On Compositional safety verification with Max-SMT

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Overview

1. Introduction
2. Program graphs
3. Algorithm overview
4. Example execution
5. Conclusion

Terms

Safety verification

Prove that an assertion is *always* true at a location

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Non-compositional safety verification

Safety verification where the whole program is analyzed in one step

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Non-compositional safety verification

Safety verification where the whole program is analyzed in one step

Compositional safety verification

Safety verification where program parts are analyzed semi-independently and composed

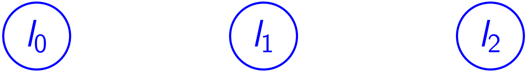
Motivation

Scalability $\longleftrightarrow$ Loss in precision

Programs

Program

$\mathcal{L} = \{\ell_0, \ell_1, \ell_2\}$



Programs

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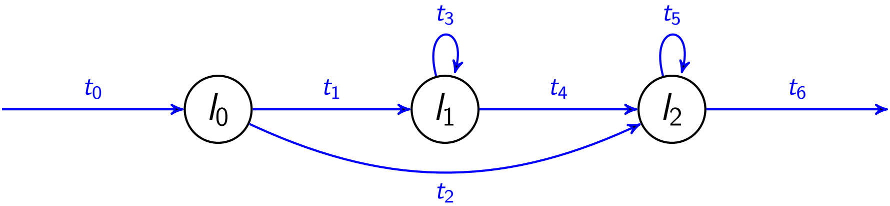
$\mathcal{L} = \{\ell_0, \ell_1, \ell_2\}$, $\mathcal{T} = \{t_i \mid i \in \{1, \ldots, 6\}\}$



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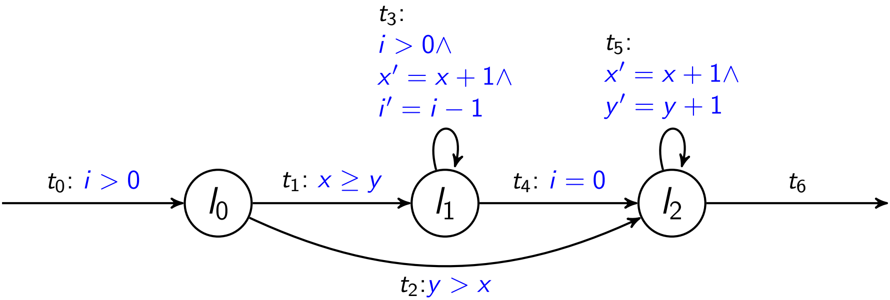
$\mathcal{L} = \{\ell_0, \ell_1, \ell_2\}$, $\mathcal{T} = \{t_i \mid i \in \{1, \ldots, 6\}\}$, $\mathcal{V} = \{x, y, i\}$, $\mathcal{V}' = \{x', y', i'\}$



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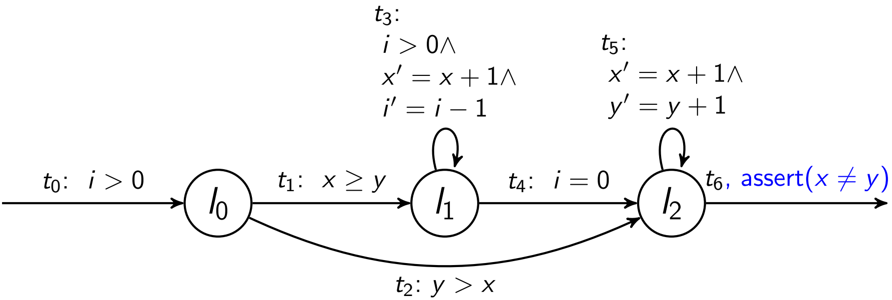

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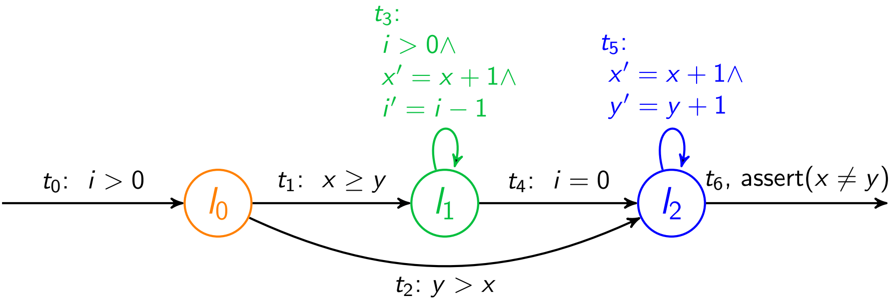
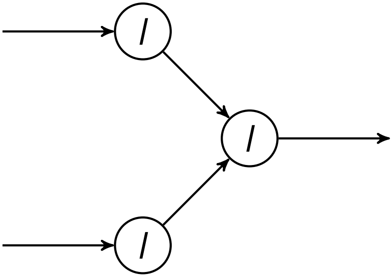


