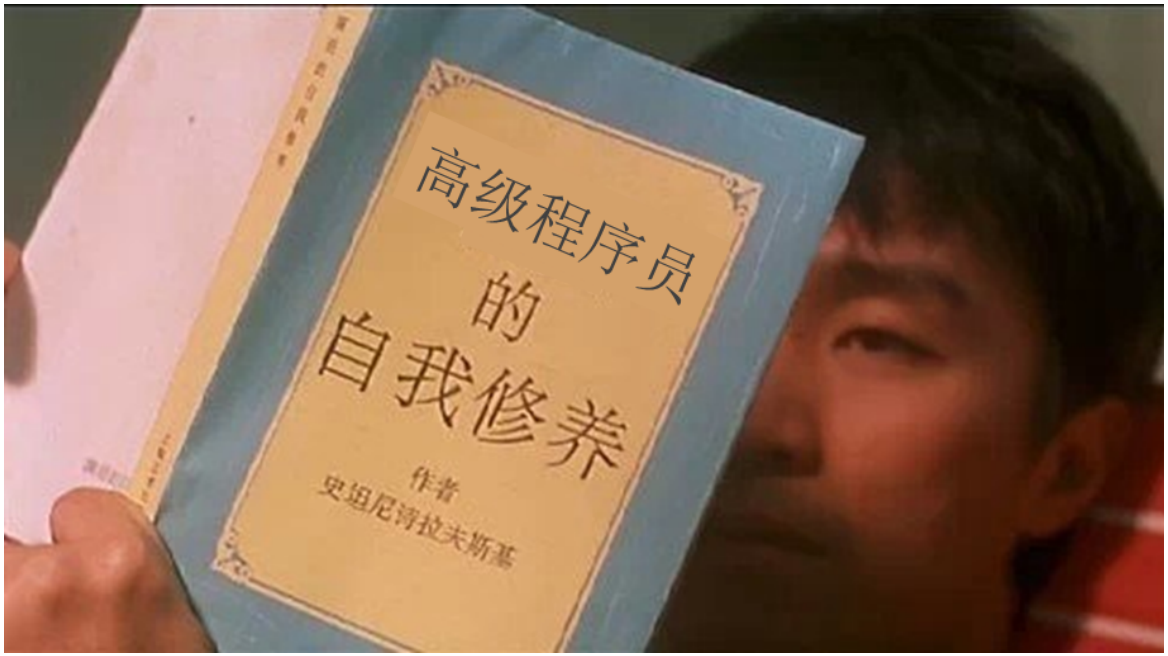
Oracle, Google, Microsoft, IBM, Facebook, …

华为、阿里巴巴、腾讯、网易、字节跳动、京东、美团、航空航天研究院、国家电网研究院、中国电信、央行金融研究院 …

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?
- Is this piece of code in *P* dead (so that it could be eliminated)?
- …

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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."

r.e. (recursively enumerable) = recognizable by a Turing-machine

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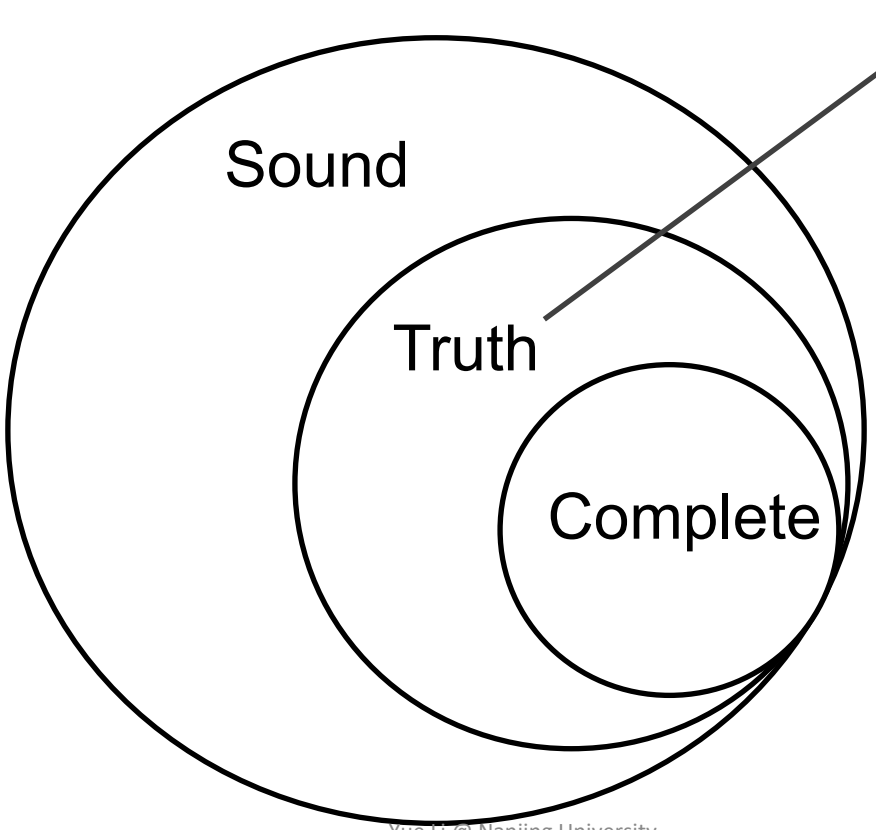

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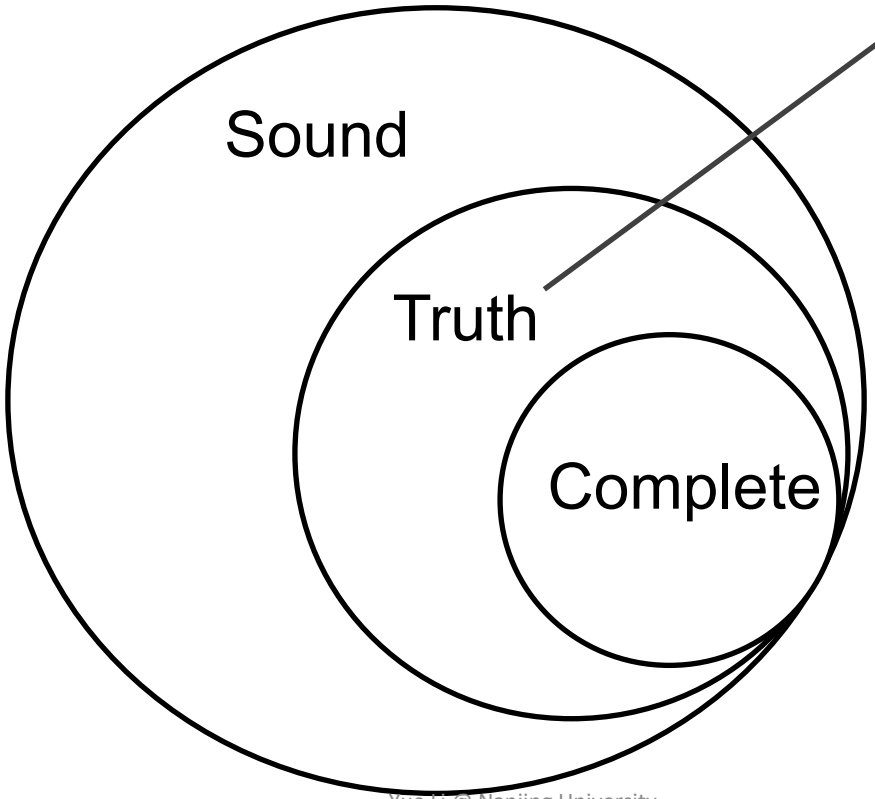

Sound & Complete

All possible true program behaviors

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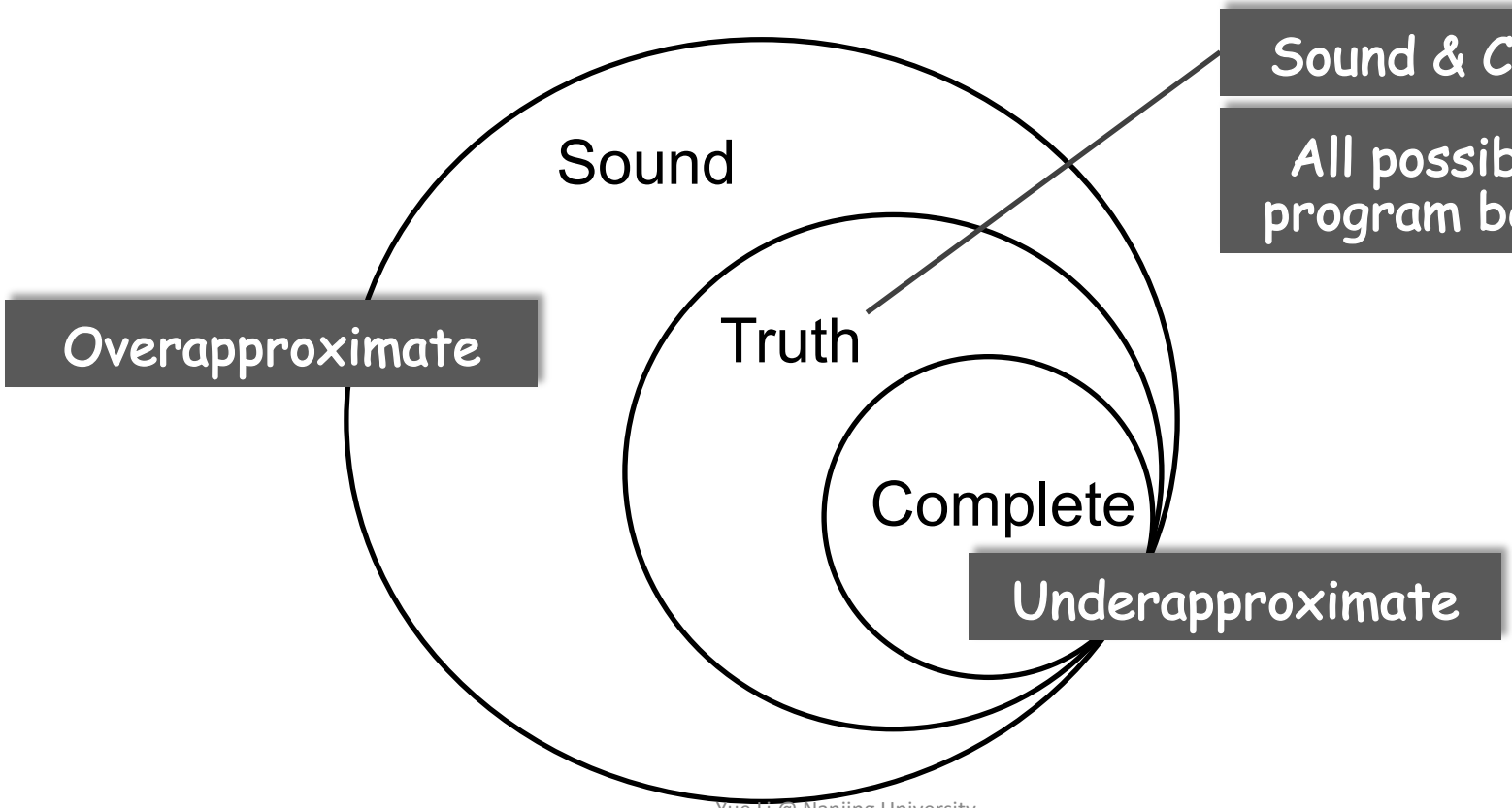

