CS162 Week 8

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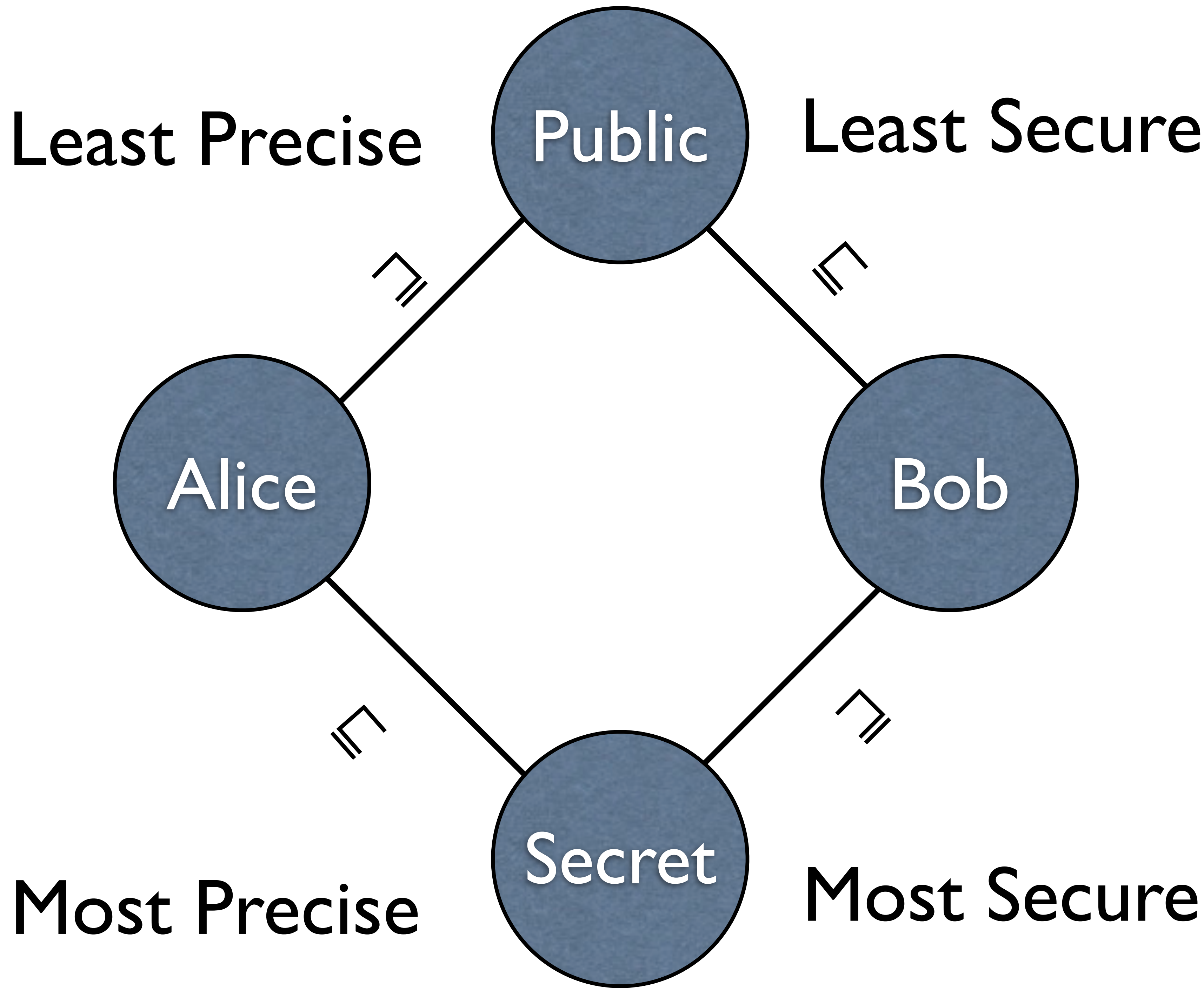
Overview

- Example online going over `fail03.not` (from the test suite) in depth
- A type system for secure information flow
- Implementing said type system

Flashback: Assignment 2

- Implemented dynamically enforced secure information flow via label tracking
  - Each `Storable` is labeled with a tag describing its security level
  - Security levels interact in well-defined ways

Security Levels



Basic Idea

- Specify which channel we output to (public, secure, etc.)
- Only output values of equal or lesser security than the specified value (i.e. do not output something secure on a public channel)
- When values interact to produce new values, the new values take the security level of the most secure thing they touched

Example

```
var x, y in

output secret "enter secret number: ";
x := input secret num;
y := x;

output public y
```

Issues

- This system works, but there are two major issues with it (well, 1.5 major issues)
  - What's problematic?