CheckSafe

Idea

Prove that an assertion is satisfied by recursively checking all entry components



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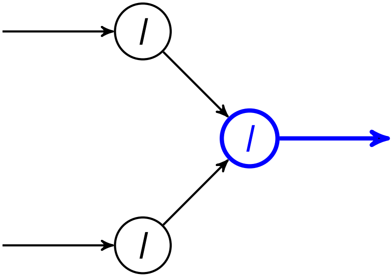

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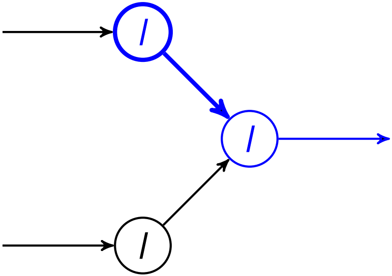

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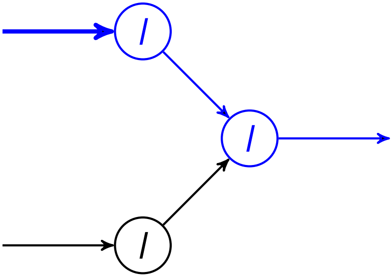

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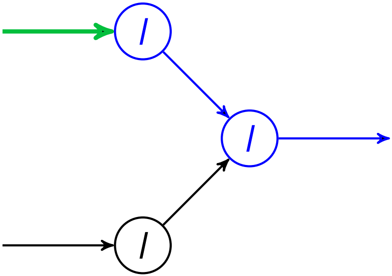

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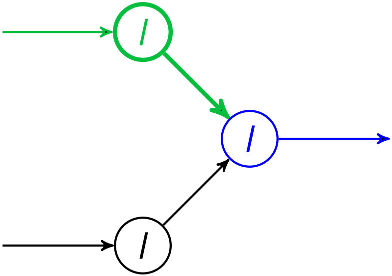

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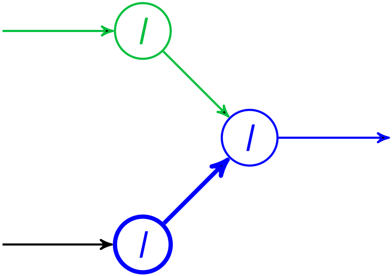

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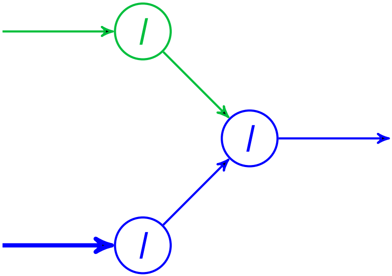

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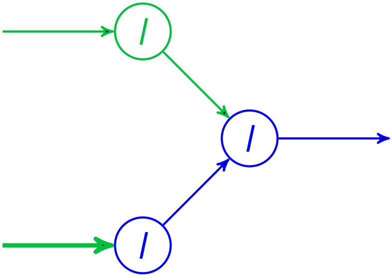

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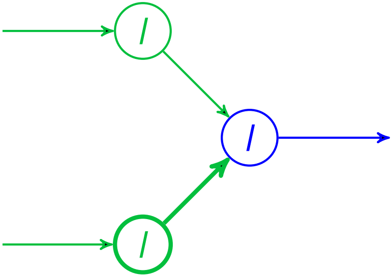

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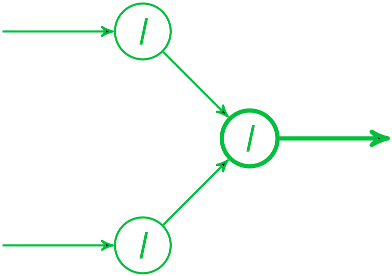
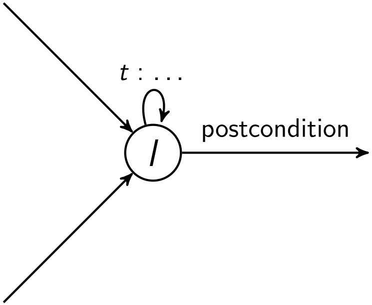


CondSafe

Idea

Find a precondition for a component such that all runs satisfying the precondition always imply the postcondition