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Perfect static analysis

AND

- Sound
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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

AND

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Useful static analysis

OR

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

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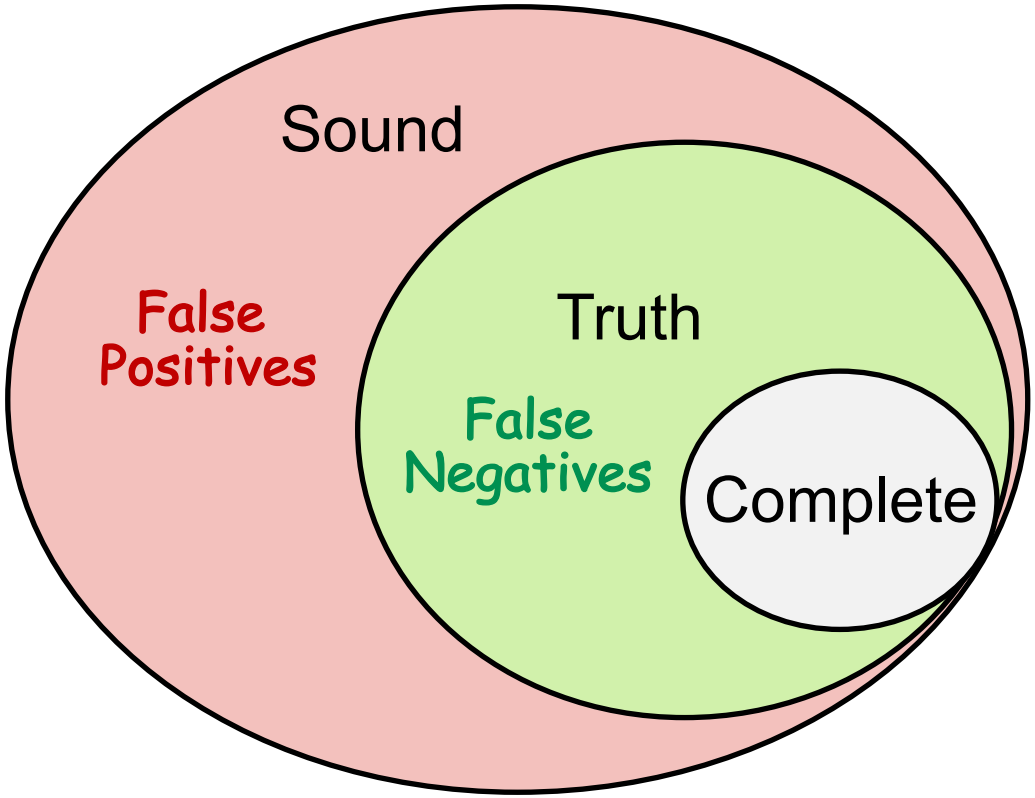

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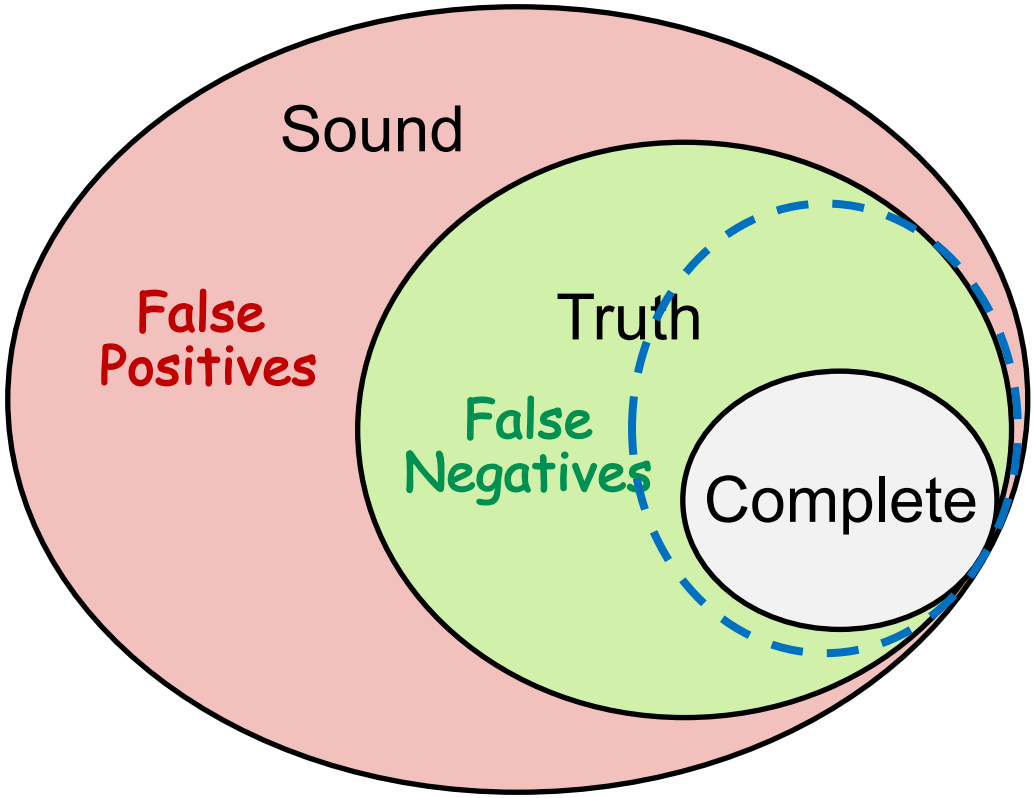

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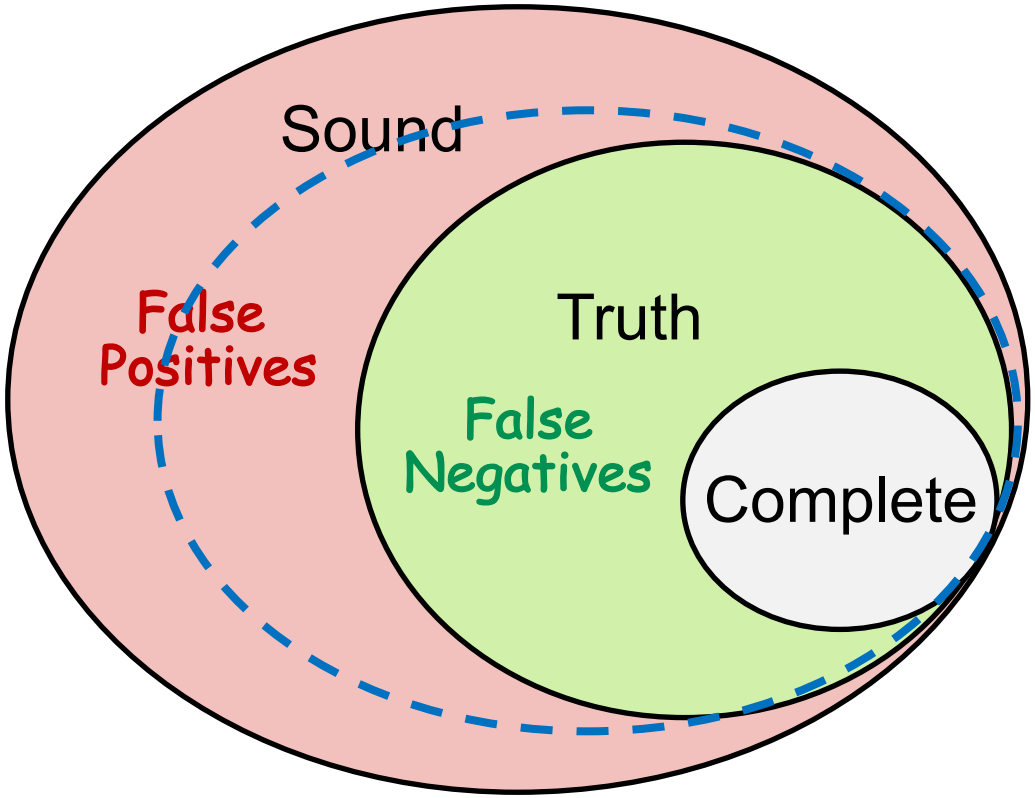

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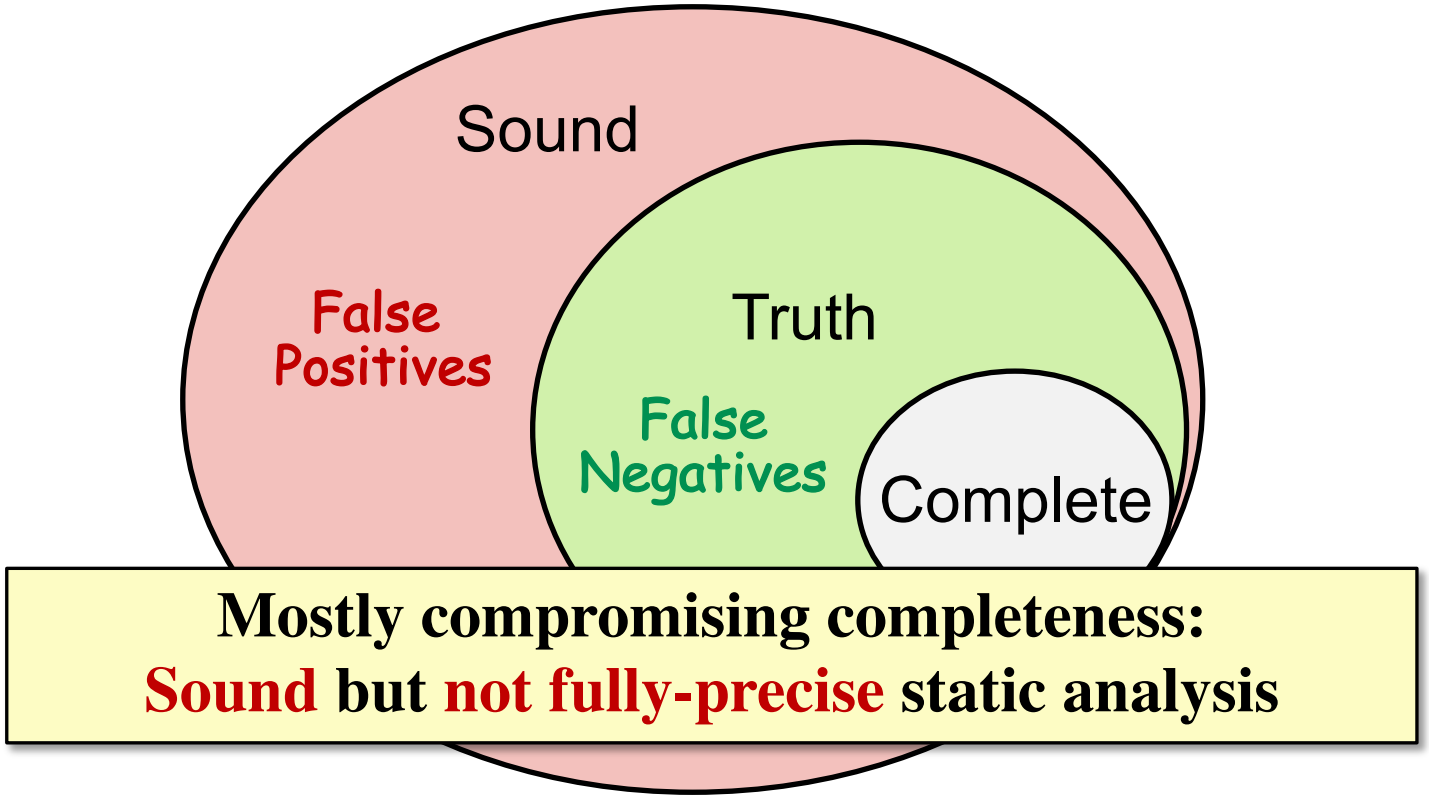

Mostly compromising completeness:
Sound but not fully-precise static analysis

Necessity of Soundness

- Soundness is critical to a collection of important (static-analysis) applications such as *compiler optimization* and *program verification*.

