SLAB: A Certifying Model Checker for Infinite-State Concurrent Systems

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Germany

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System Description:

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System Description:

- transition systems described by linear constraints

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System Description:

- transition systems described by linear constraints
- safety properties

Certification

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Standard practice for model checkers

- Error found $\Longrightarrow$ Counterexample
- Error unreachable $\Longrightarrow$ "Correct"

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We need a **certificate as a proof** of correctness

- Should be independently and automatically checkable
- Provides higher degree of confidence in the verification results
- Helps understanding the reason of system correctness

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Certificates

- In graphical format
- In SMT-LIB format
- Independently checkable by standard SMT solvers

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Coming soon...

- Integration into theorem proving process
- Interfacing with Coq

SLAB Certificate Example

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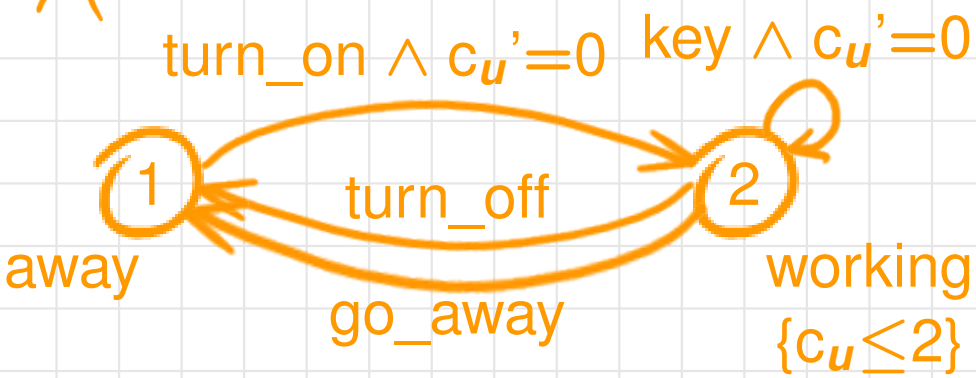
c_u, c_L: clock

turn_on, key, ... : event



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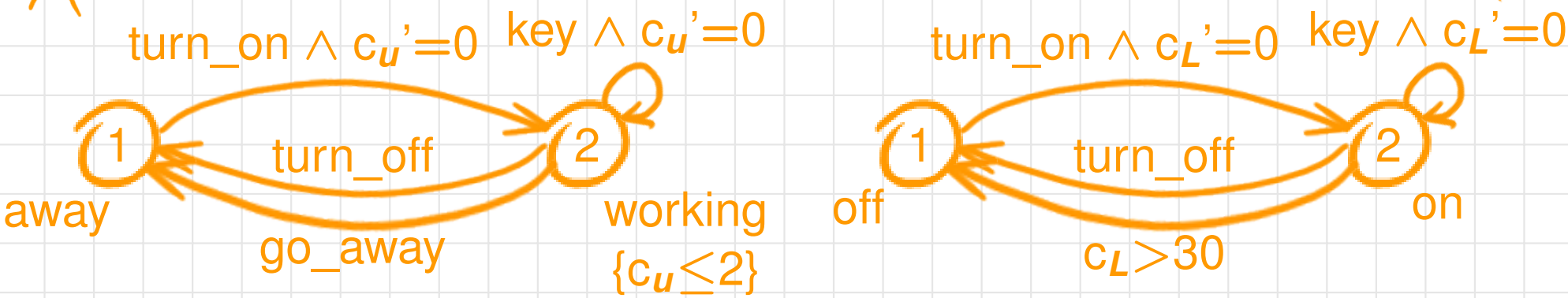

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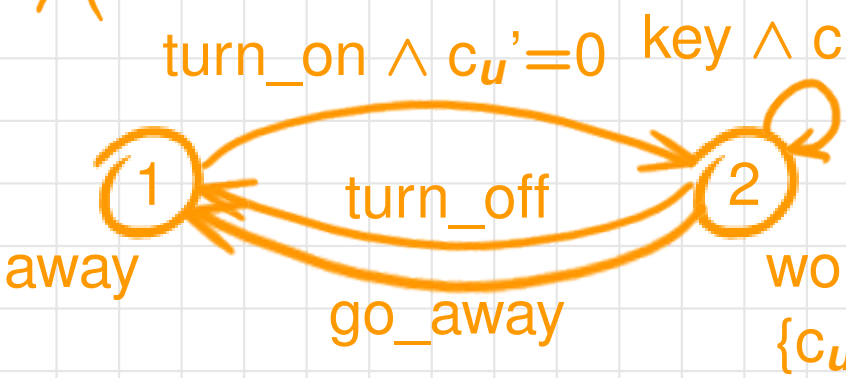
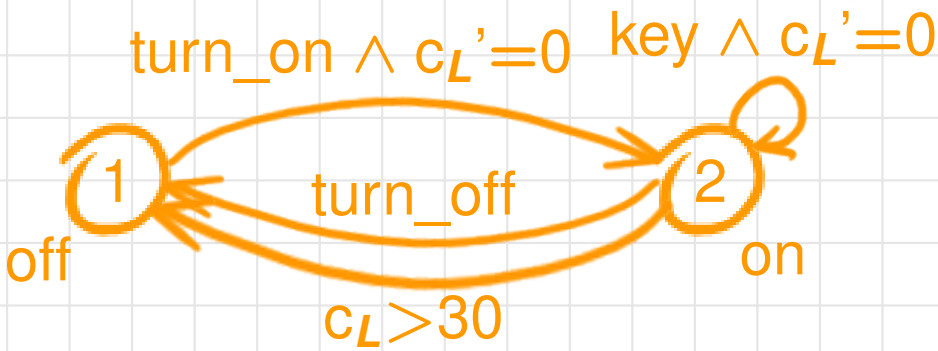
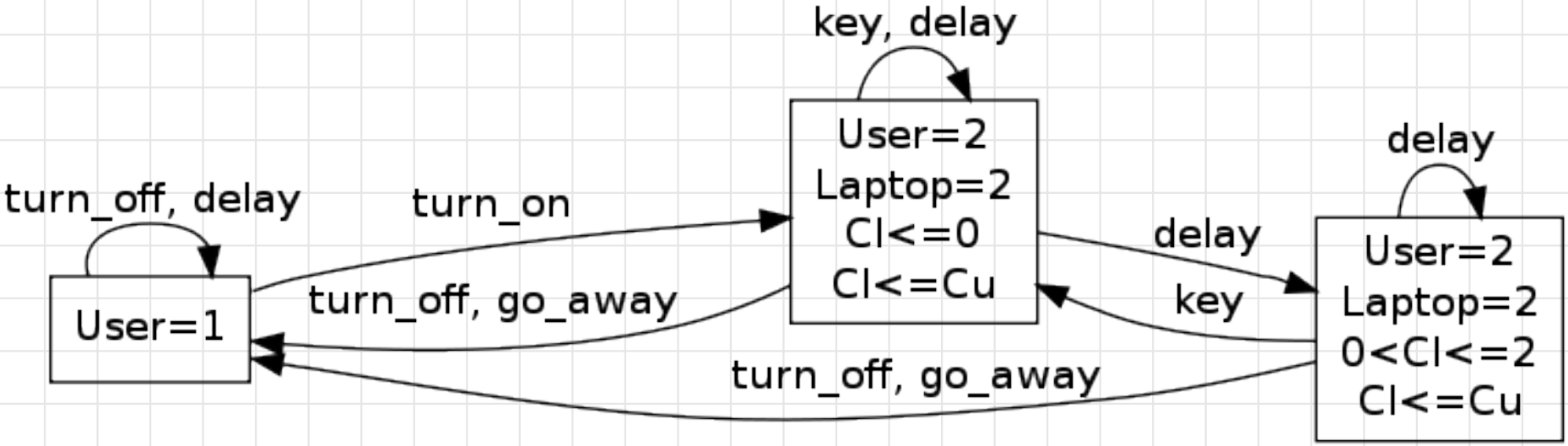
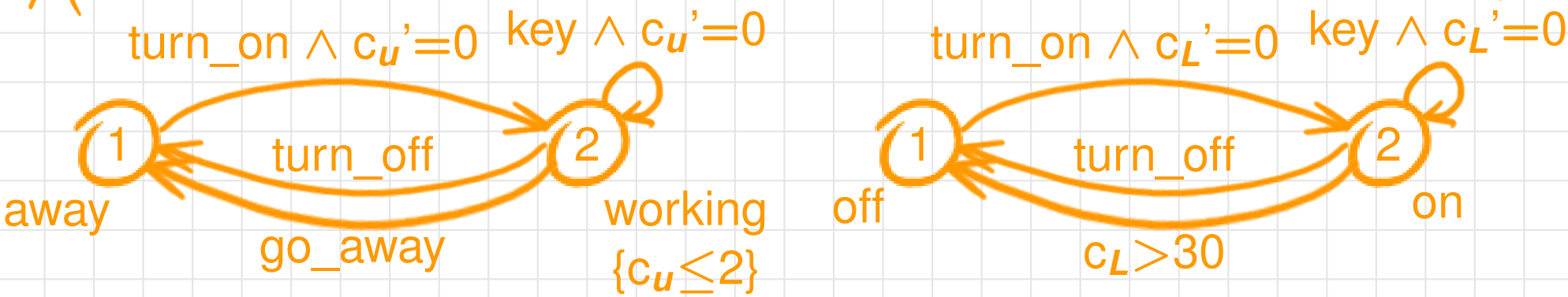






SLAB Certificate Example (2)



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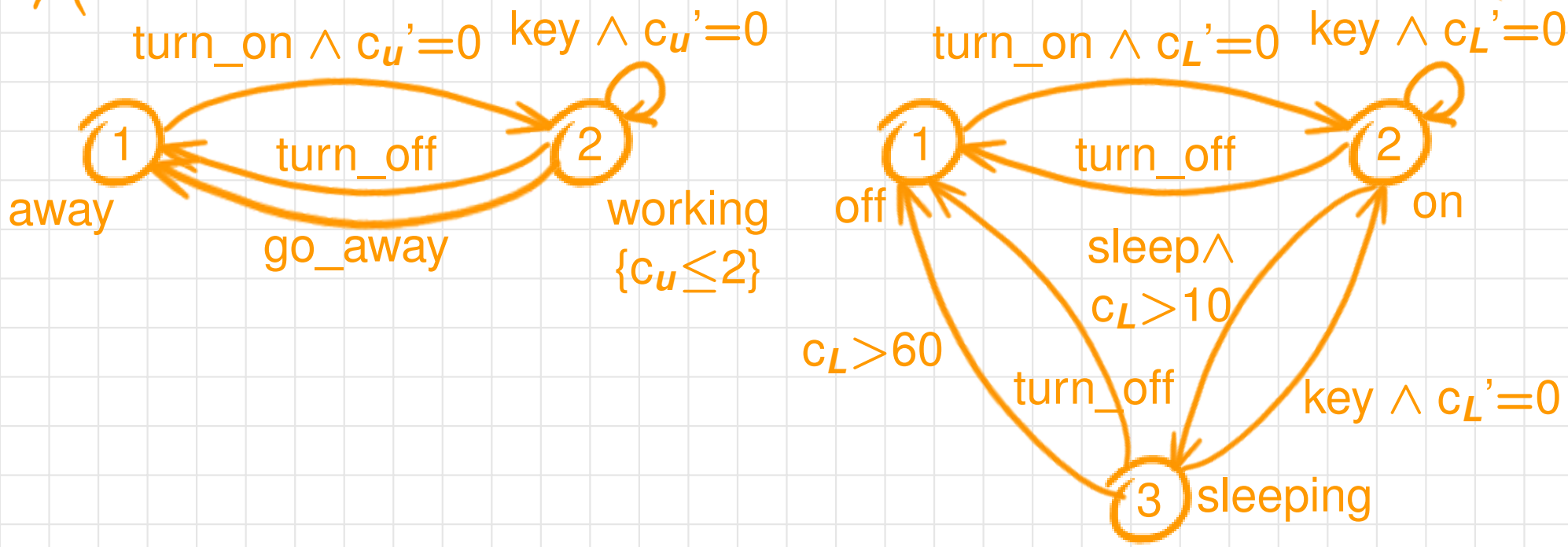

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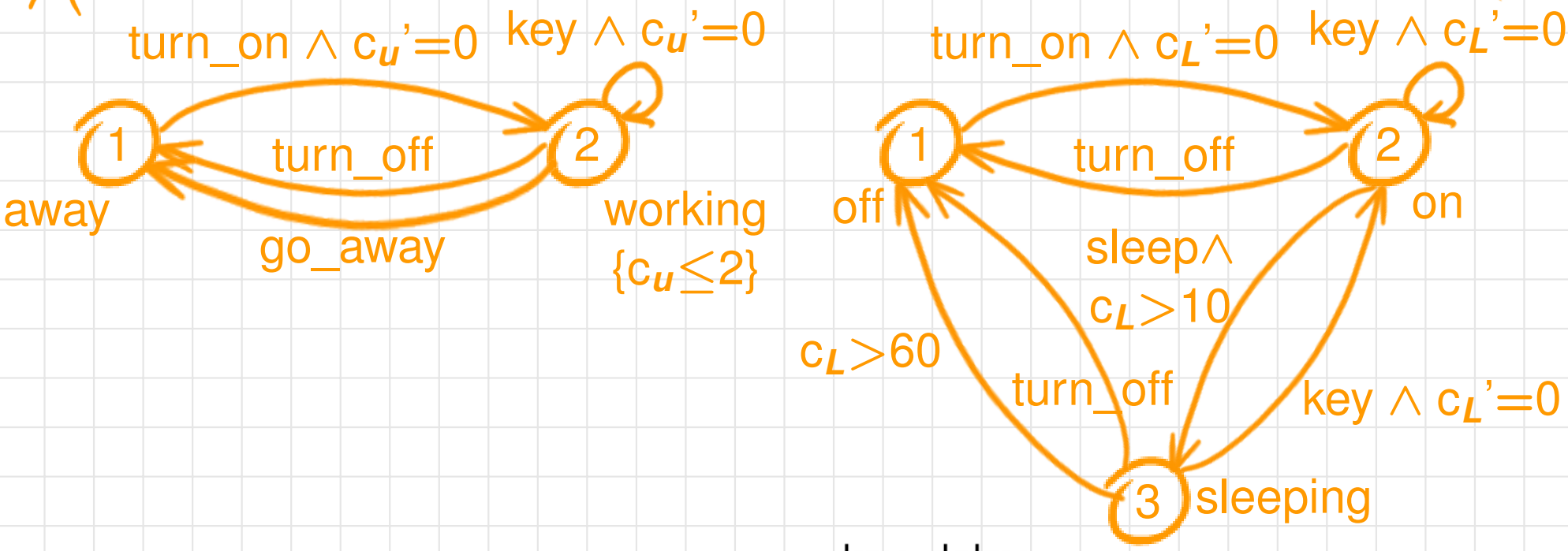

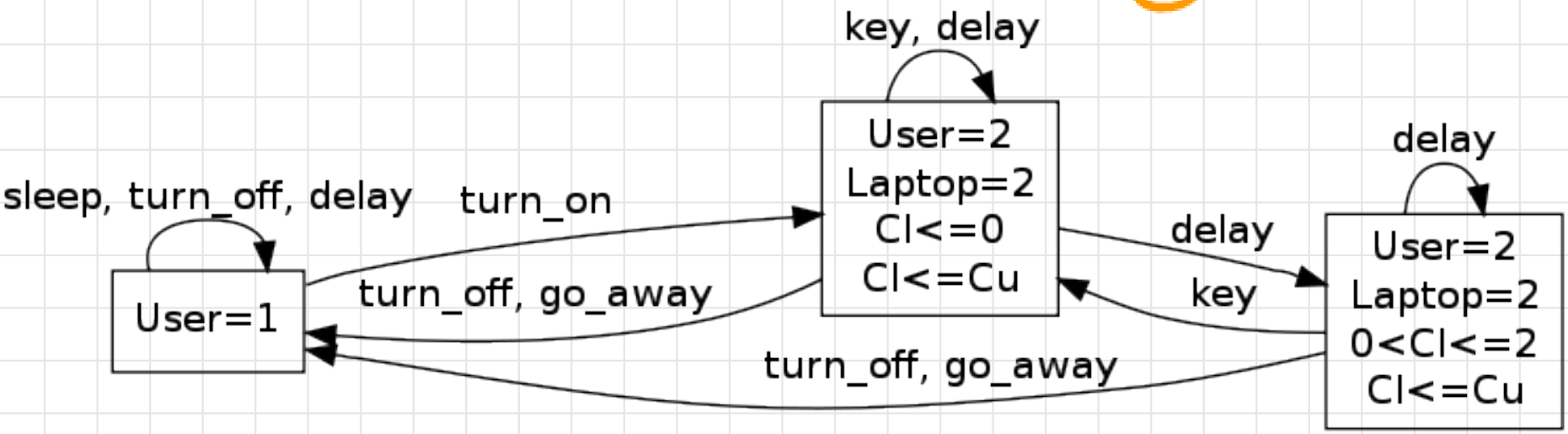

System and Certificate

Transition System $\mathcal{S} = (\mathit{init}, \mathcal{T}, \mathit{error})$

- Initial condition $\mathit{init}(V)$
- Set of system transitions $\mathcal{T}$: $\tau_i(V, V')$
- Error condition $\mathit{error}(V)$
- init, error, τ_i are linear arithmetic constraints

Certificate $\mathcal{C} = (N, E, \varphi, \eta)$

- Finite graph with nodes N and edges E
- Node labeling: $\varphi : N \rightarrow \mathit{Asrt}(V)$
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$x, y : \mathbb{Z}$

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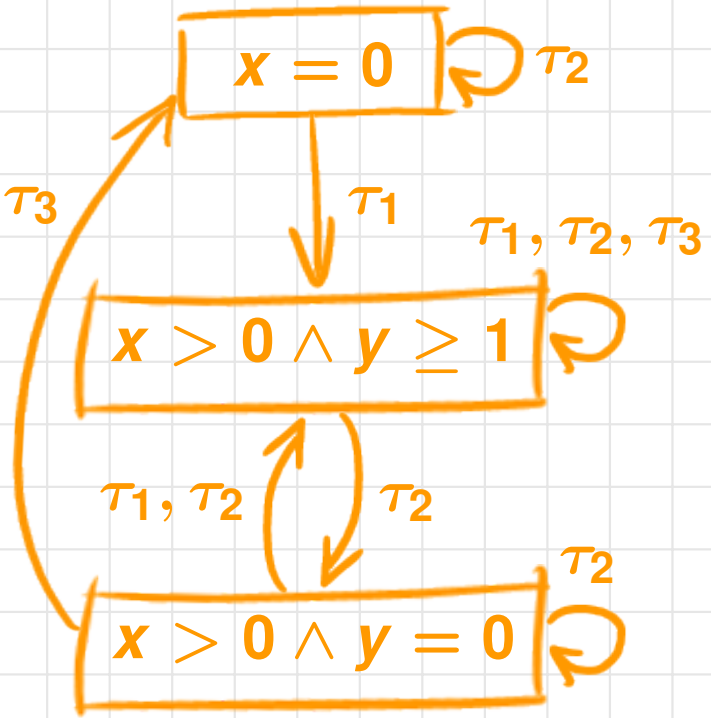

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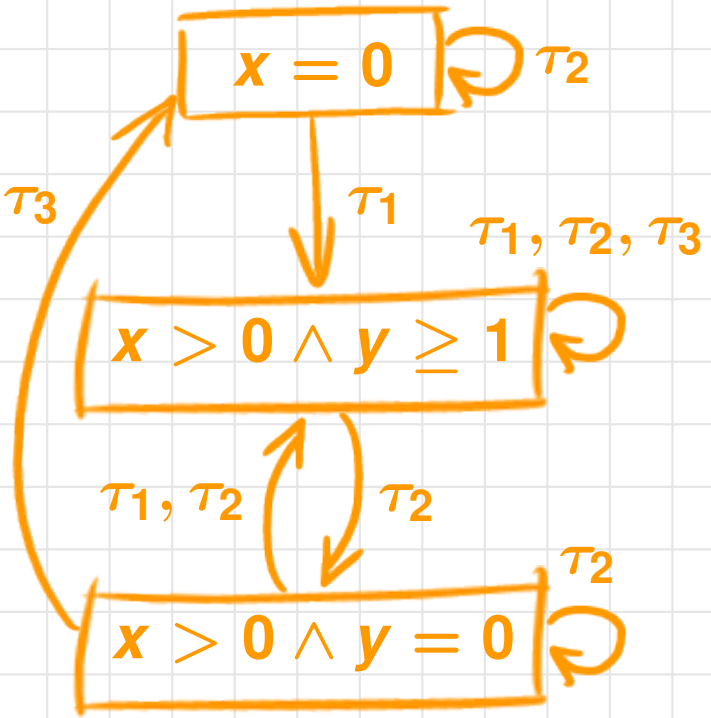

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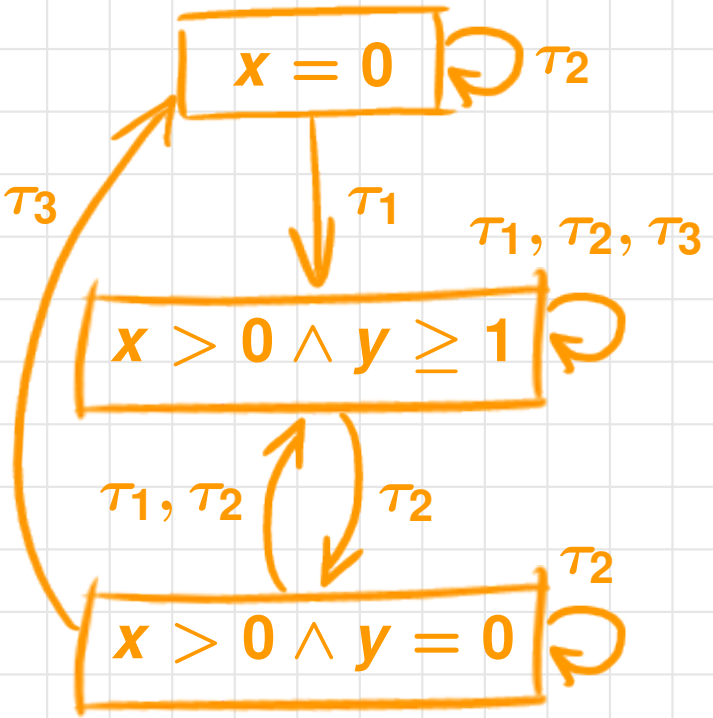

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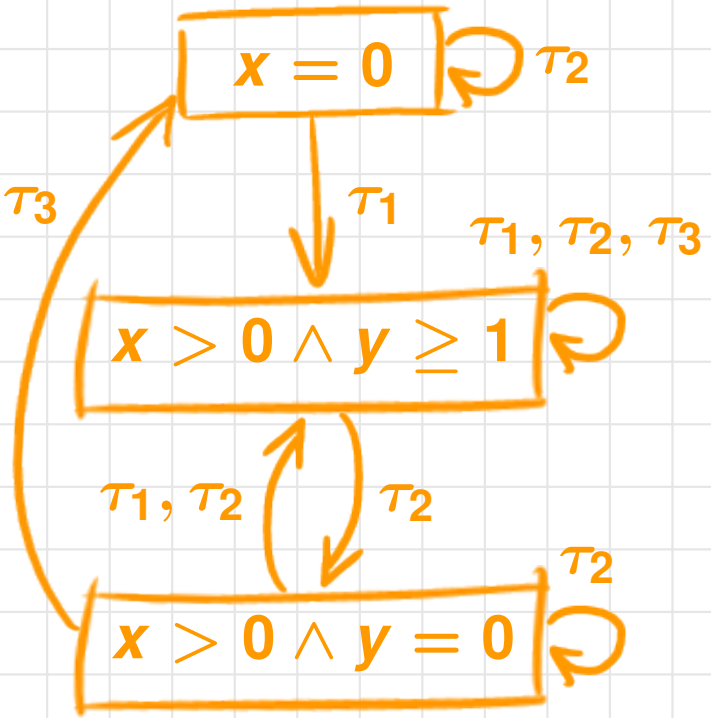