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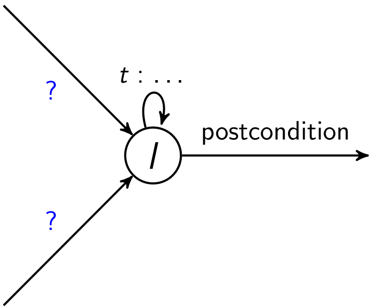
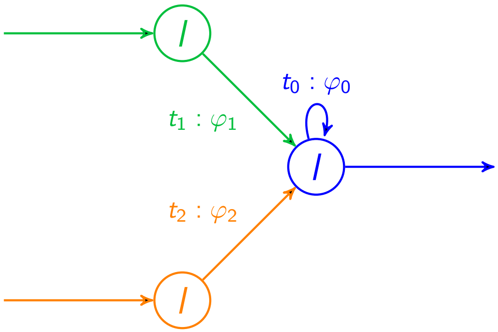


Narrowing

Idea

Manipulate the program such that new preconditions can be found



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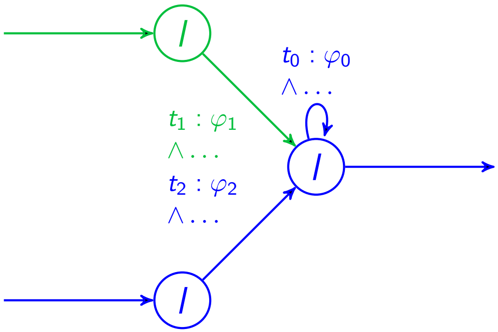

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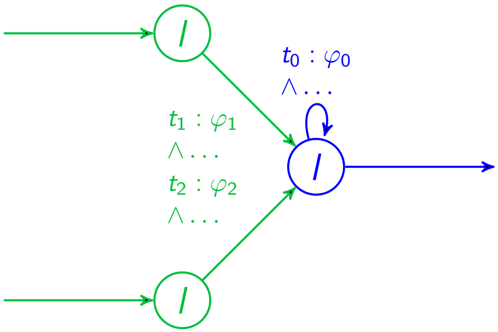

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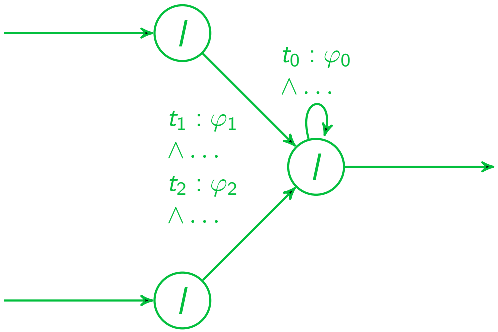
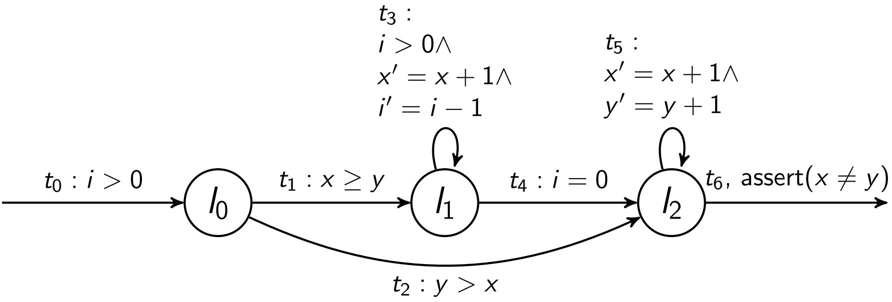
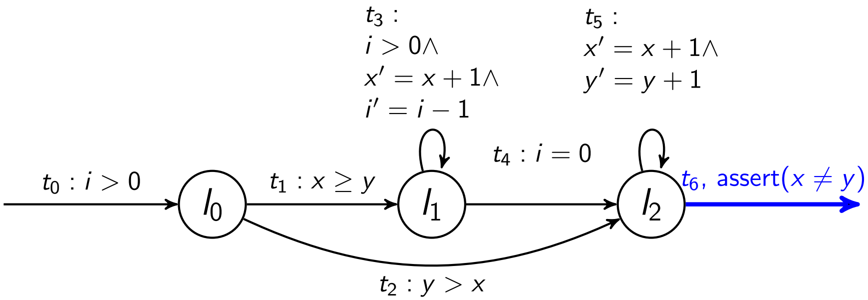


