Trace Abstraction vs. IMPACT

A Study of Software Model Checkers based on Interpolation

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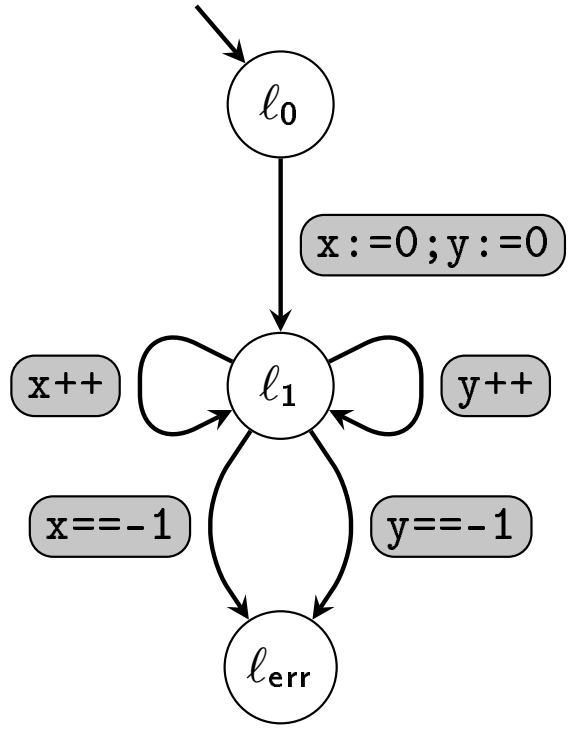
Fragestellung

IMPACT und Trace Abstraction: zwei auf Interpolation basierende Software Model Checker

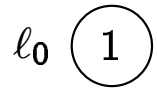
- Frage nach der Vergleichbarkeit von IMPACT und Trace Abstraction
- Suche nach geeigneten Vergleichskriterien
- Ist das eine durch das andere ausdrückbar/eine Variante oder Teilmenge des anderen?

Vorstellung der beiden Verfahren - Beispielprogramm

```
x:=0
y:=0
while(*) {
 if(+)
  x++
 else
  y++
}
assert(x!=-1)
assert(y!=-1)
```



Kurzvorstellung IMPACT



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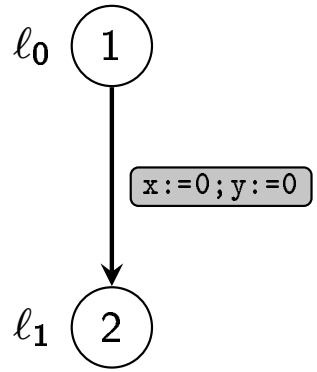

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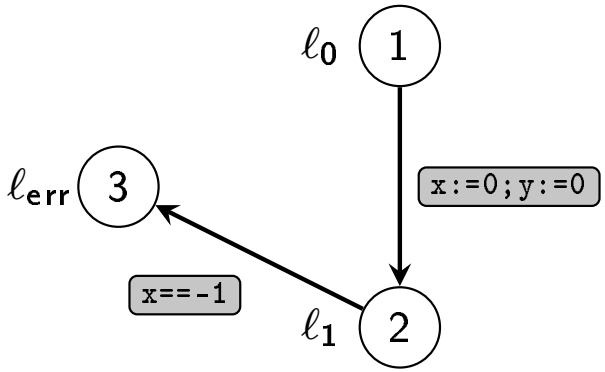

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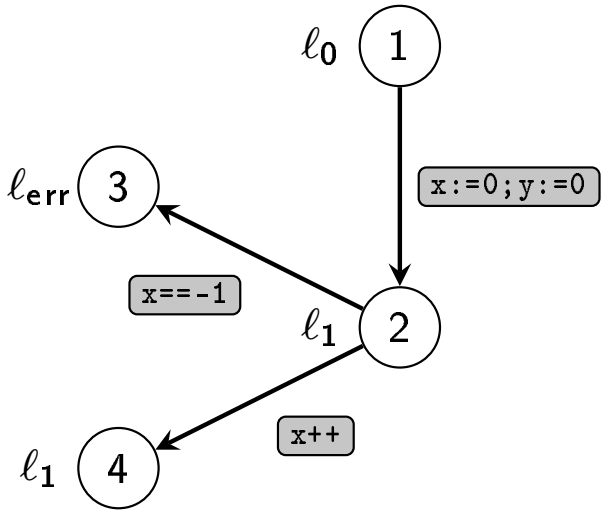

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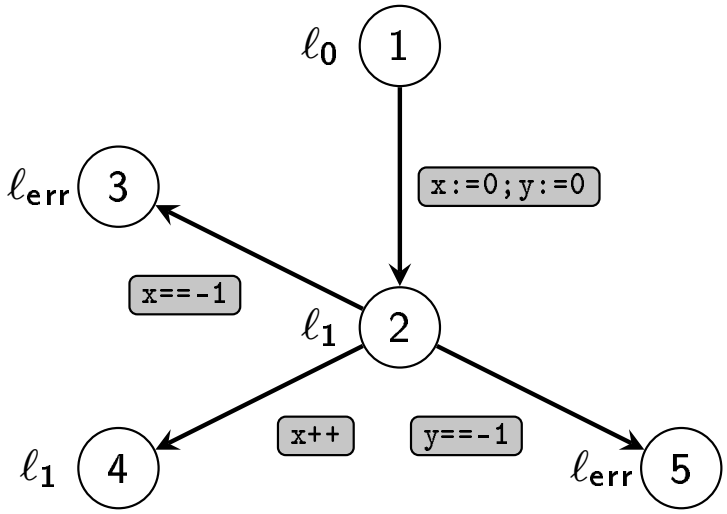

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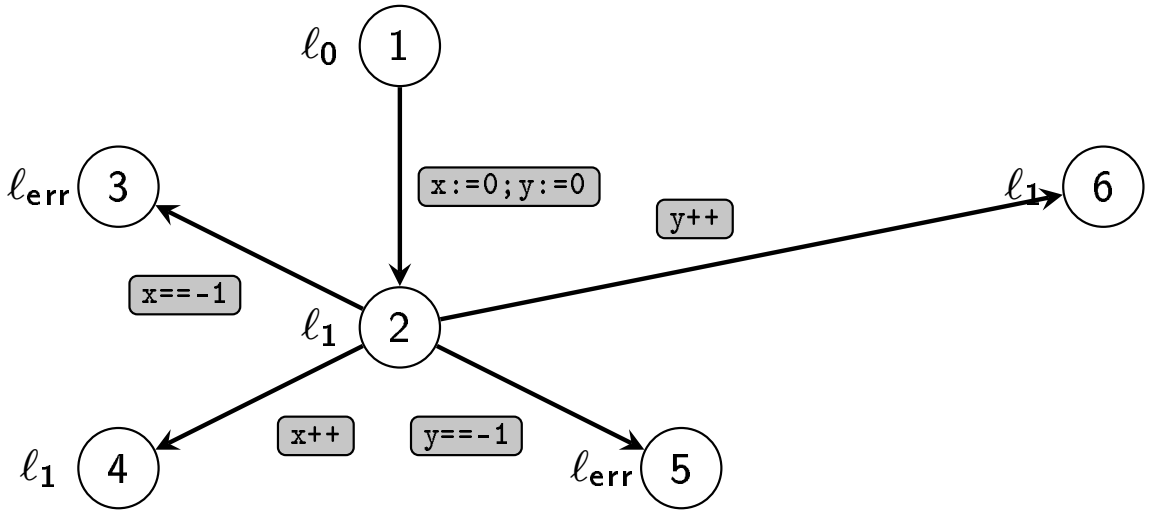

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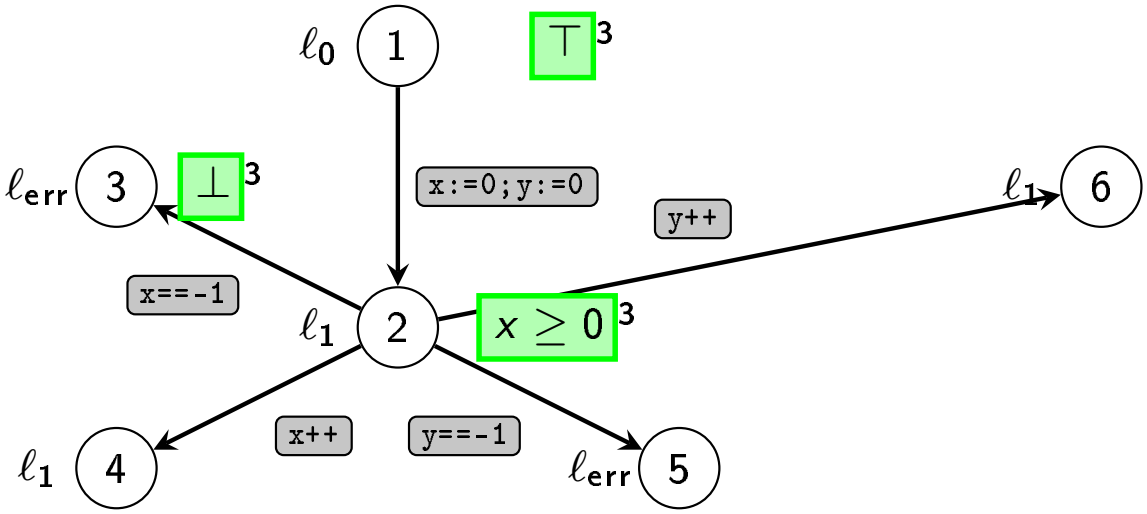

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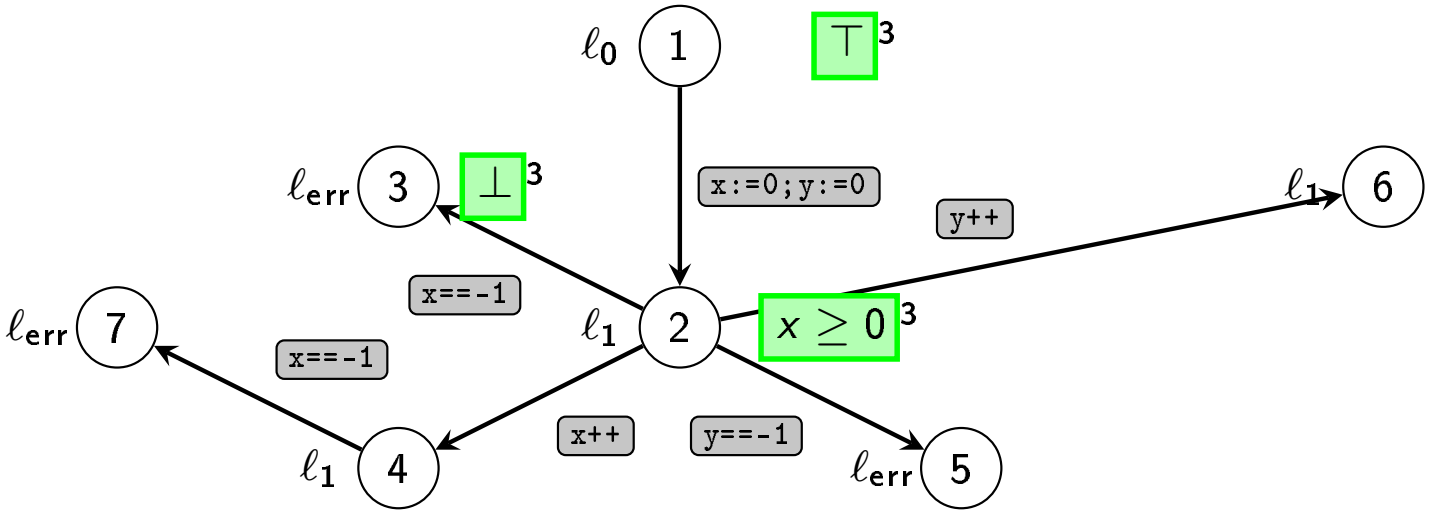

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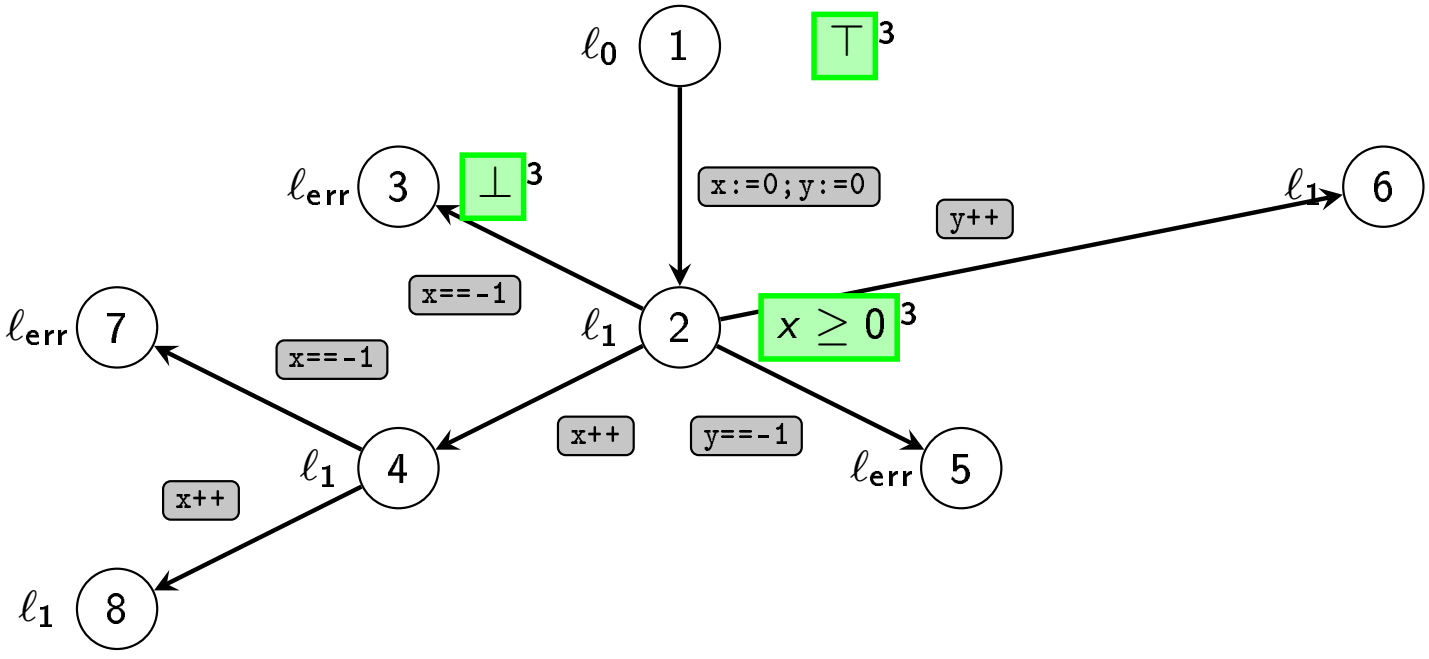

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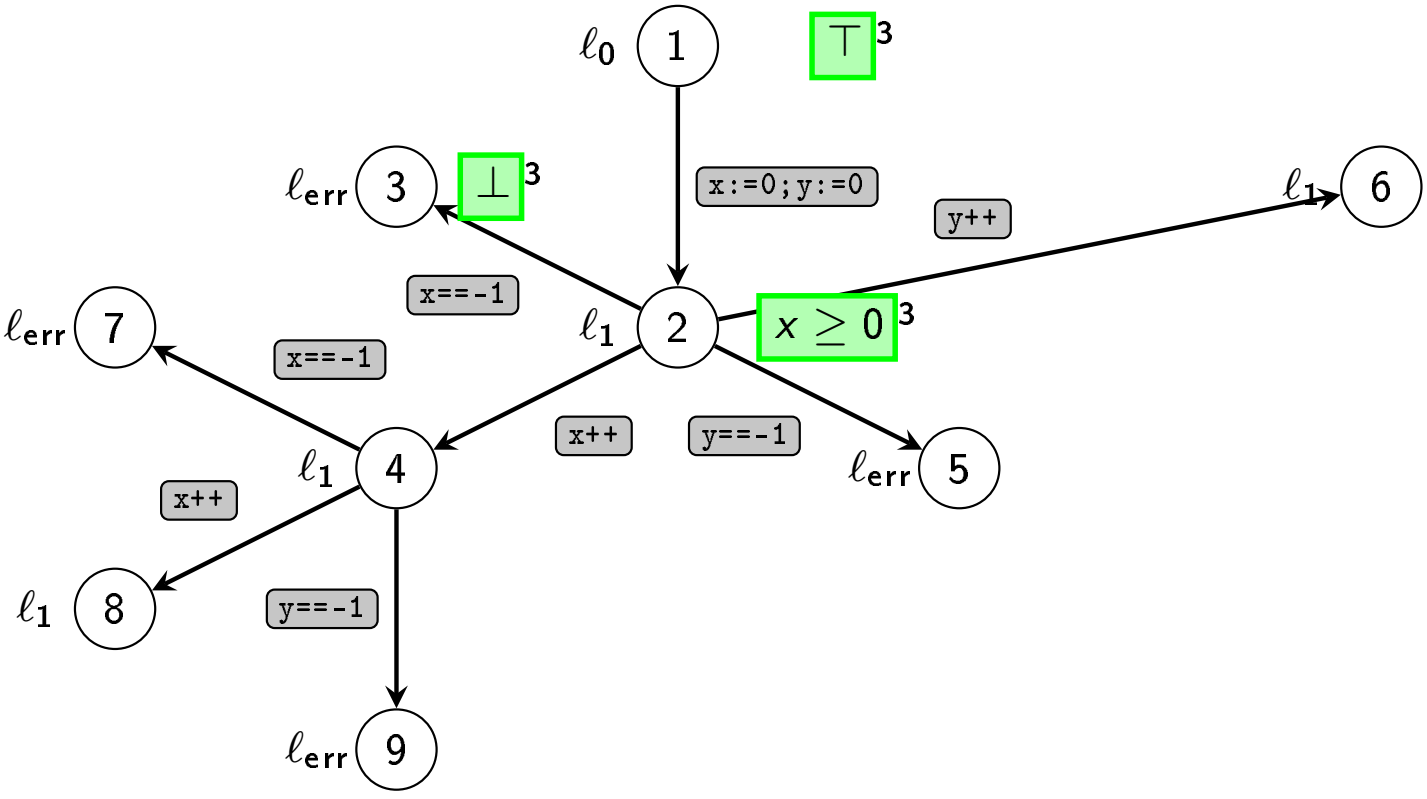