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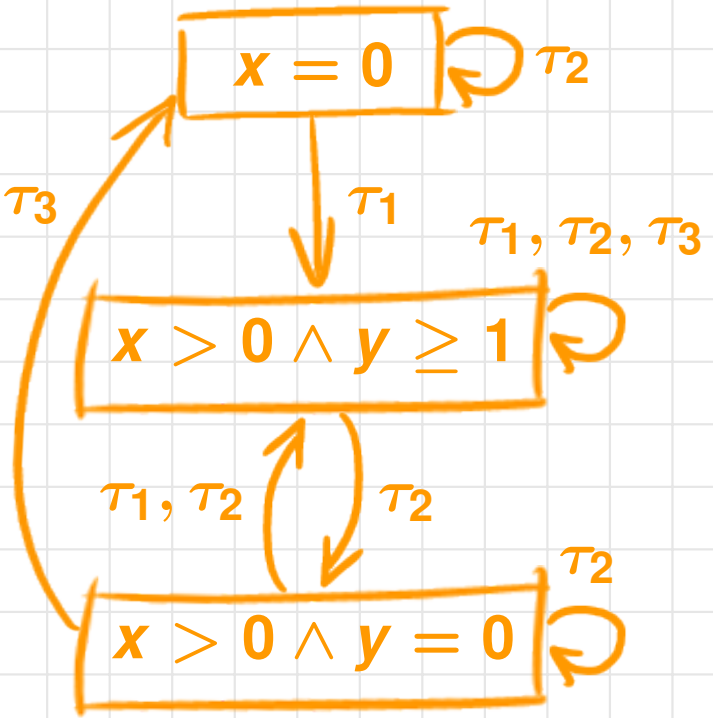

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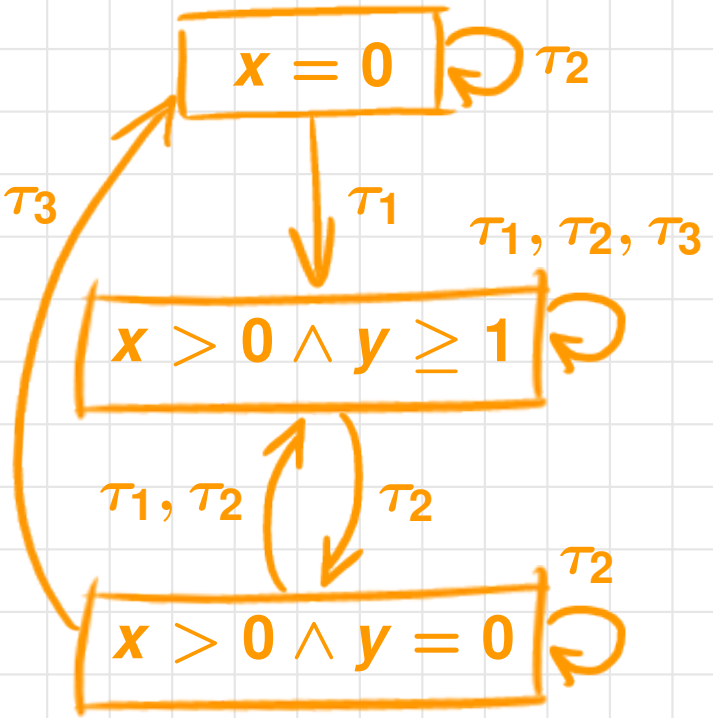

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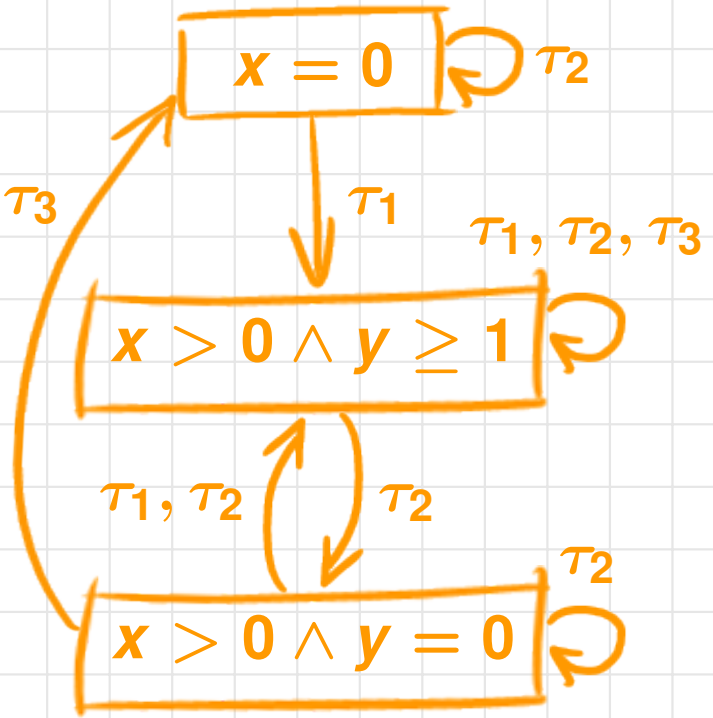

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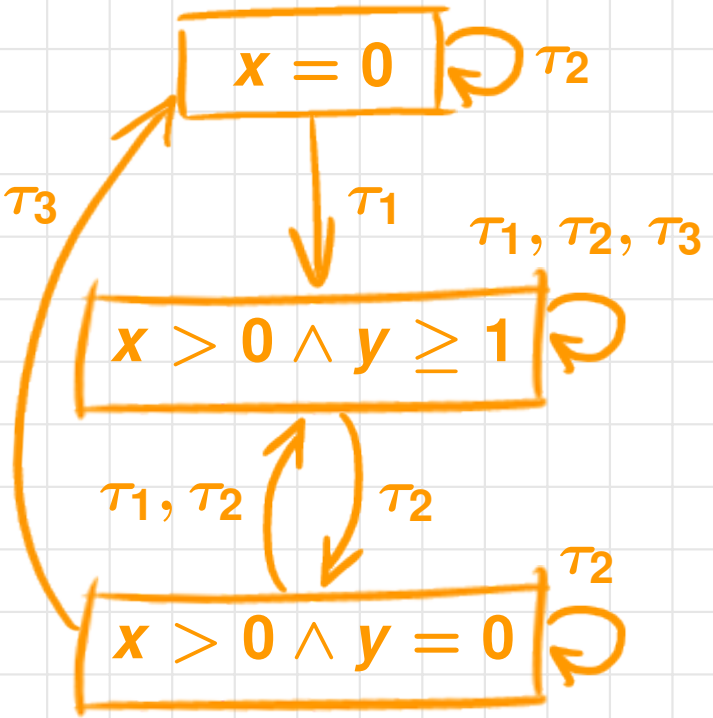

Certificate Correctness

Inductive Invariant

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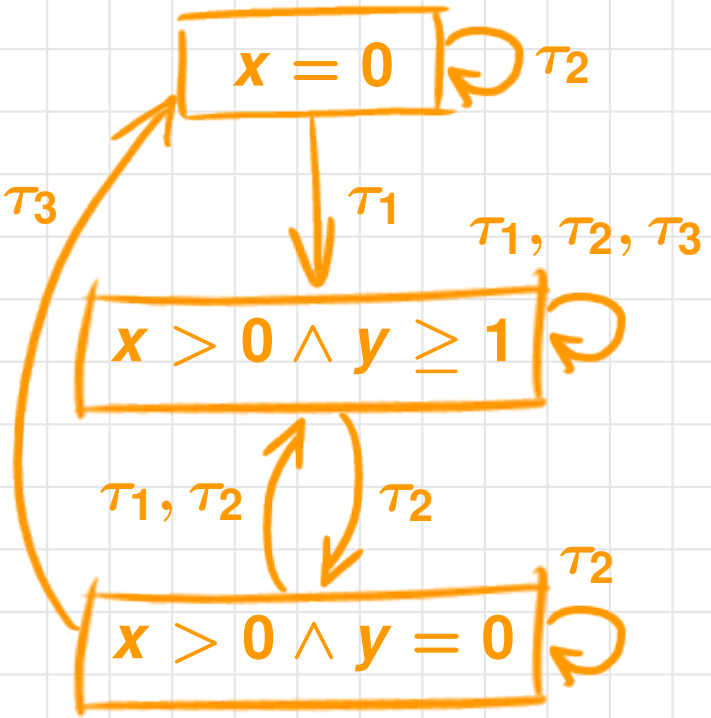
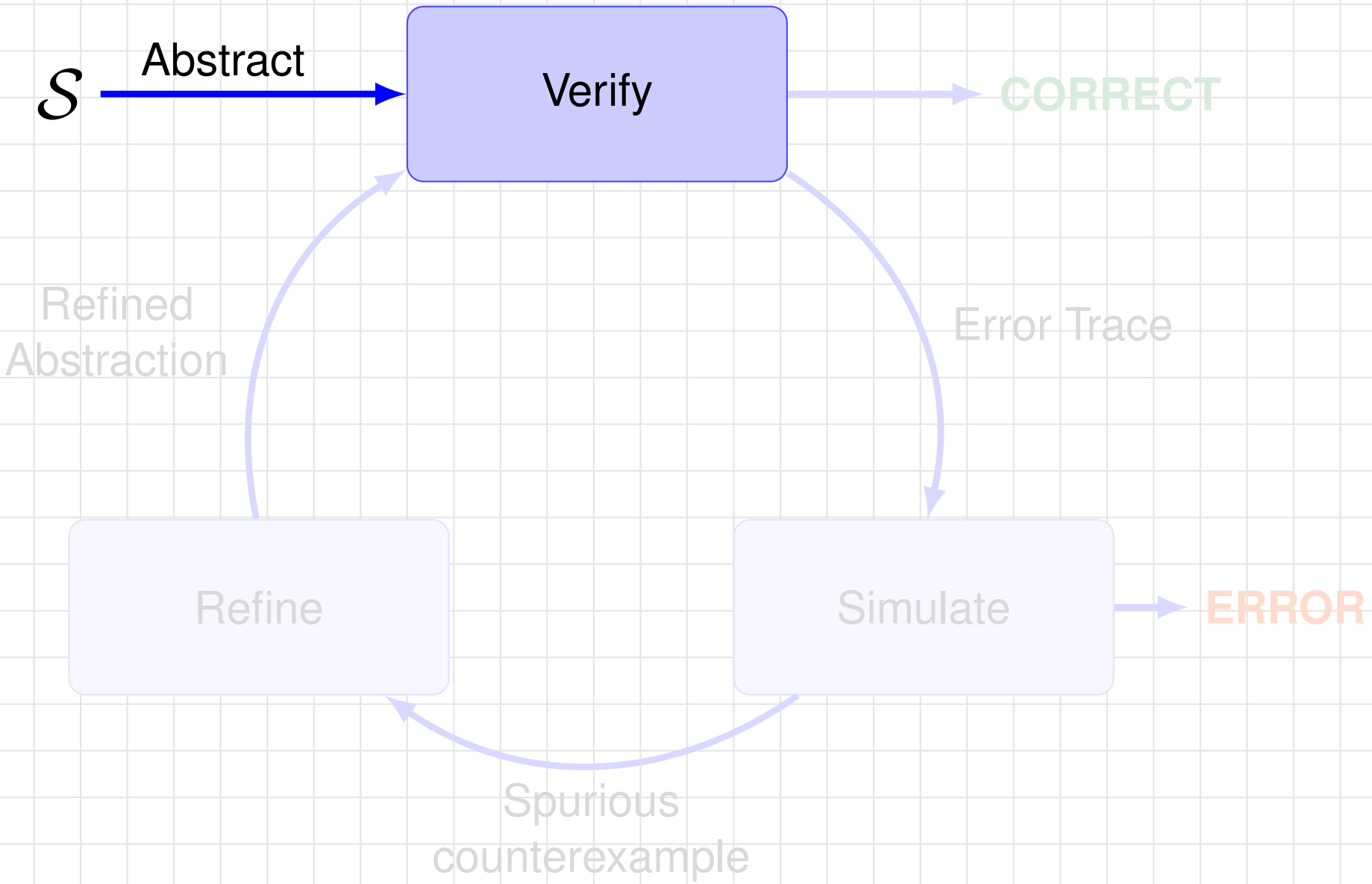


Counterexample-Guided Abstraction Refinement



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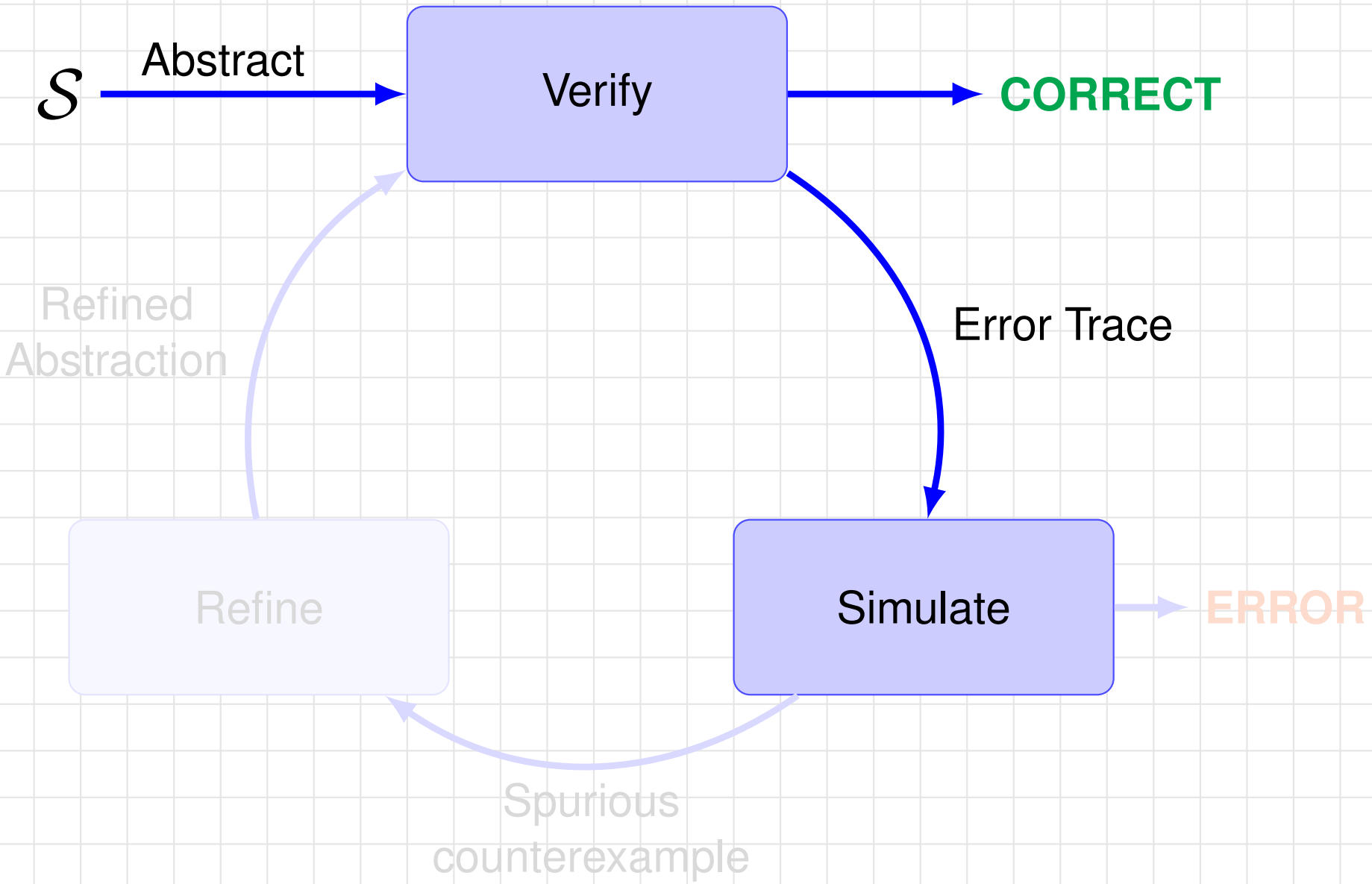

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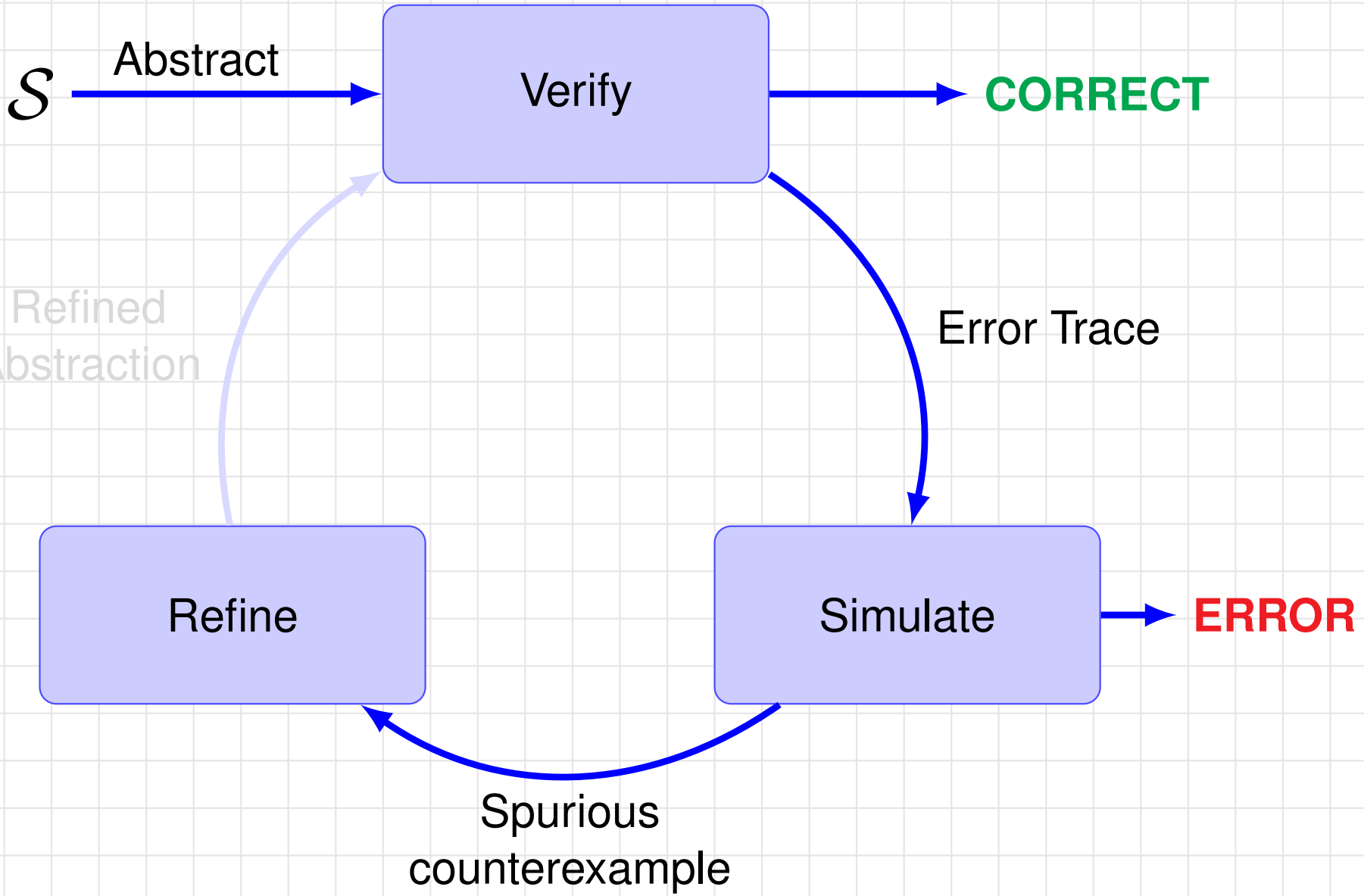

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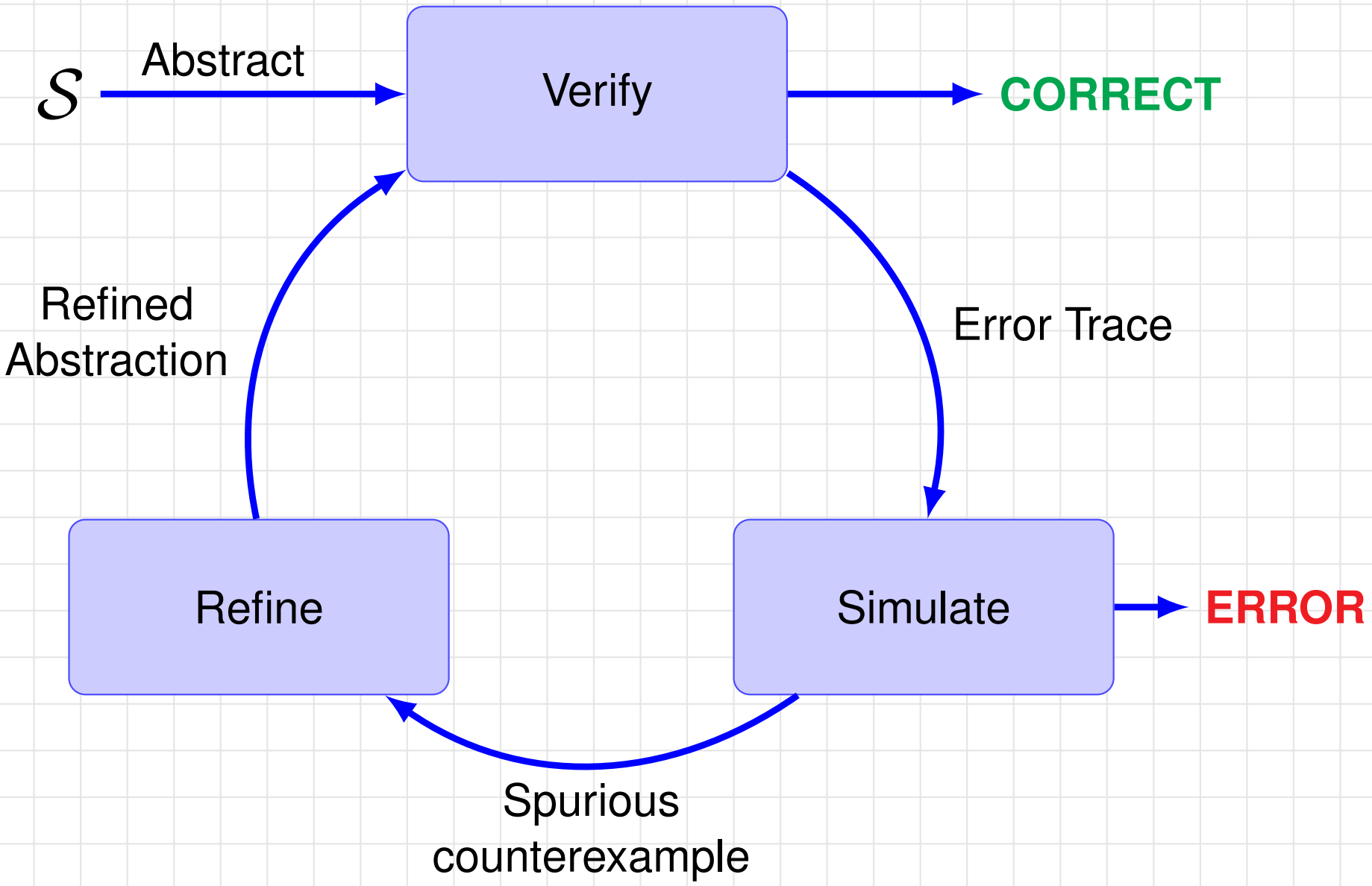