Example program



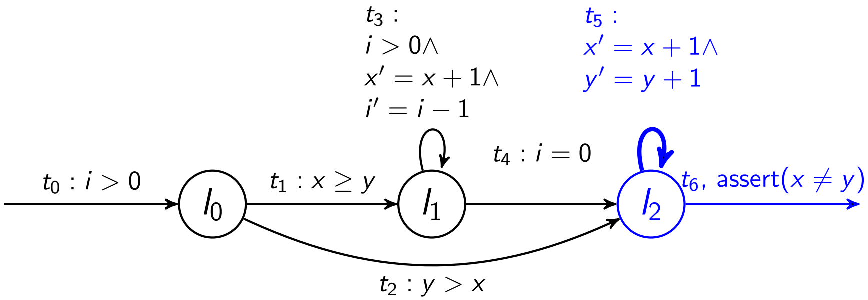
Example execution



Task

Prove that the program is safe for $x \neq y$ at t_6

Example execution



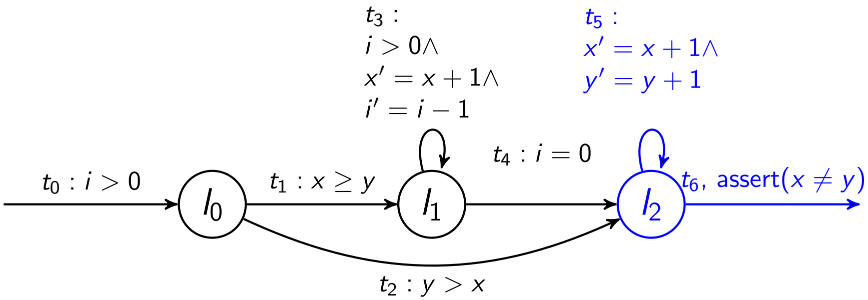
CheckSafe on $\{\ell_2\}$ for $x \neq y$

t_6 does not already imply $x \neq y$

t_6 is not an initial transition

Call CondSafe

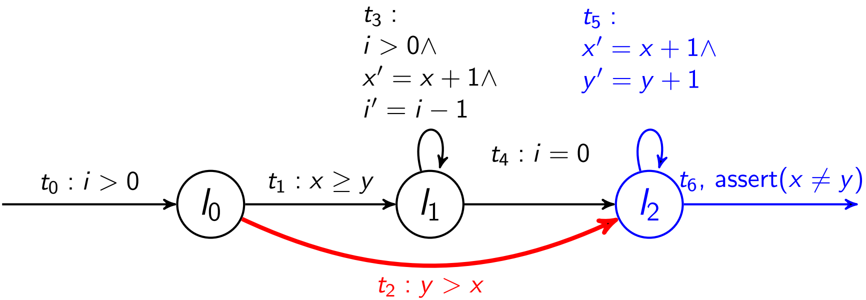
Example execution



Max-SMT on $\{\ell_2\}$ for $x \neq y$

$$I_{\ell_2,1}(\{x, y, i\}) \equiv i_{\ell_2,1} + i_{\ell_2,1,x} * x + i_{\ell_2,1,y} * y + i_{\ell_2,1,i} * i \leq 0$$

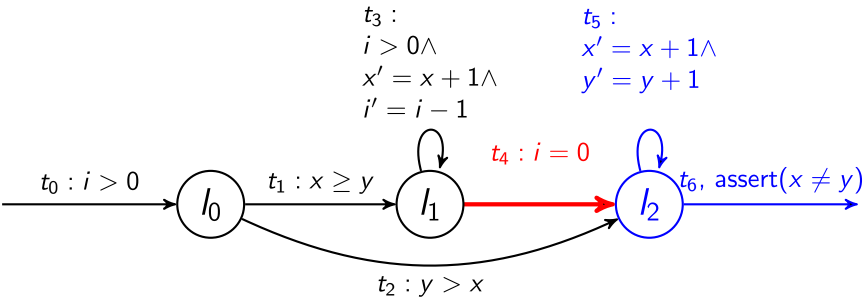
Example execution



Max-SMT on $\{\ell_2\}$ for $x \neq y$

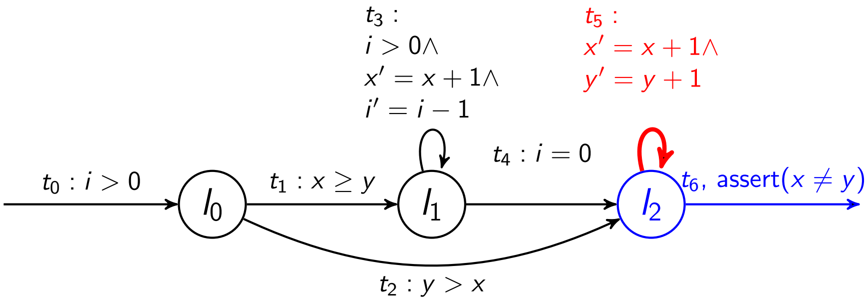
$$\mathbb{I}_{t_2,1,1} \equiv y > x \wedge i' = i \wedge x' = x \wedge y' = y \Rightarrow I'_{\ell_2,1,1}$$