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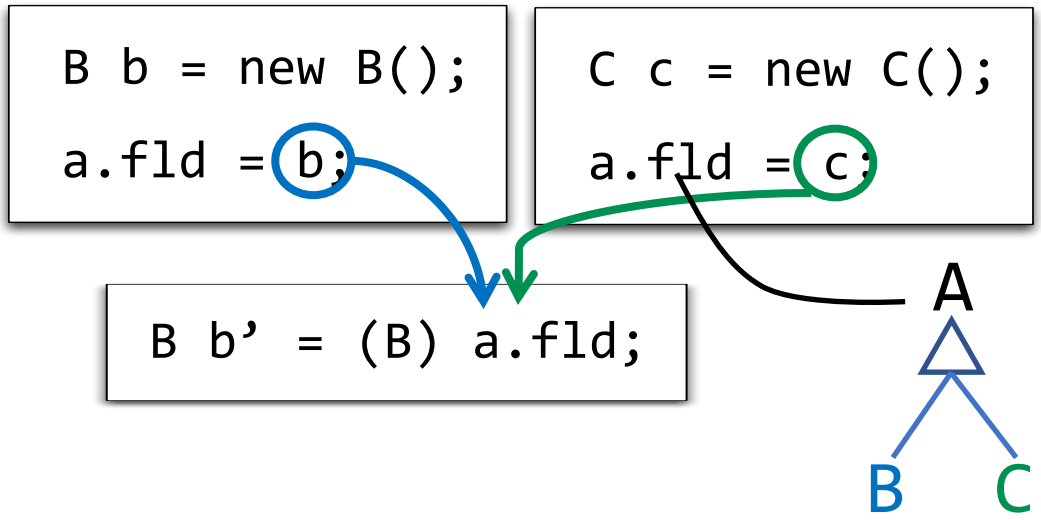
Unsound

"Safe Cast": wrong conclusion



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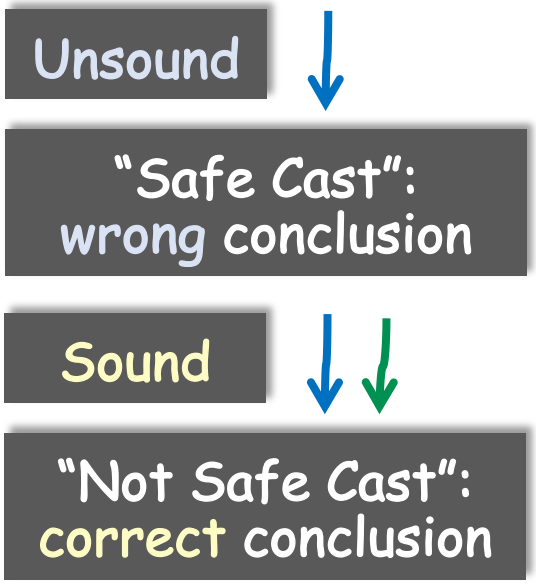

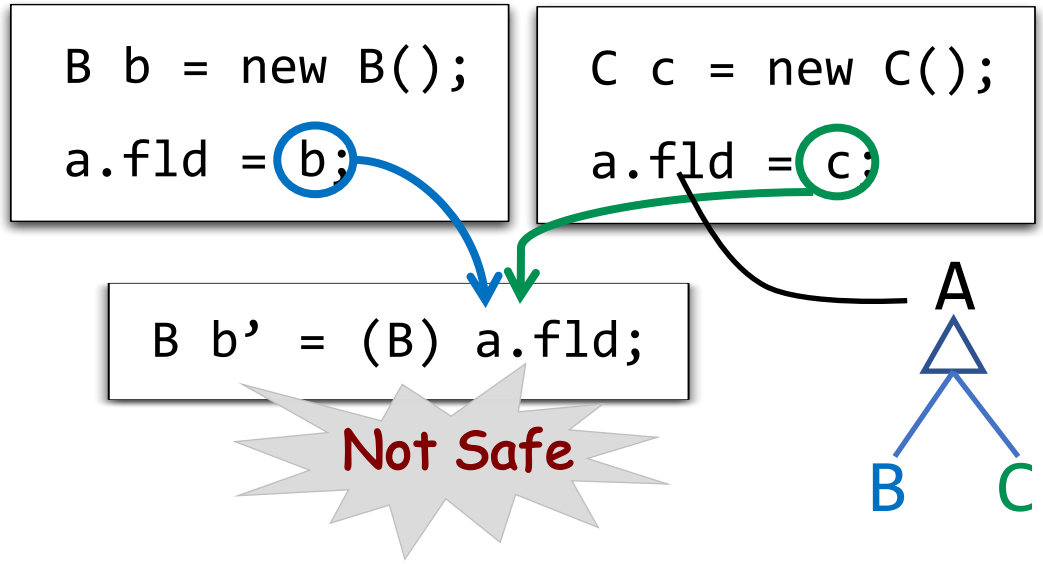

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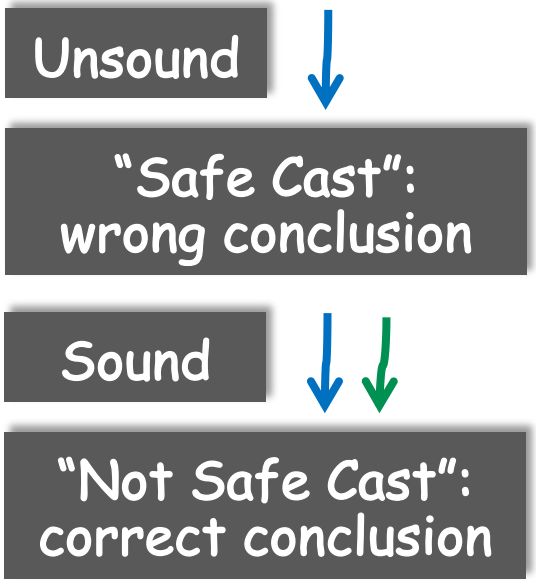

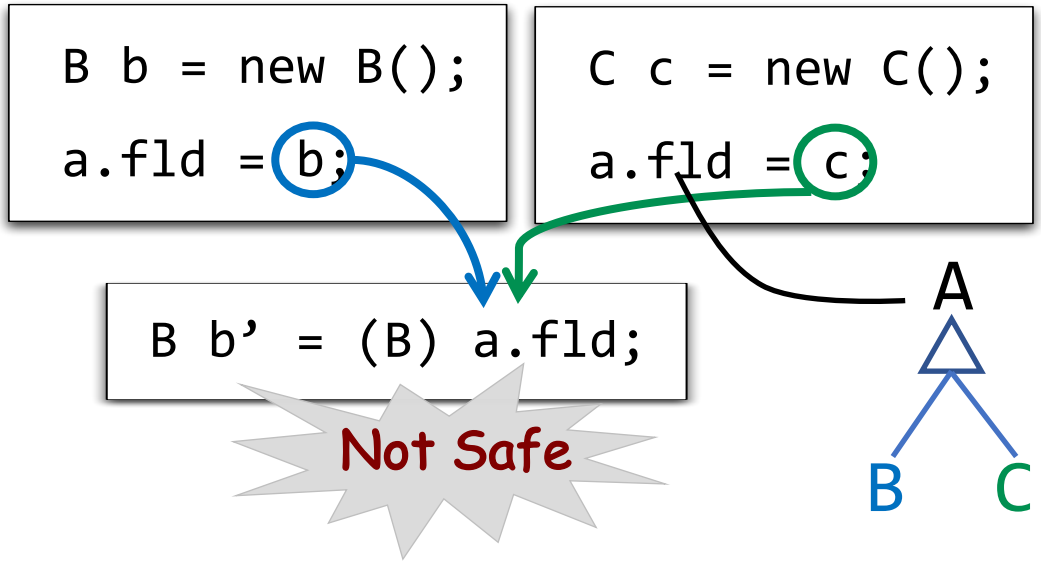

- Soundness is also preferable to other (static-analysis) applications for which soundness is not demanded, e.g., *bug detection*, as better soundness implies more bugs could be found.