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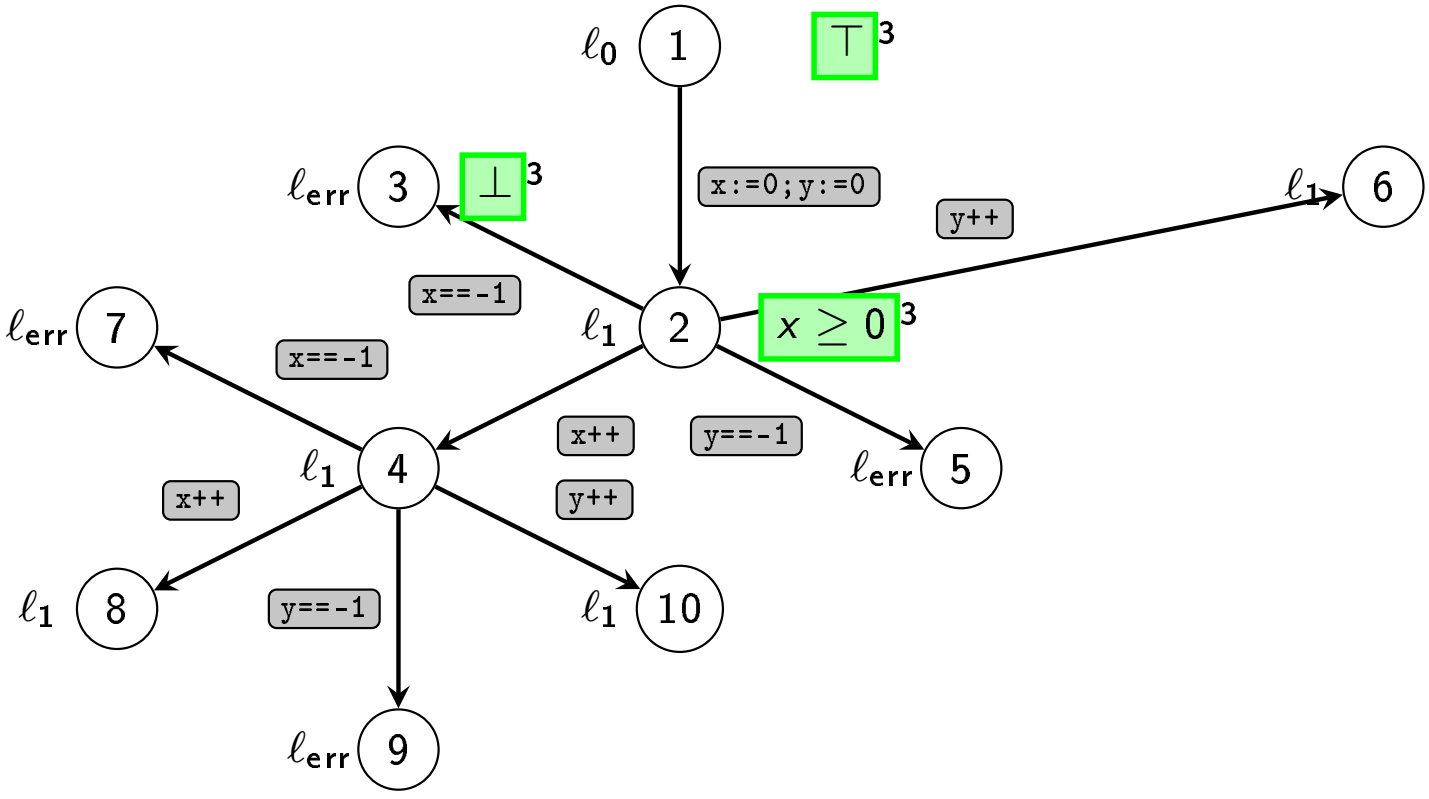

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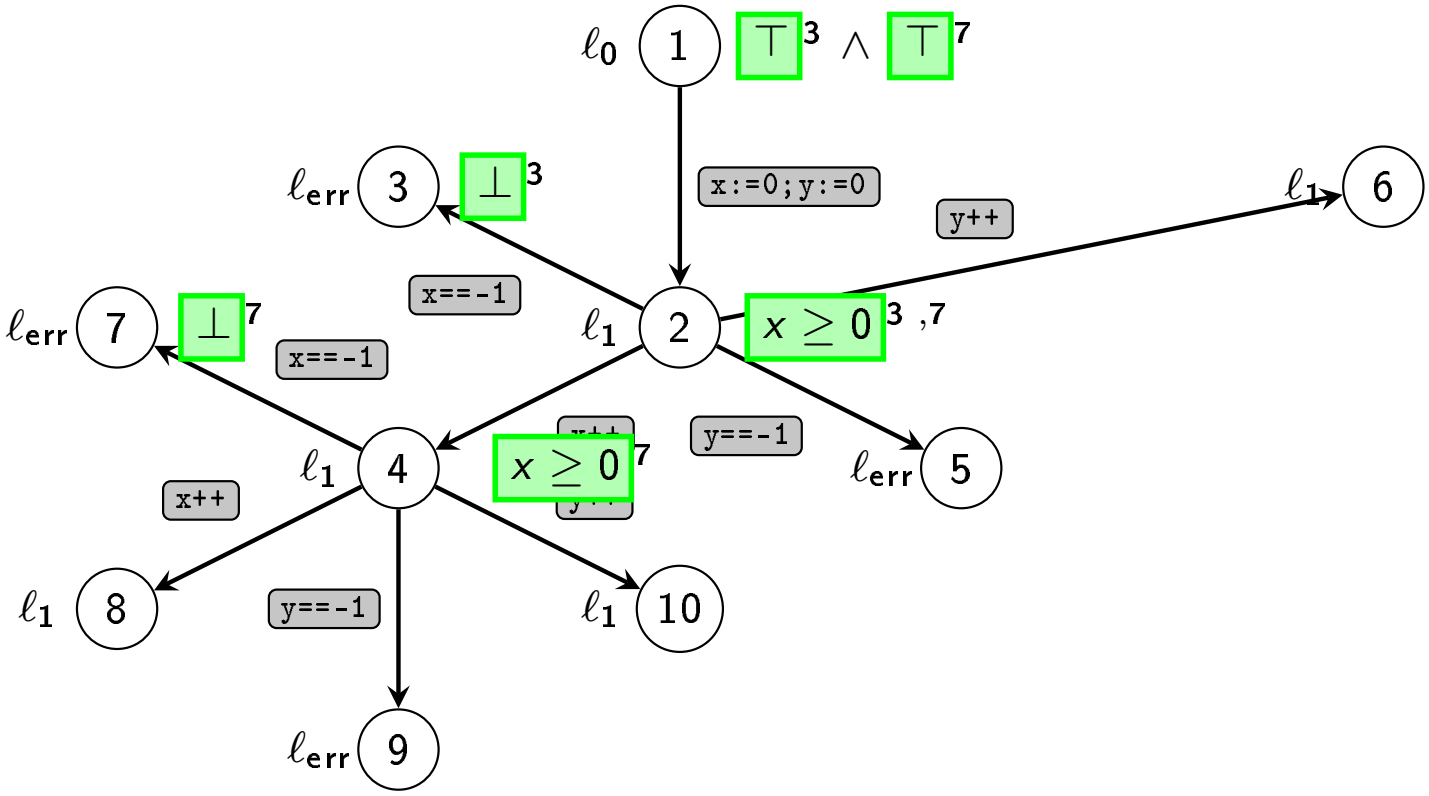

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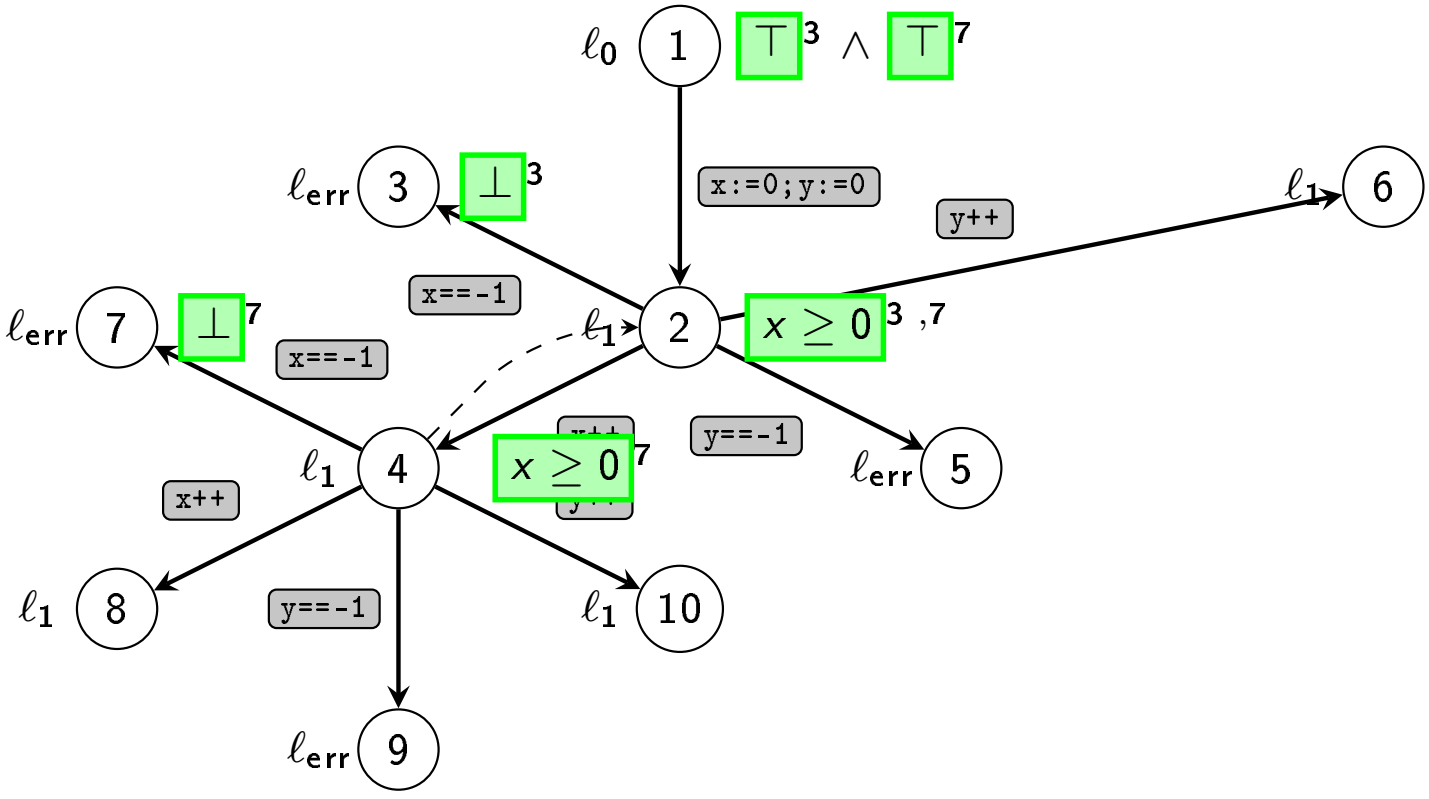

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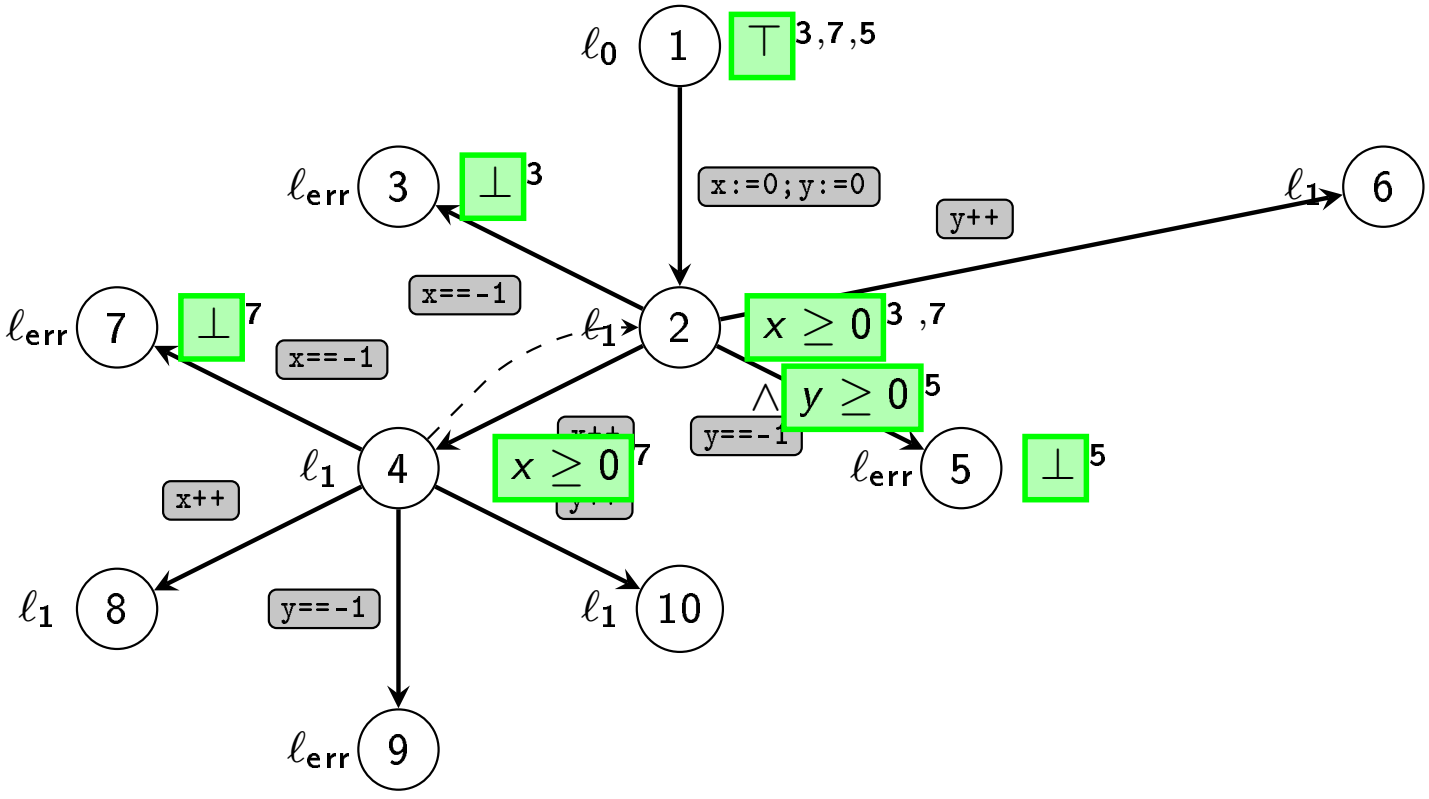