Example execution



Max-SMT on $\{\ell_2\}$ for $x \neq y$

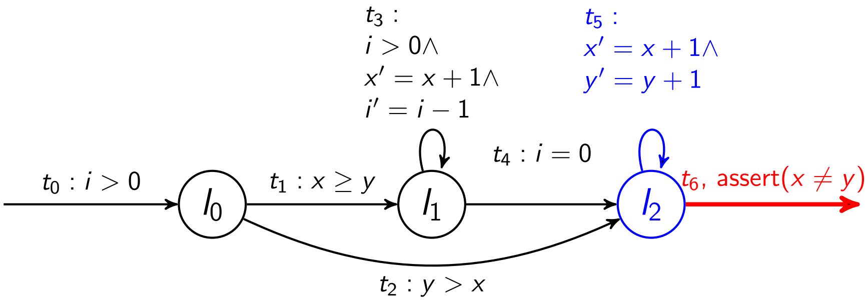
$$\mathbb{I}_{t_4,1,1} \equiv i = 0 \wedge i' = i \wedge x' = x \wedge y' = y \Rightarrow I'_{\ell_2,1,1}$$



Max-SMT on $\{\ell_2\}$ for $x \neq y$

$$\mathbb{C}_{t_5,1} \equiv I_{\ell_2,1} \wedge x' = x + 1 \wedge y' = y + 1 \wedge i' = i \Rightarrow I'_{\ell_2,1}$$

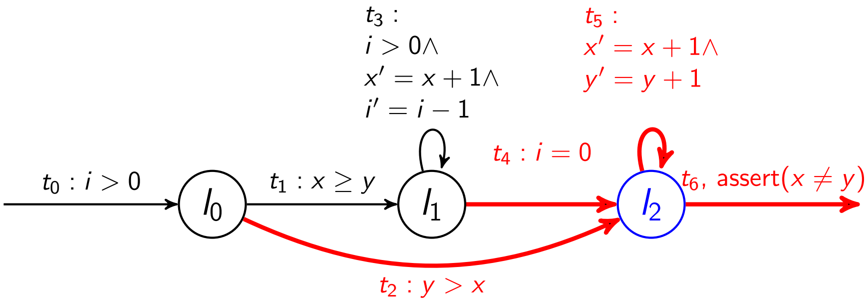
Example execution



Max-SMT on $\{\ell_2\}$ for $x \neq y$

$\mathbb{S}_1 \equiv I_{\ell_2,1} \wedge\ i' = i \wedge x' = x \wedge y' = y \Rightarrow x' \neq y'$

Example execution

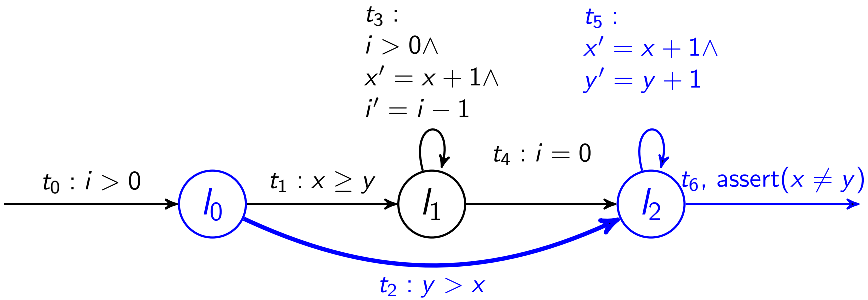


Max-SMT on $\{\ell_2\}$ for $x \neq y$

$\mathbb{F}_1 \equiv \mathbb{C}_{t_5,1} \wedge \mathbb{S}_1 \wedge (\mathbb{I}_{t_2,1,1} \vee \neg p_{t_2}) \wedge (\mathbb{I}_{t_4,1,1} \vee \neg p_{t_4}) \wedge [p_{t_2}, 1] \wedge [p_{t_4}, 1]$

Assume $x > y$ does satisfy $\mathbb{F}_1$

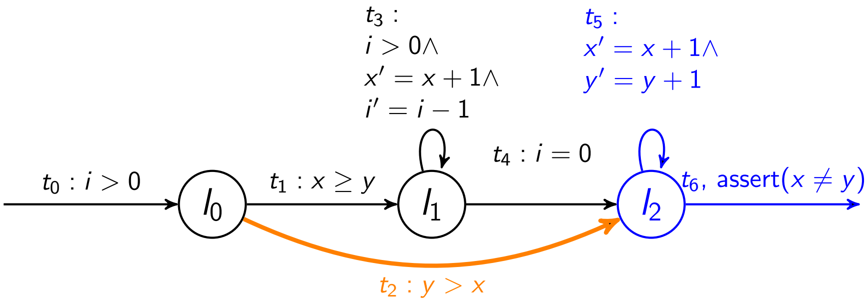
Example execution



CheckSafe on $\{\ell_0\}$ for $x > y$

t_2 does not already imply $x > y$
t_2 is not an initial transition
Call CondSafe