Static Analysis — Bird's Eye View

```
    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)

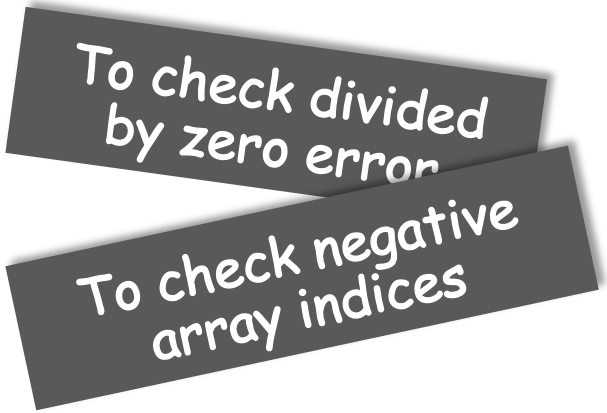
Two Words to Conclude Static Analysis

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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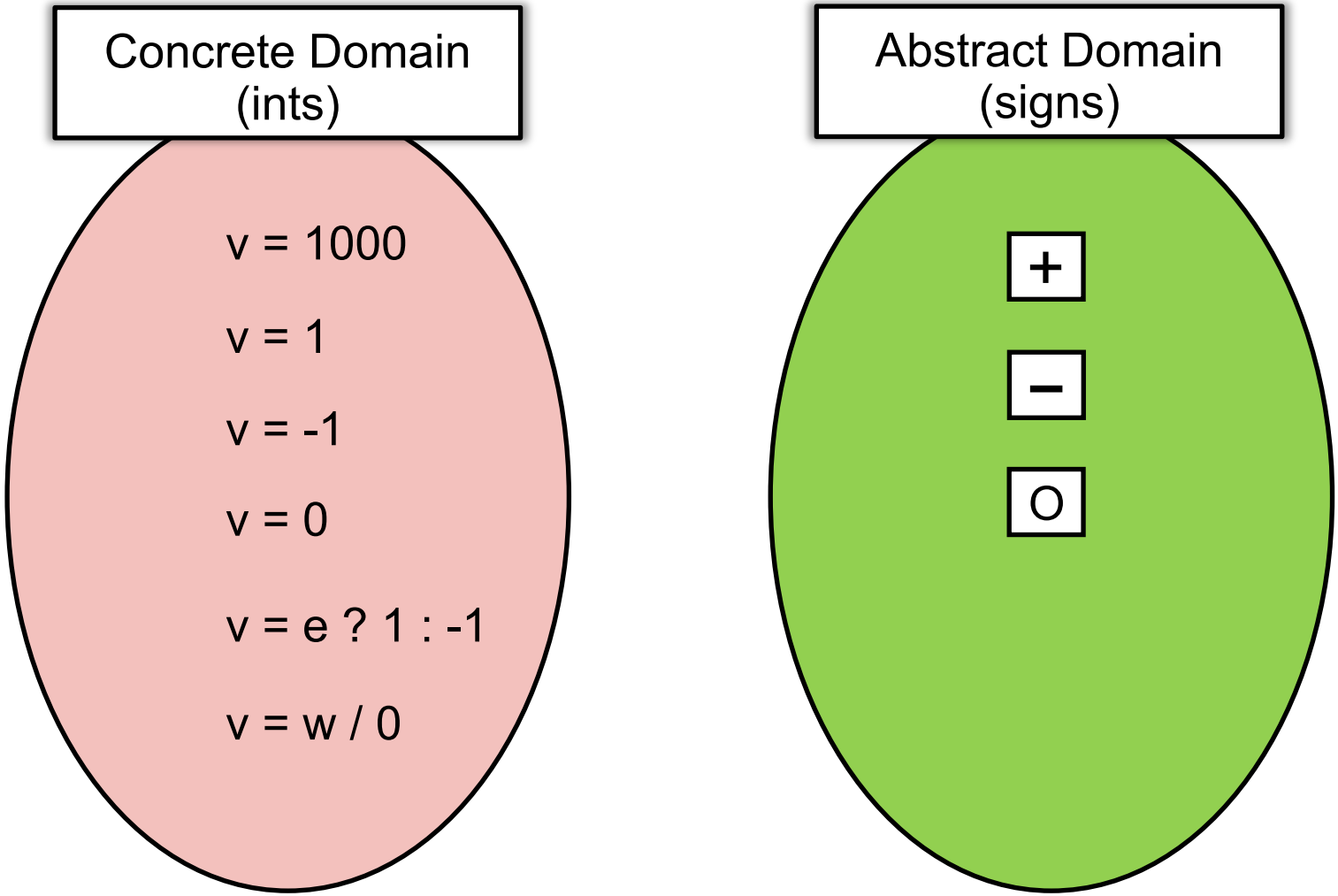

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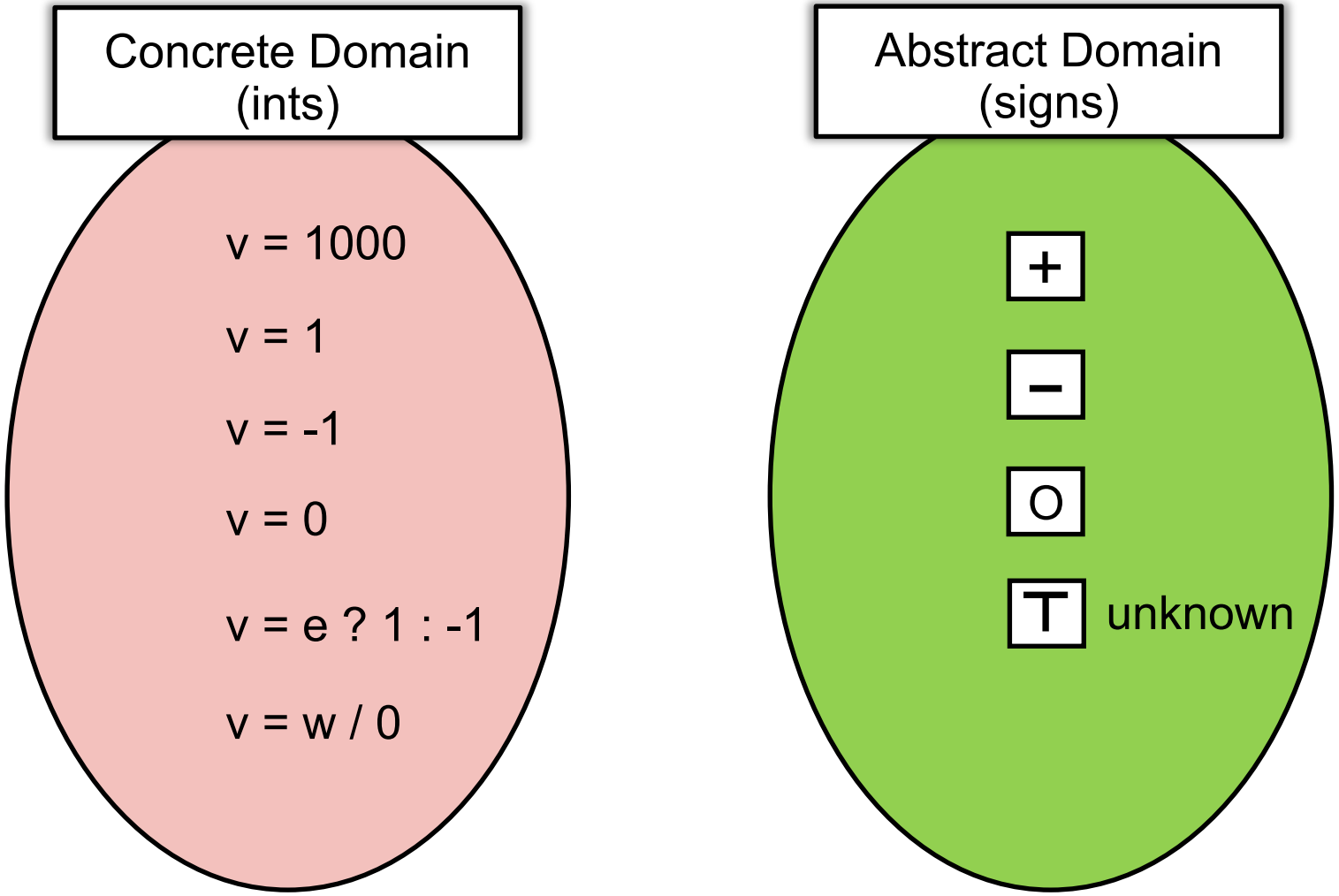

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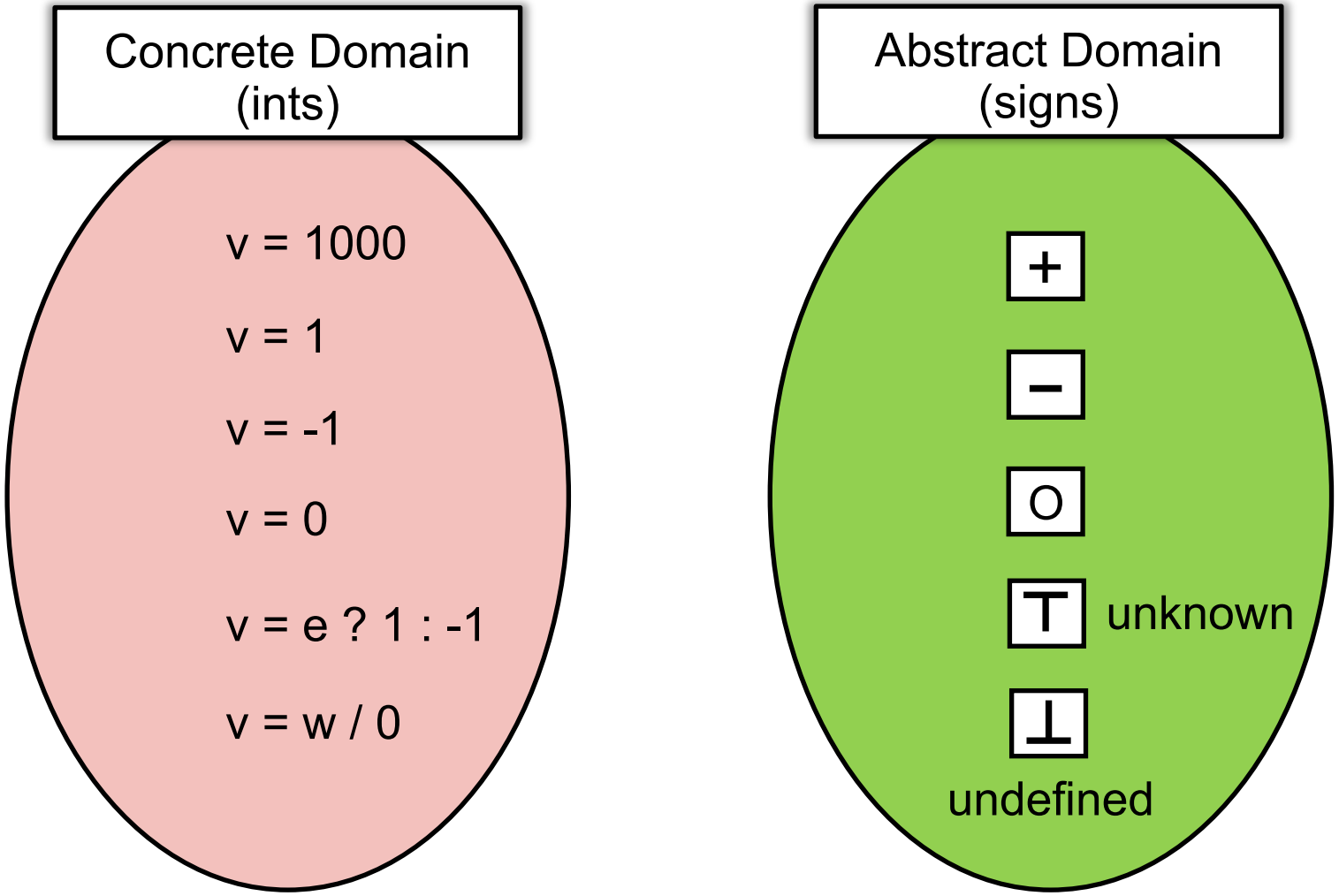

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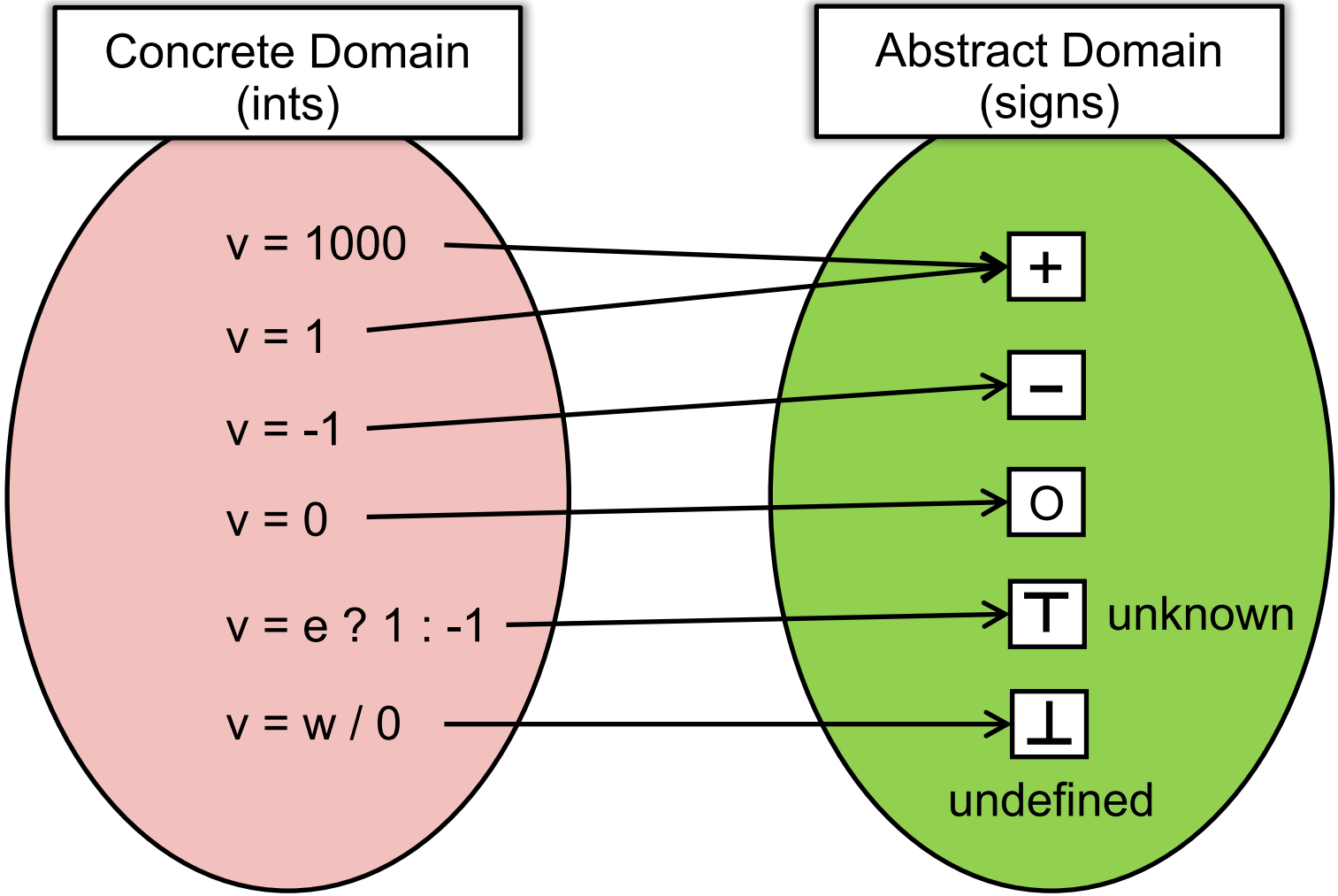

Over-approximation: Transfer Functions

- 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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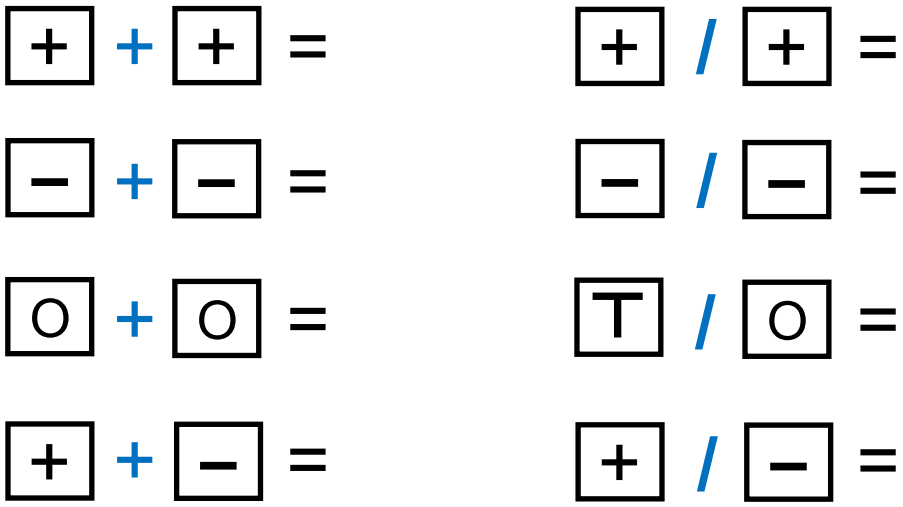

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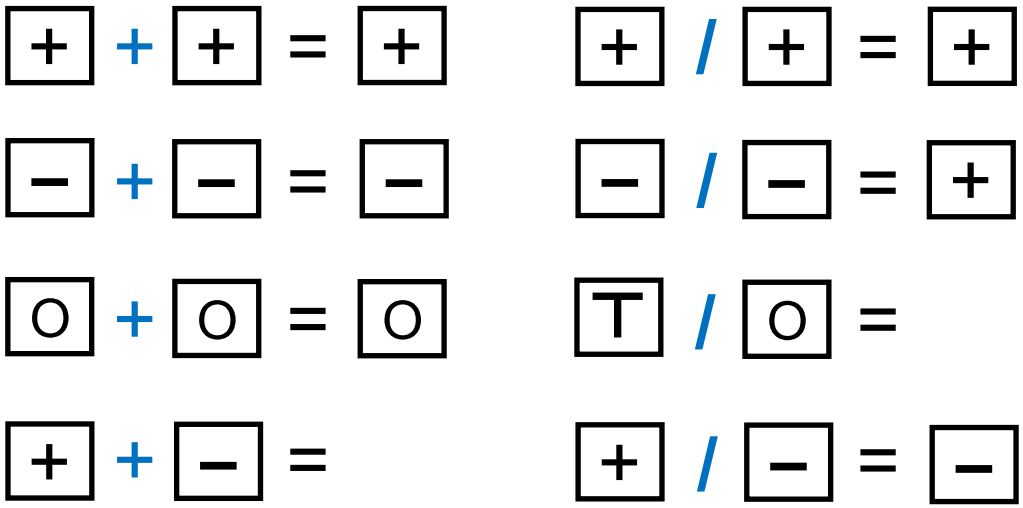

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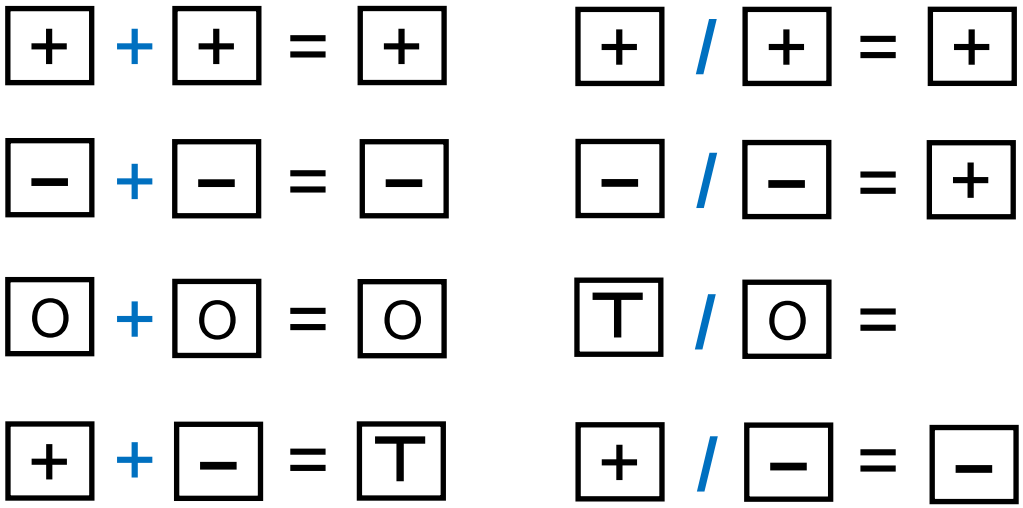

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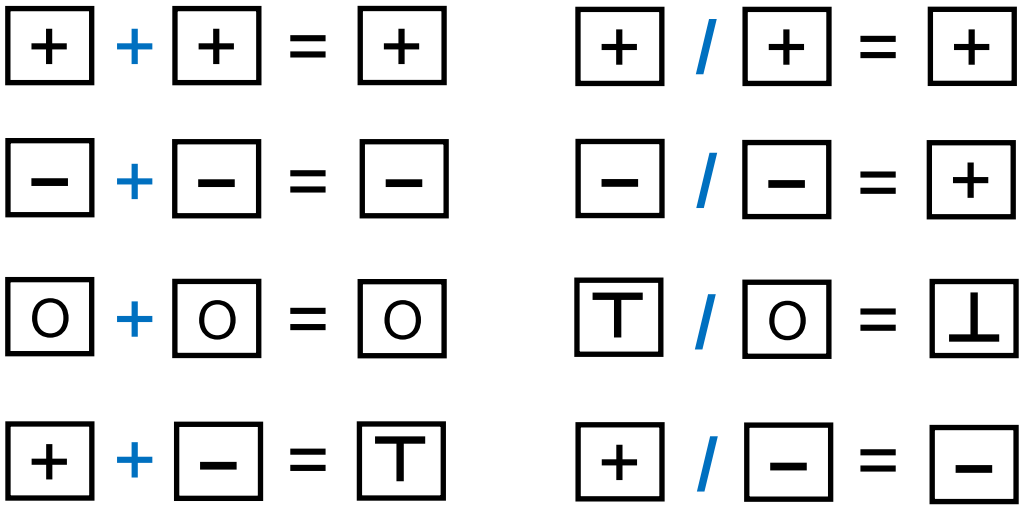

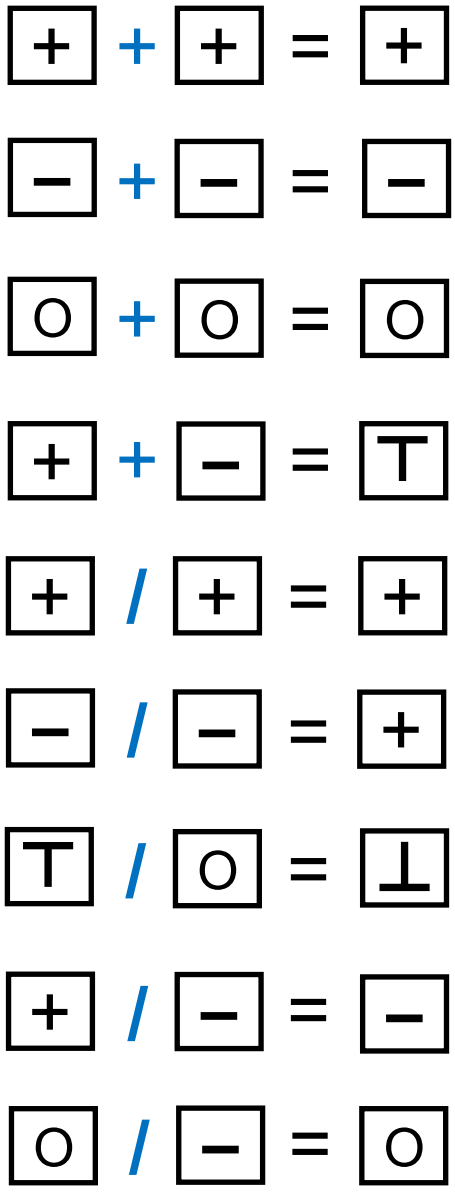
+ + + = +
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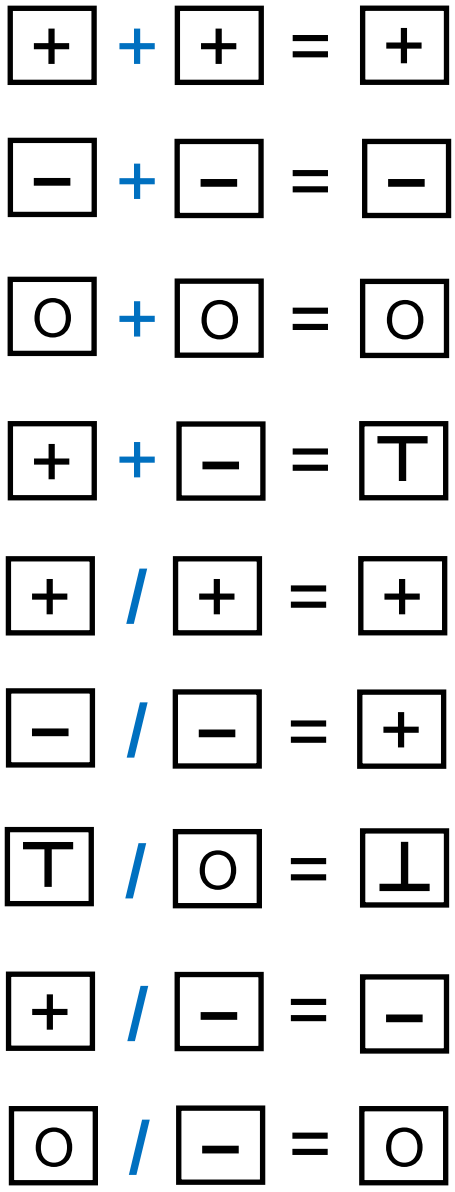
. . . . . .

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y = -1;
z = 0;
a = x + y;
b = z / y;
c = a / b;
p = arr[y];
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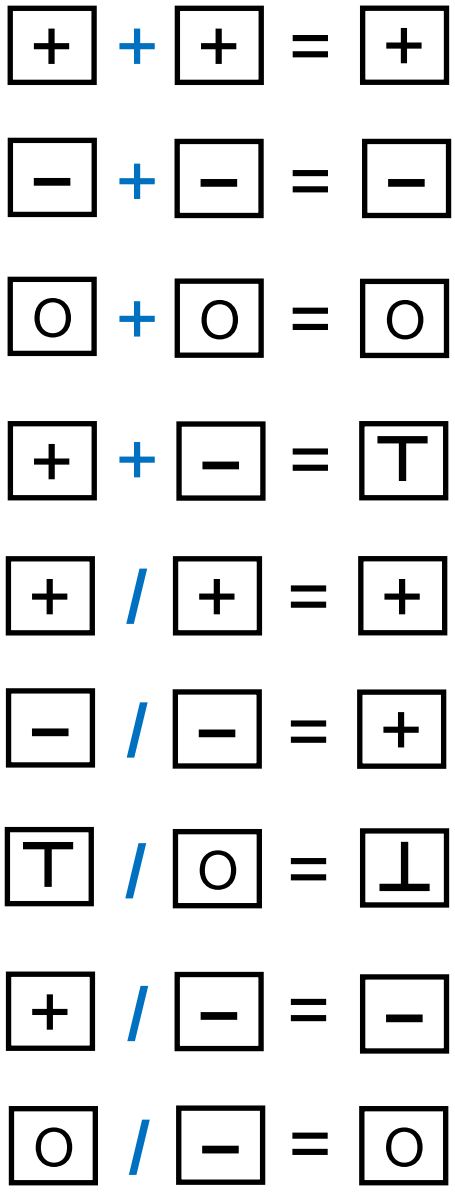


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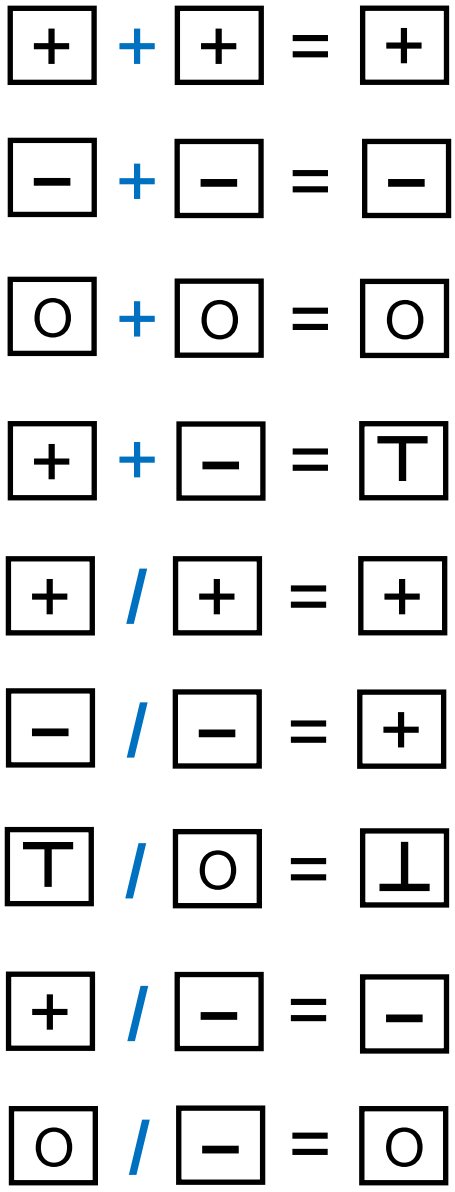


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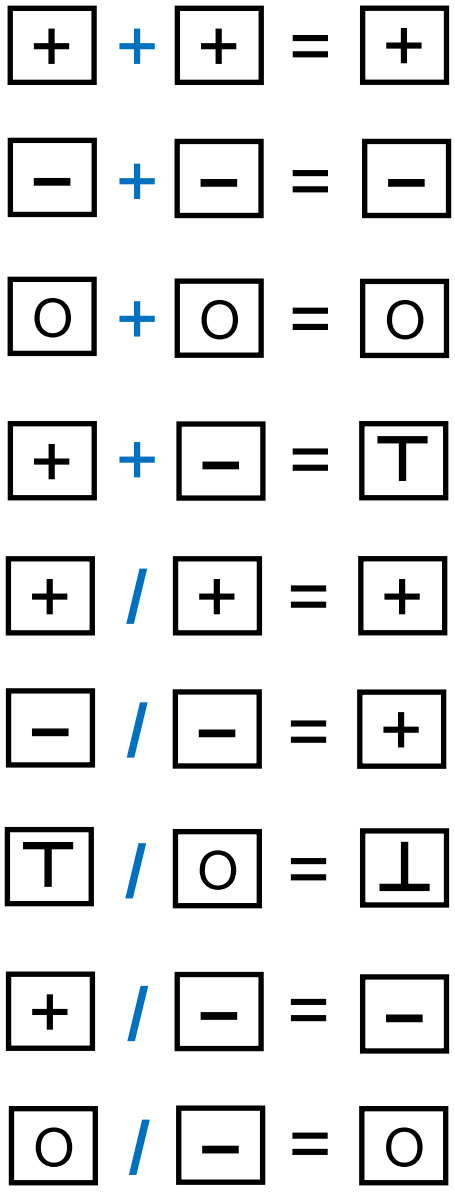
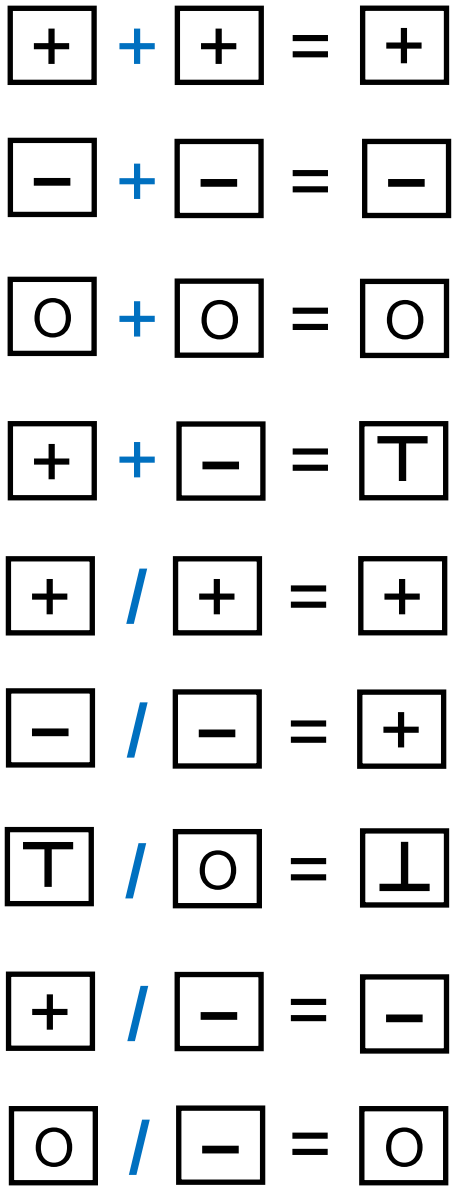