Slicing Abstraction Refinement

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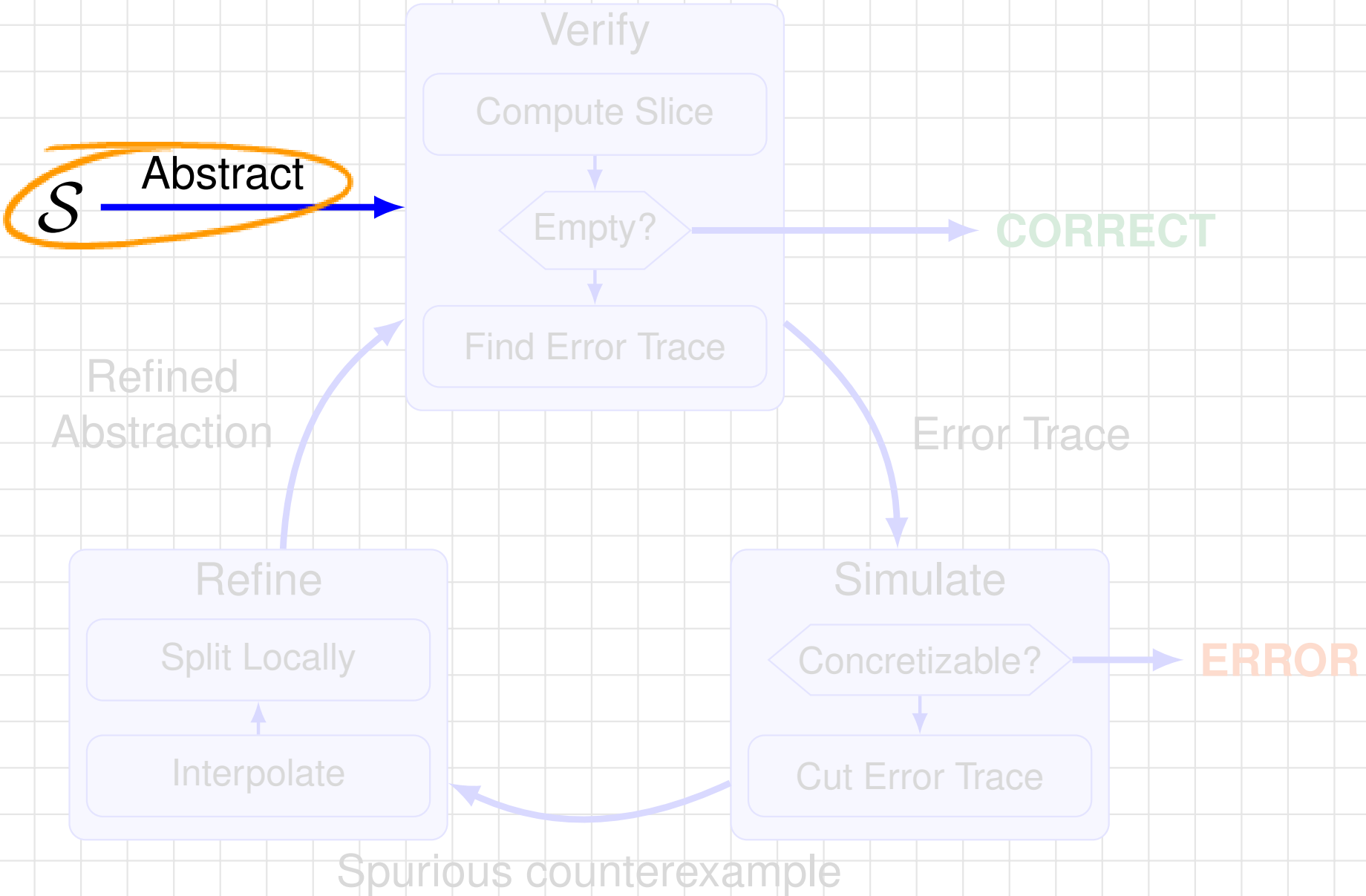

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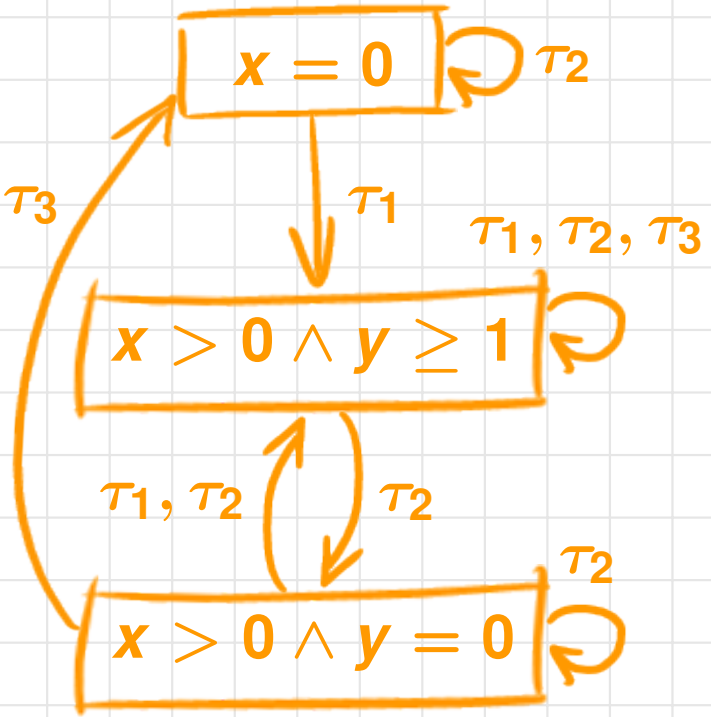

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System and Abstraction

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Abstraction $\mathcal{A} = (N, E, \varphi, \eta, I, F)$

- Finite graph with nodes N and edges E
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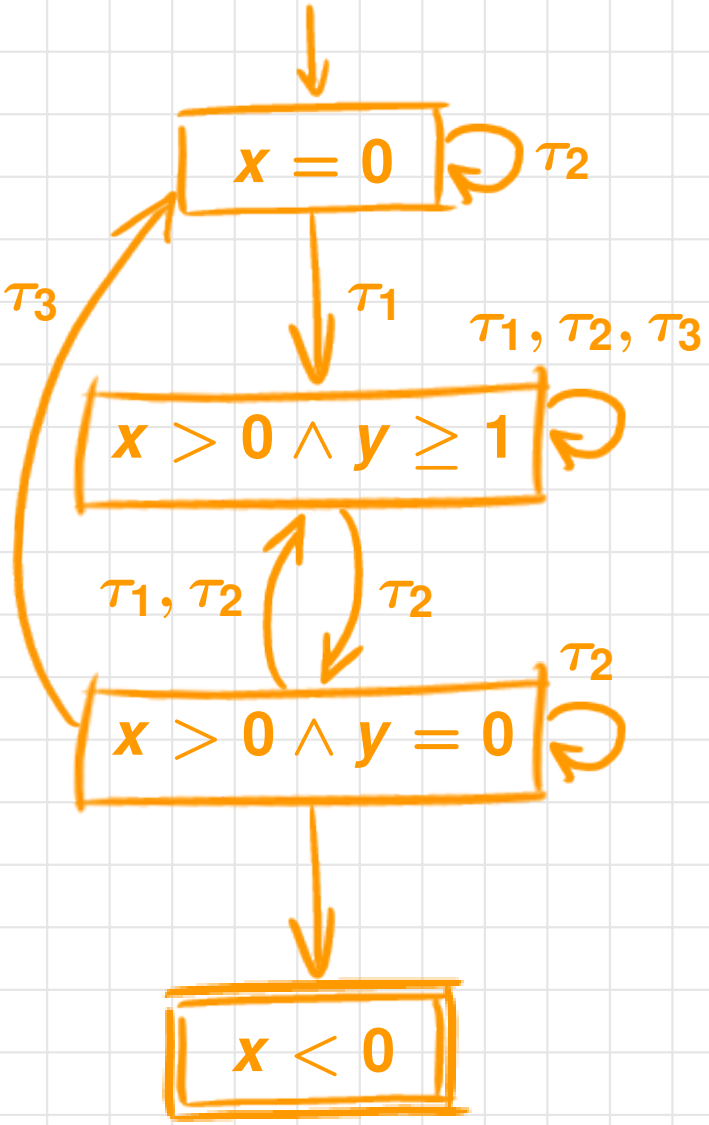
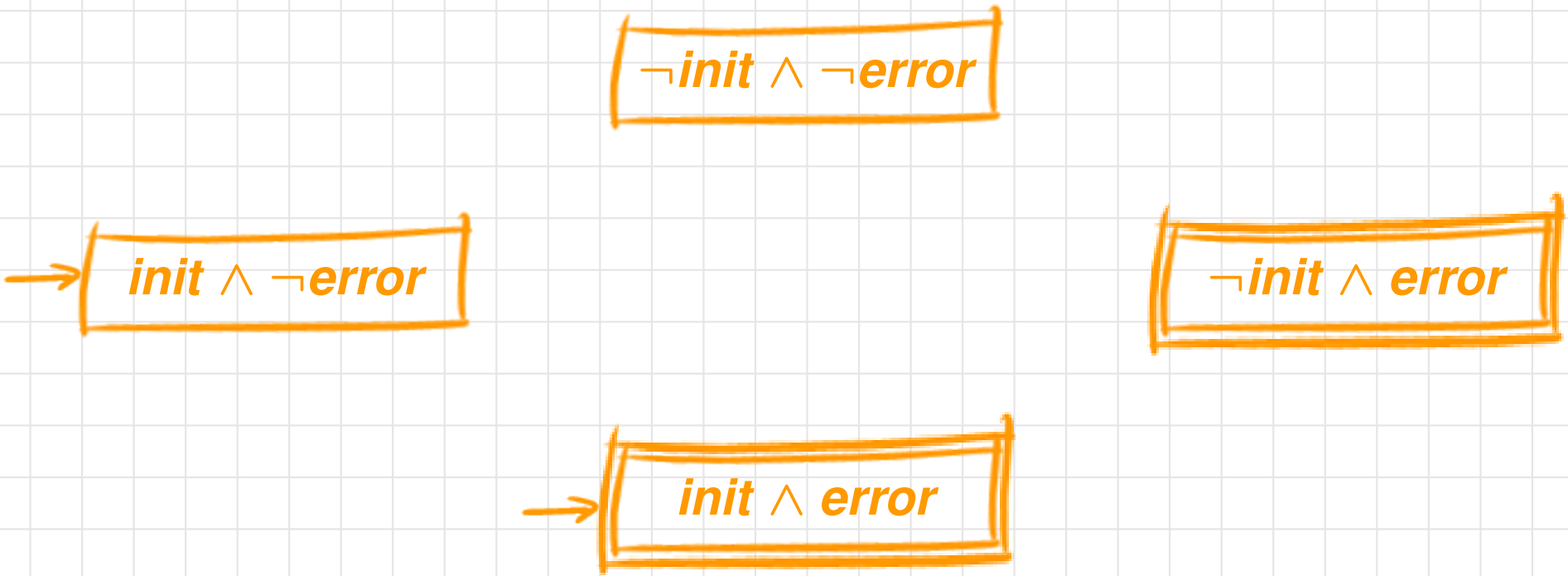
- Initial nodes $I \subseteq N$, final nodes $F \subseteq N$



Initial Abstraction

- Initial abstraction over *init*, *error*



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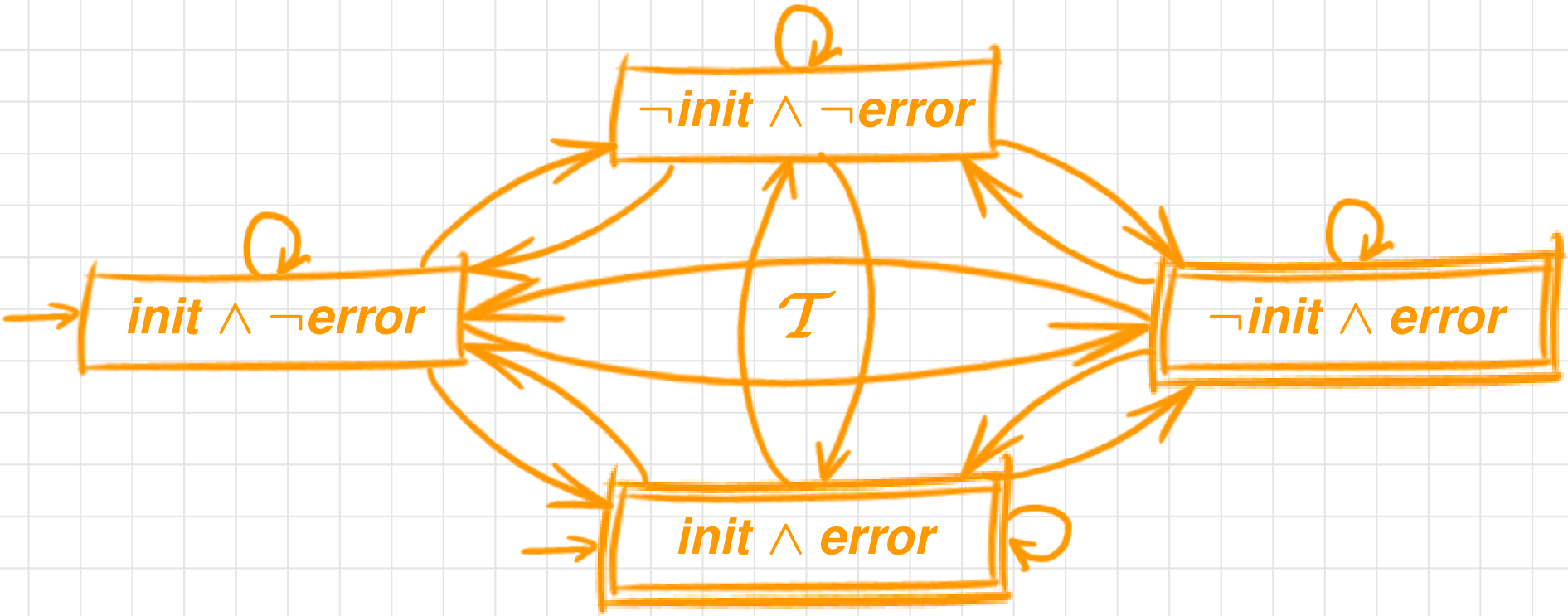

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- Initial abstraction over *init*, *error*
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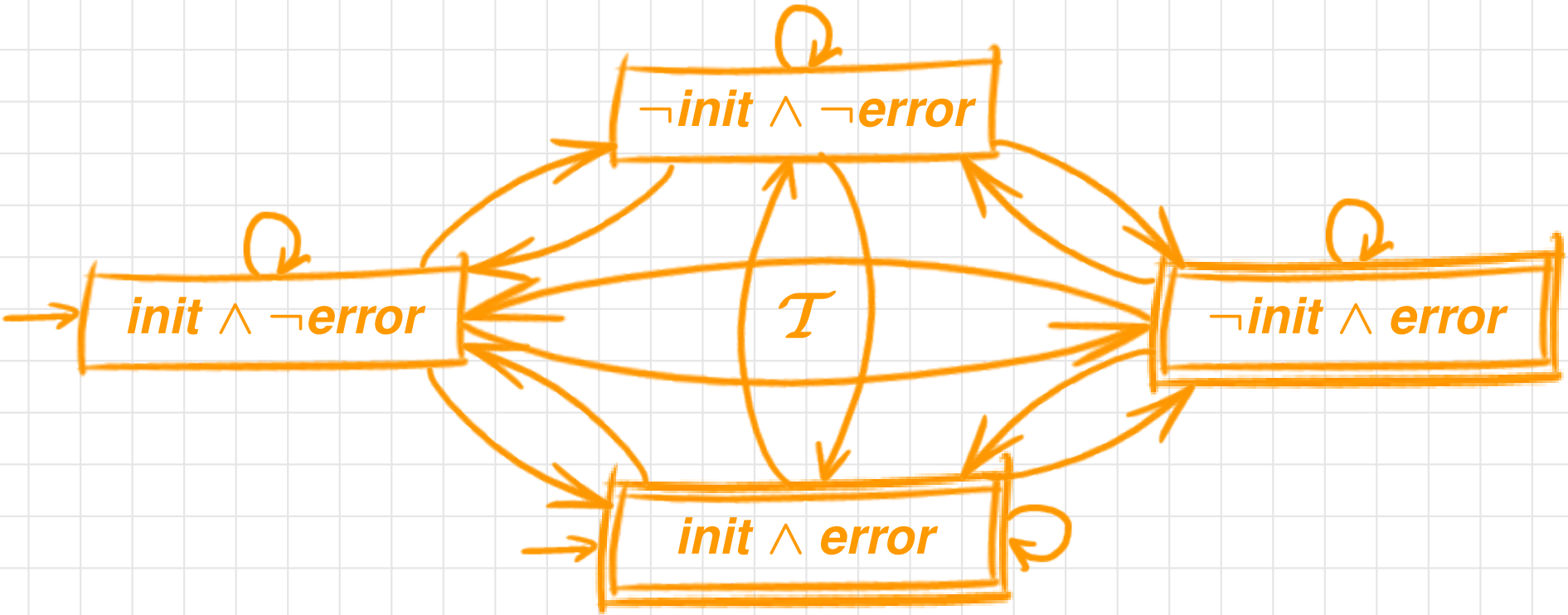

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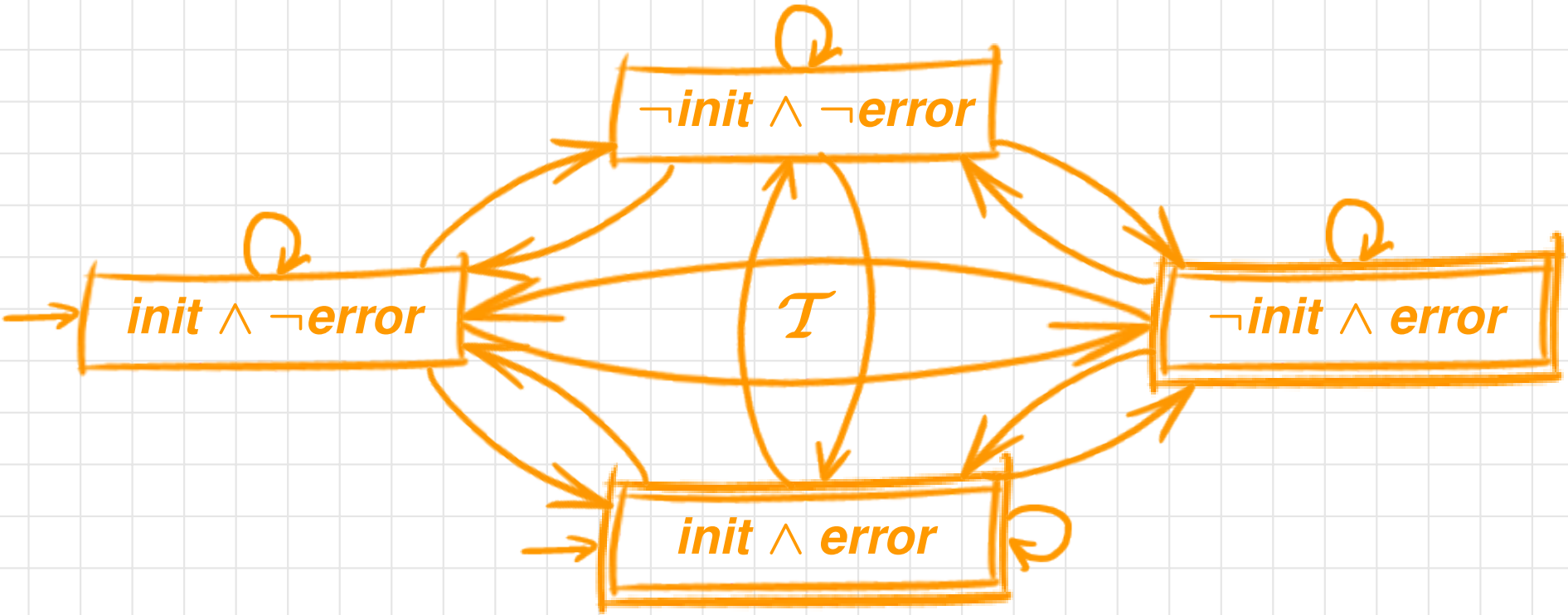

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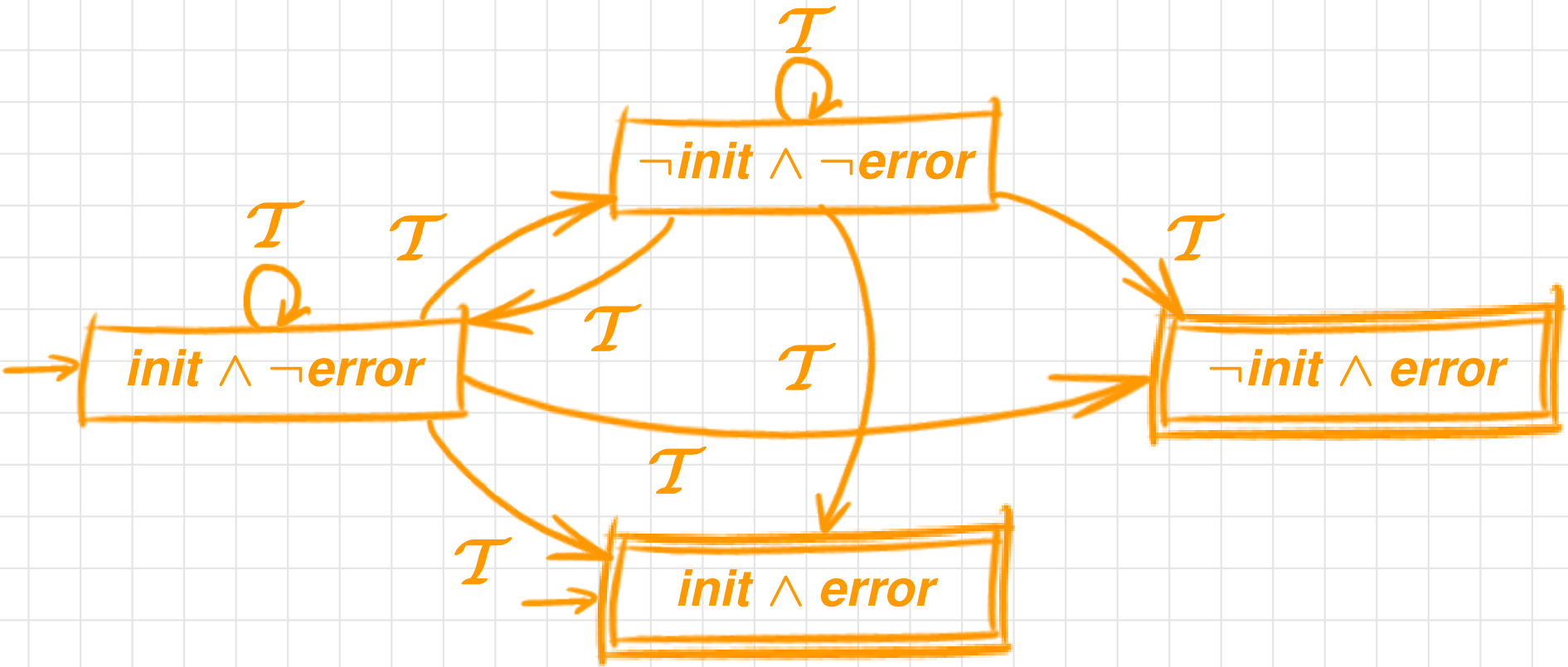