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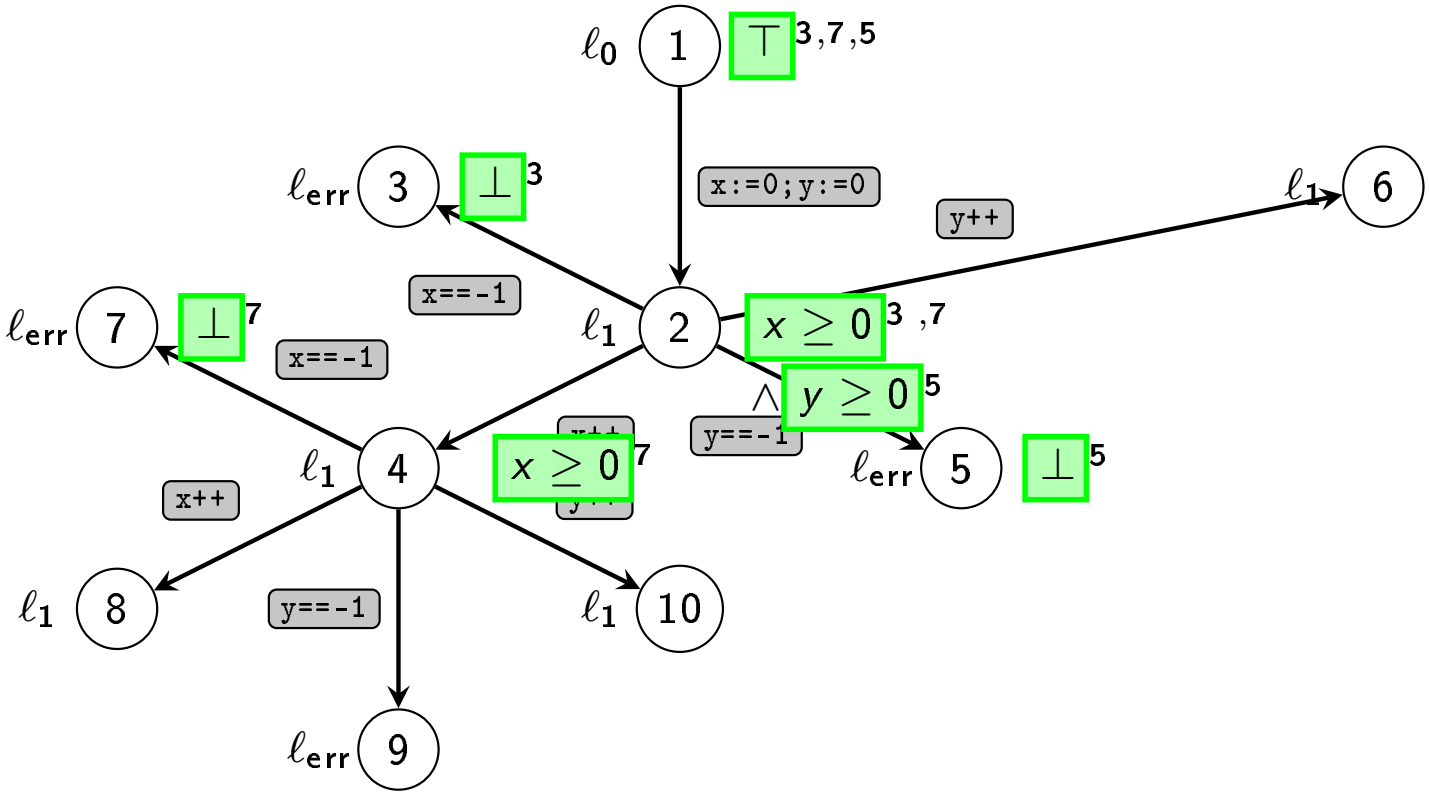

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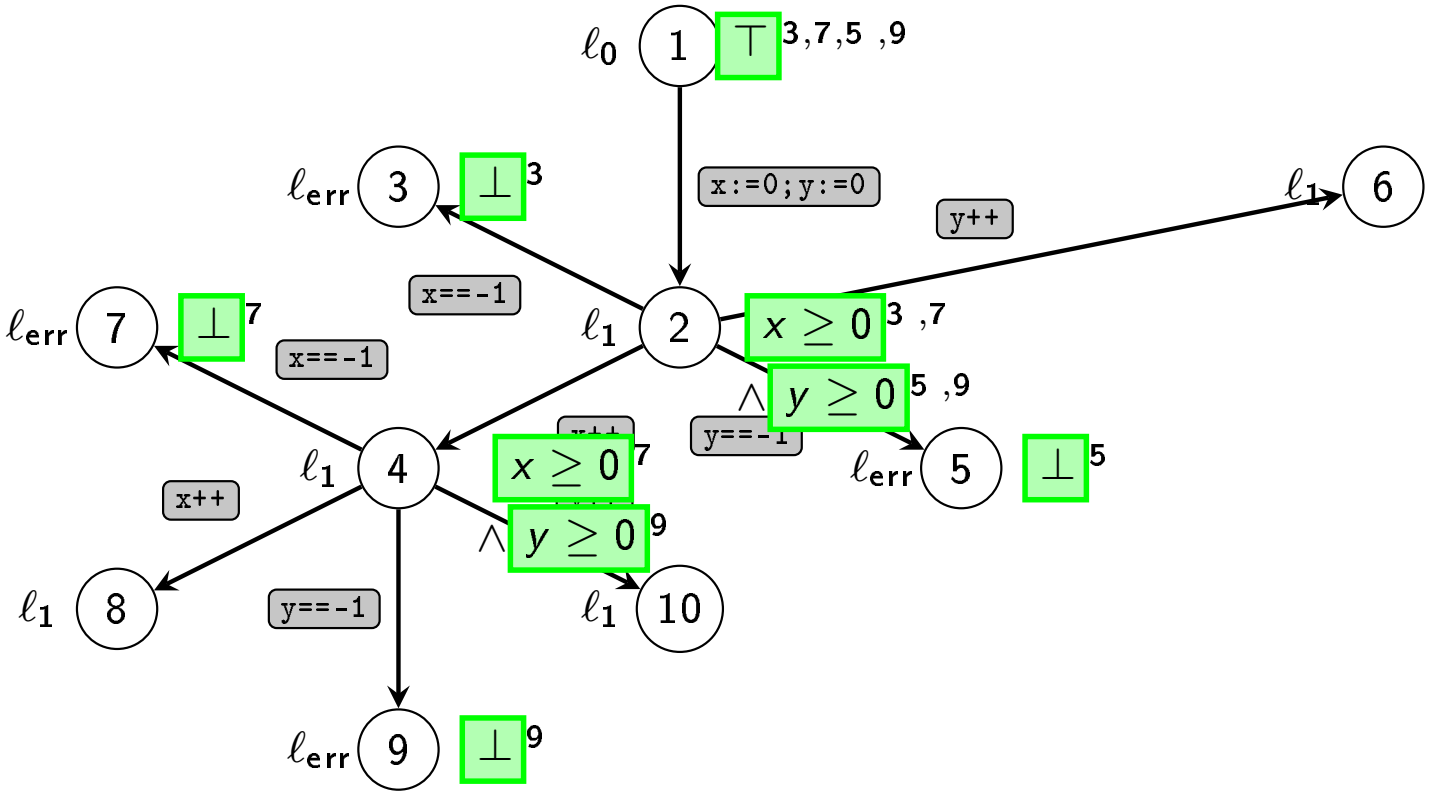

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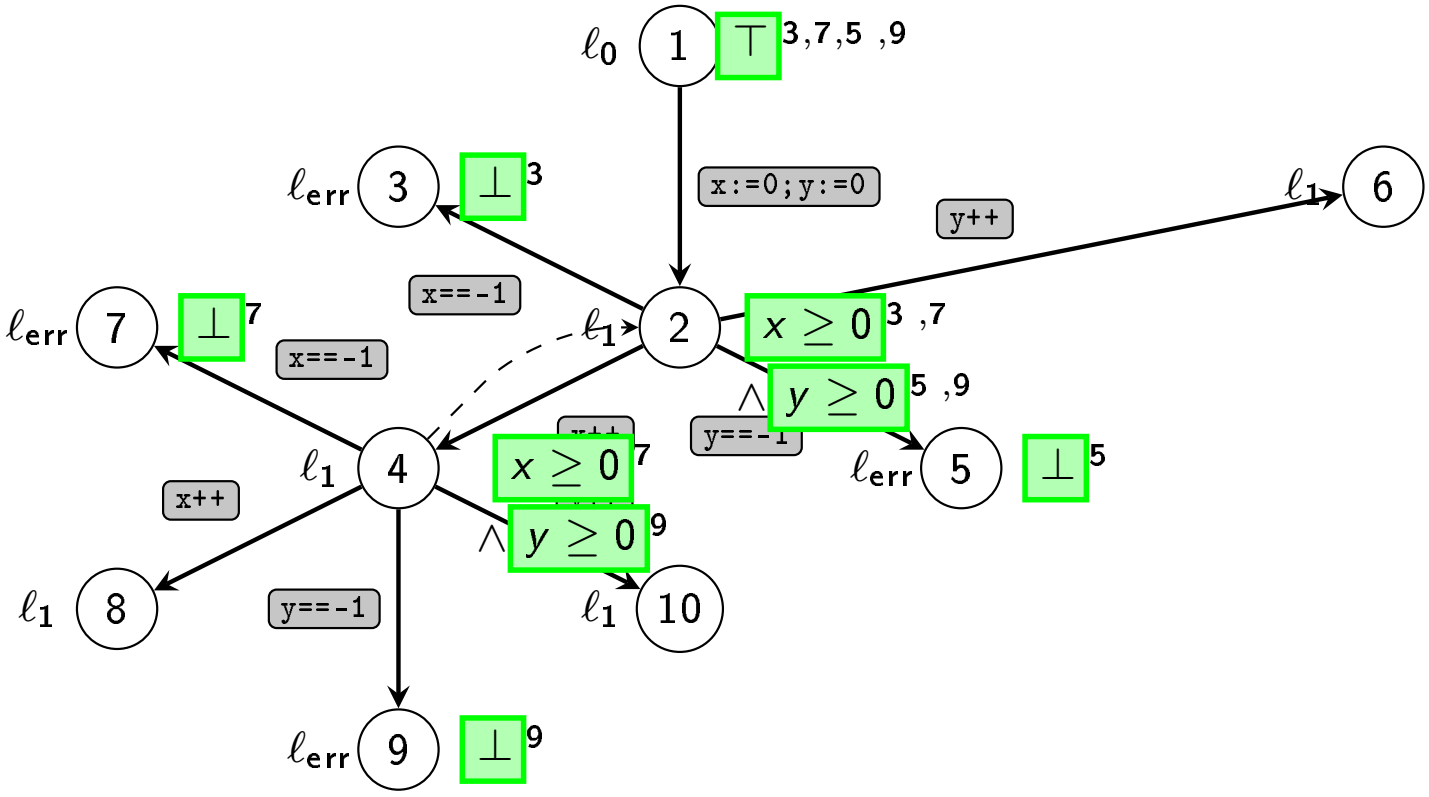

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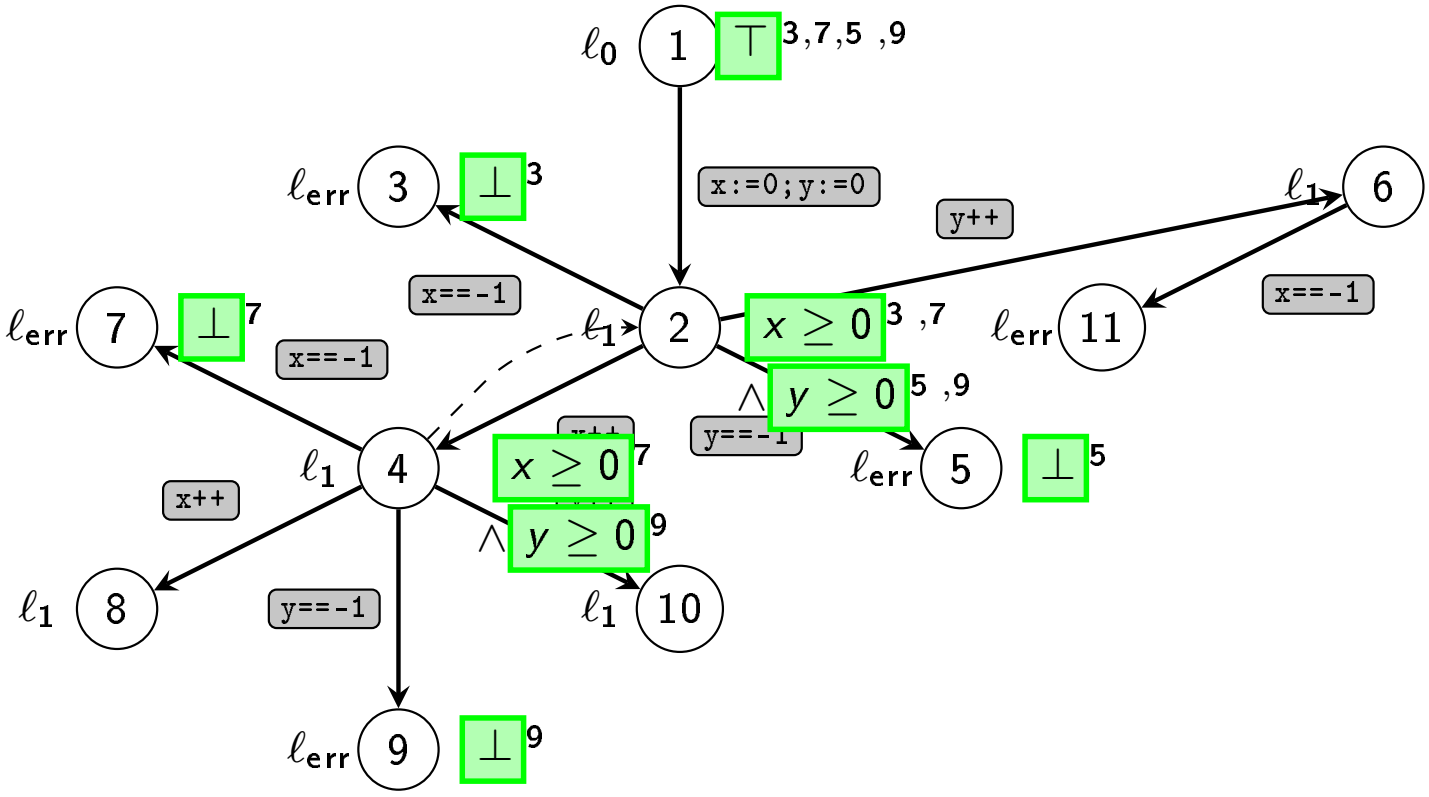

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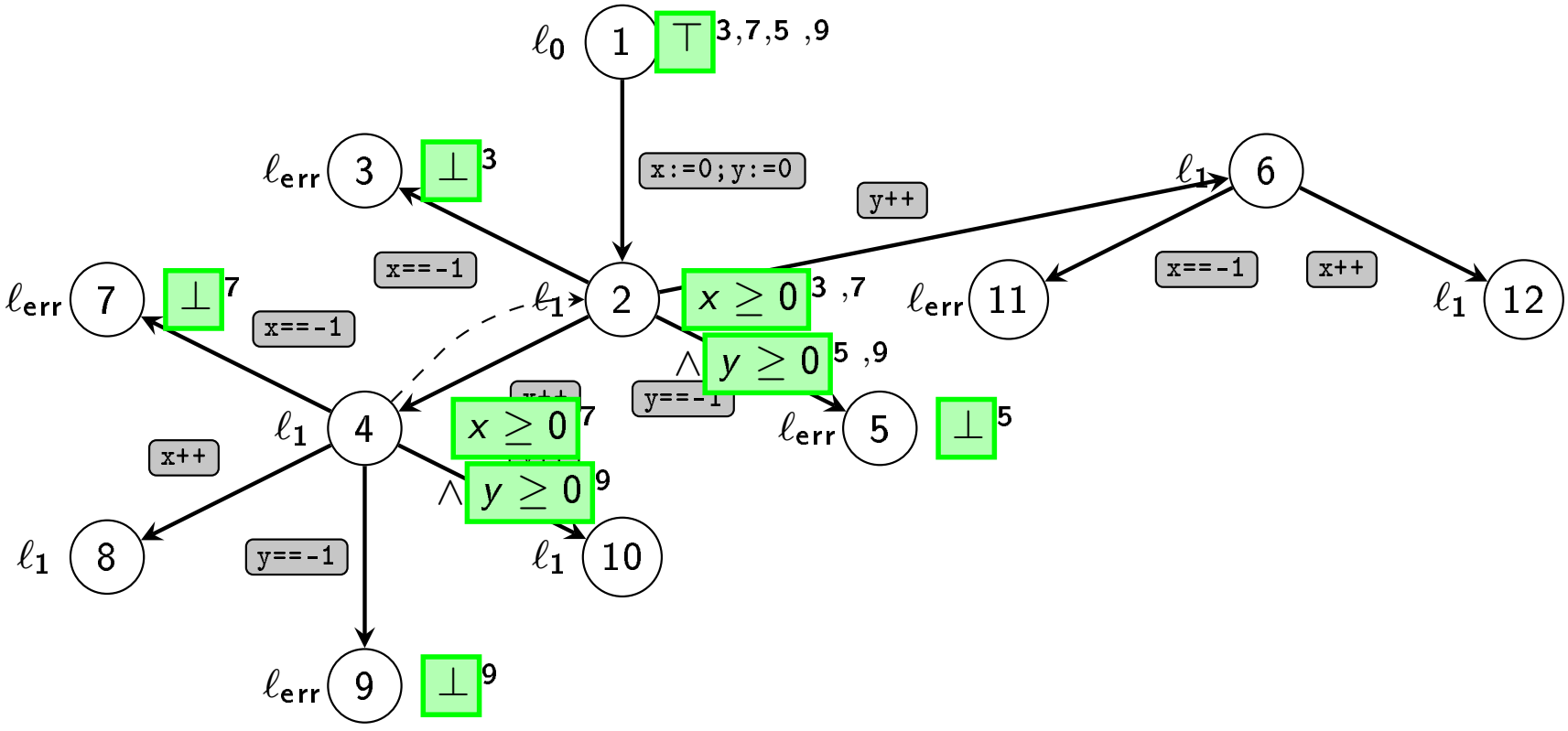