```
x = 10;
y = -1;
z = 0;
a = x + y;
b = z / y;
c = a / b;
p = arr[y];
q = arr[a];
```

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

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```
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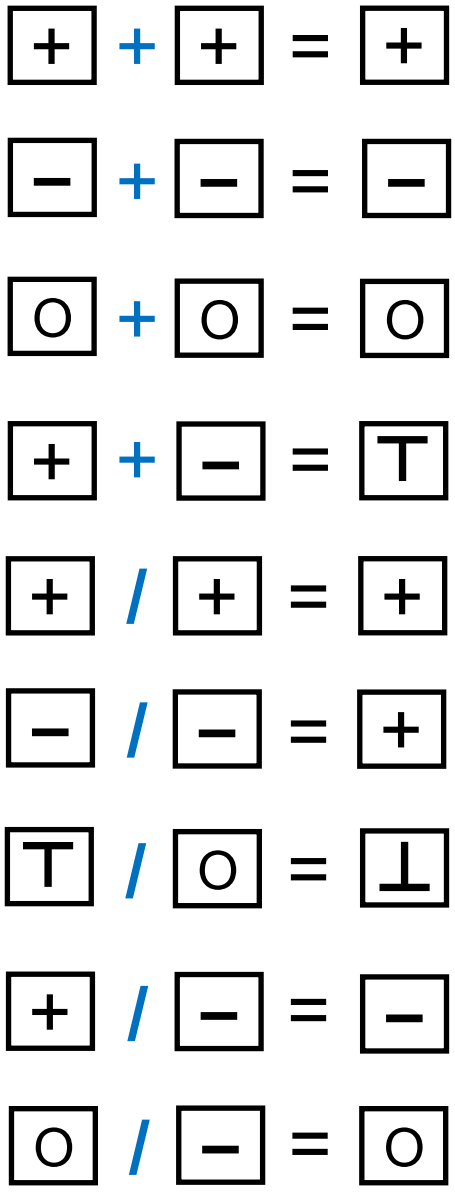
z = O
a = ⊤
b = O
c = ⊥
p =
q =
```