#1: Termination Leaks

- Whether or not a program halts can leak a bit to an attacker
- In a dynamic system, certain kinds of leaks are transformed into termination leaks
  - I.e. instead of outputting a secret value to public, throw an exception and terminate instead

#2: Dynamic

```
var x, y in
 x := input secret num;
 y := input public num;
 if (y = 42) {
   output public x
 }
```

A Solution

- A static type system and type checker, specifically for secure information flow
- If a program typechecks, then it is **guaranteed** that it is secure
- Type systems being type systems, if it does not typecheck, it still *might* be secure

Assignment 5

- Implement a type checker for secure information flow for miniJS
  - Same syntax from assignment 2
  - Implicitly typed
- The type system, along with all the necessary rules, is provided
- Overall very similar to the type system coverage in the lecture

Major Difference from Lecture

- Lecture is using equivalence constraints
  - Solved using the union-find data structure
- This assignment will use subset constraints
  - These slides cover how to solve these

Three Core Challenges

1. Understanding the math
2. Implementing the math
3. Solving the constraints

#1 Understanding The Math

- Basics needed to understand it covered extensively in lecture
- Biggest difference from lecture: L is used as a type variable instead of T, since L is a security level

#2 Implementing Math

- General rule: implement as close to the math as possible
- The more it deviates, the more difficult it is to reason about whether or not they are equivalent
  - ...and the more difficult it becomes to track down bugs

Implementing Math

$$\frac{\ell_w \sqsubseteq L \qquad \ell \sqsubseteq L}{\rho \cdot \ell_w \vdash \textbf{input}\ \ell\ \mathit{typ} : L}$$

```
case In(typ, l) => {
  val L = LevelVariable()
  lw ⊑ L
  l ⊑ L
  L
}
```

#3: Solving the Constraints

Constraint Generation

- Very similar to how constraints were generated in lecture
- Based on subsets instead of equality

$$\frac{\ell_w \sqsubseteq L \qquad \ell \sqsubseteq L}{\rho{\cdot}\ell_w \vdash \textbf{input}\ \ell\ \mathit{typ} : L}$$

Constraint Generation

Once all the rules have completed, we end up with a bunch of constraints like these:

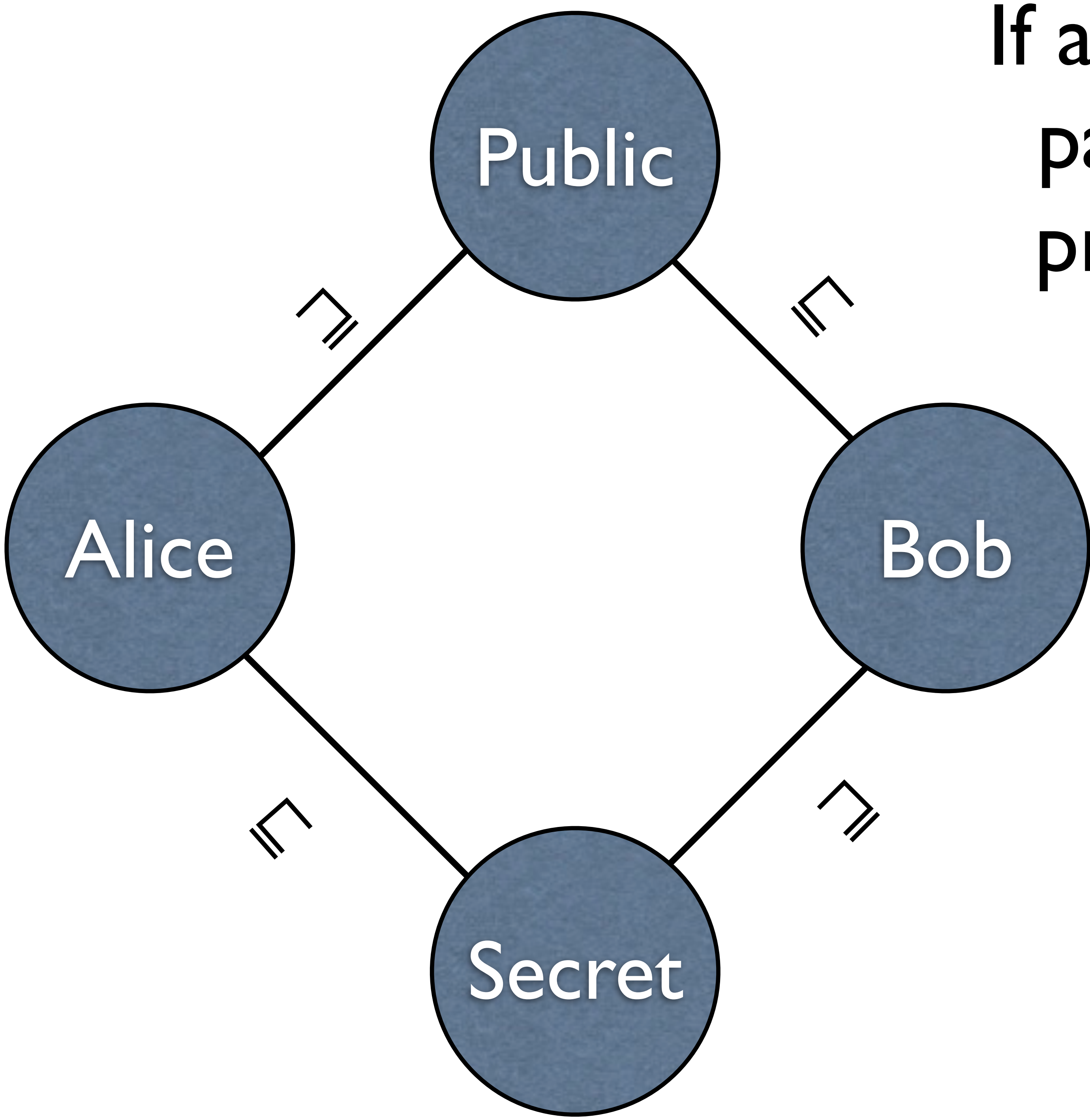
```
Public ⊑ L1
Public ⊑ L2
Public ⊑ Secret
Public ⊑ L3
L3 ⊑ L1
L2 ⊑ L4
Secret ⊑ L4
```

...where `L1`, `L2`, and `L3` are type variables

Constraint Meaning

- These constraints show what the syntax of the program says about the security lattice
- We already know what the security lattice looks like
  - If the two are consistent, the program typechecks
  - If there are inconsistencies, the program fails to typecheck

Finding Inconsistencies



If any constraints violate this partial order, it means the program is not well-typed