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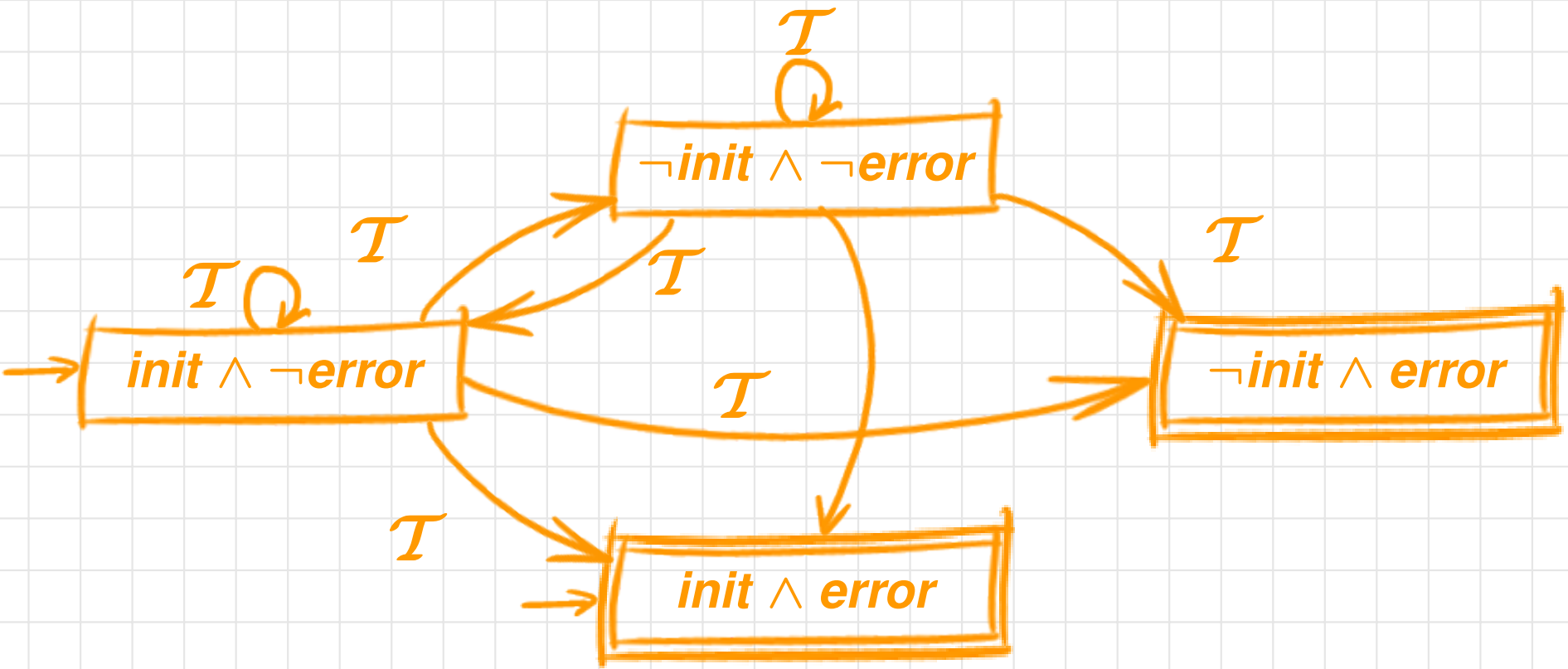

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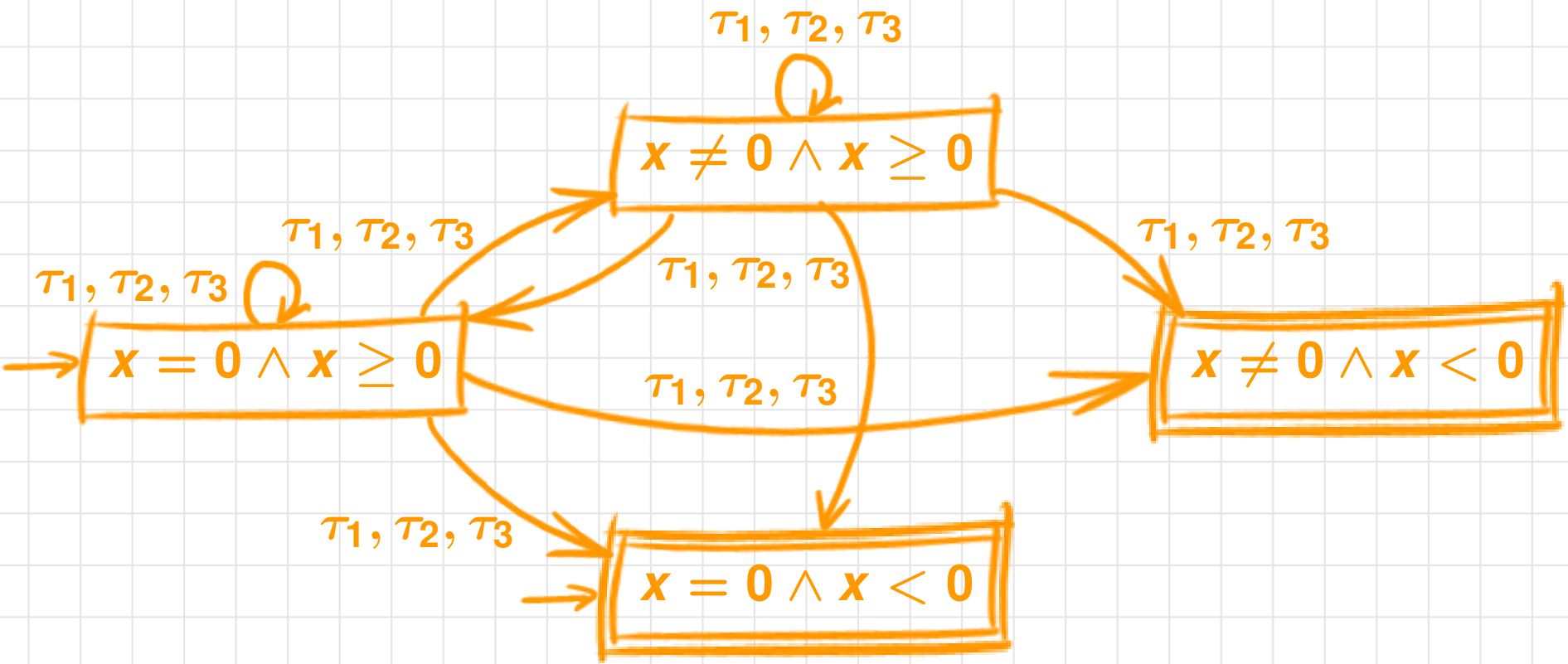
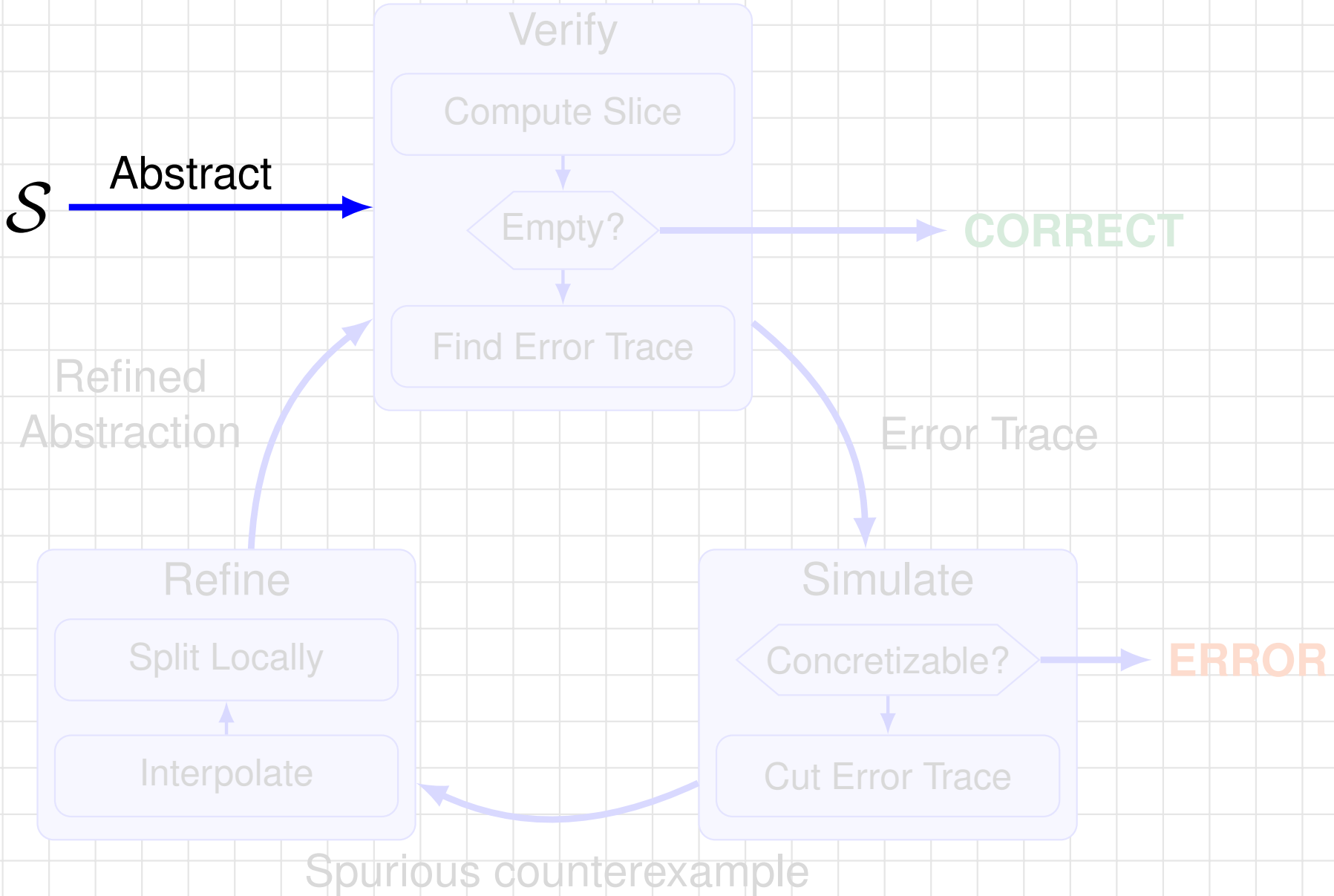
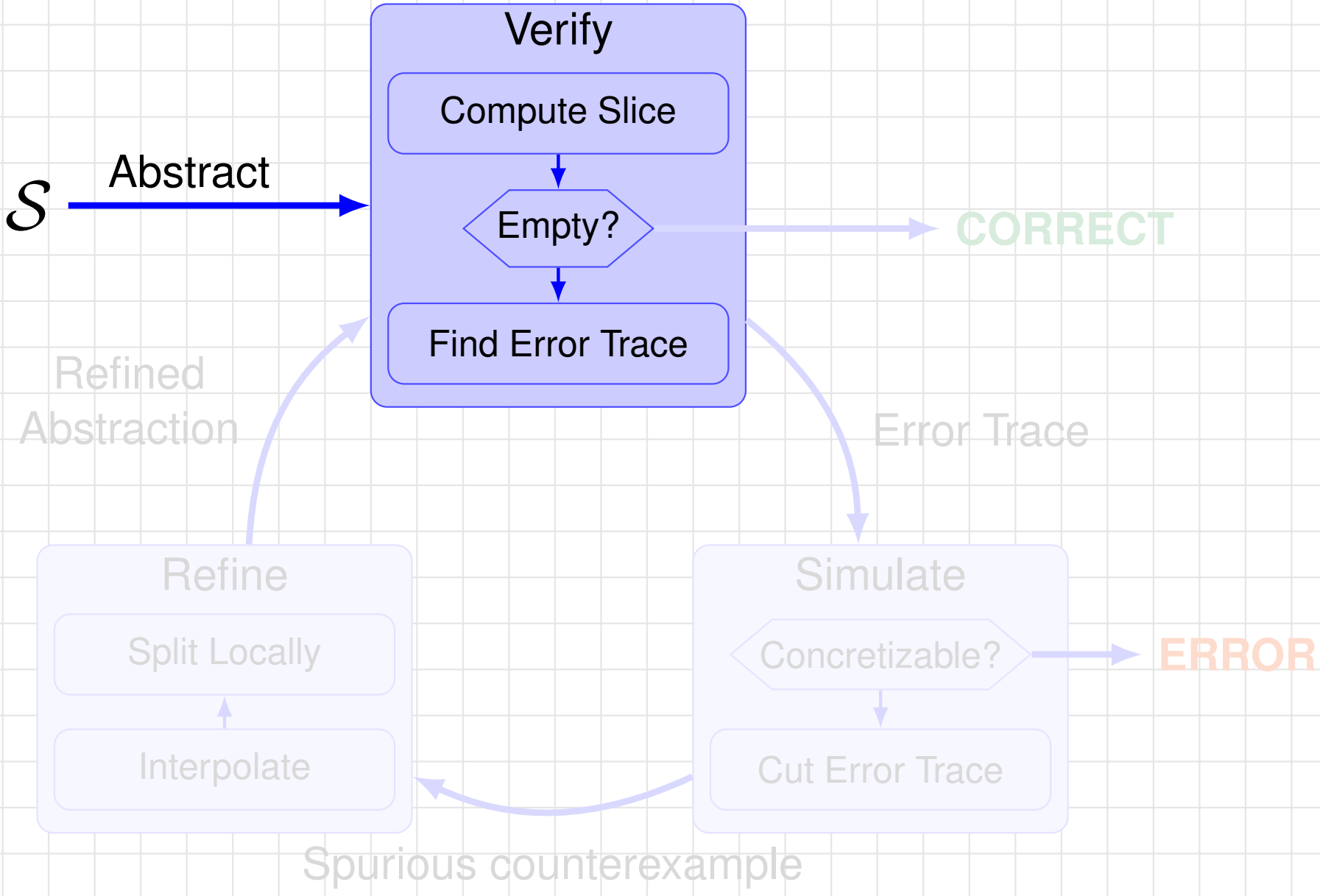


Slicing Abstraction Refinement



Slicing Abstraction Refinement



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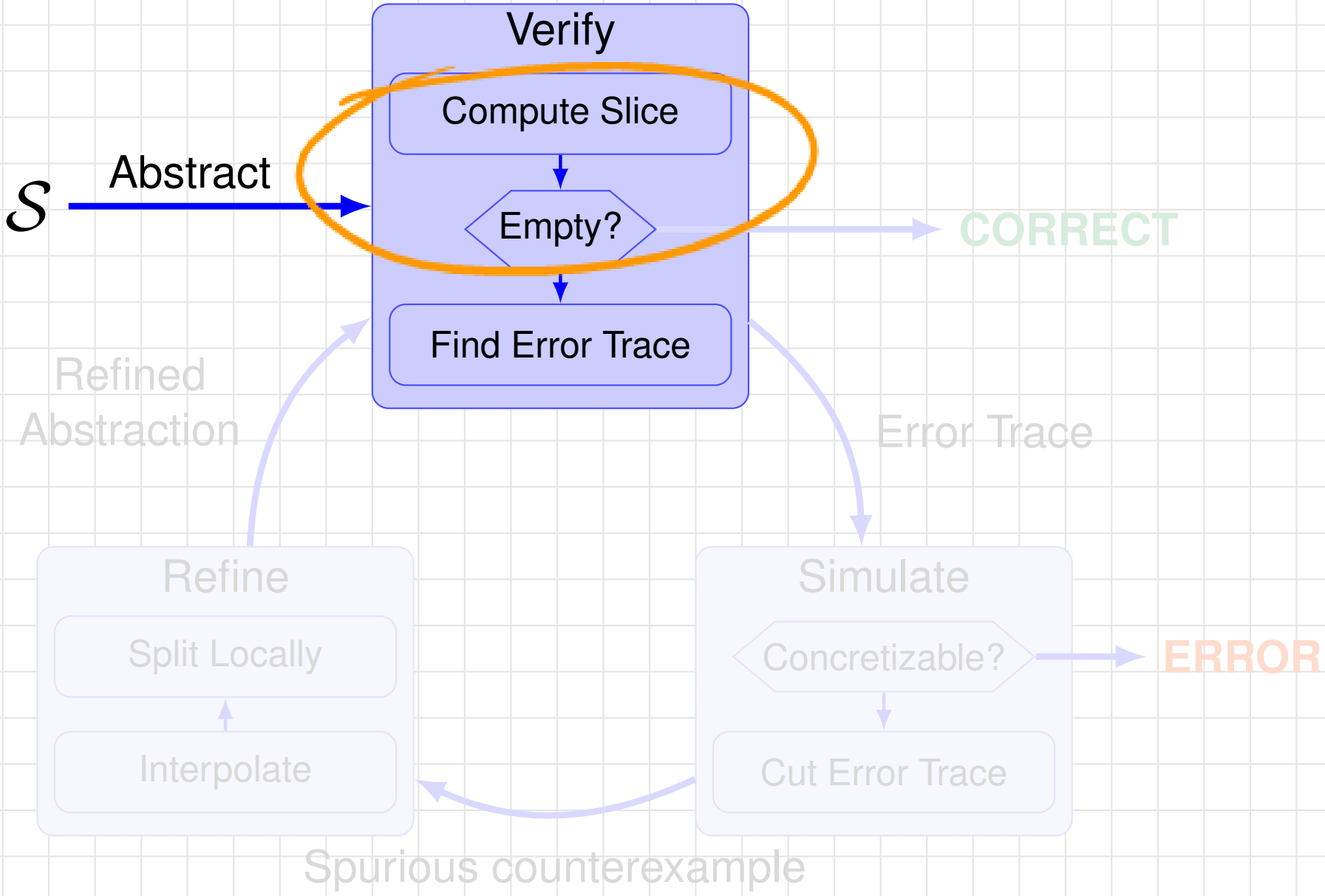

Slicing

Slicing

- Inconsistent nodes

Slicing

- Inconsistent nodes

Slicing

- Inconsistent nodes

- Unreachable nodes

Slicing

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Slicing

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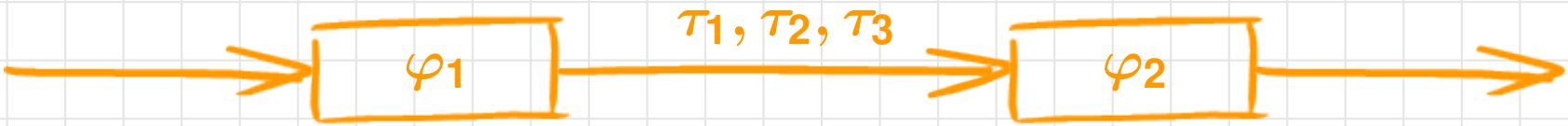
- Unreachable nodes

- Inconsistent transitions



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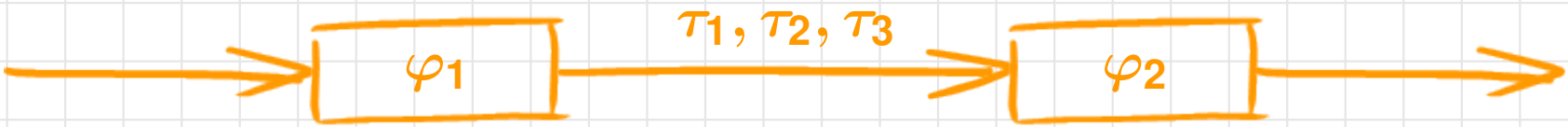

$\varphi_1 \wedge \tau_2 \wedge \varphi_2$ unsatisfiable

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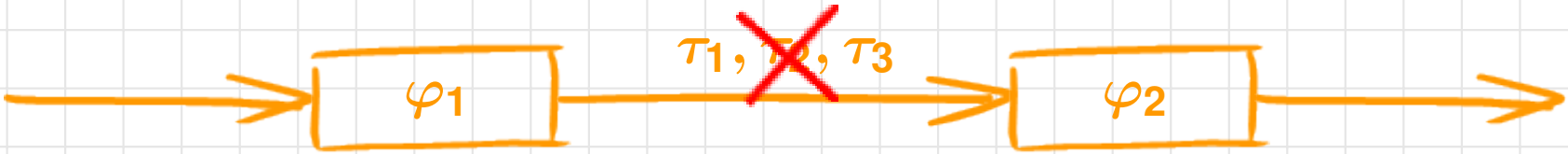

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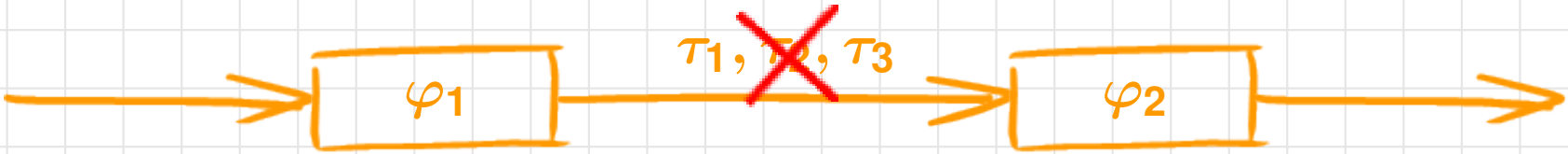

$\varphi_1 \wedge \tau_2 \wedge \varphi_2$ unsatisfiable

- Empty edges

Slicing

- Inconsistent nodes

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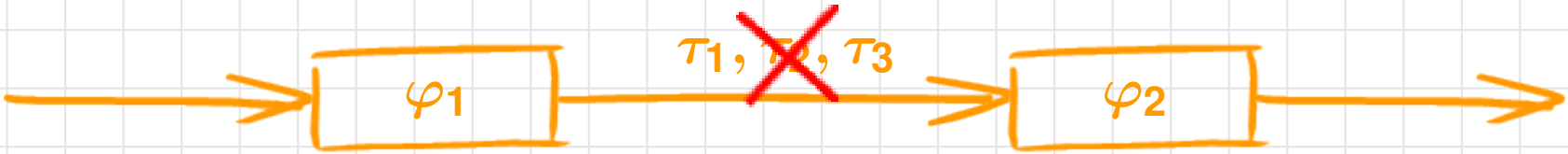