Example execution

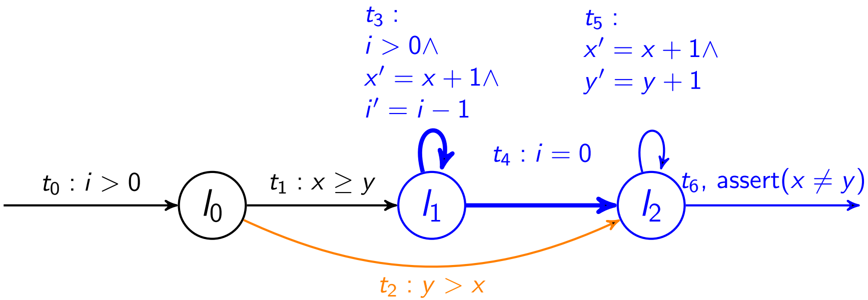


CheckSafe on $\{\ell_0\}$ for $x > y$

No precondition, since $y > x$ contradicts $x > y$

Path is maybe safe, but not for $x > y$

Example execution



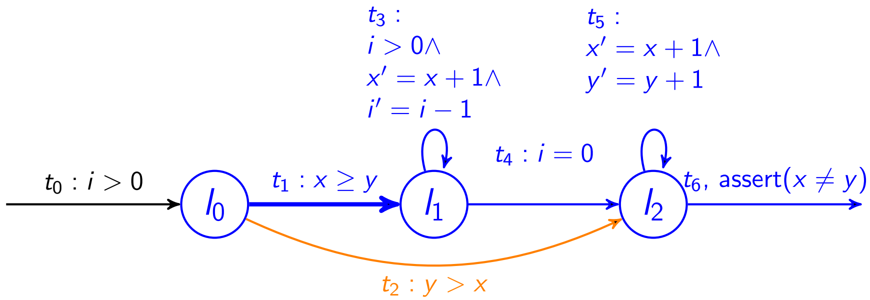
CheckSafe on $\{\ell_1\}$ for $x > y$

t_4 does not already imply $x > y$

t_4 is not an initial transition

Call CondSafe, get $i > 0 \wedge x \geq y$ as precondition

Example execution



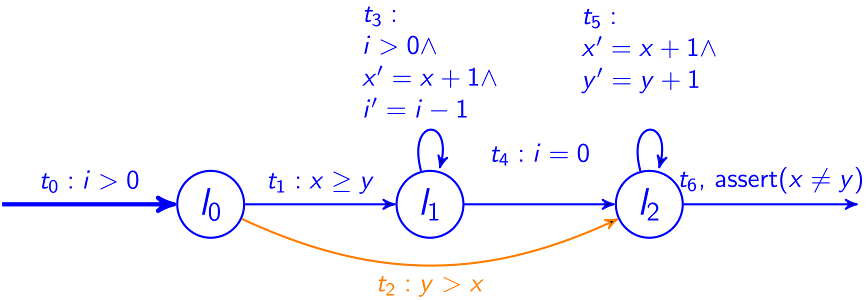
CheckSafe on $\{\ell_0\}$ for $i > 0$

t_1 does not already imply $i > 0$

t_1 is not an initial transition

Call CondSafe, get $i > 0$ as precondition

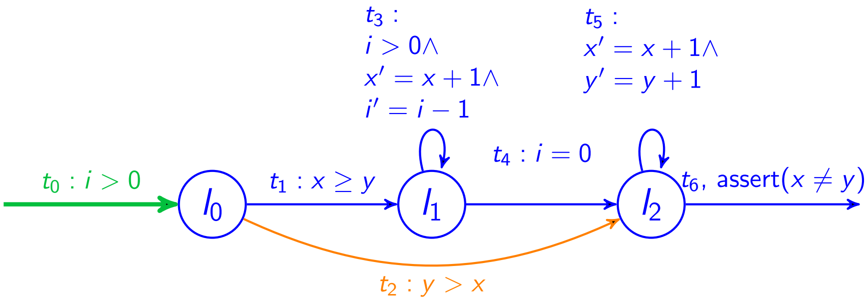
Example execution



CheckSafe on initial SCC for $i > 0$

t_0 does already imply $i > 0$

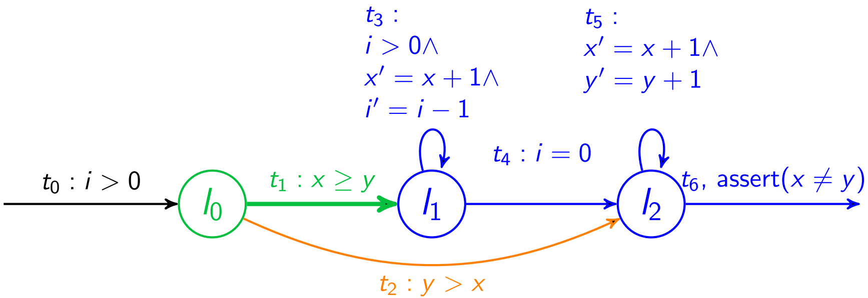
Example execution