Secret $\not\sqsubseteq$ Public

Secret $\not\sqsubseteq$ Bob

Secret $\not\sqsubseteq$ Alice

Bob $\not\sqsubseteq$ Public

Alice $\not\sqsubseteq$ Public

Bob $\not\sqsubseteq$ Alice

Alice $\not\sqsubseteq$ Bob

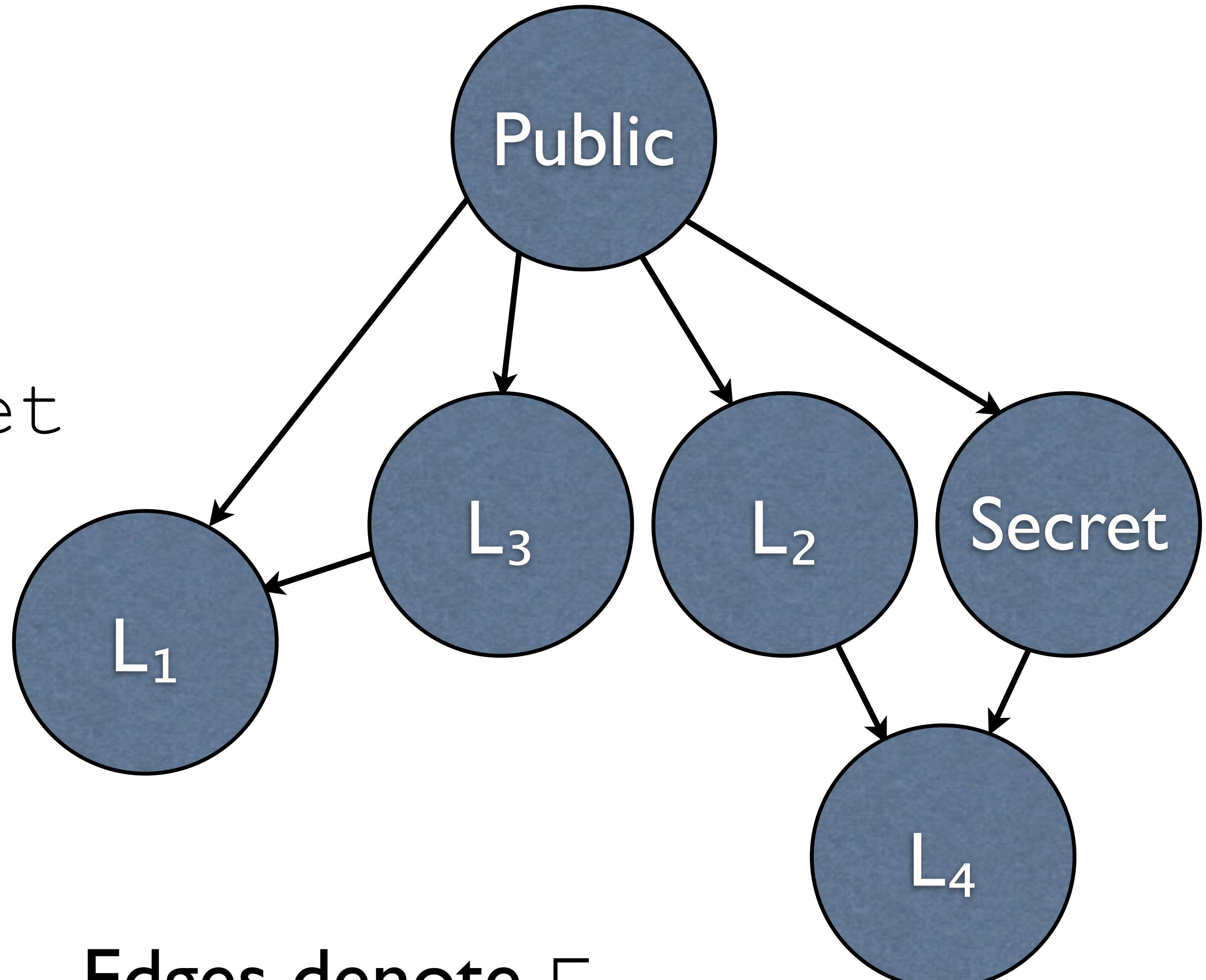
Not that Easy

- What about type variables?
- Need a way to map these back to concrete types

```
Public ⊑ L1
Public ⊑ L2
Public ⊑ Secret
Public ⊑ L3
L3 ⊑ L1
L2 ⊑ L4
Secret ⊑ L4
```