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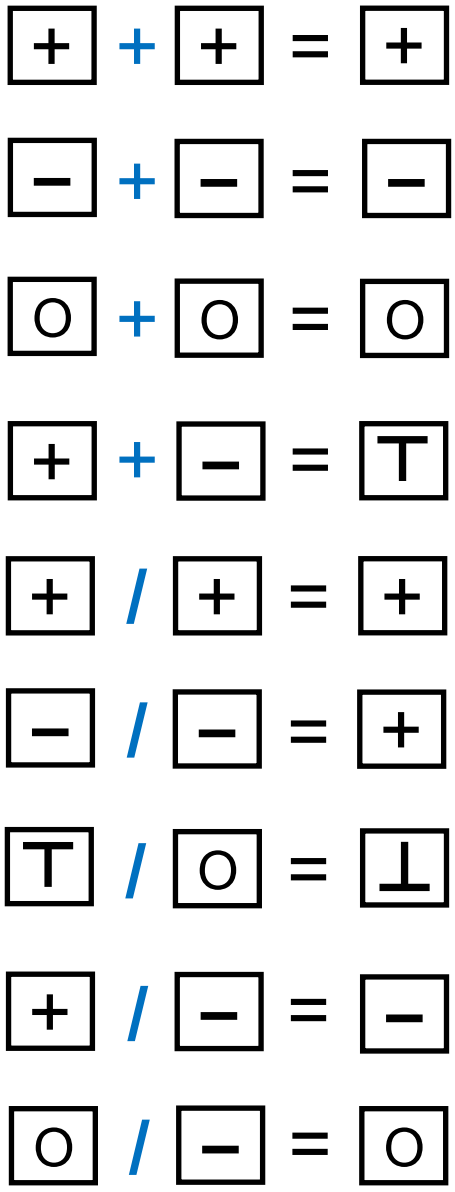