CheckSafe on initial SCC for $i > 0$

Path is safe for $i > 0$

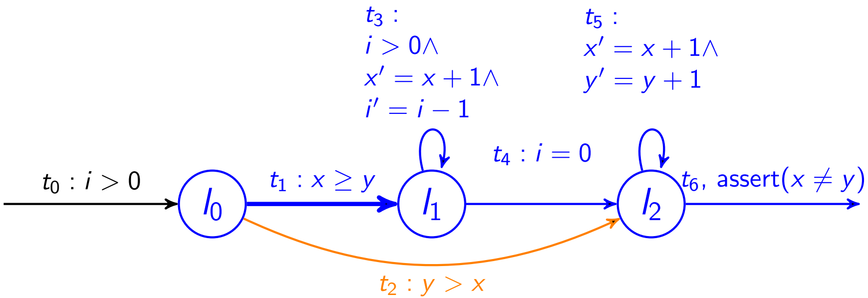
Example execution



CheckSafe on $\{\ell_0\}$ for $i > 0$

Path is safe for $i > 0$

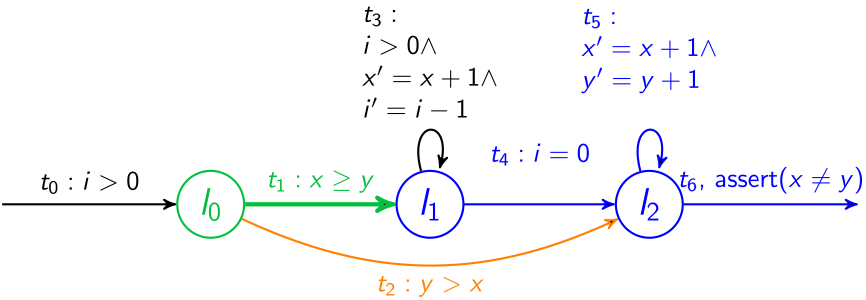
Example execution



CheckSafe on $\{\ell_0\}$ for $x \geq y$

t_1 does already imply $x \geq y$

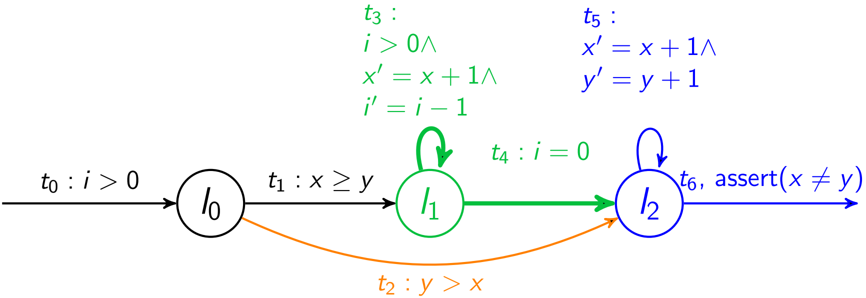
Example execution



CheckSafe on $\{\ell_0\}$ for $x \geq y$

Path is safe for $x \geq y$

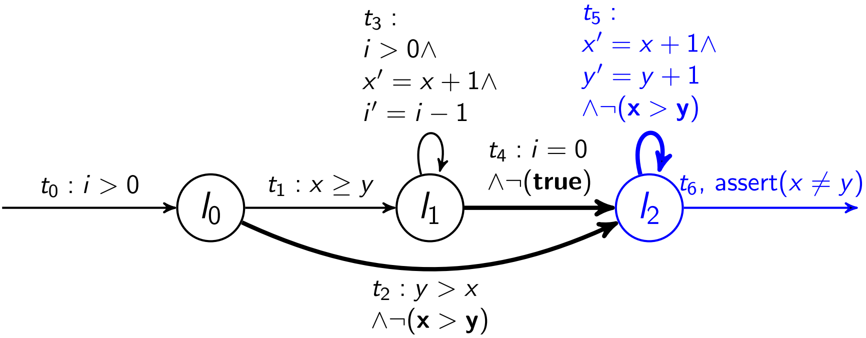
Example execution



CheckSafe on $\{\ell_1\}$ for $x > y$

Path is safe for $x > y$

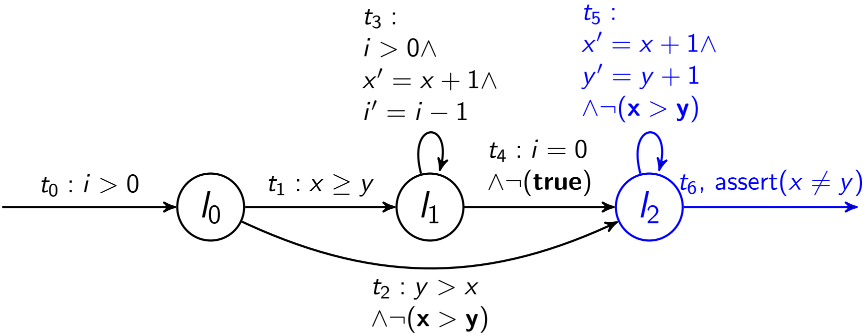
Example execution



Narrow on $\{\ell_2\}$

Add $\neg(x > y)$ to t_2
Add $\neg(x > y)$ to t_5
Remove t_4

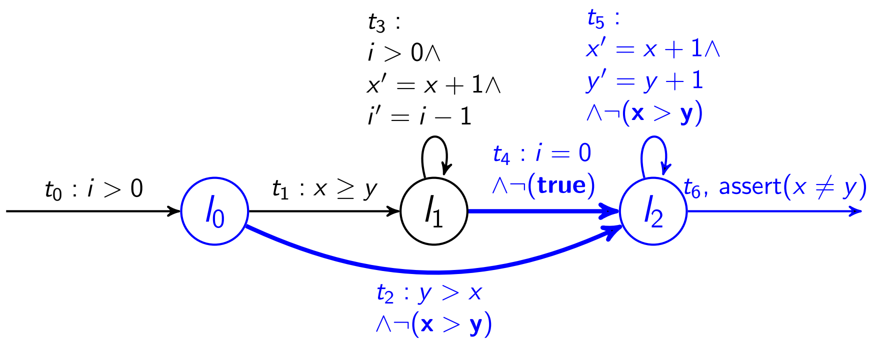
Example execution



CheckSafe on $\{\ell_2\}$ for $x \neq y$