Coalescing Constraints

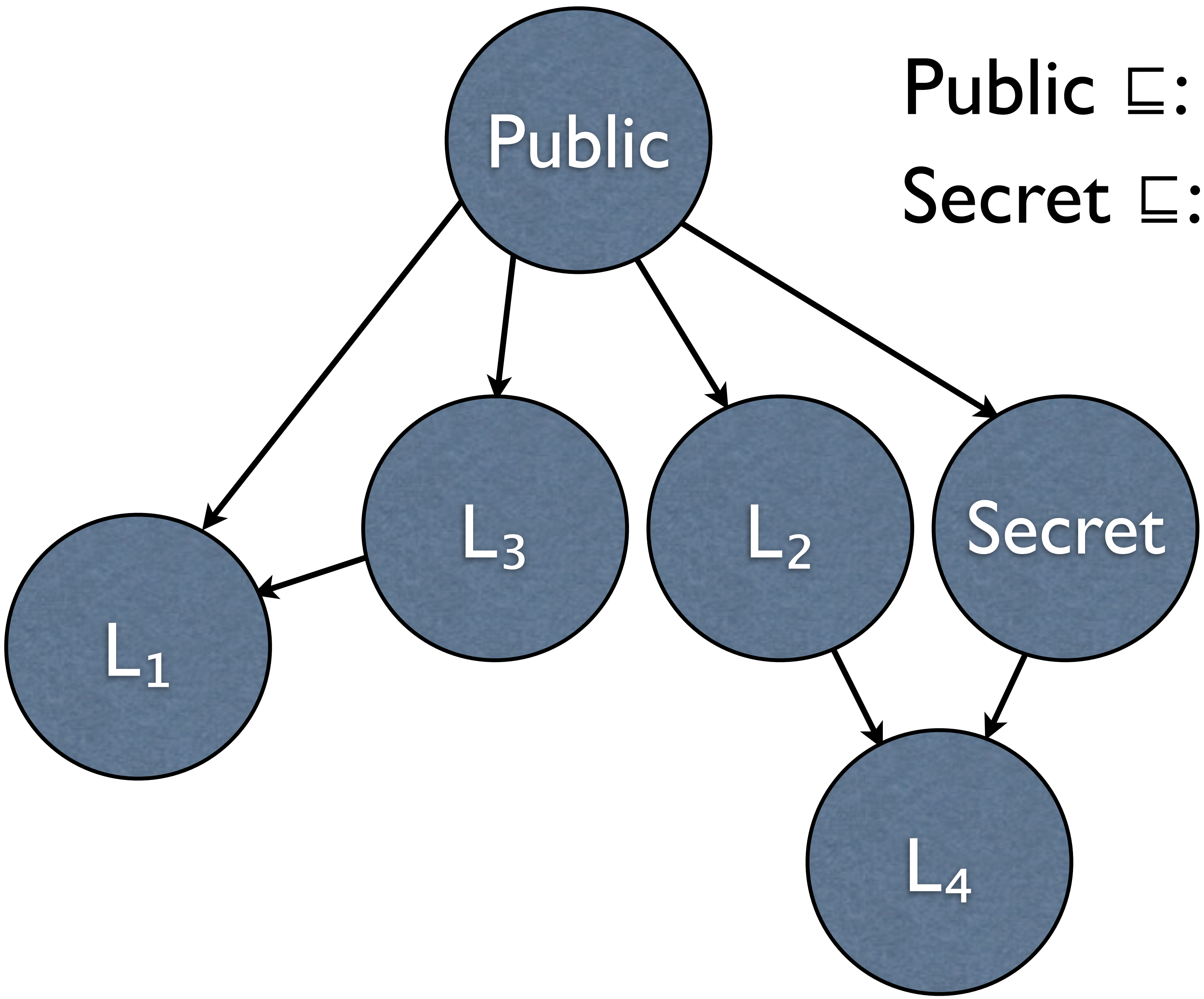
```
Public ⊑ L1
Public ⊑ L2
Public ⊑ Secret
Public ⊑ L3
L3 ⊑ L1
L2 ⊑ L4
Secret ⊑ L4
```