$\varphi_1 \wedge \tau_2 \wedge \varphi_2$ unsatisfiable

- Empty edges

Example: Slicing

$\tau_1 : x' = 1 \wedge y' = x + 1$

$\tau_2 : y' = x - 1 \wedge x' = x$

$\tau_3 : x \geq 1 \wedge x' = y \wedge y' = y$

$init : x = 0$

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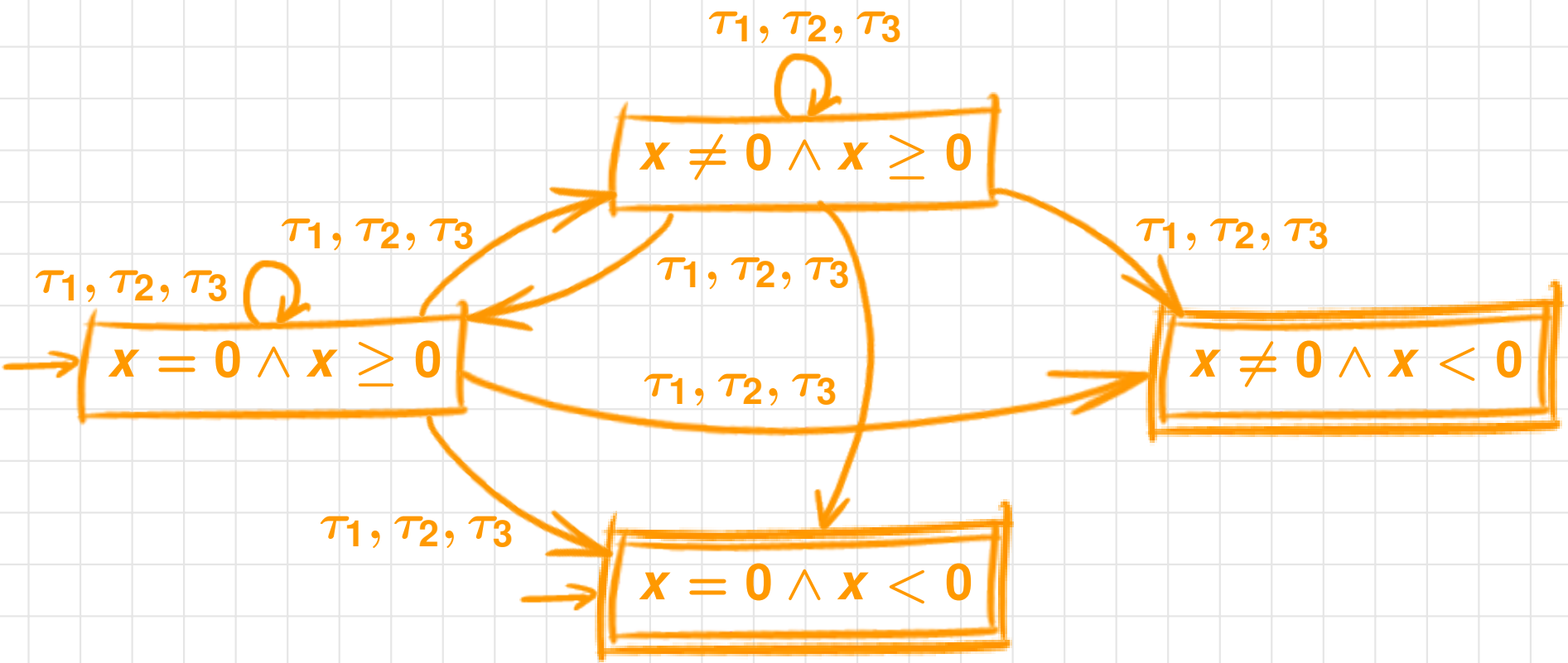

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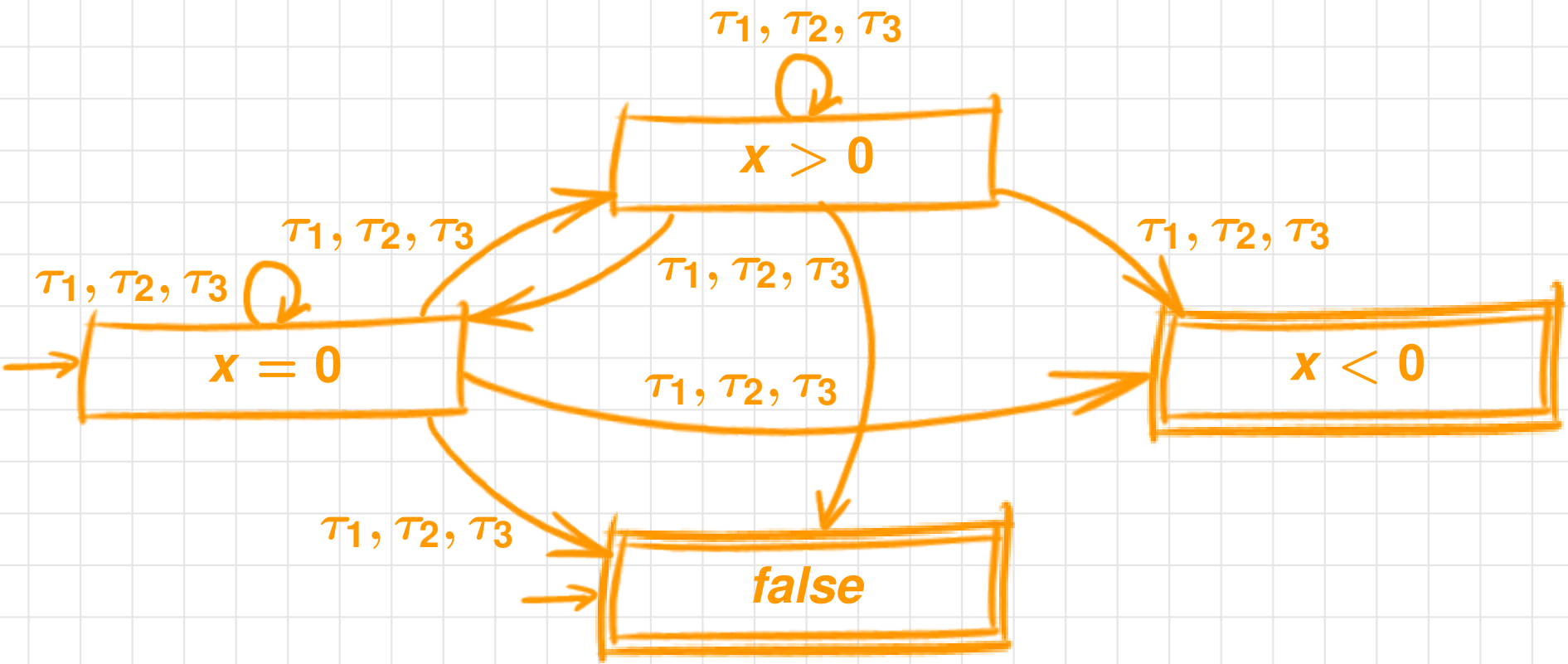

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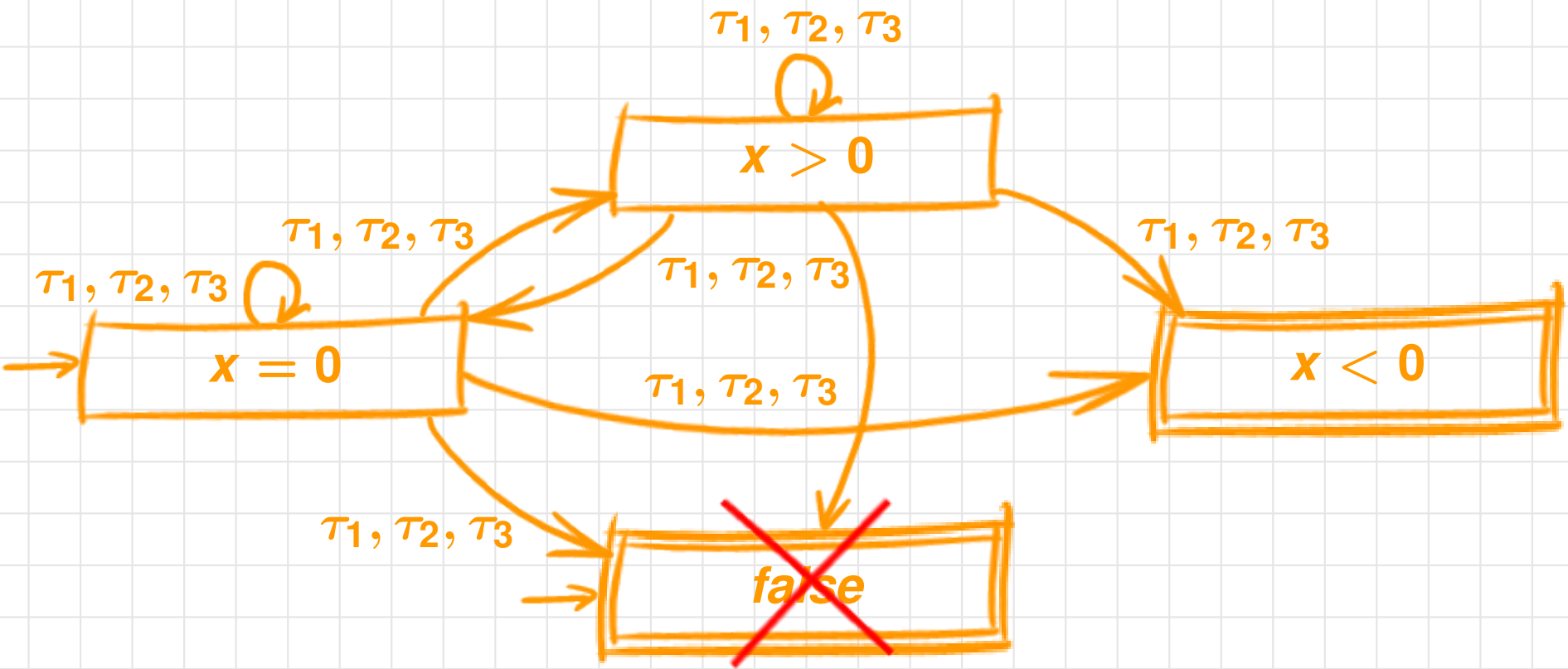

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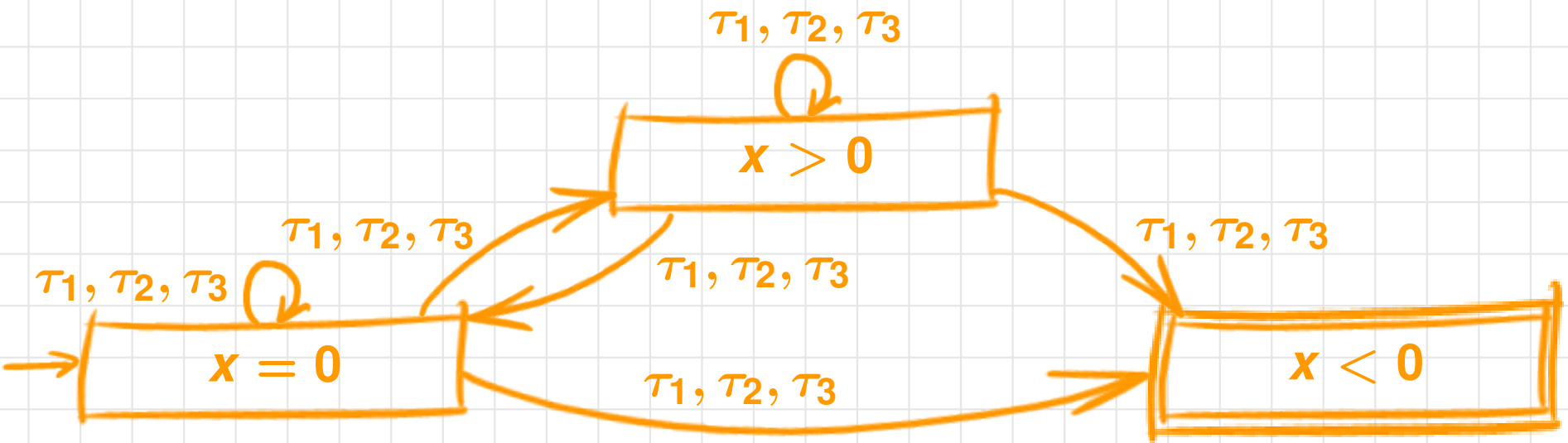

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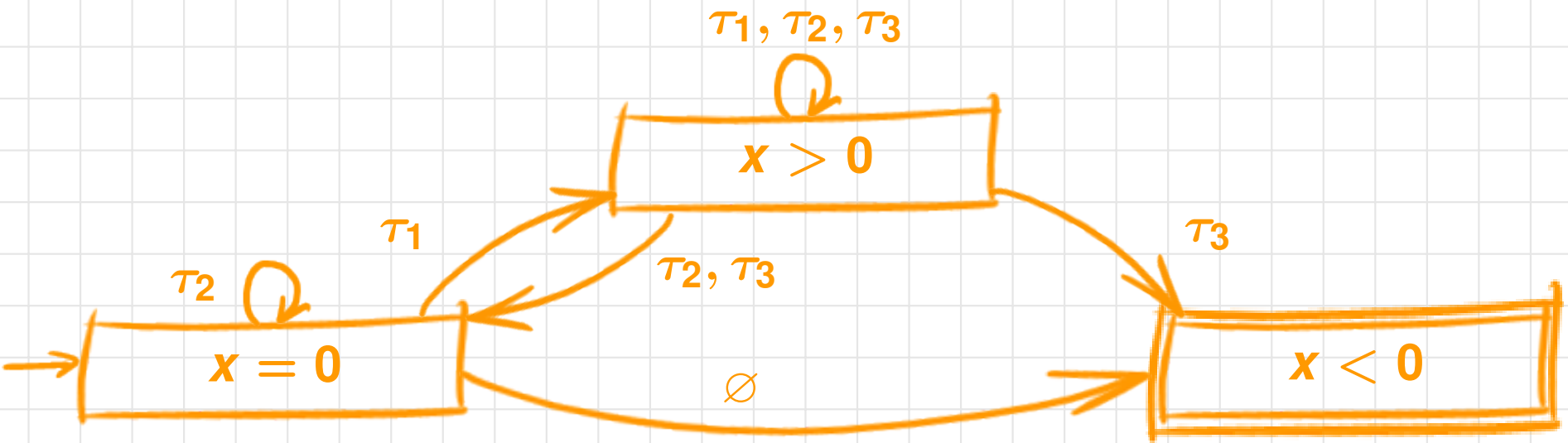

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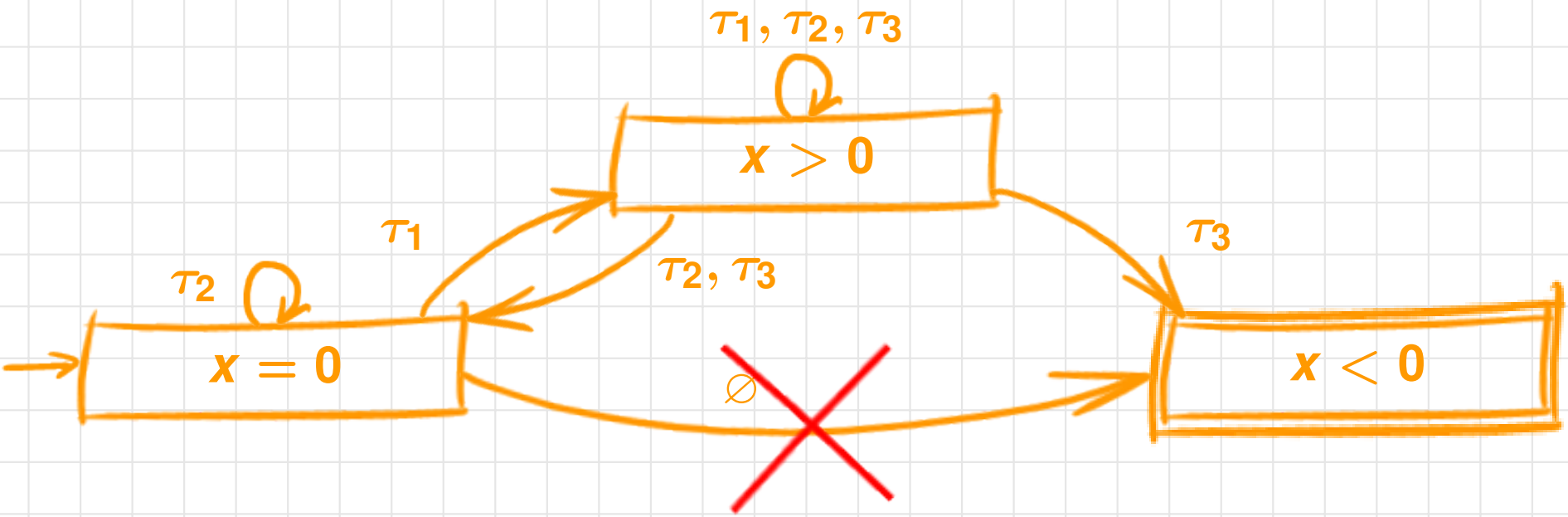

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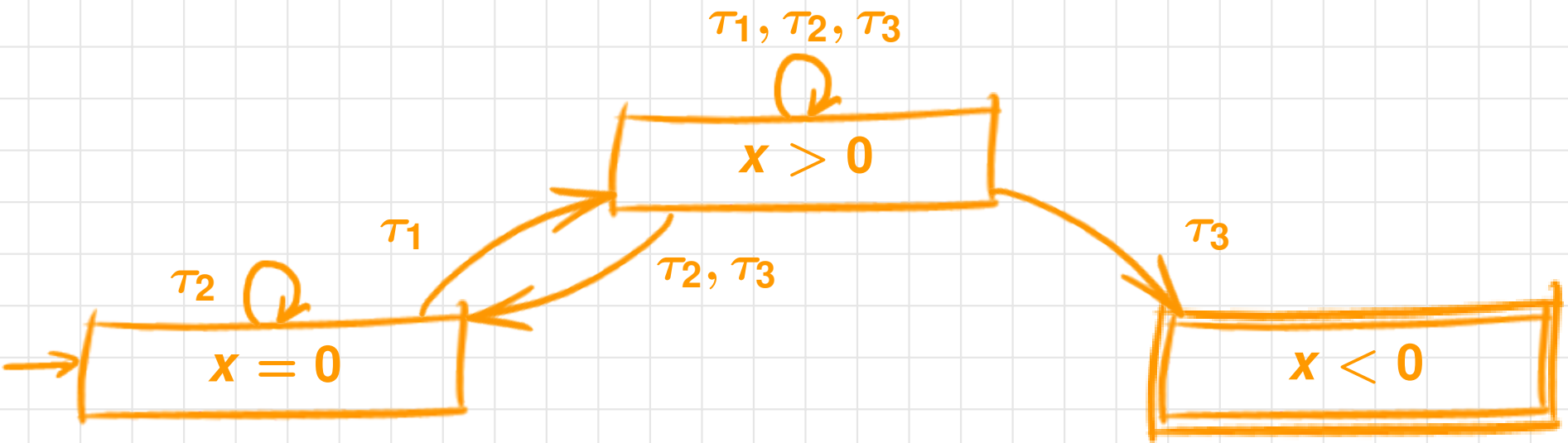
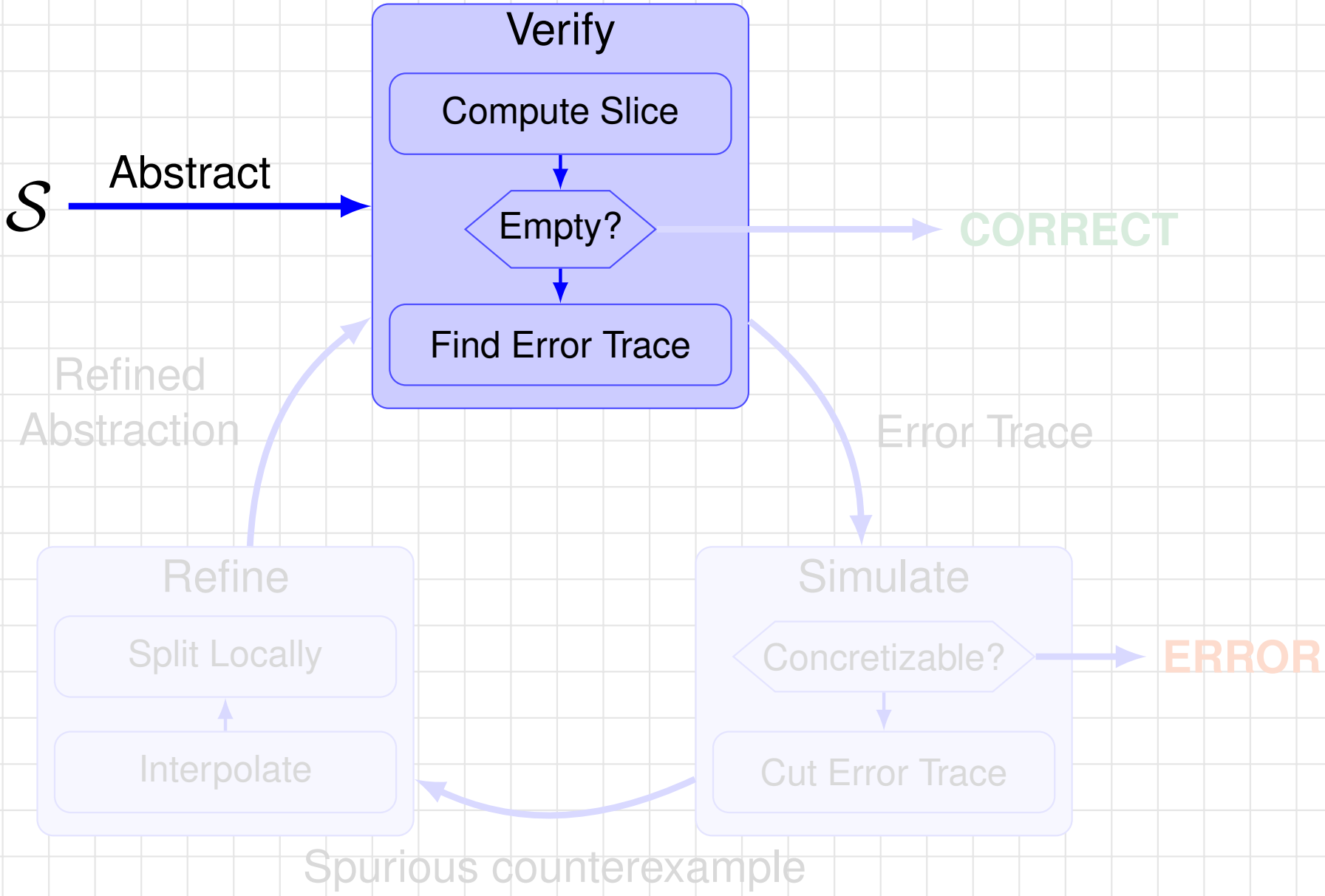
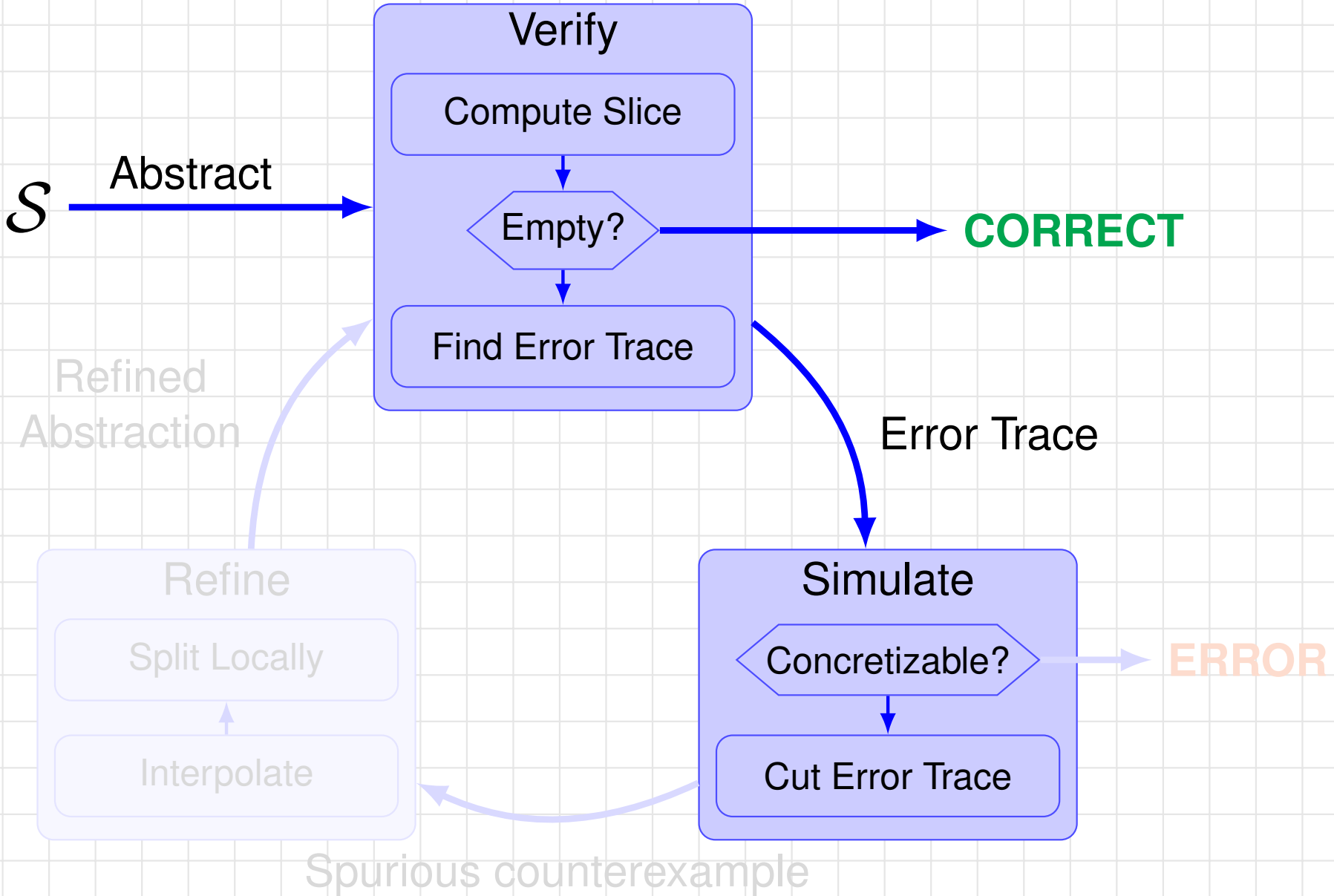