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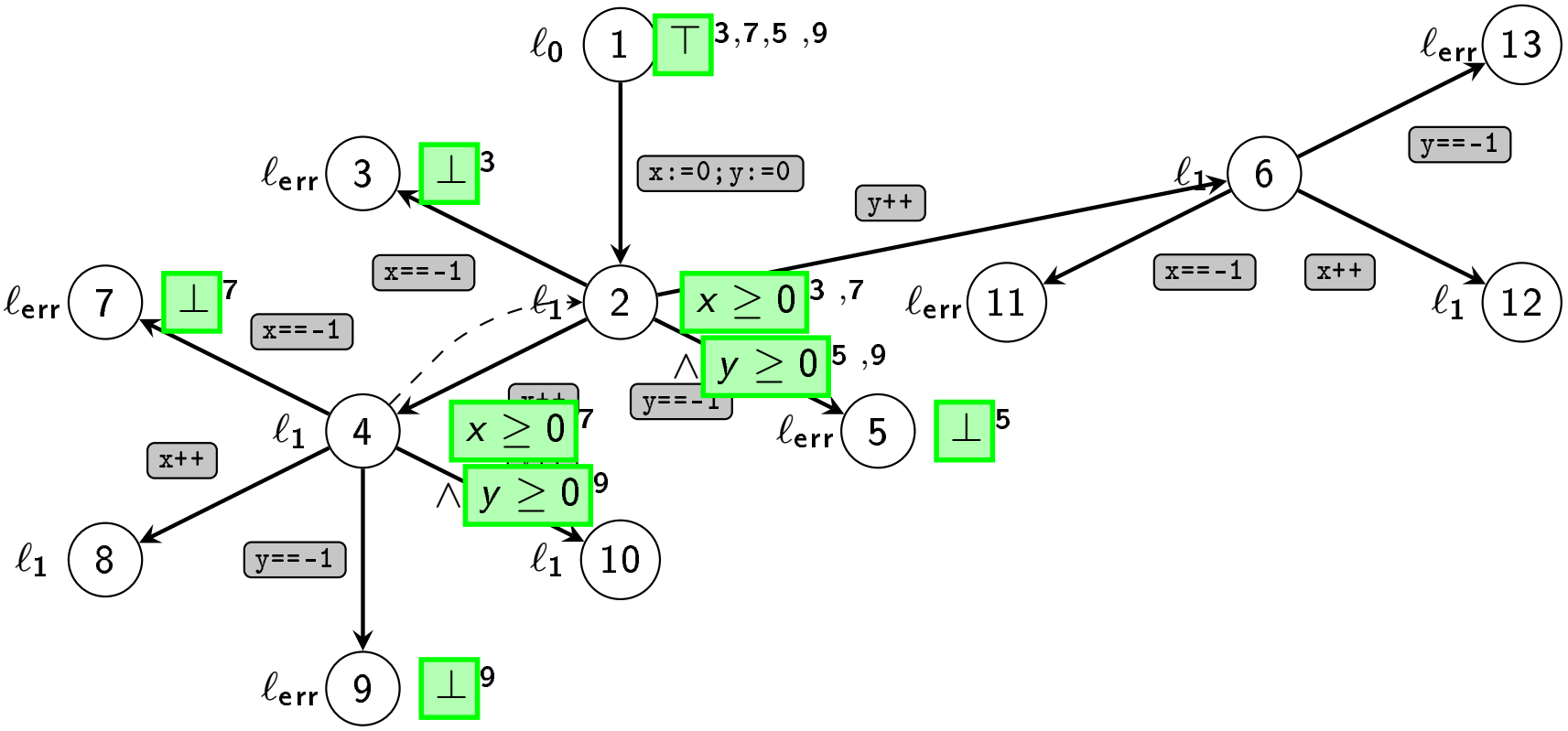

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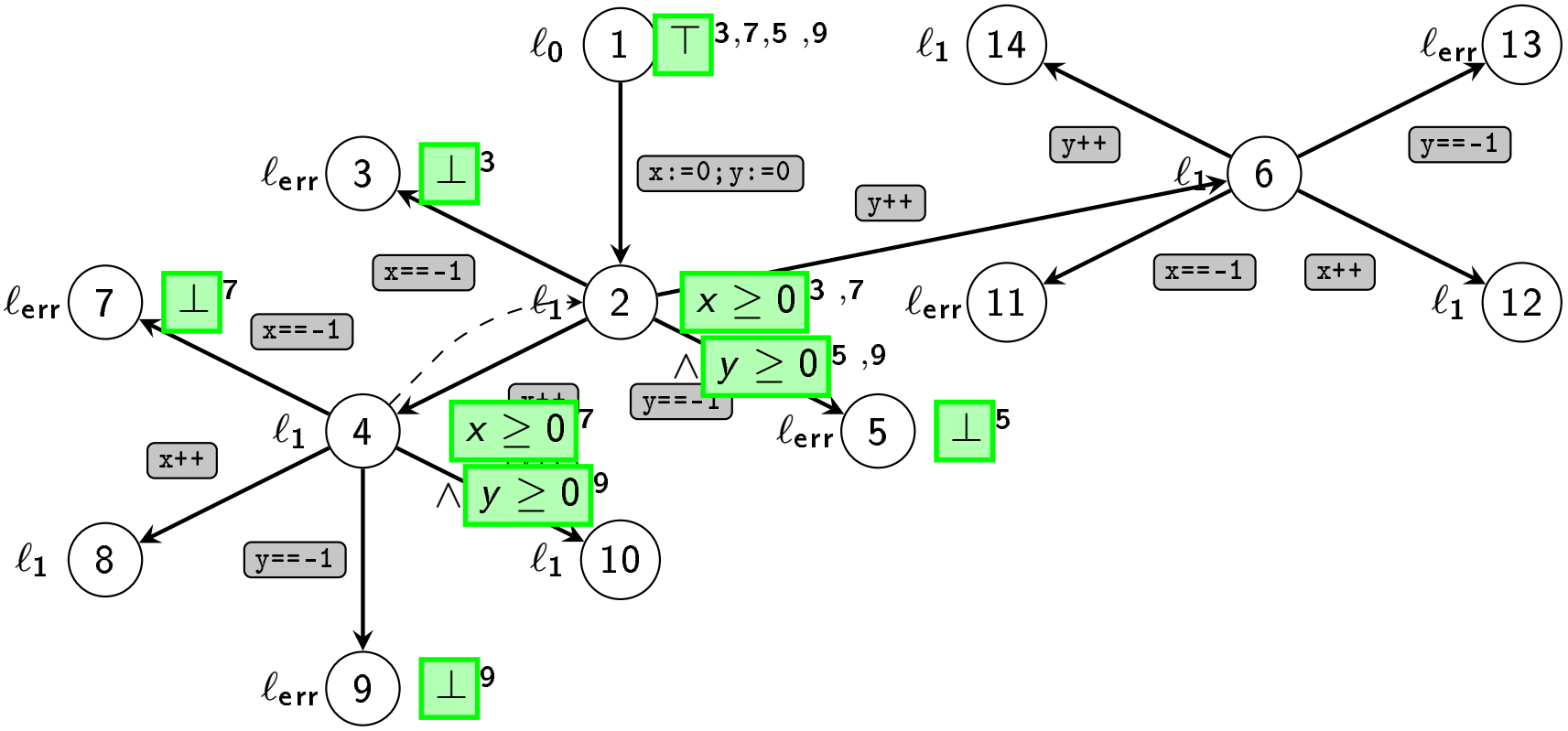

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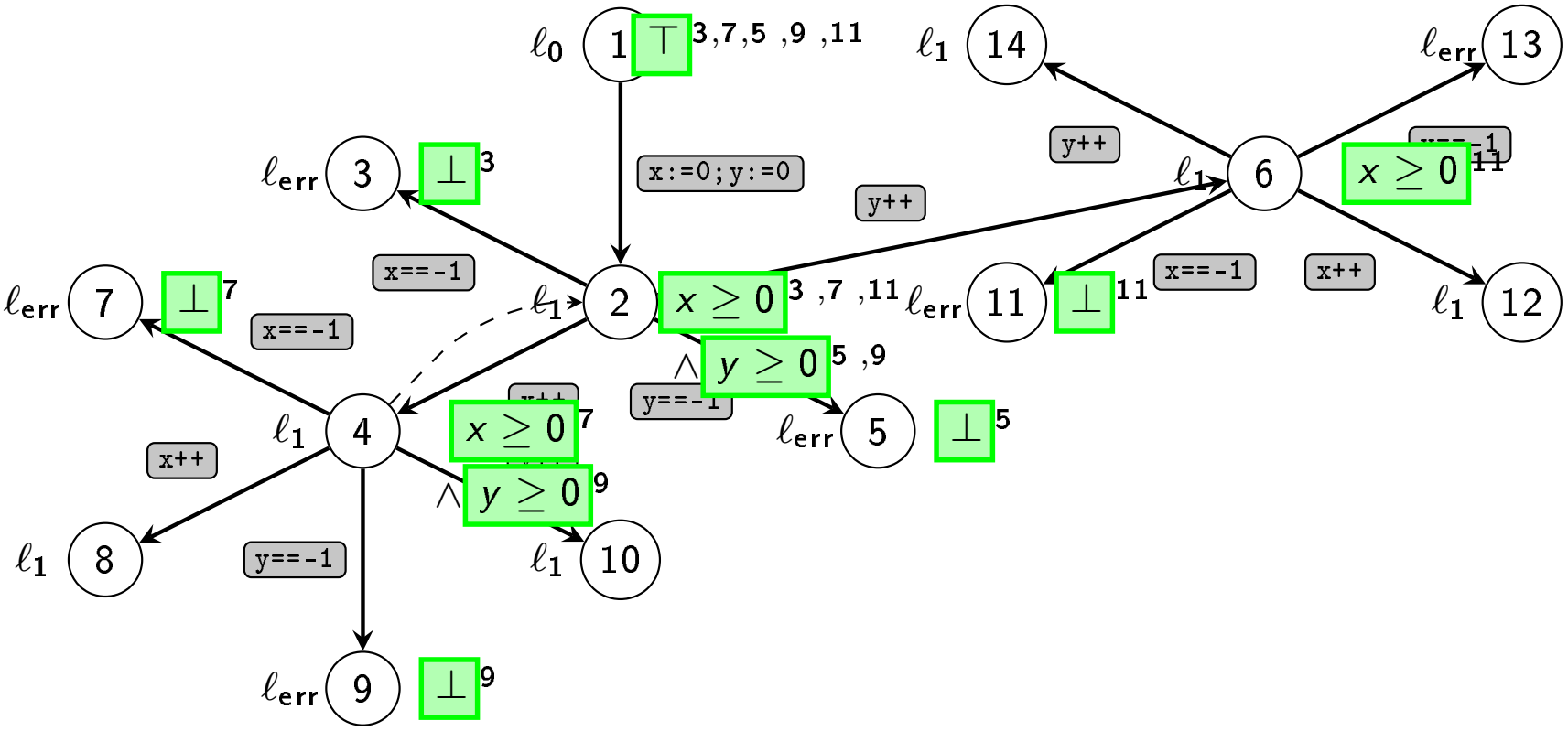

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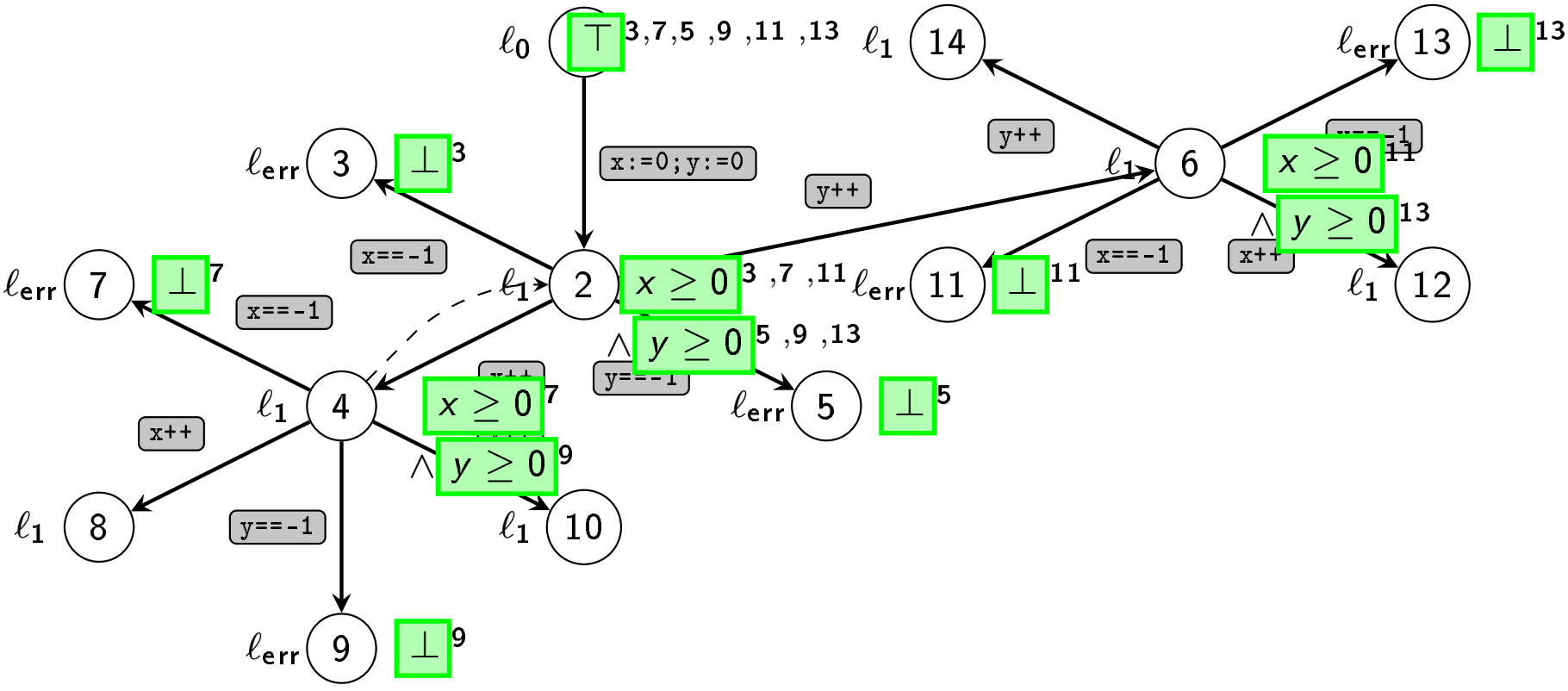