Edges denote ⊑

Getting the Full $\sqsubseteq$

If node n_1 can reach node n_2, then $n_1 \sqsubseteq n_2$

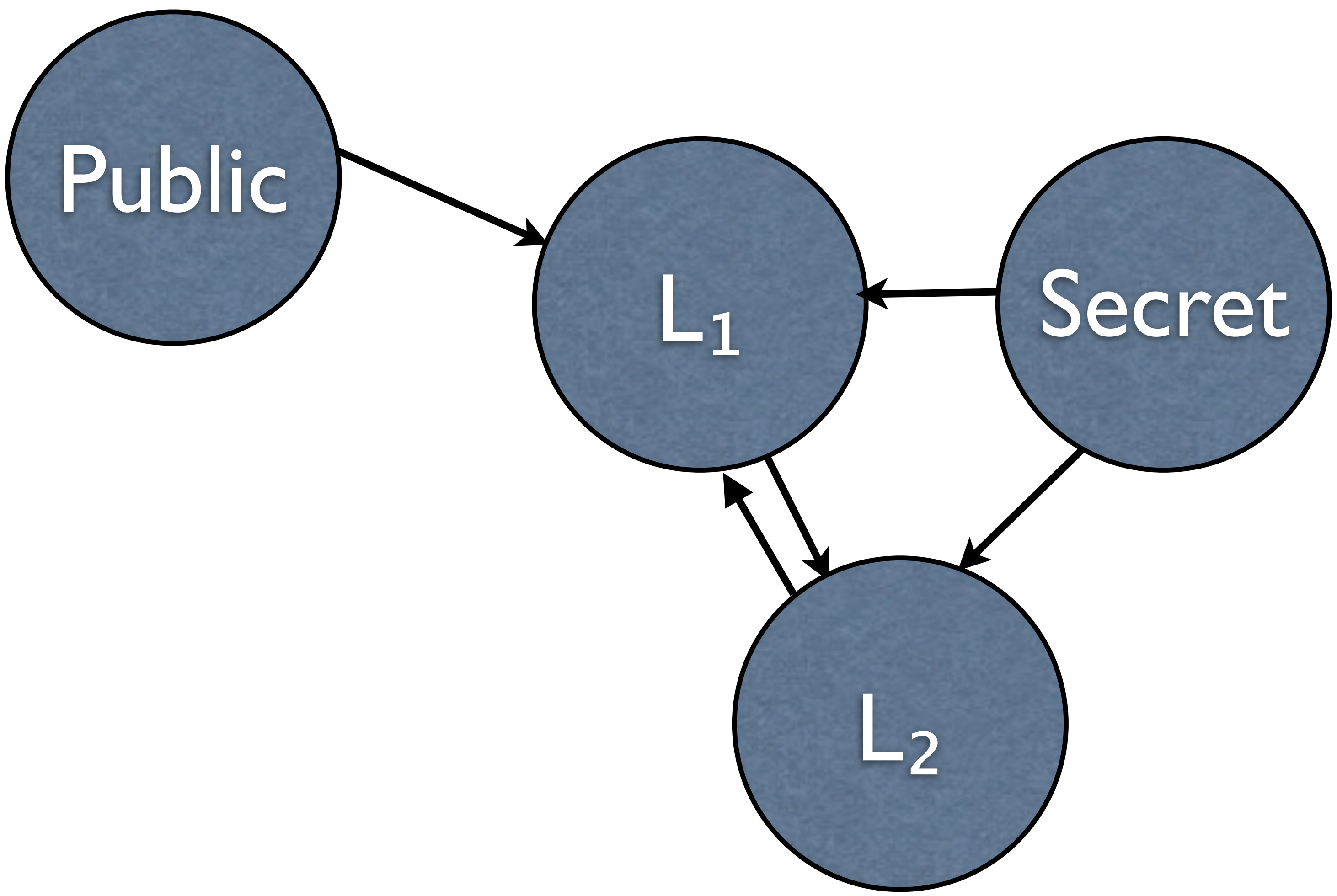


Public $\sqsubseteq$: $\{L_1, L_2, L_3, L_4, Secret\}$

Secret $\sqsubseteq$: $\{L_4\}$

Cycles

- The graph can contain cycles
- This should not break anything



Public $\sqsubseteq$: $\{L_1, L_2\}$

Secret $\sqsubseteq$: $\{L_1, L_2\}$

Final Step

- Verify the full sets are consistent
- Only need to consider concrete security levels (public, secure, etc.)

`Secret` $\not\sqsubseteq$ `Public`	Secret cannot reach Public
`Secret` $\not\sqsubseteq$ `Bob`	Secret cannot reach Bob
`Secret` $\not\sqsubseteq$ `Alice`	Secret cannot reach Alice
`Bob` $\not\sqsubseteq$ `Public`	Bob cannot reach Public
`Alice` $\not\sqsubseteq$ `Public`	Alice cannot reach Public
`Bob` $\not\sqsubseteq$ `Alice`	Bob cannot reach Alice
`Alice` $\not\sqsubseteq$ `Bob`	Alice cannot reach Bob

Constraint Solver Implementation

- Free to use mutability
- It is not necessary to make an explicit graph, but you are free to do so if you wish
  - It is likely easier to avoid it if possible
- For each constraint, add an edge and possibly nodes to this graph
  - A global counter will be needed for generating unique type variables

Removed for Simplicity

- Each node should have an edge pointing to itself
  - Since the definition of $\sqsubseteq$ includes equality, for all levels `l`, `l` $\sqsubseteq$ `l`
  - Hint: this can be exploited in implementations that do not have an explicit graph

The Math in Depth

`fail03.not` Example