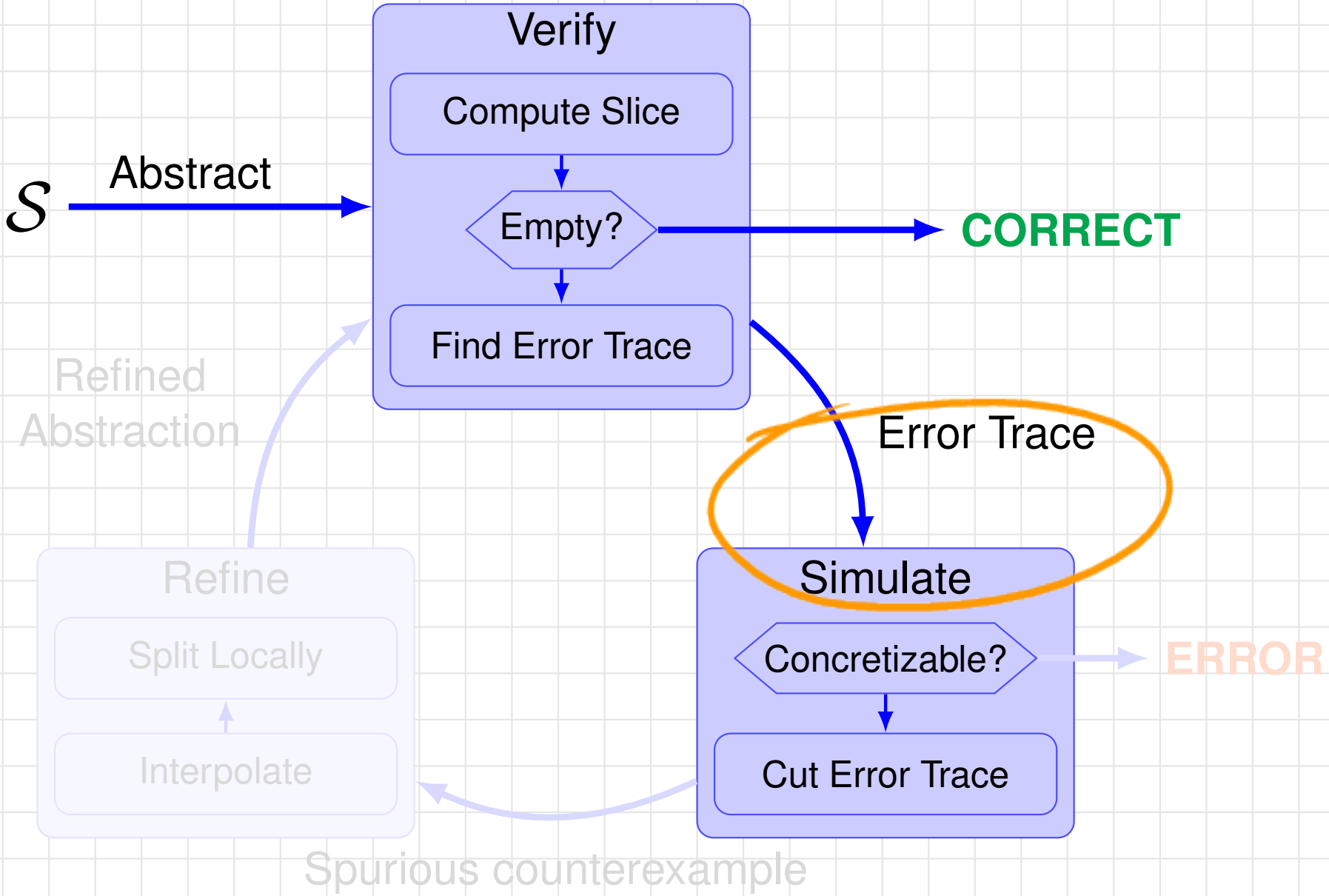
Slicing Abstraction Refinement



Slicing Abstraction Refinement



Slicing Abstraction Refinement



Example: Error Path Analysis

$\tau_1 : x' = 1 \wedge y' = x + 1$

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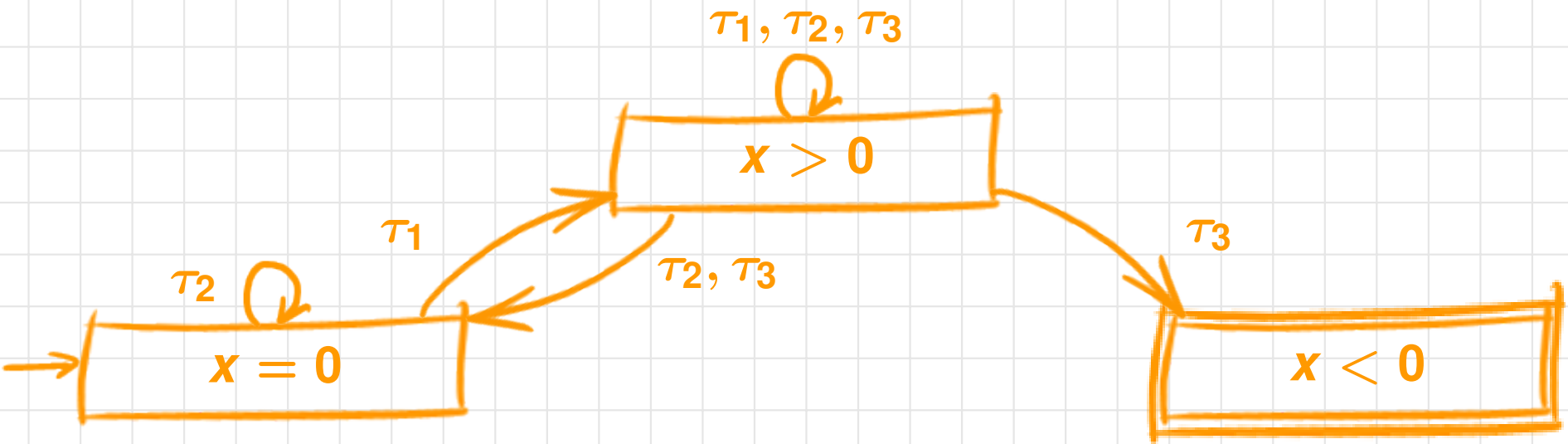

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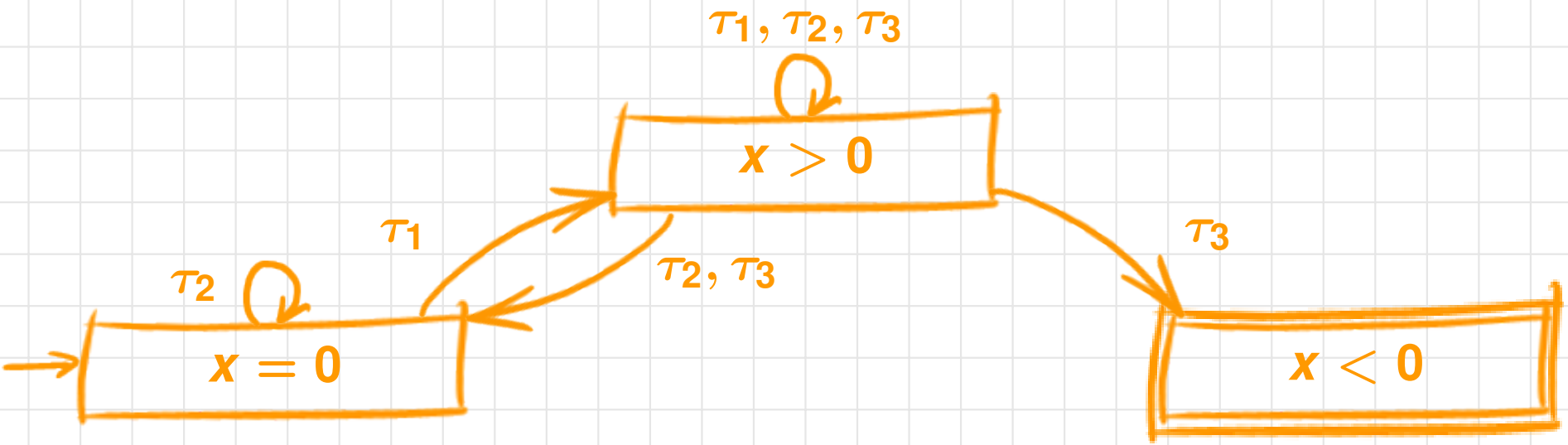

$x^0 = 0$

$\Phi =$

Example: Error Path Analysis

$\tau_1 : x' = 1 \wedge y' = x + 1$

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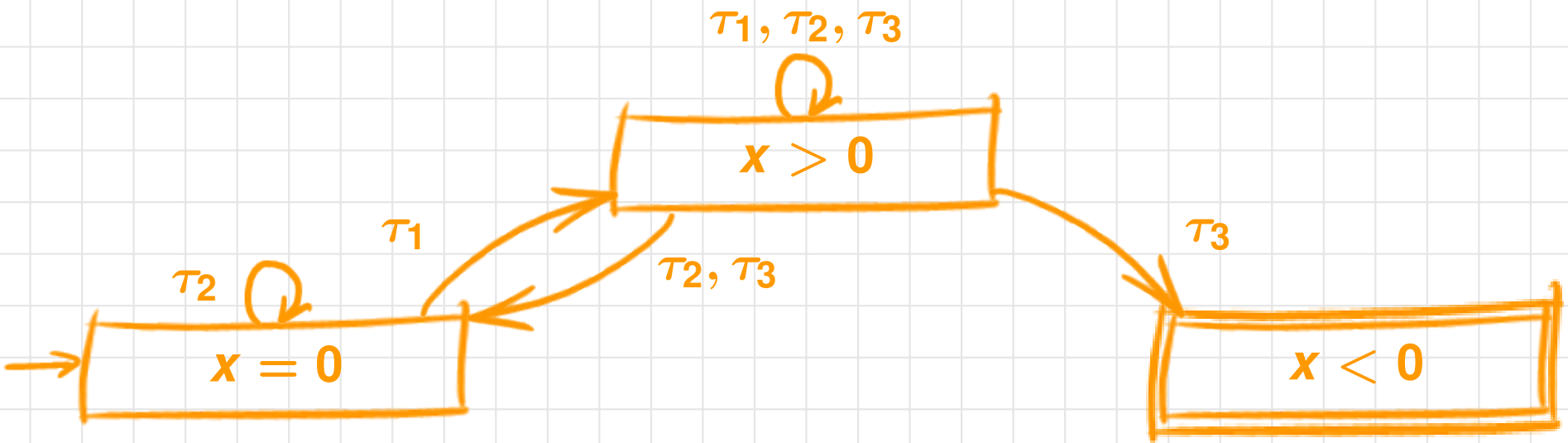

$$\Phi = x^0 = 0 \wedge x^1 = 1 \wedge y^1 = x^0 + 1$$

Example: Error Path Analysis

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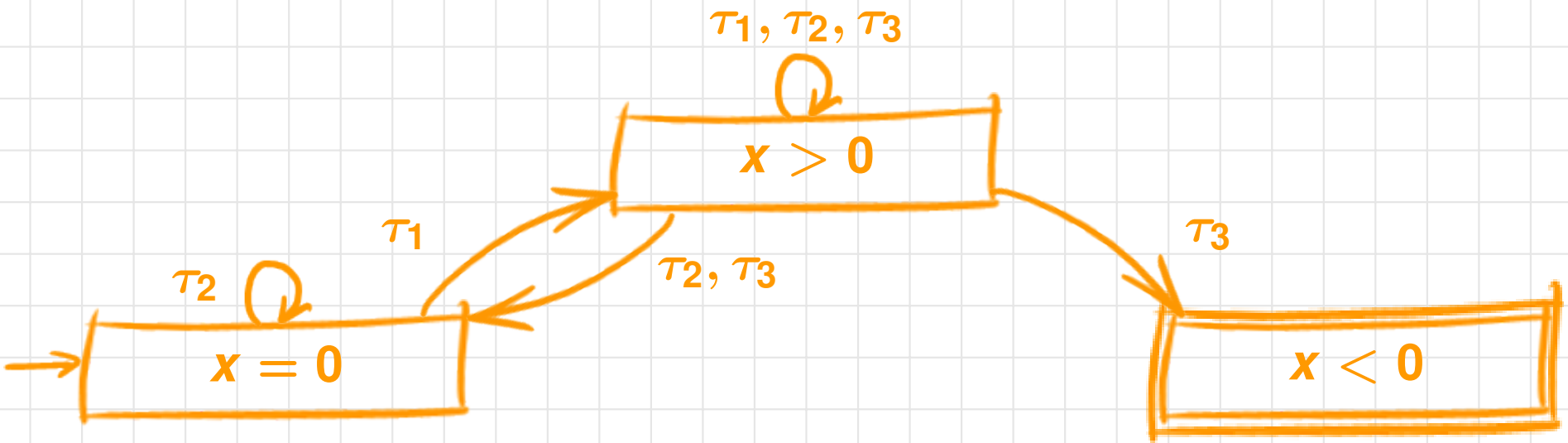

$$\Phi = x^0 = 0 \wedge x^1 > 0 \wedge x^1 = 1 \wedge y^1 = x^0 + 1$$

Example: Error Path Analysis

$\tau_1 : x' = 1 \wedge y' = x + 1$

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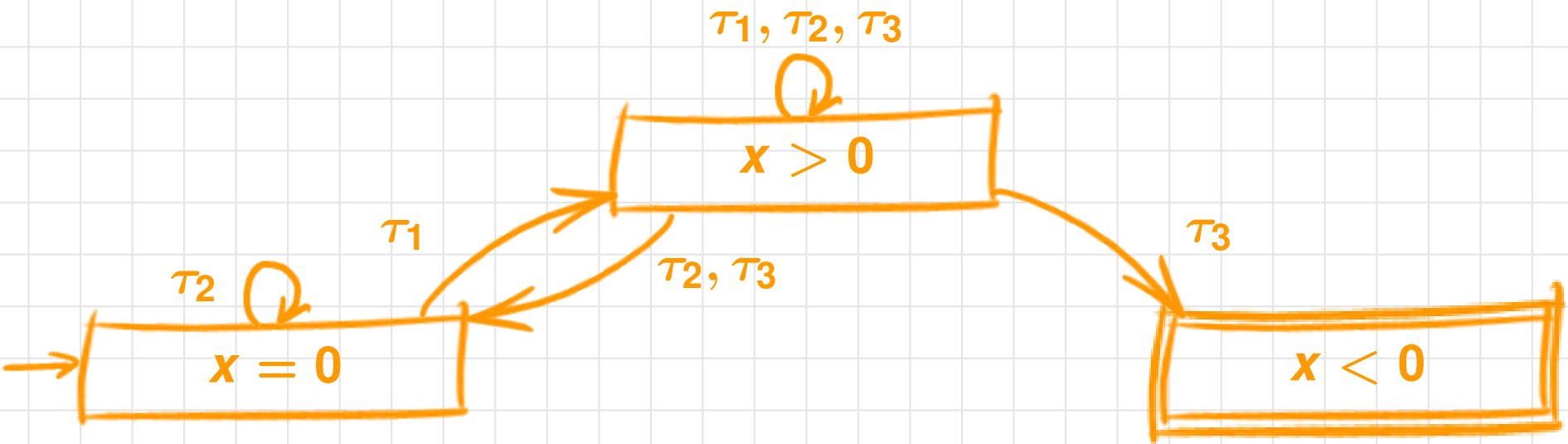

$$\Phi = \underbrace{x^0 = 0}_{} \wedge \underbrace{x^1 > 0}_{} \wedge \underbrace{x^1 = 1 \wedge y^1 = x^0 + 1}_{} \wedge \underbrace{x^1 \geq 1 \wedge x^2 = y^1 \wedge y^2 = y^1}_{}$$

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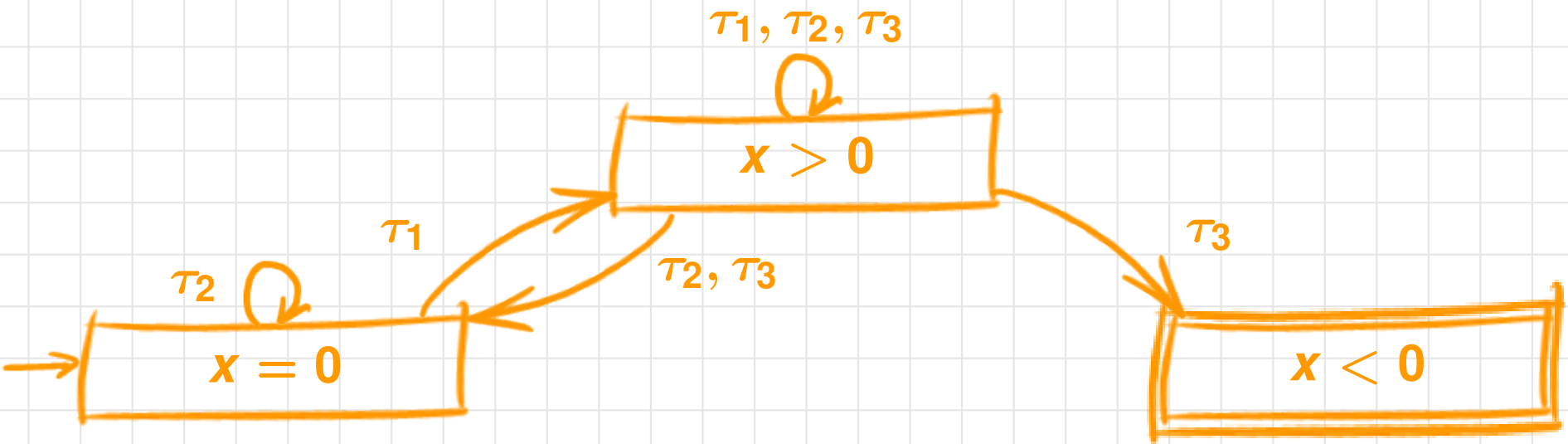

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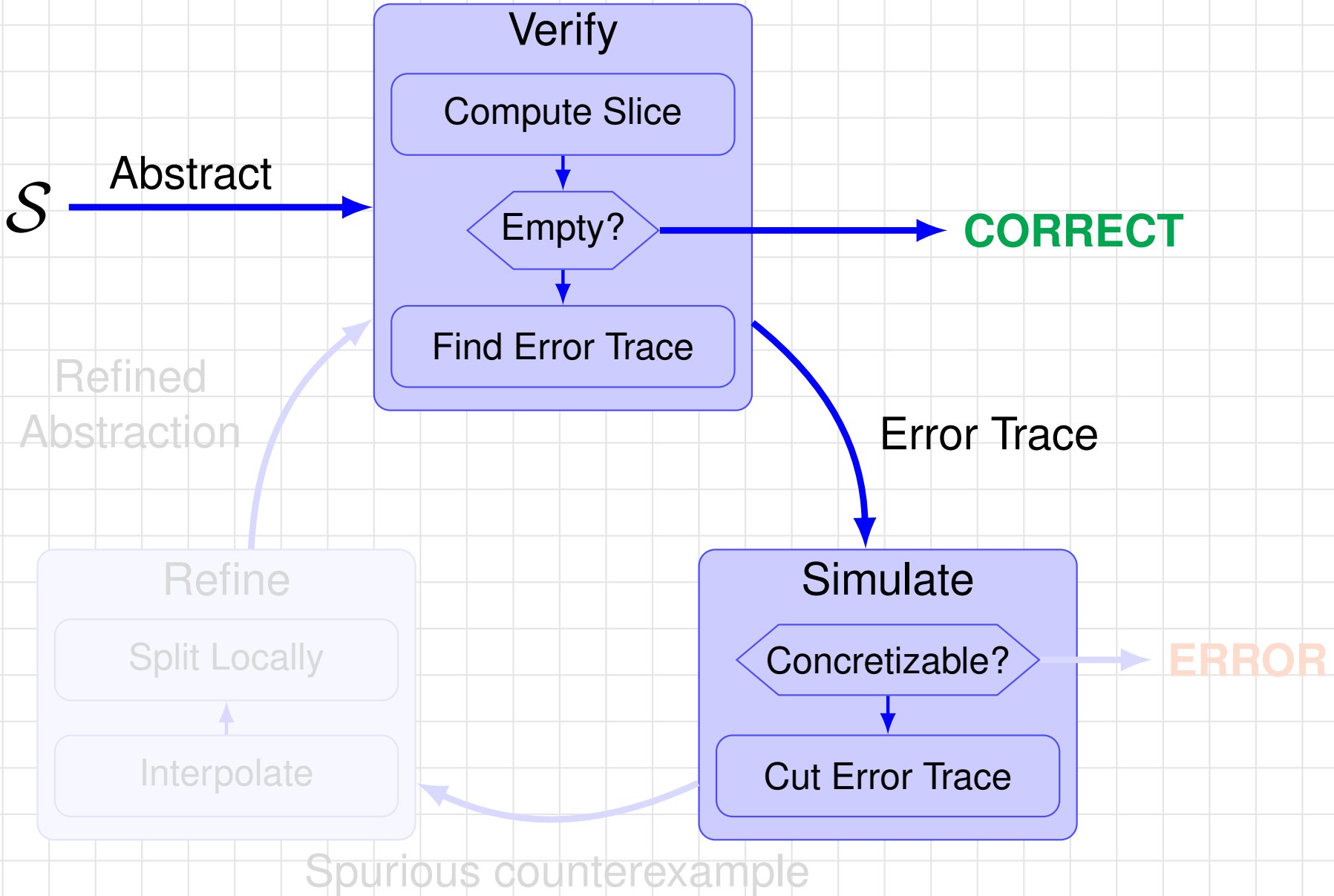
Slicing Abstraction Refinement