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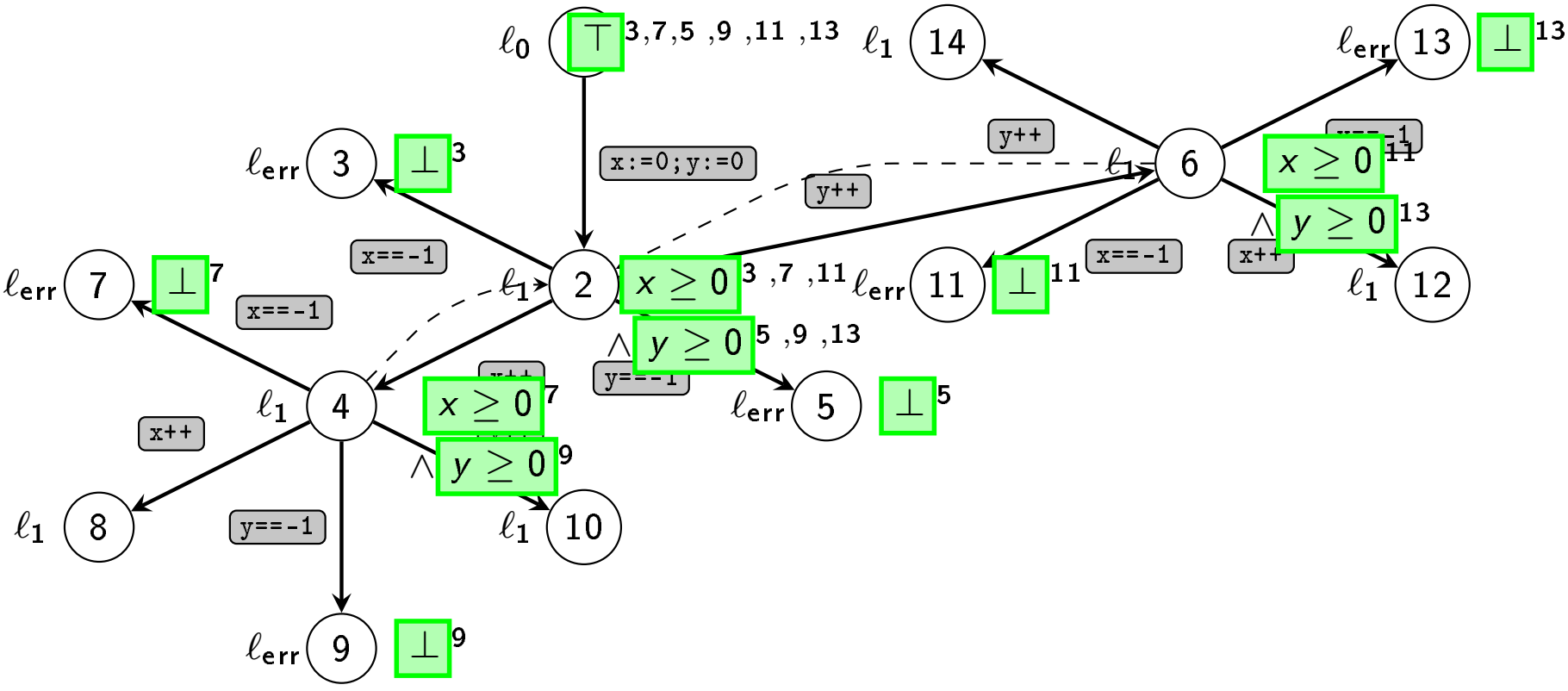
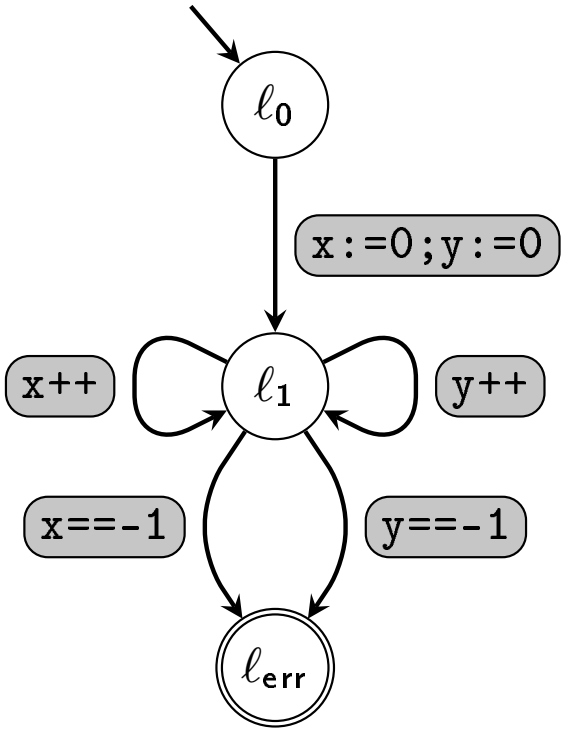


Vorstellung Trace Abstraction

A_P :



$A := A \cap \overline{A_I}$

Wiederhole bis $\mathcal{L}(A) = \emptyset$

1. Finde Error Trace π in A
2. Theorembeweiser:
   1. Falls π infeasible: liefere Interpolantensequenz
   2. Sonst: Programm unsafe
3. Konstruiere Interpolantenautomat A_I
4. $A := A \cap \overline{A_I}$

Vorstellung Trace Abstraction

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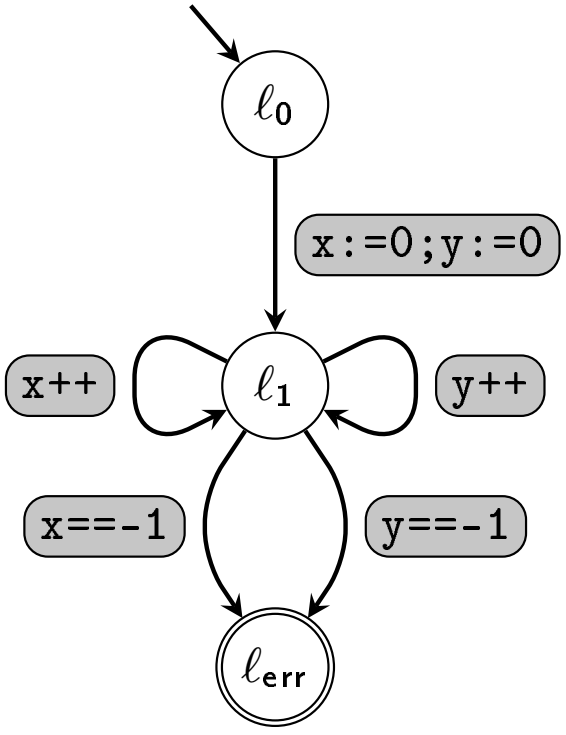

π = (x:=0;y:=0);x++;x==-1

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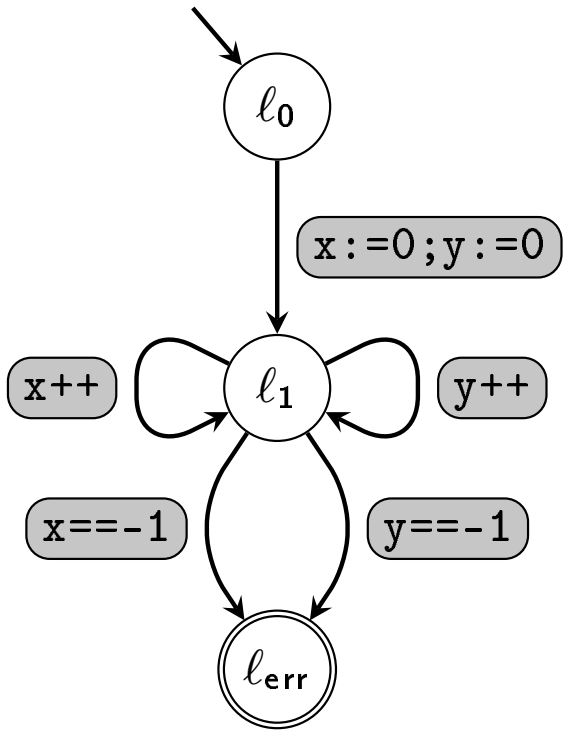

$\pi = (\texttt{x:=0;y:=0})\,;\texttt{x++};\texttt{x==-1}$

$I = \top, x \geq 0, x \geq 0, \bot$

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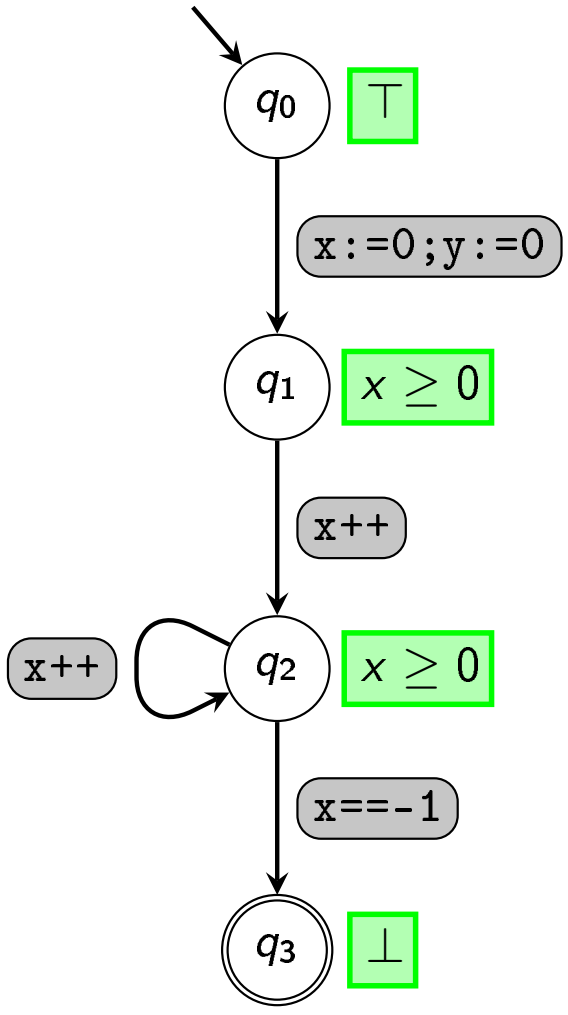
Vorstellung Trace Abstraction

A_I :



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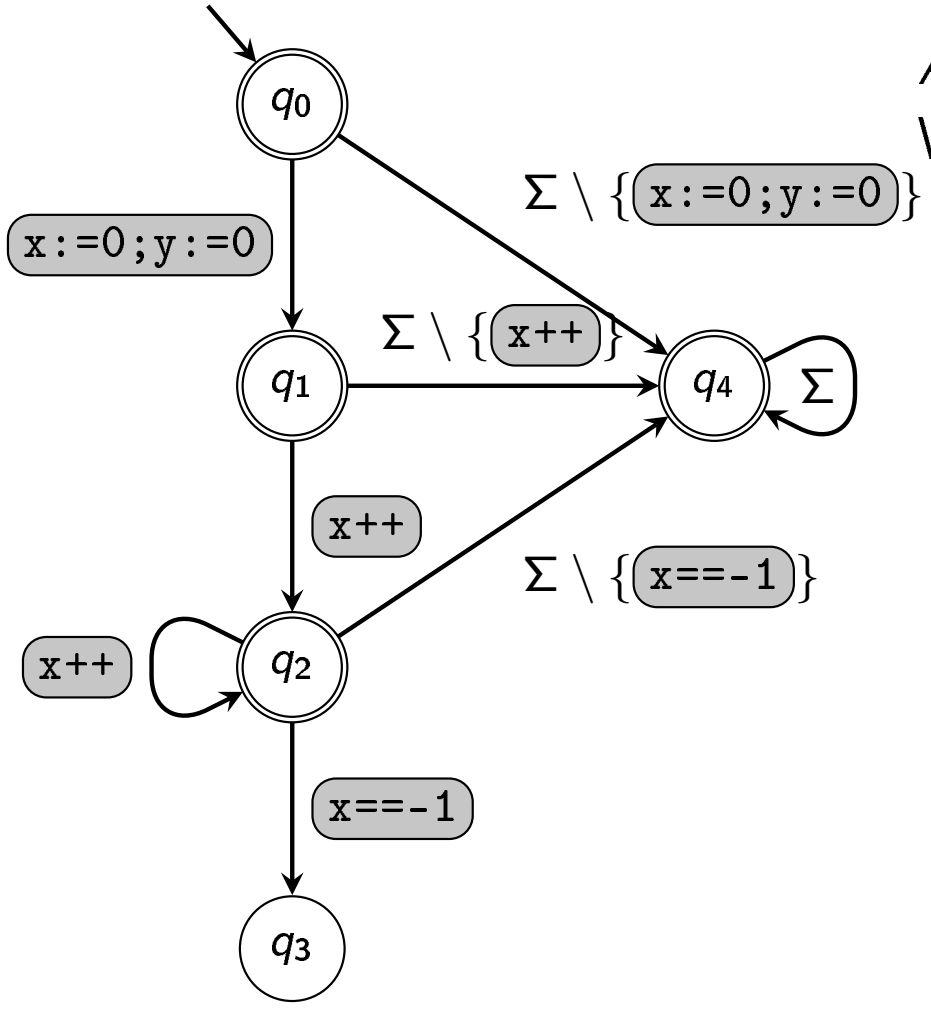
Vorstellung Trace Abstraction

$\overline{A_I}$:



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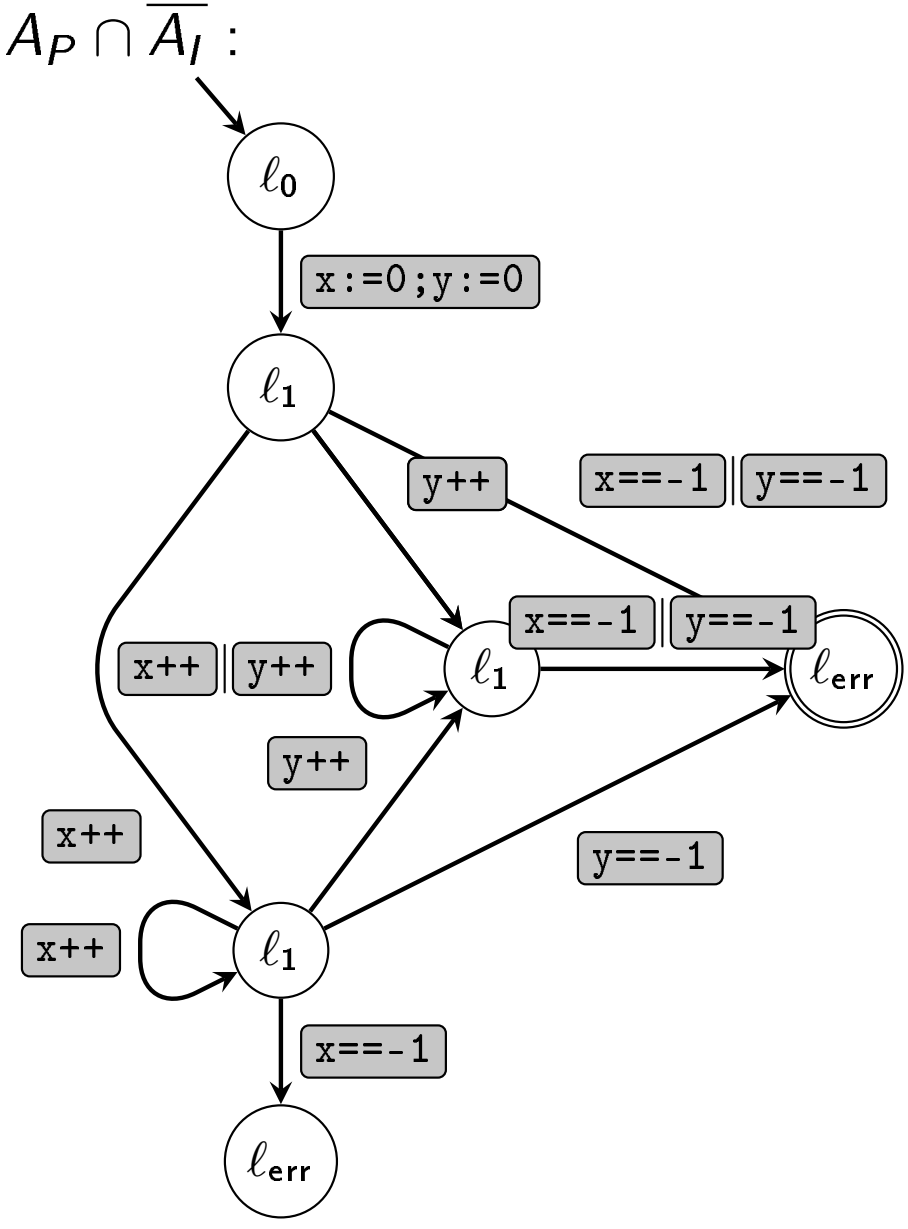
Vorstellung Trace Abstraction



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Vorstellung Trace Abstraction

Canonical Interpolant Automaton: 14 Interpolantenautomaten nötig

1 `x:=0;y:=0` `x==-1`

2 `x:=0;y:=0` `y==-1`

3+4 `x:=0;y:=0` (`x++`)$^+$ (`x==-1` | `y==-1`)

5+6 `x:=0;y:=0` (`y++`)$^+$ (`x==-1` | `y==-1`)

7+8 `x:=0;y:=0` ((`x++`)$^+$(`y++`)$^+$)$^+$ (`x==-1` | `y==-1`)

9+10 `x:=0;y:=0` ((`y++`)$^+$(`x++`)$^+$)$^+$ (`x==-1` | `y==-1`)

11+12 `x:=0;y:=0` (((`x++`)$^+$ (`y++`)$^+$)$^+$ (`x++`)$^+$)$^+$ (`x==-1` | `y==-1`)

`x:=0;y:=0` ((`x++`)$^+$ ((`y++`)$^+$ (`x++`)$^+$)$^+$)$^+$ (`x==-1` | `y==-1`)

13+14 `x:=0;y:=0` (((`y++`)$^+$ (`x++`)$^+$)$^+$ (`y++`)$^+$)$^+$ (`x==-1` | `y==-1`)

`x:=0;y:=0` ((`y++`)$^+$ ((`x++`)$^+$ (`y++`)$^+$)$^+$)$^+$ (`x==-1` | `y==-1`)

Erste Gegenüberstellung

	IMPACT	Trace Abstraction
Datenstruktur	Unwinding	DEA/NEA
Endlichkeit	covering	backedges
Terminierung	alle knoten gecovert oder mit $\perp$ markiert	$\mathcal{L}(A) = \emptyset$

Überblick

1. Gemeinsame Darstellungen: IMPACT mit Automaten, Trace Abstraction mit Unwindings
2. Vergleiche von Variationen von IMPACT mit Trace Abstraction

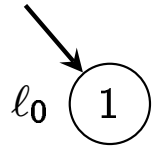
Unwindings als Automaten

Für jeden IMPACT-Iterationsschritt: Gib die aktuelle Unterapproximation der Infeasible Traces an

- Fasse Unwindings als endliche Automaten auf
- Error locations, die mit $\perp$ markiert sind werden als akzeptierend markiert
- Covering edges werden zu ϵ-Transitionen

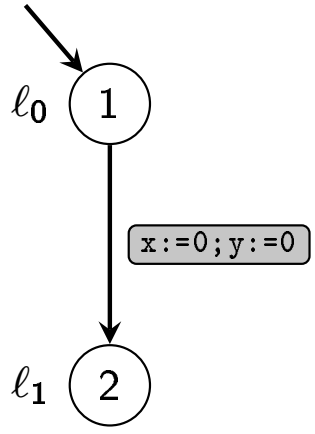
Die jeweils akzeptierte Sprache ist die aktuelle Unterapproximation.