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q = arr[a];
```
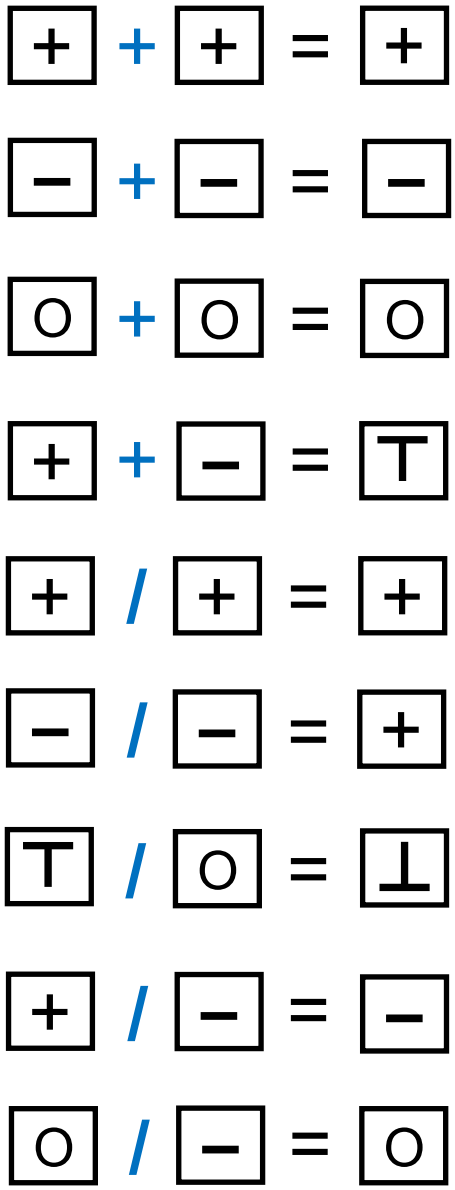

```
x = +
y = −
z = O
a = T
b = O
c = ⊥
p = ⊥
q = ⊥
```

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c = a / b;
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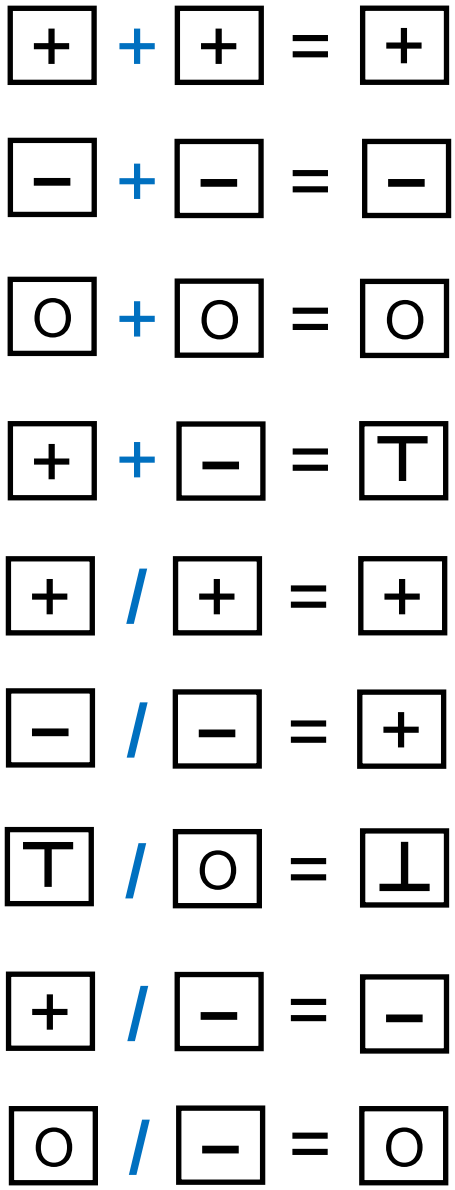
```

1

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

Divided by zero

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2 p = arr[y];
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```
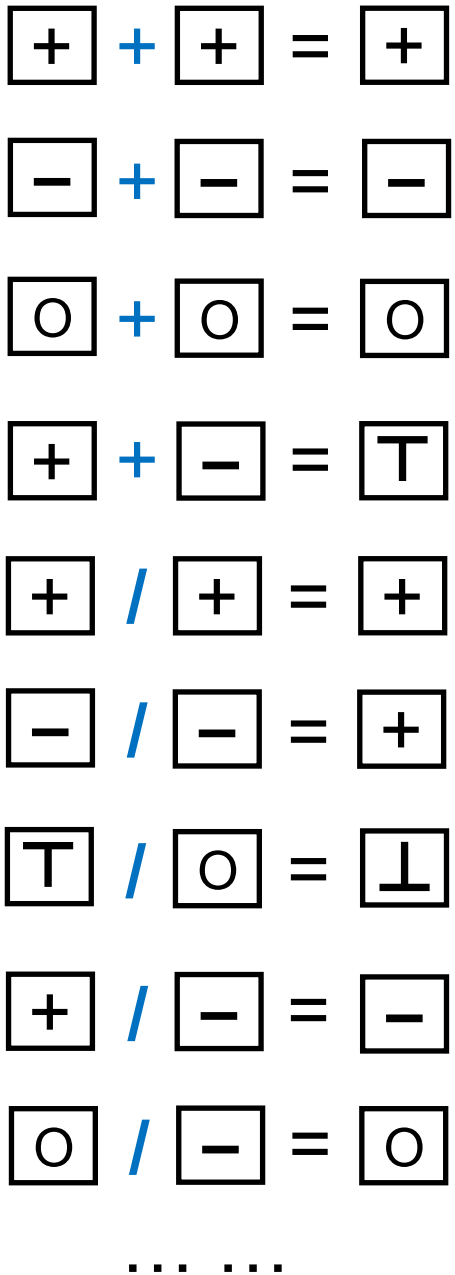

Divided by zero

negative array index

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b = O
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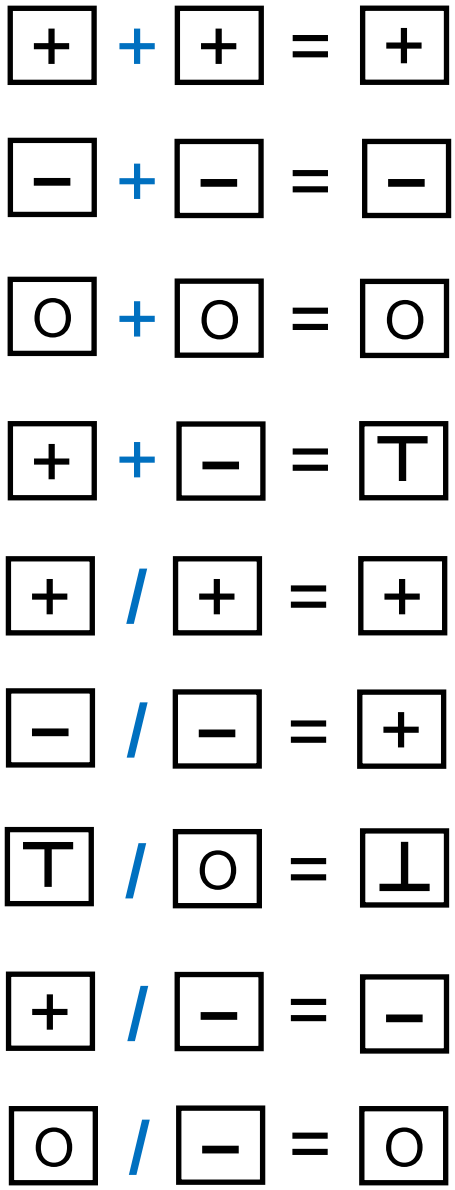
p = ⊥
q = ⊥
```

Divided by zero

negative array index

1 2 Static analysis is useful

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q = ⊥
```