Call CondSafe, get $y > x$ instead of $x > y$ as precondition

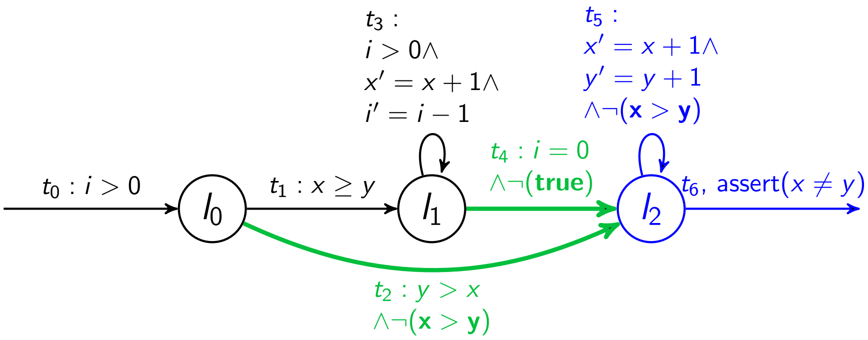
Example execution



CheckSafe on $\{\ell_0\}$ for $y > x$

t_2 does already imply $y > x$ t_4 does already imply $y > x$

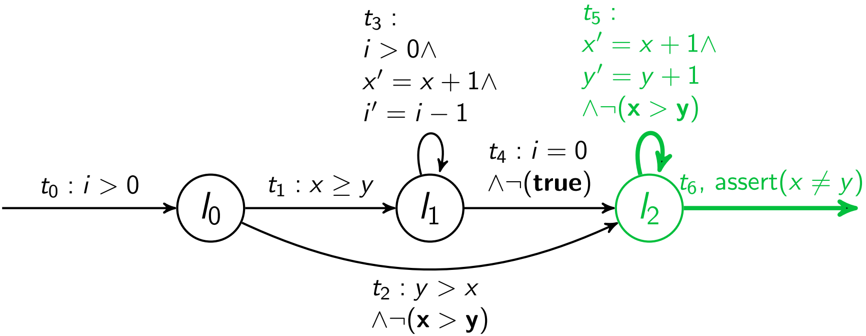
Example execution



CheckSafe on $\{\ell_0\}$ for $y > x$

Paths are safe for $y > x$

Example execution



CheckSafe on $\{\ell_0\}$ for $y > x$

Program is safe for $x \neq y$

Conclusion

We saw:

1. The exploration of multiple entry SCCs by CheckSafe
2. The effect of narrowing if a path to the SCC is proved safe and another could not be proved safe
3. The behavior of CheckSafe if a precondition with multiple conjunctions is found

We didn't saw:

1. SCCs with multiple transitions (effects consecution conditions in Max-SMT and entry locations in Narrowing)