Unwindings als Automaten



$$\mathcal{L} =$$

Unwindings als Automaten



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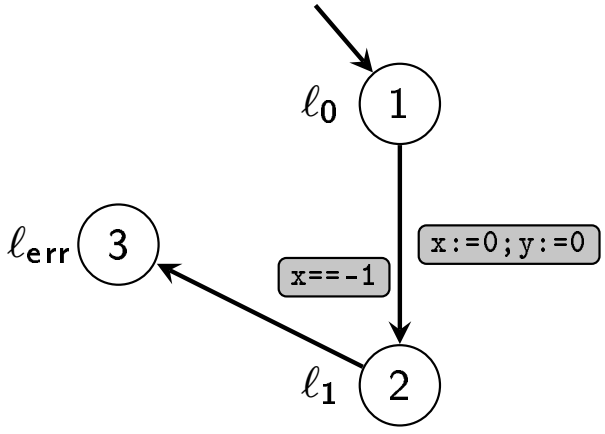

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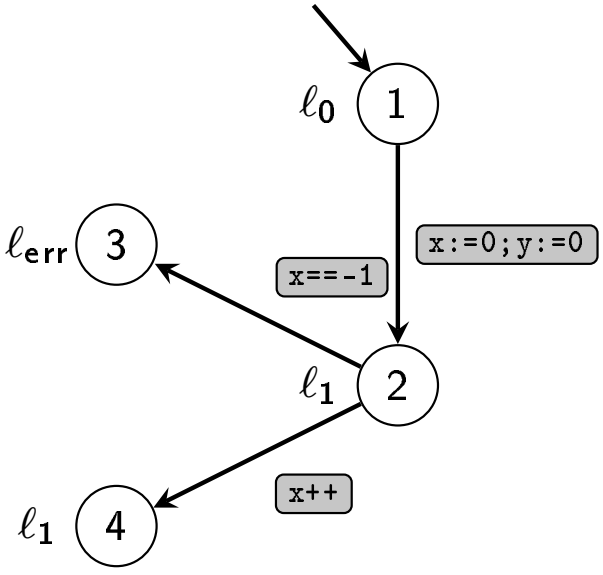

$$\mathcal{L} =$$

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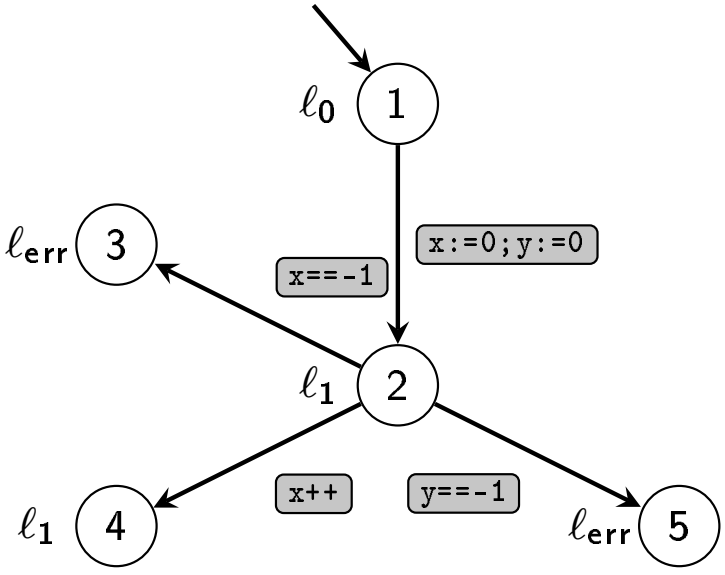

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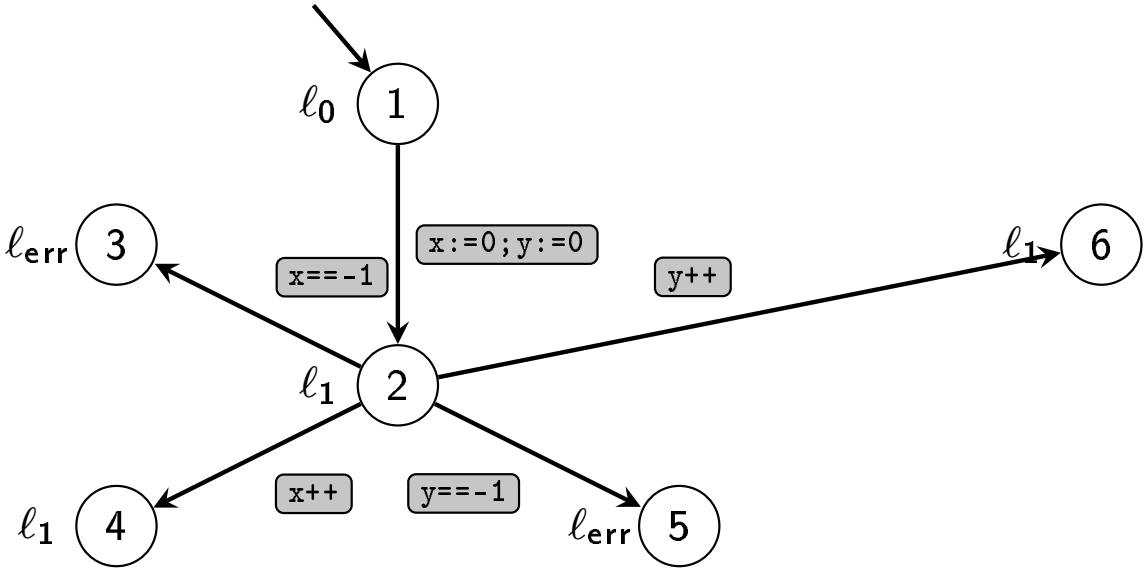

$\mathcal{L} =$

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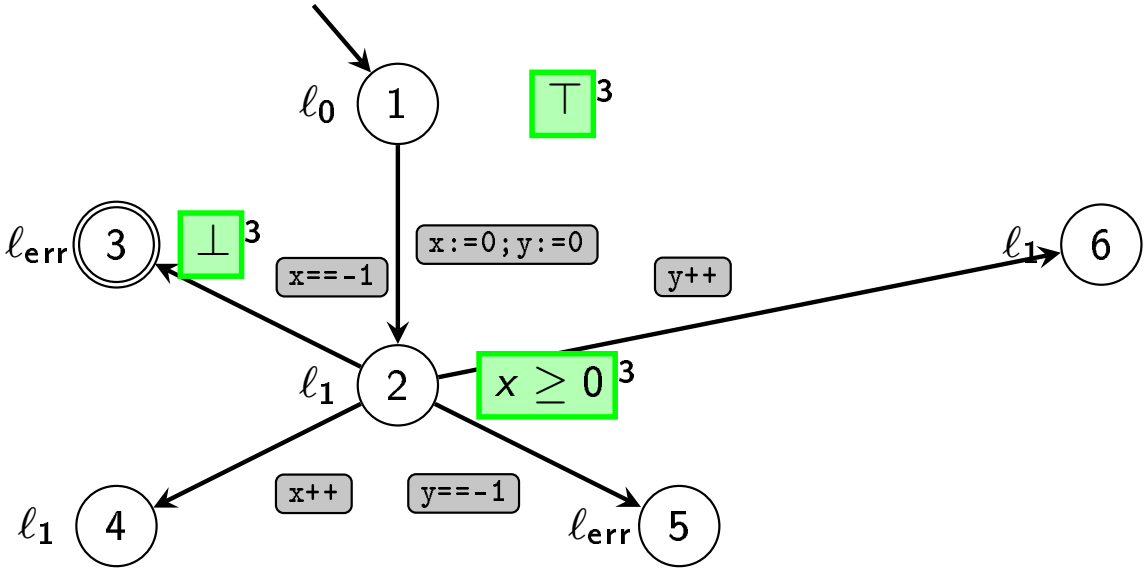
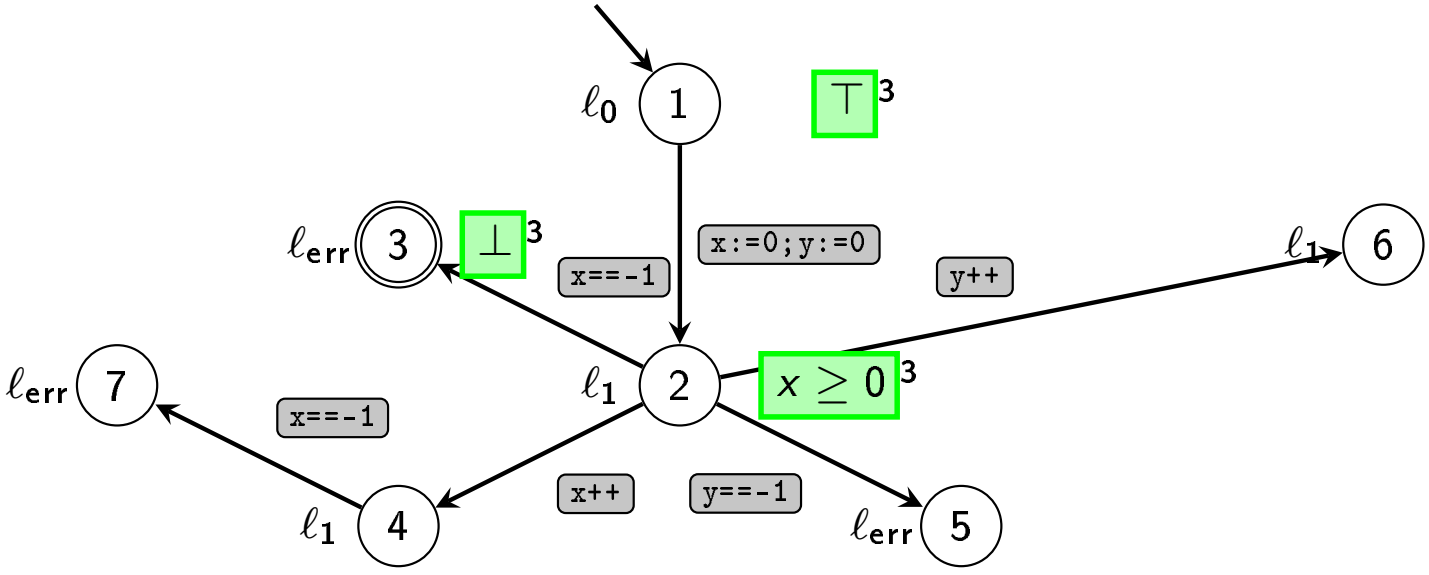


$\mathcal{L} =$

3: `x:=0;y:=0` `x==-1`

Unwindings als Automaten



$\mathcal{L} =$

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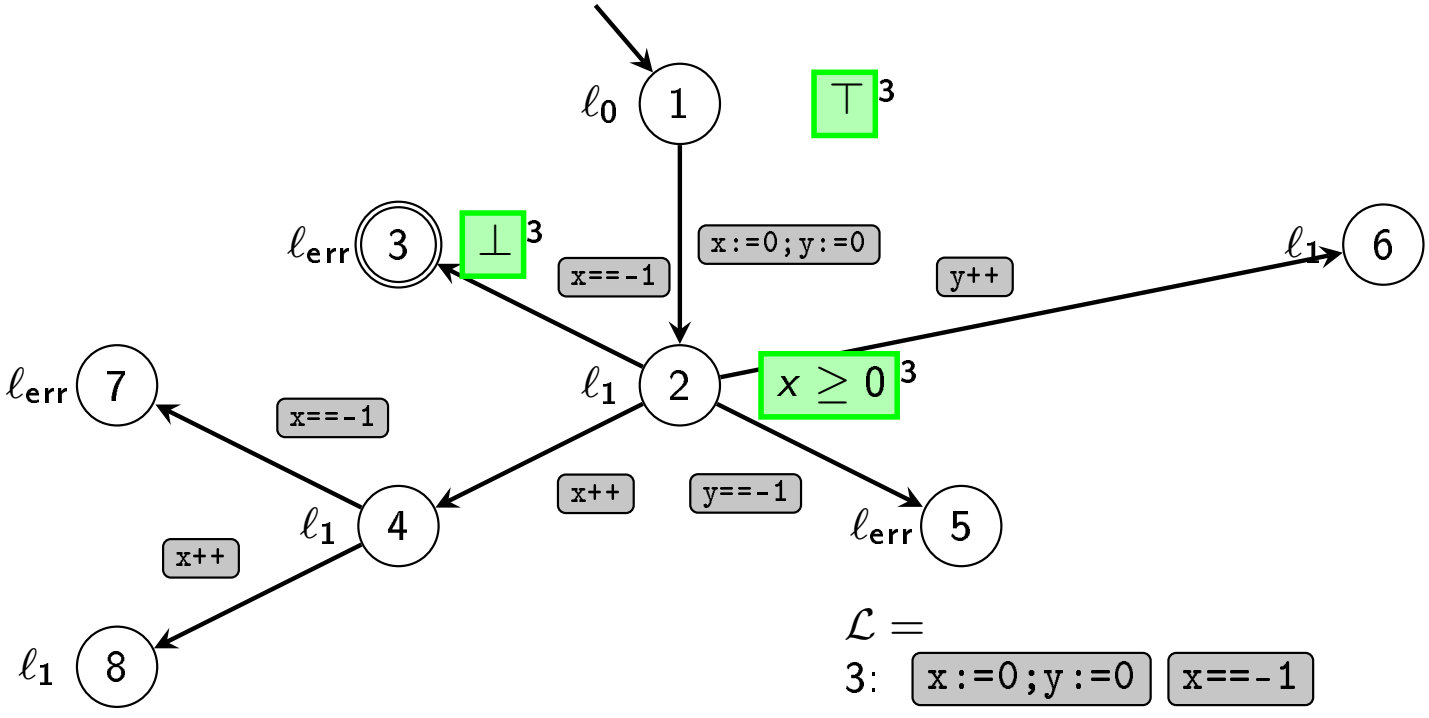