Divided by zero

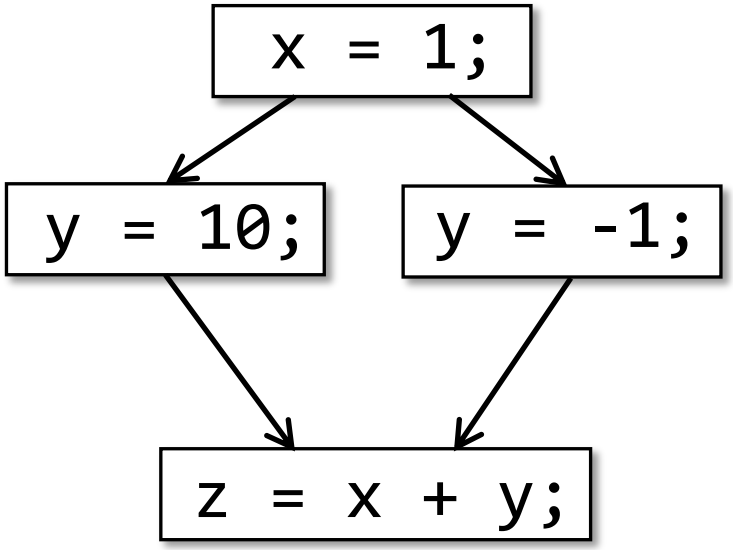
negative array index

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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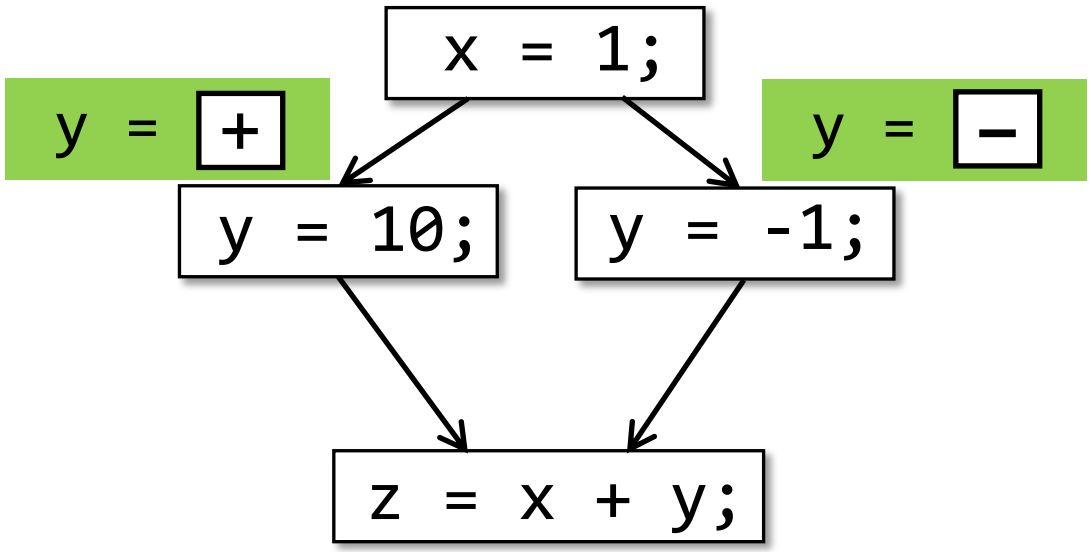

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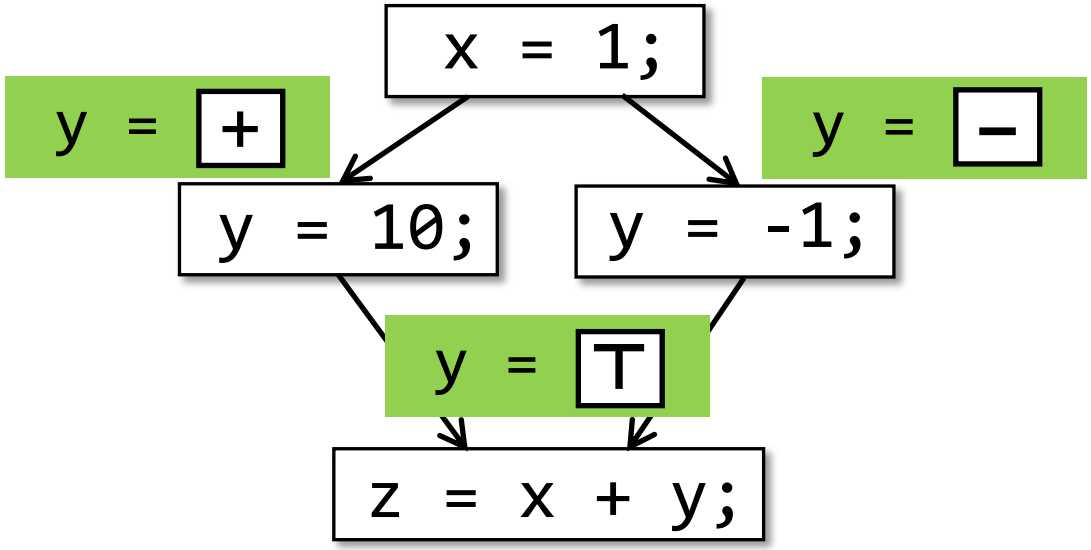

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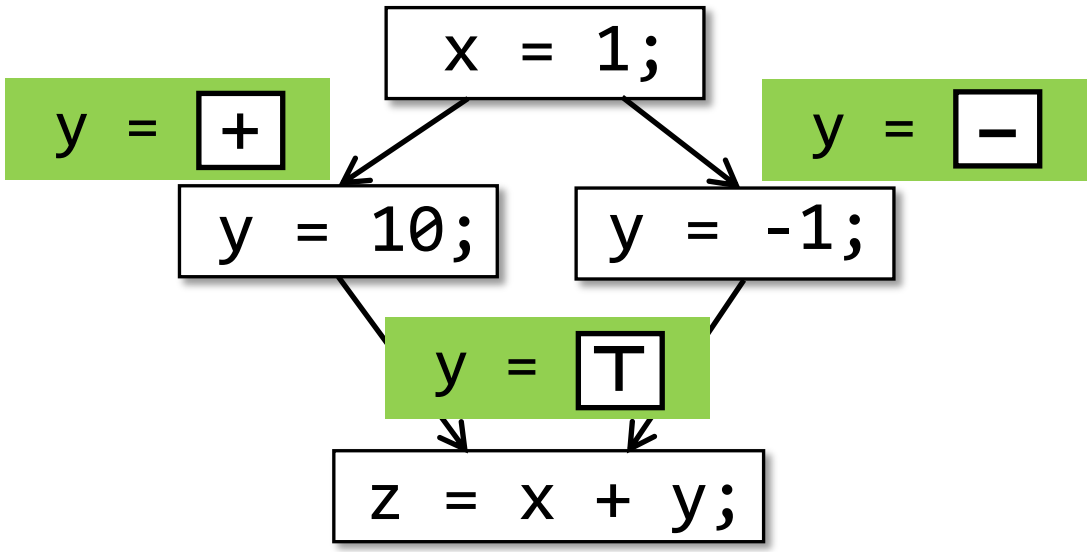

As it's impossible to enumerate all paths in practice, flow merging (as a way of over-approximation) is taken for granted in most static analyses.

Over-approximation: Control Flows

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  y = 10;
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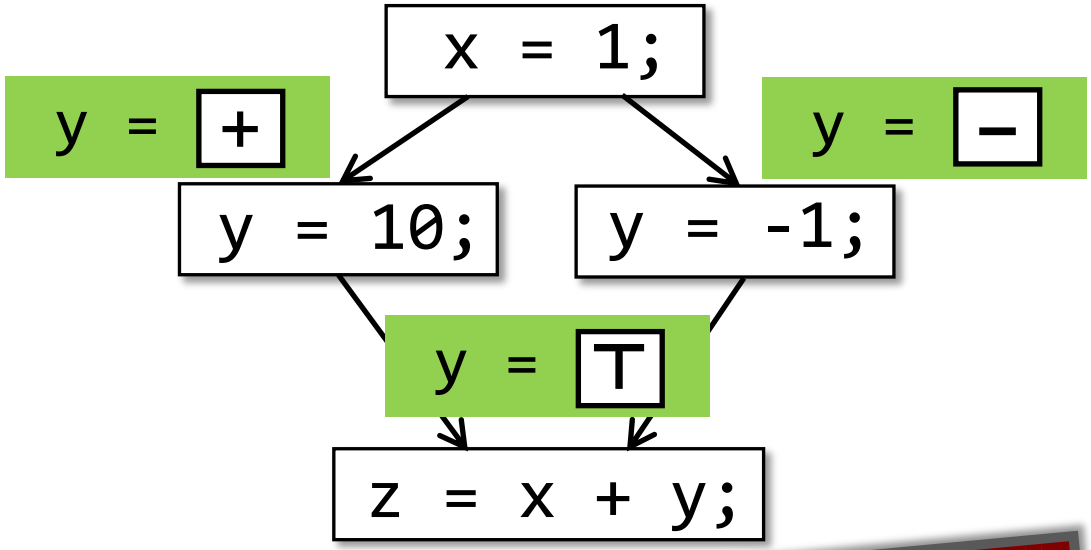

Over-approximation: transfer function + control flows ?

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

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

Evaluation Criteria

- Coding Assignments 40% http://tai-e.pascal-lab.net
- Final Exam 60%

OJ注意事项：

- 用学校邮箱注册
- 填写Student ID
- Nickname用真实姓名
- 抄袭：第一次发现，该次作业0分
  第二次发现，课程成绩0分
- 不交：得5%诚信分
- 迟交：扣得分5% x D, D为迟交天数
- 每帮助找出1个新的有效test case，实验分数+1

Coding Assignments

A1 → A2 → A3

Learn how to incorporate different analyses to build new analysis

A2 → A4 → A7

Learn how to improve analysis precision by handling method calls and aliasing

A5 → A6 → A7/A8

Learn how the precision of fundamental analysis affects the precision of its clients

Intraprocedural

Interprocedural

A1	Live Variable Analysis and Iterative Solver
A2	Constant Propagation and Worklist Solver
A3	Dead Code Detection
A4	CHA and Interprocedural Constant Propagation
A5	Context-Insensitive Pointer/Alias Analysis
A6	Context-Sensitive Pointer/Alias Analysis
A7	Alias-Aware Interprocedural Constant Propagation
A8	Taint Analysis

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?


進撃の巨人
attack on titan
Season 2
计算机系楼
副楼536室