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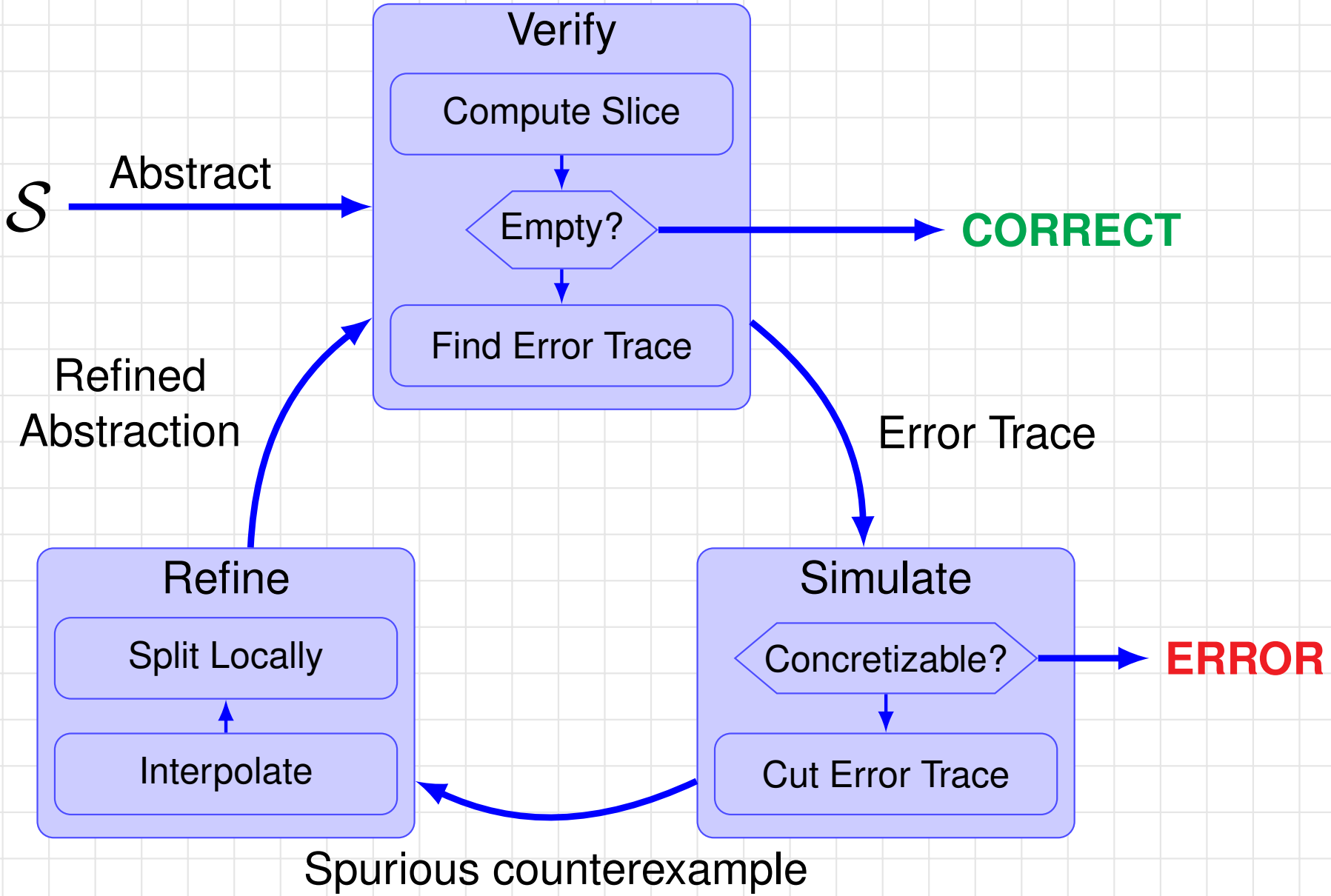

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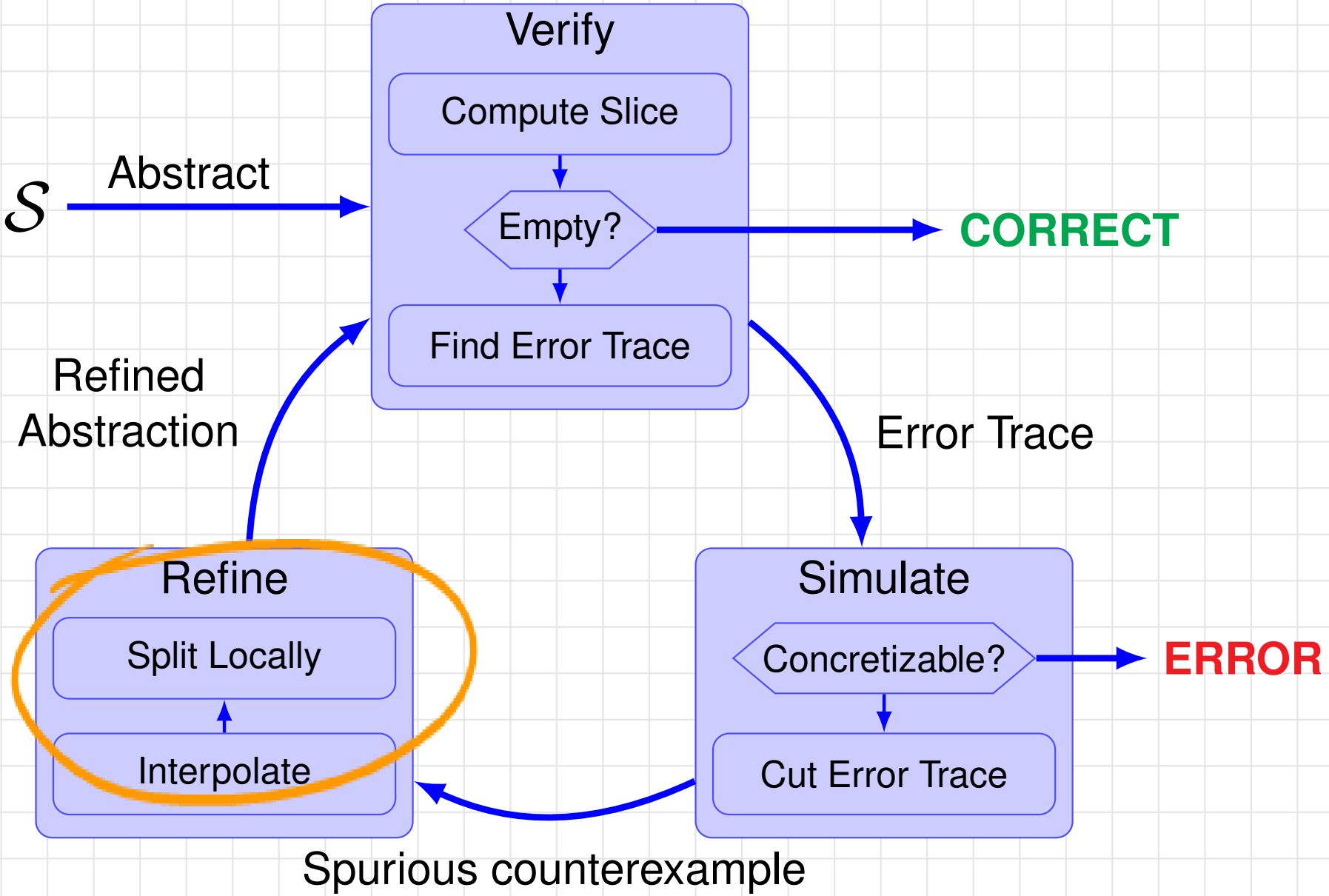

Abstraction Refinement

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Spurious counterexample

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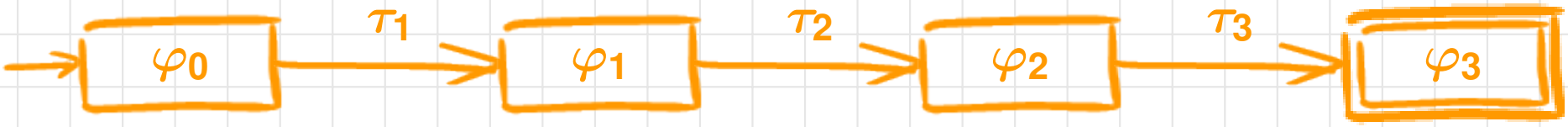
$$\Phi = \varphi_0(V^0) \wedge \tau_1(V^0, V^1) \wedge \varphi_1(V^1) \wedge \tau_2(V^1, V^2) \wedge \varphi_2(V^2) \wedge \tau_3(V^2, V^3) \wedge \varphi_3(V^3)$$

Abstraction Refinement

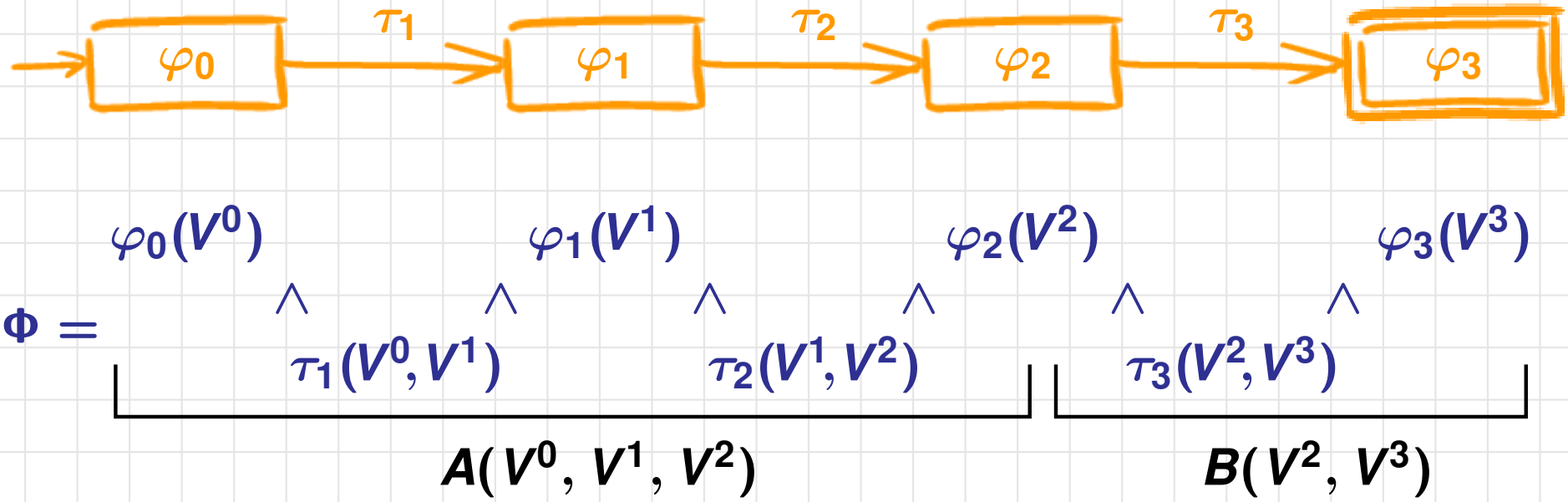
Spurious counterexample



$$\Phi = \underbrace{\varphi_0(V^0) \wedge \tau_1(V^0, V^1) \wedge \varphi_1(V^1) \wedge \tau_2(V^1, V^2) \wedge \varphi_2(V^2)}_{A(V^0, V^1, V^2)} \wedge \underbrace{\tau_3(V^2, V^3) \wedge \varphi_3(V^3)}_{B(V^2, V^3)}$$

Abstraction Refinement

Spurious counterexample

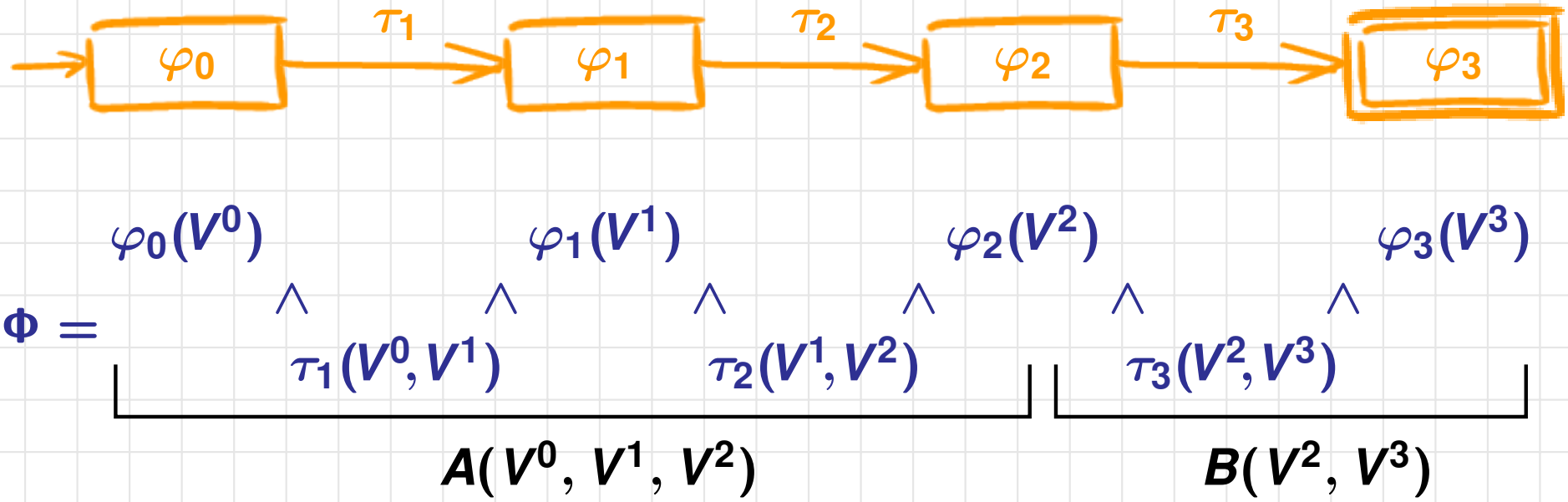


$A \wedge B$ unsat, but A, B sat $\rightsquigarrow$ Craig interpolant η:

- $A \models \eta$
- $B \models \neg\eta$
- $Var(\eta) \subseteq Var(A) \cap Var(B)$

Abstraction Refinement

Spurious counterexample



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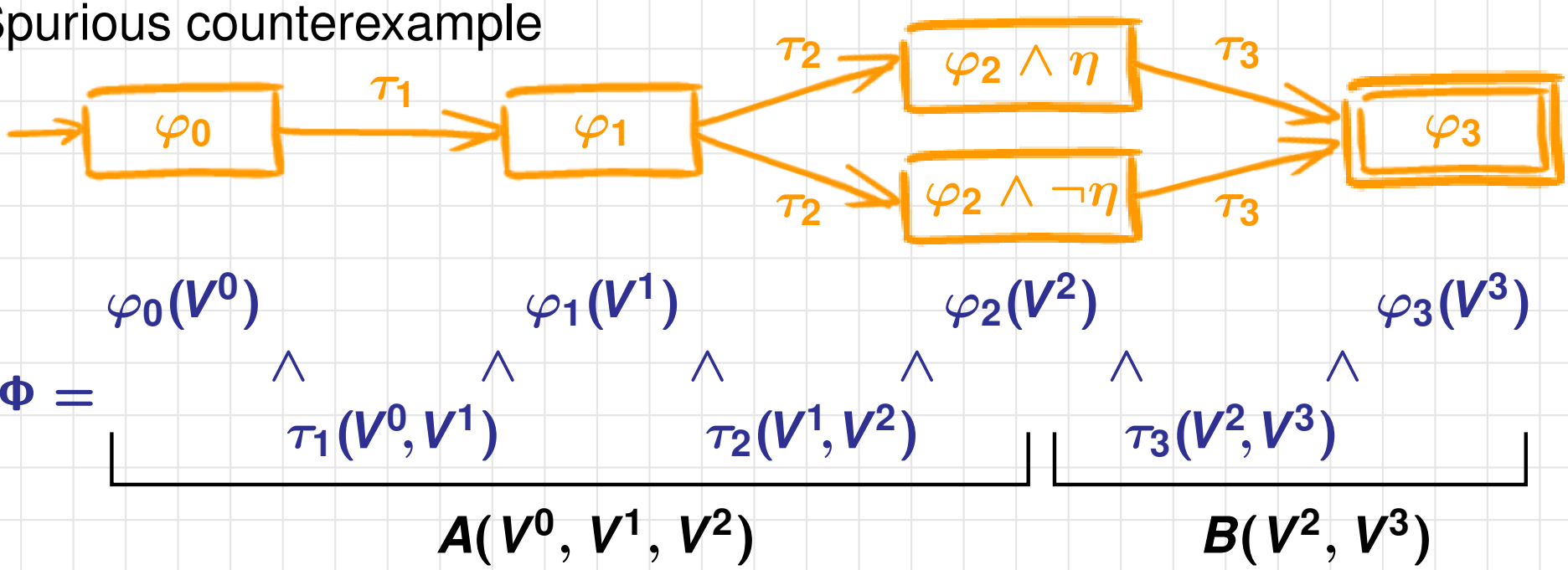
Abstraction Refinement

Spurious counterexample



$A \wedge B$ unsat, but A, B sat $\rightsquigarrow$ Craig interpolant η:

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- $Var(\eta) \subseteq Var(A) \cap Var(B)$

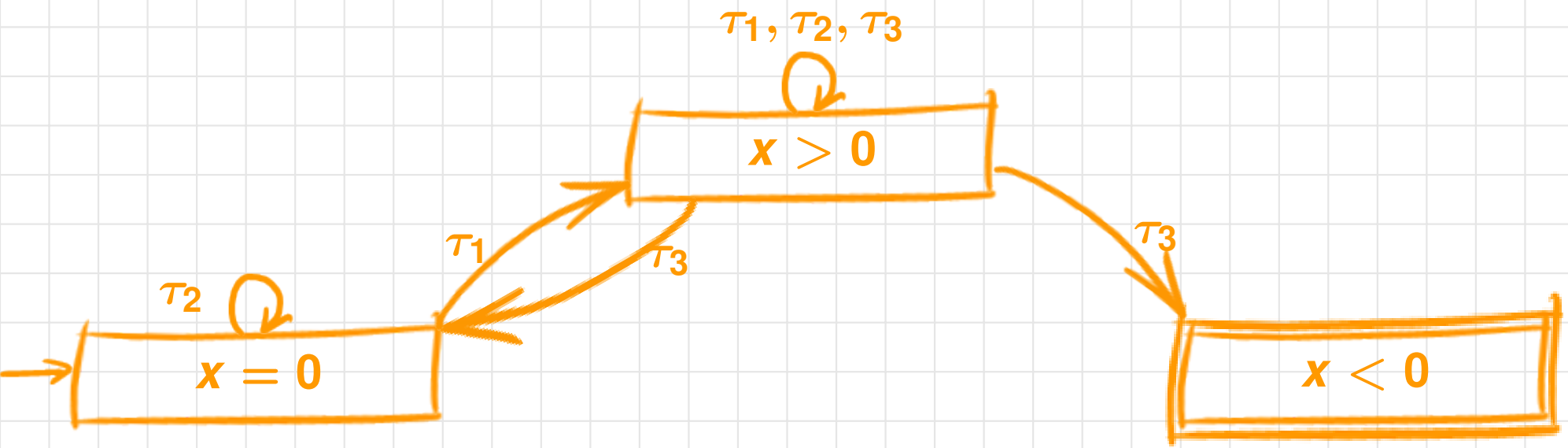
$\rightsquigarrow$ split locally with $\eta, \neg\eta$

Example: Abstraction Refinement

$\tau_1 : x' = 1 \wedge y' = x + 1$

$init : x = 0$ $\quad \tau_2 : y' = x - 1 \wedge x' = x$ $\quad error : x < 0$

$\tau_3 : x \geq 1 \wedge x' = y \wedge y' = y$



$\Phi = x^0 = 0 \wedge x^1 > 0 \wedge x^2 < 0 \wedge x^1 = 1 \wedge y^1 = x^0 + 1 \wedge x^1 \geq 1 \wedge x^2 = y^1 \wedge y^2 = y^1$

Example: Abstraction Refinement

$\tau_1 : x' = 1 \wedge y' = x + 1$

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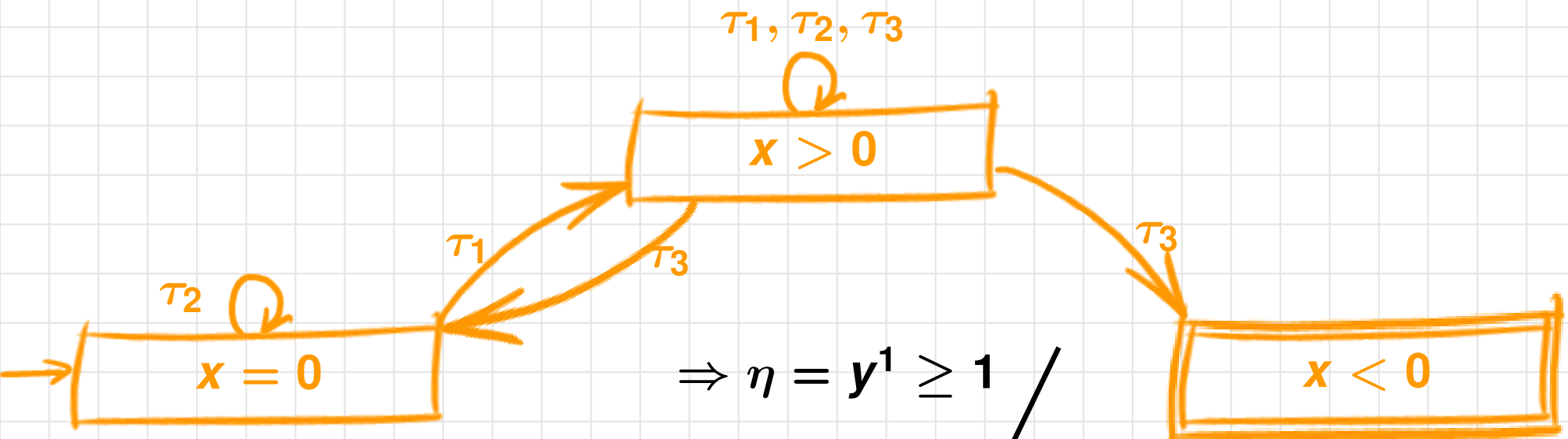

$\Rightarrow \eta = y^1 \geq 1$

$x^0 = 0 \quad x^1 > 0 \quad x^2 < 0$

$\Phi = \quad \wedge \quad \wedge \quad \wedge \quad \wedge$

$x^1 = 1 \wedge y^1 = x^0 + 1 \qquad x^1 \geq 1 \wedge x^2 = y^1 \wedge y^2 = y^1$