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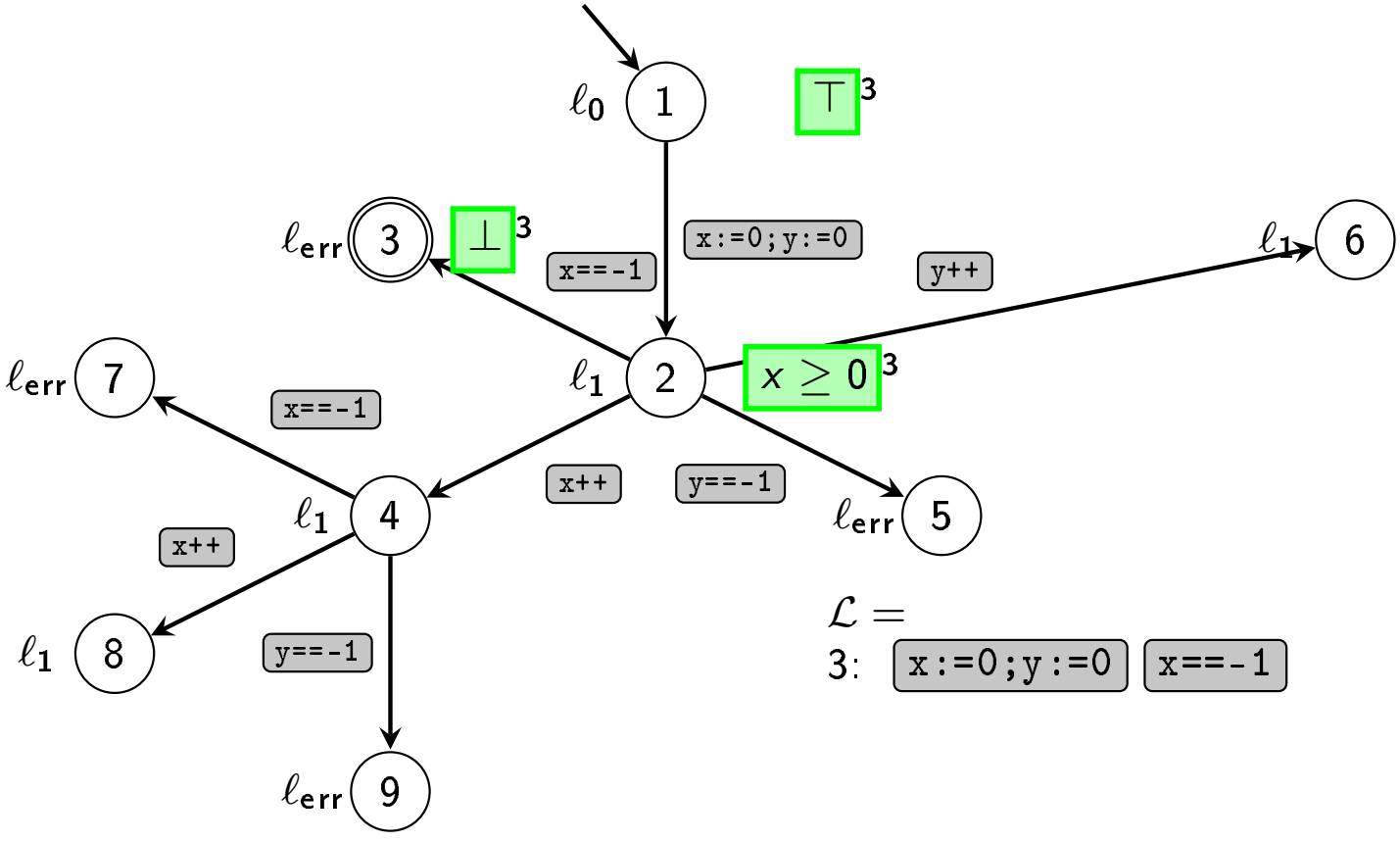

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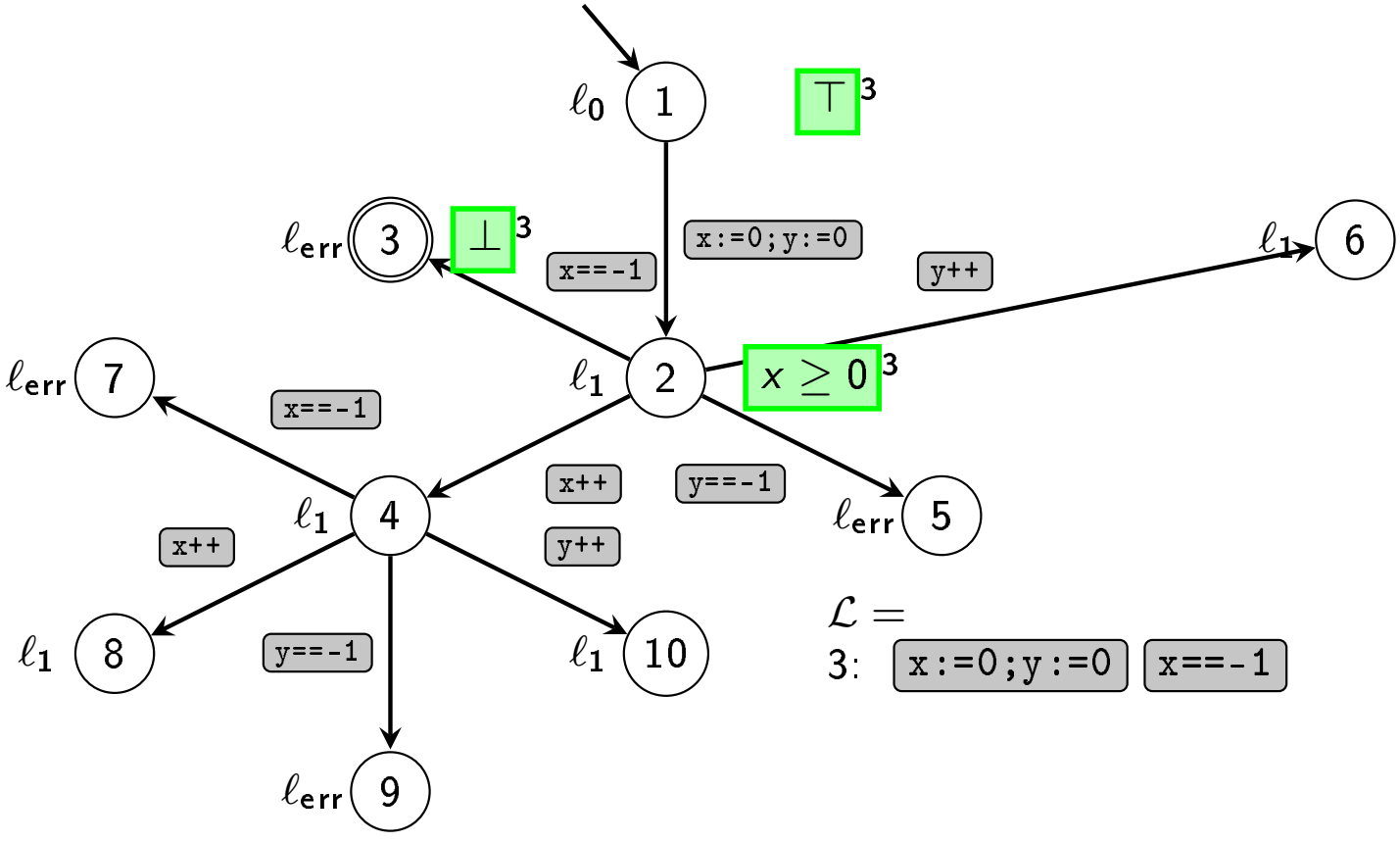

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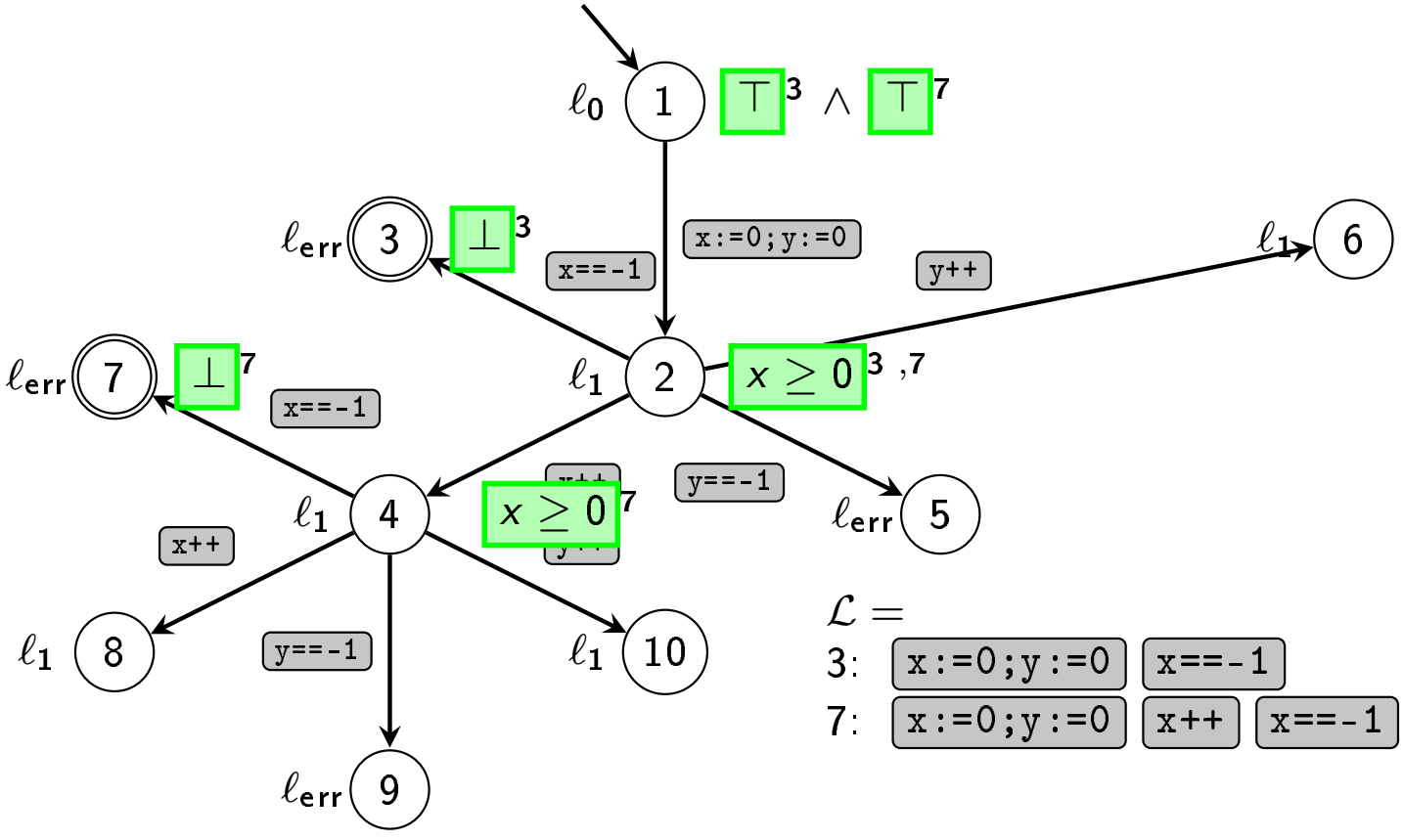

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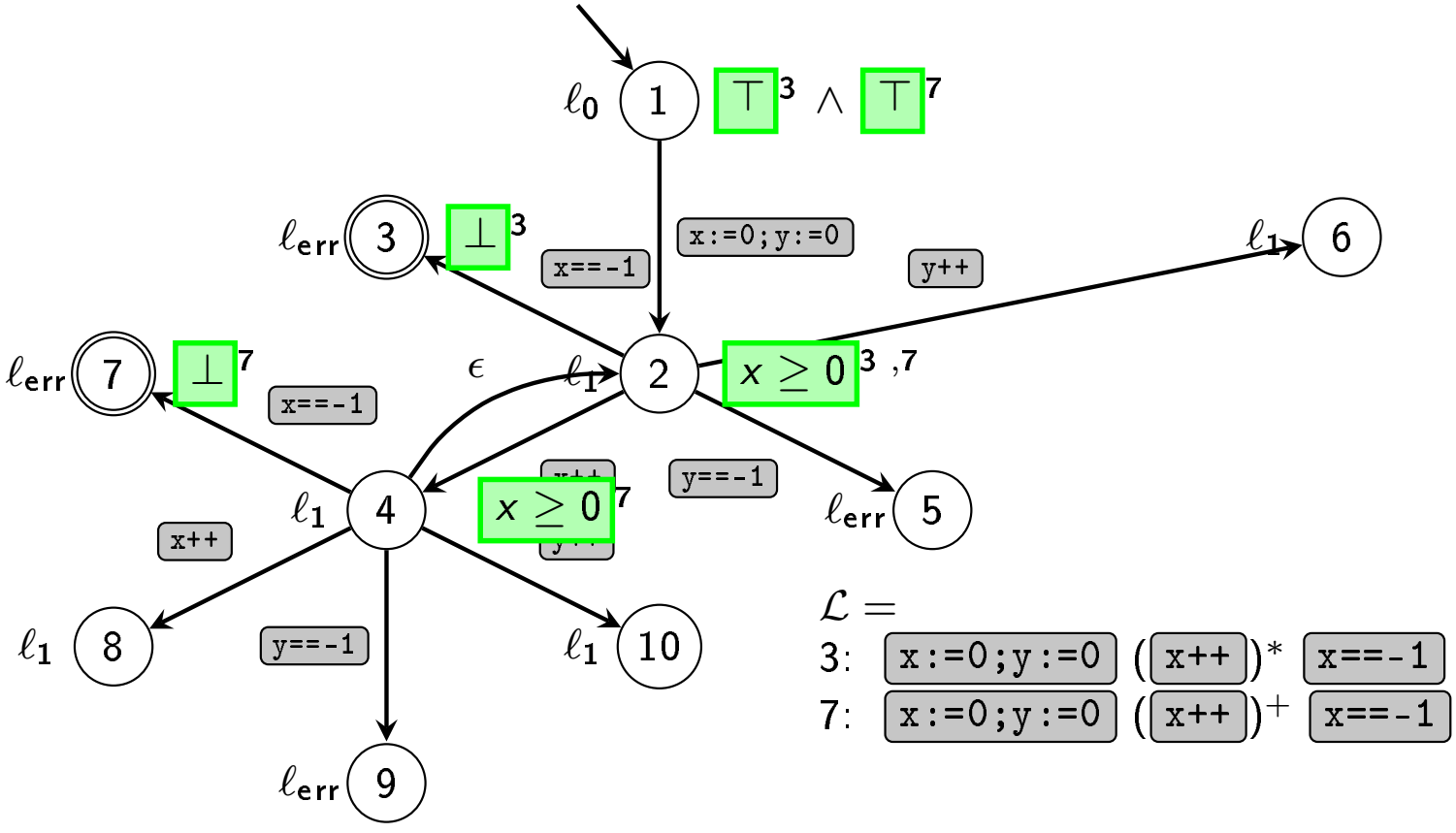