Example: Abstraction Refinement

$\tau_1 : x' = 1 \wedge y' = x + 1$

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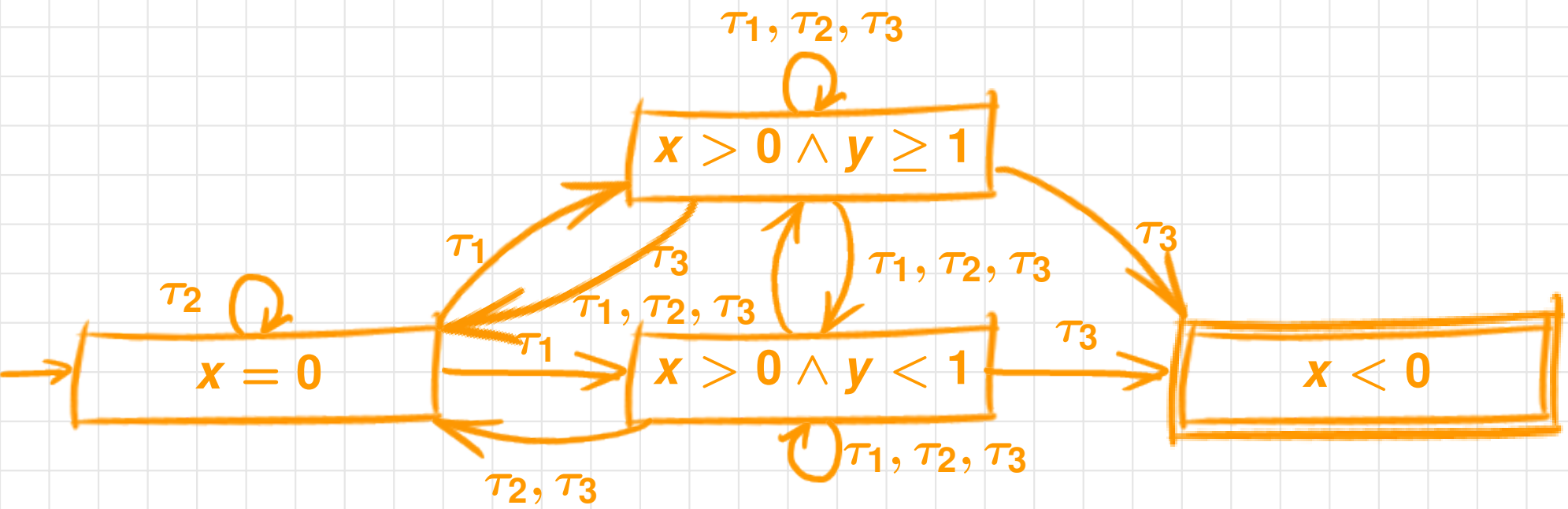

Example: Slicing (2)

$\tau_1 : x' = 1 \wedge y' = x + 1$

$\tau_2 : y' = x - 1 \wedge x' = x$

$\tau_3 : x \geq 1 \wedge x' = y \wedge y' = y$

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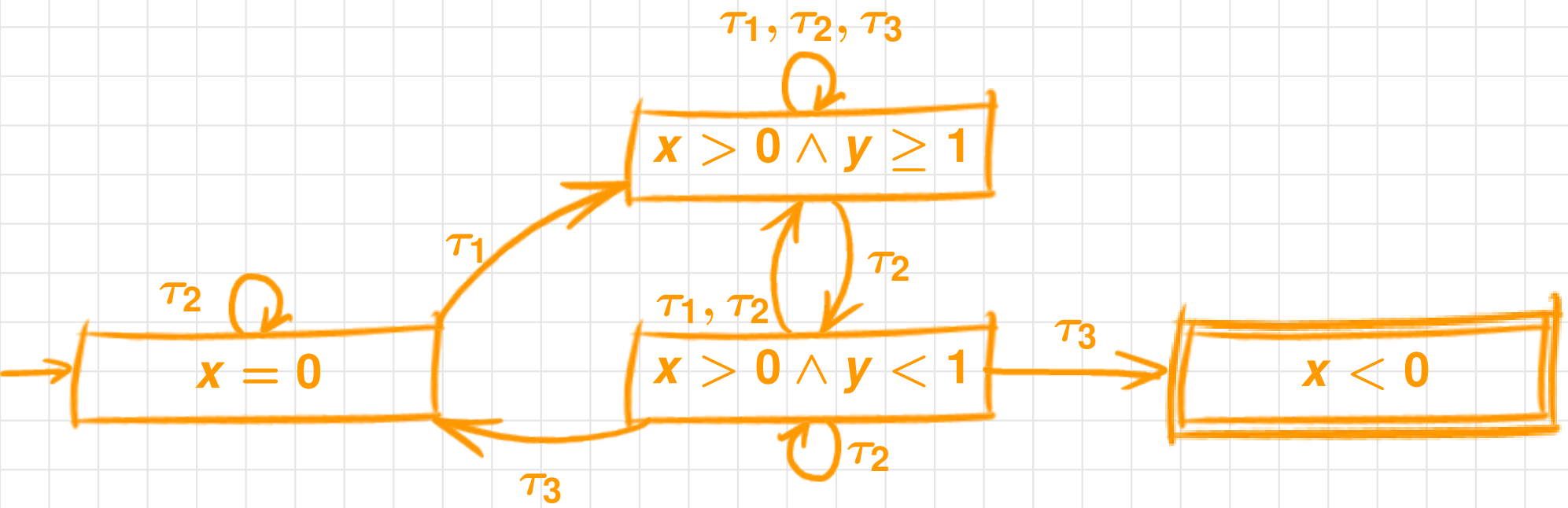

Example: Abstraction Refinement (2)

$\tau_1 : x' = 1 \wedge y' = x + 1$

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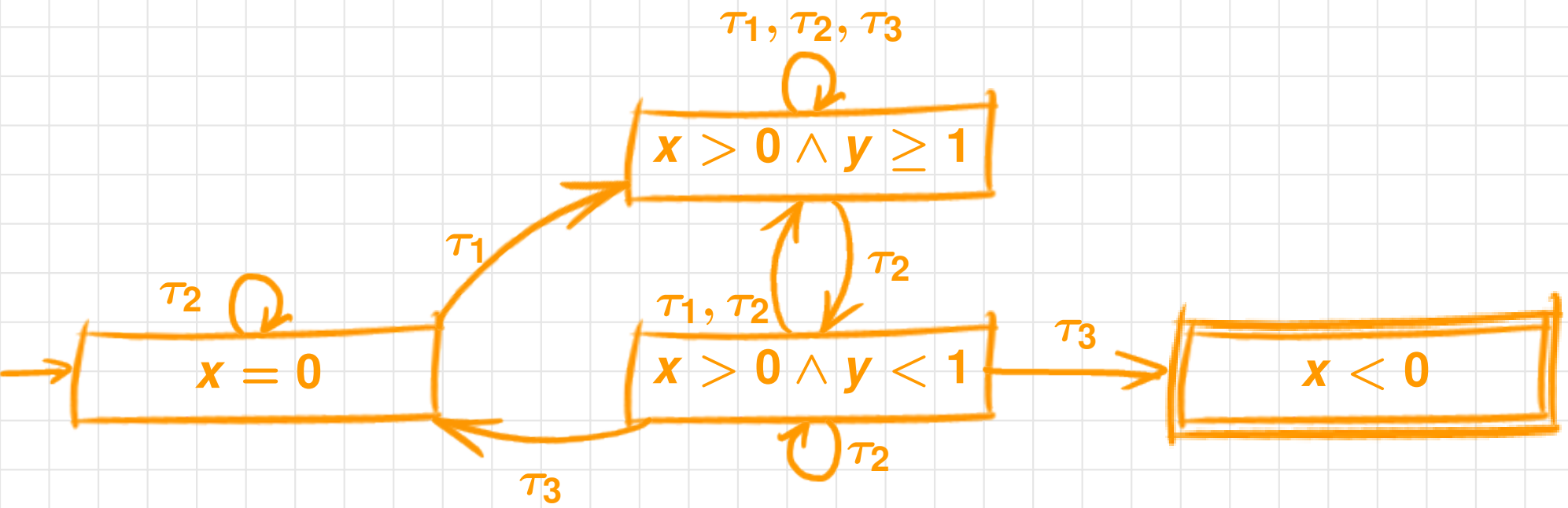

Example: Abstraction Refinement (2)

$\tau_1 : x' = 1 \wedge y' = x + 1$

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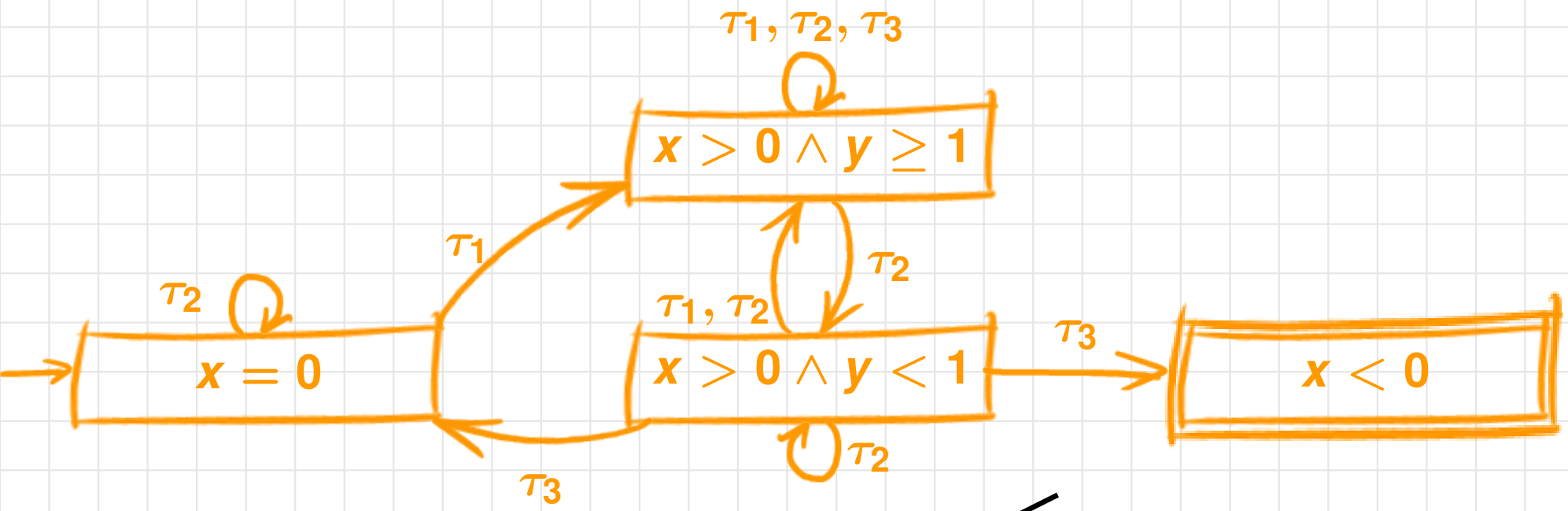

$\Rightarrow \eta = y^2 \geq 0$

Example: Abstraction Refinement (2)

$\tau_1 : x' = 1 \wedge y' = x + 1$

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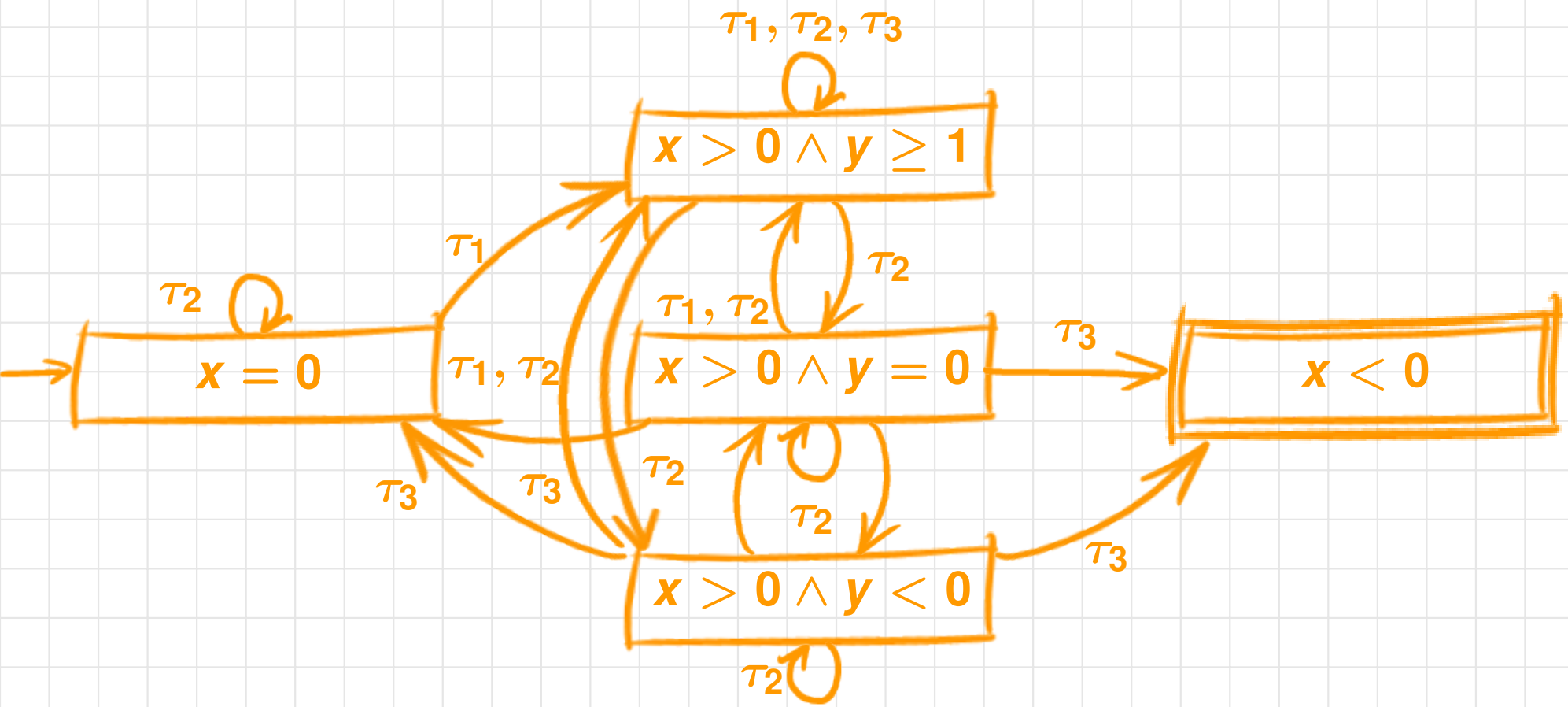

Example: Slicing (3)

$\tau_1 : x' = 1 \wedge y' = x + 1$

$\tau_2 : y' = x - 1 \wedge x' = x$

$\tau_3 : x \geq 1 \wedge x' = y \wedge y' = y$

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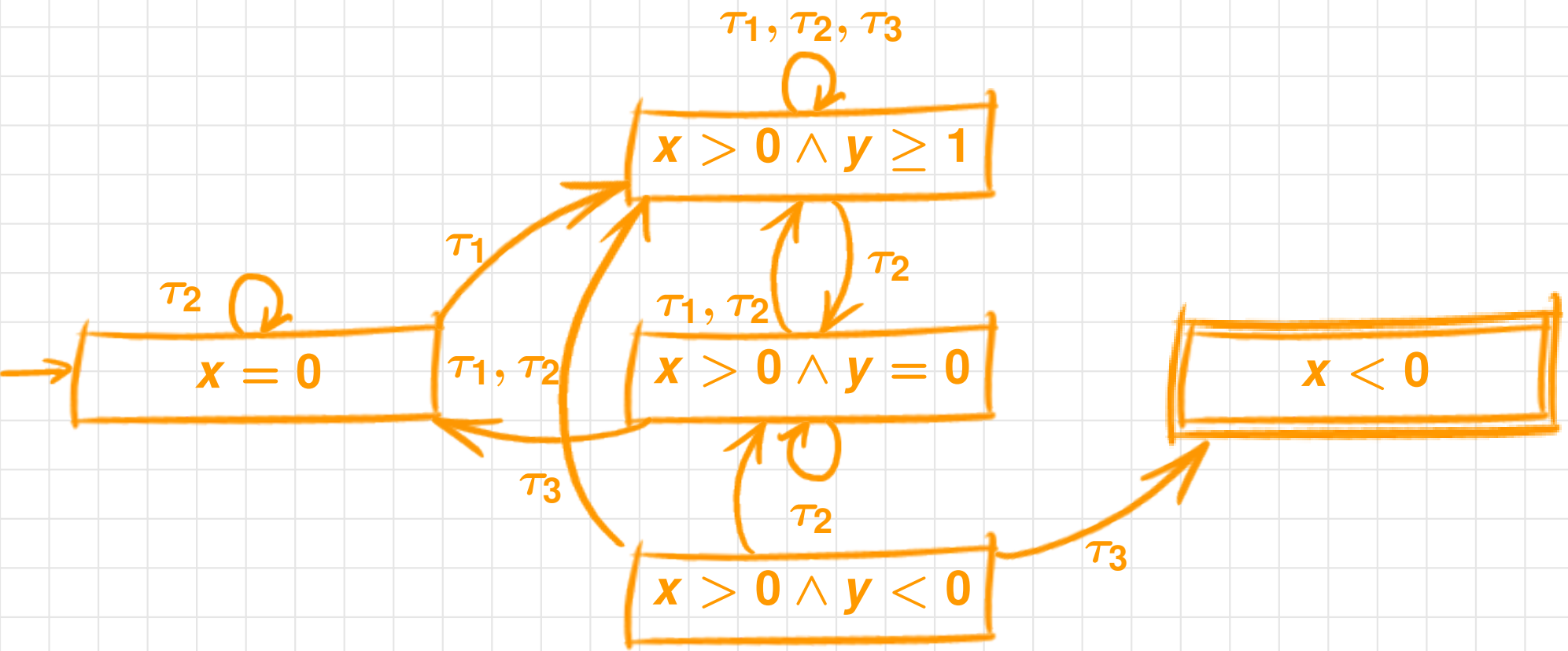

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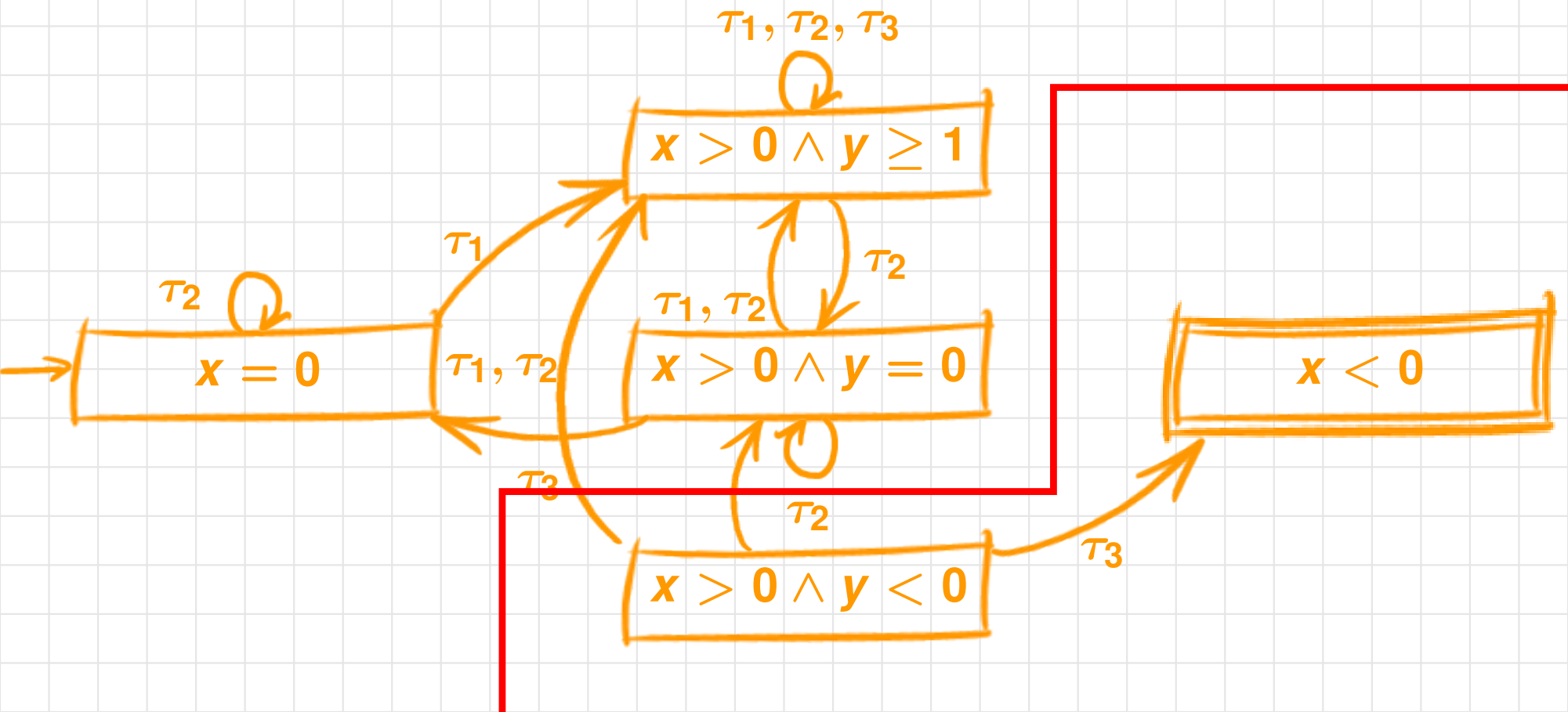

Example: Certificate

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$\tau_2 : y' = x - 1 \wedge x' = x$

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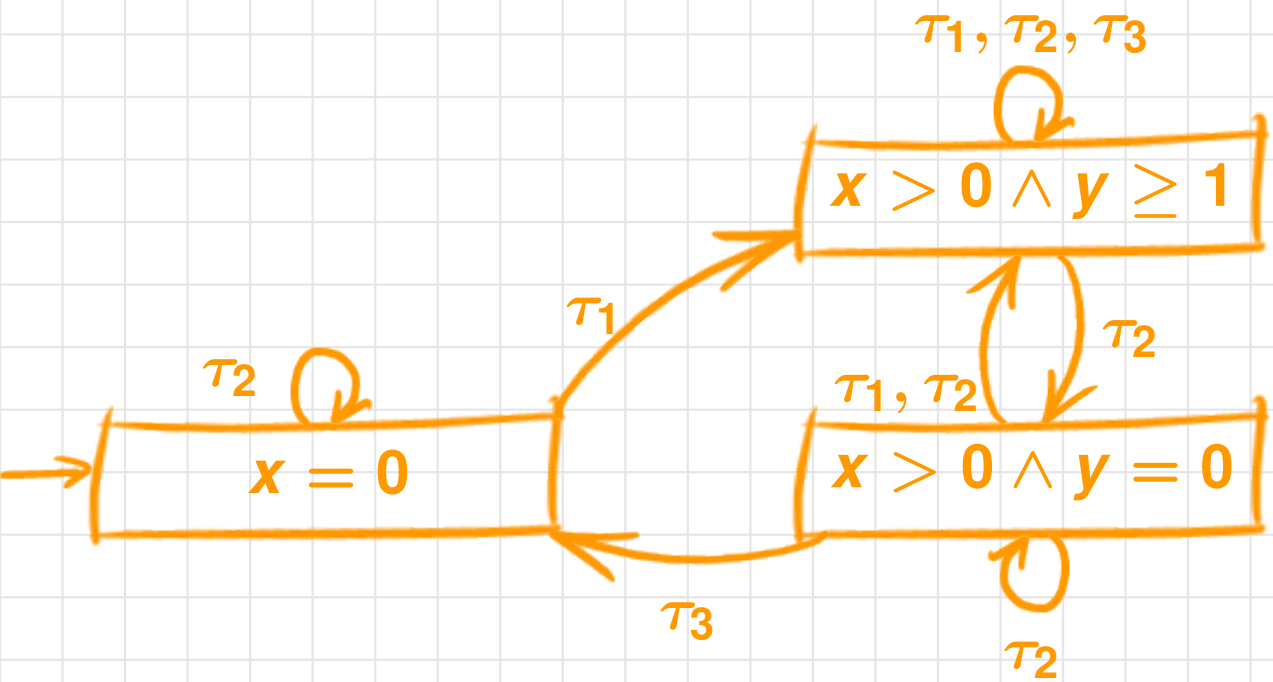
$init : x = 0$

$error : x < 0$



Demo

Summary

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SLAB is a Model Checker for:

- **infinite state** (real time, infinite datatypes, ...)
- **concurrent systems** (communication protocols, control systems,...)
- which can produce **certificates** if the system is correct

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- In SMT-LIB format
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Thank you for attention!