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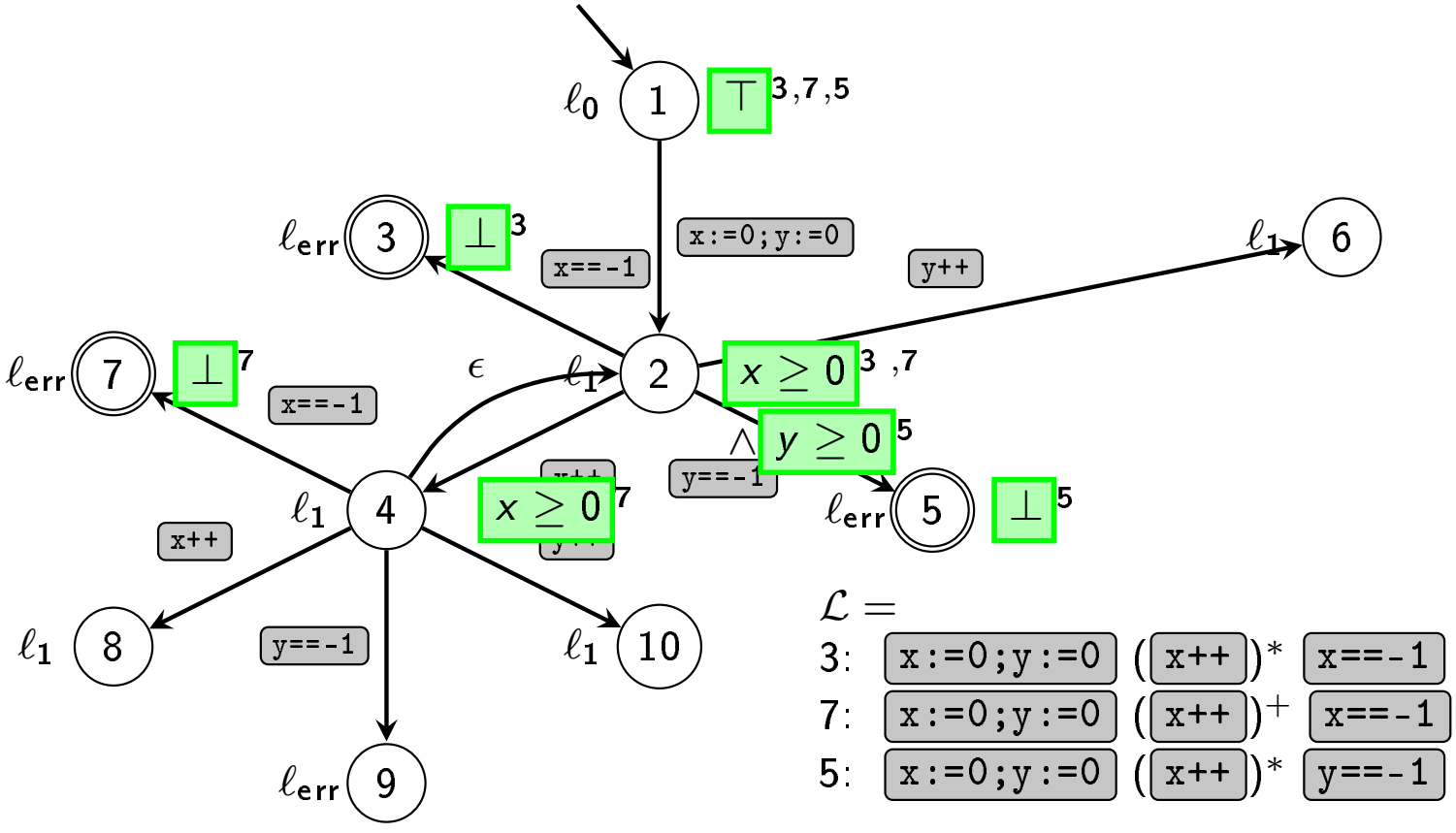
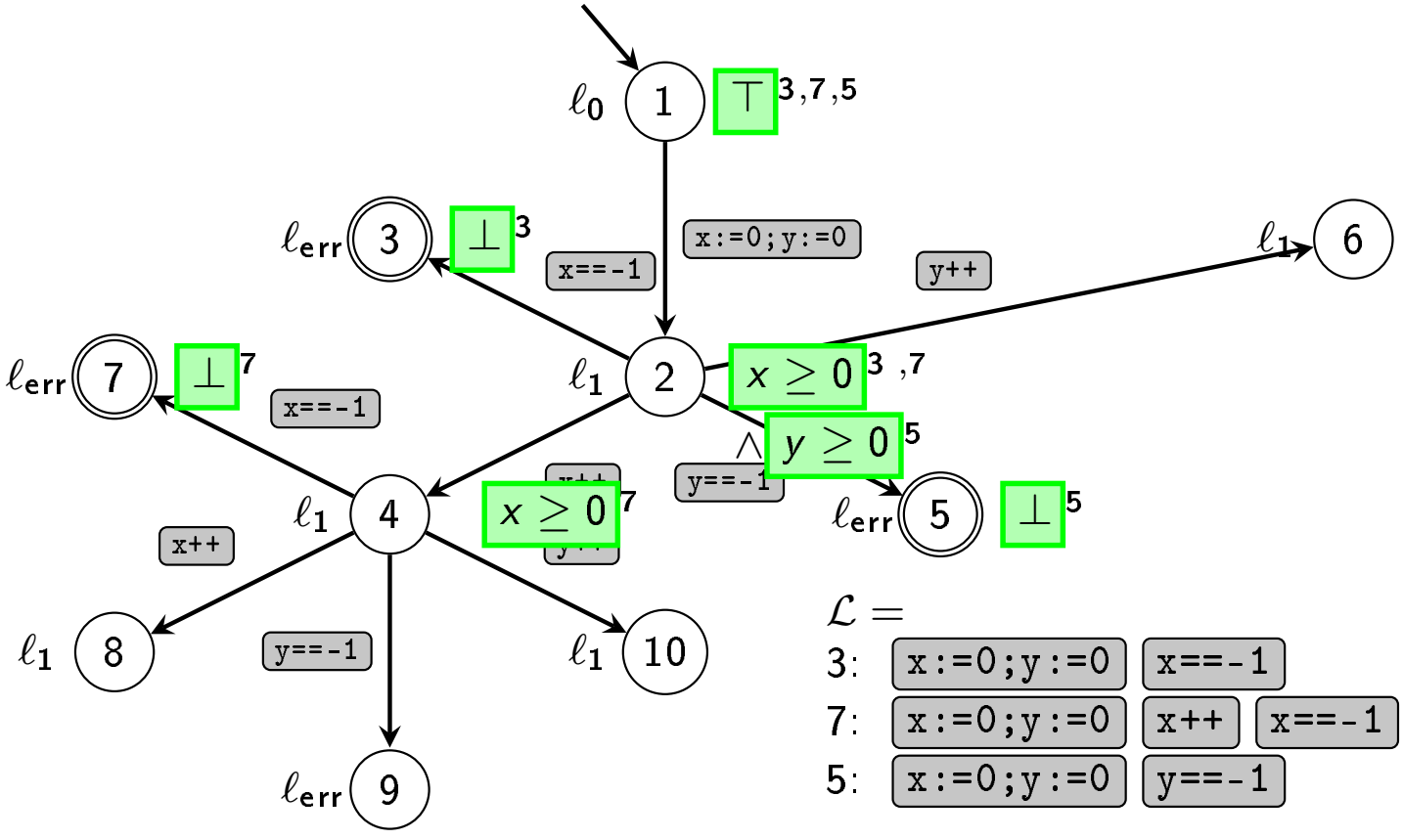
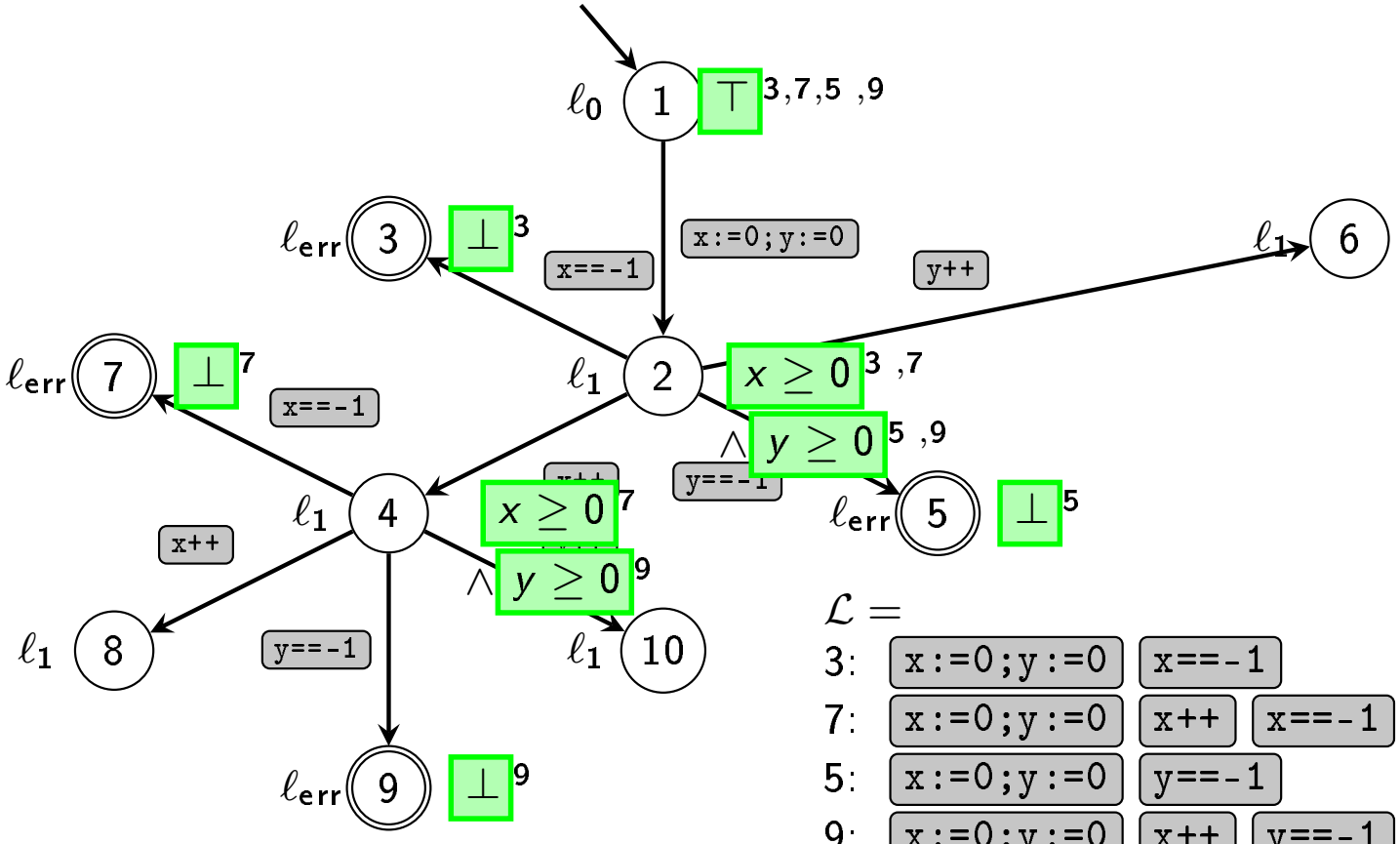


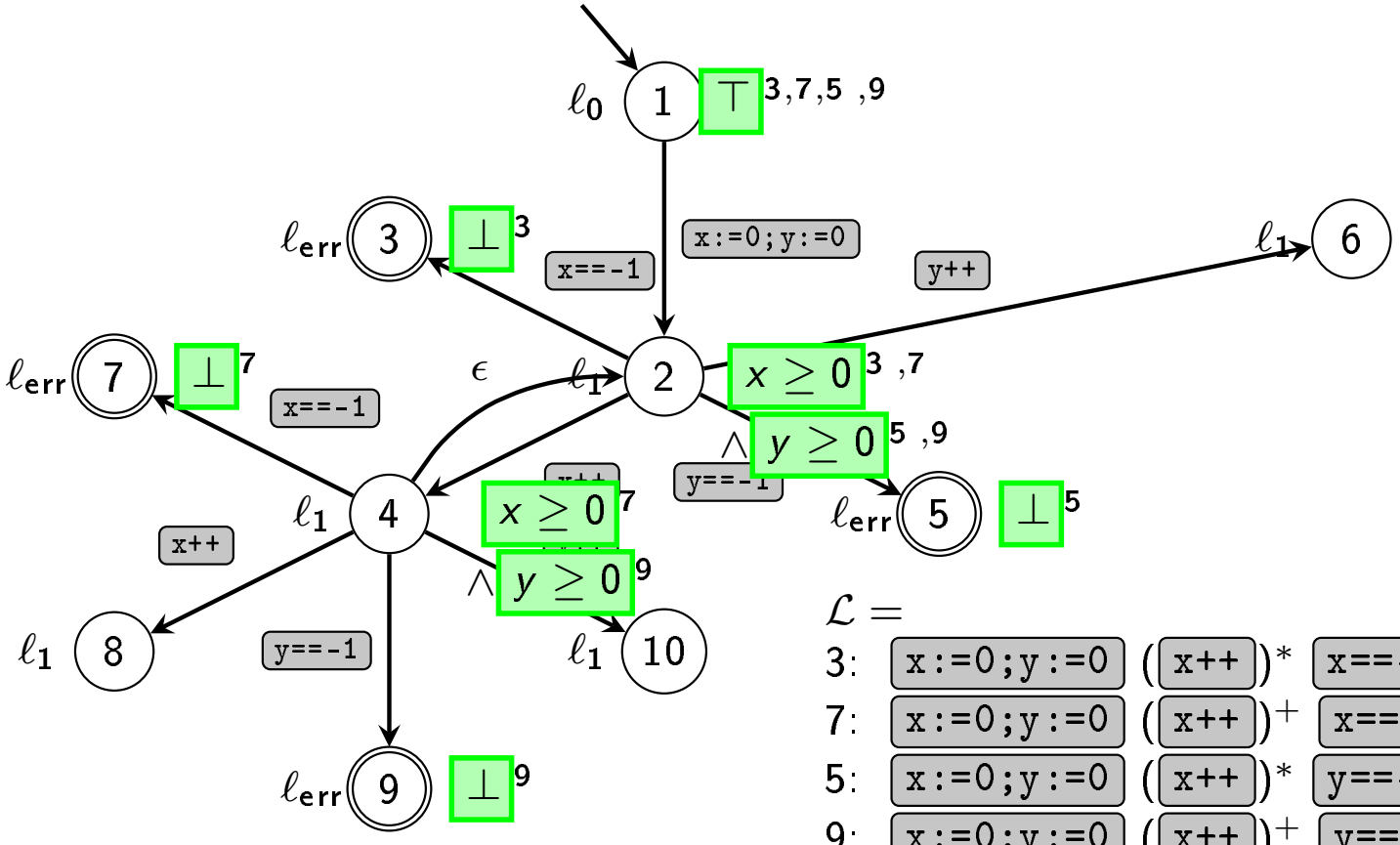
Unwindings als Automaten



Unwindings als Automaten



Unwindings als Automaten



$\mathcal{L} =$

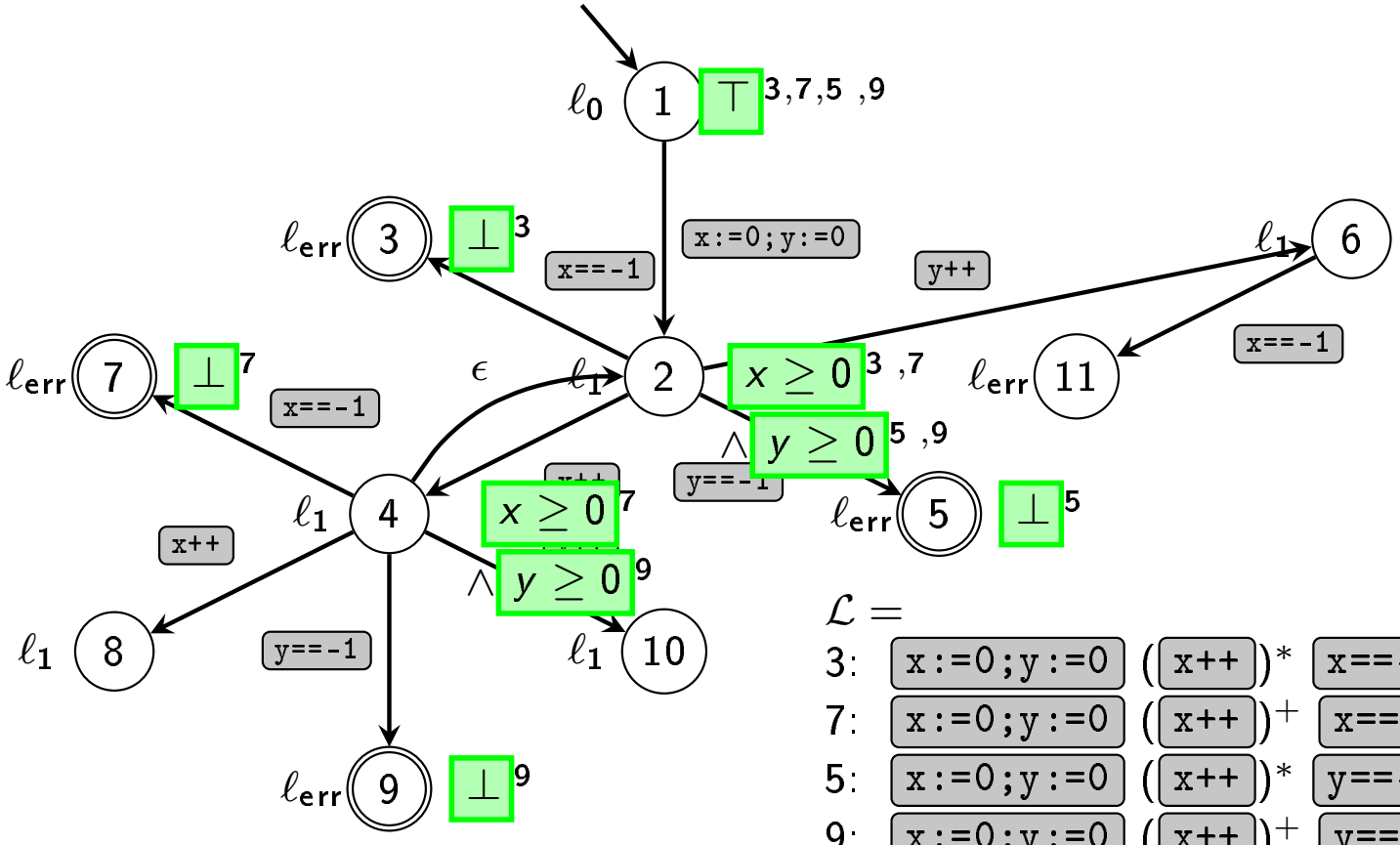
3: x:=0;y:=0 (x++)* x==-1

7: x:=0;y:=0 (x++)+ x==-1

5: x:=0;y:=0 (x++)* y==-1

9: x:=0;y:=0 (x++)+ y==-1

Unwindings als Automaten



$\mathcal{L} =$

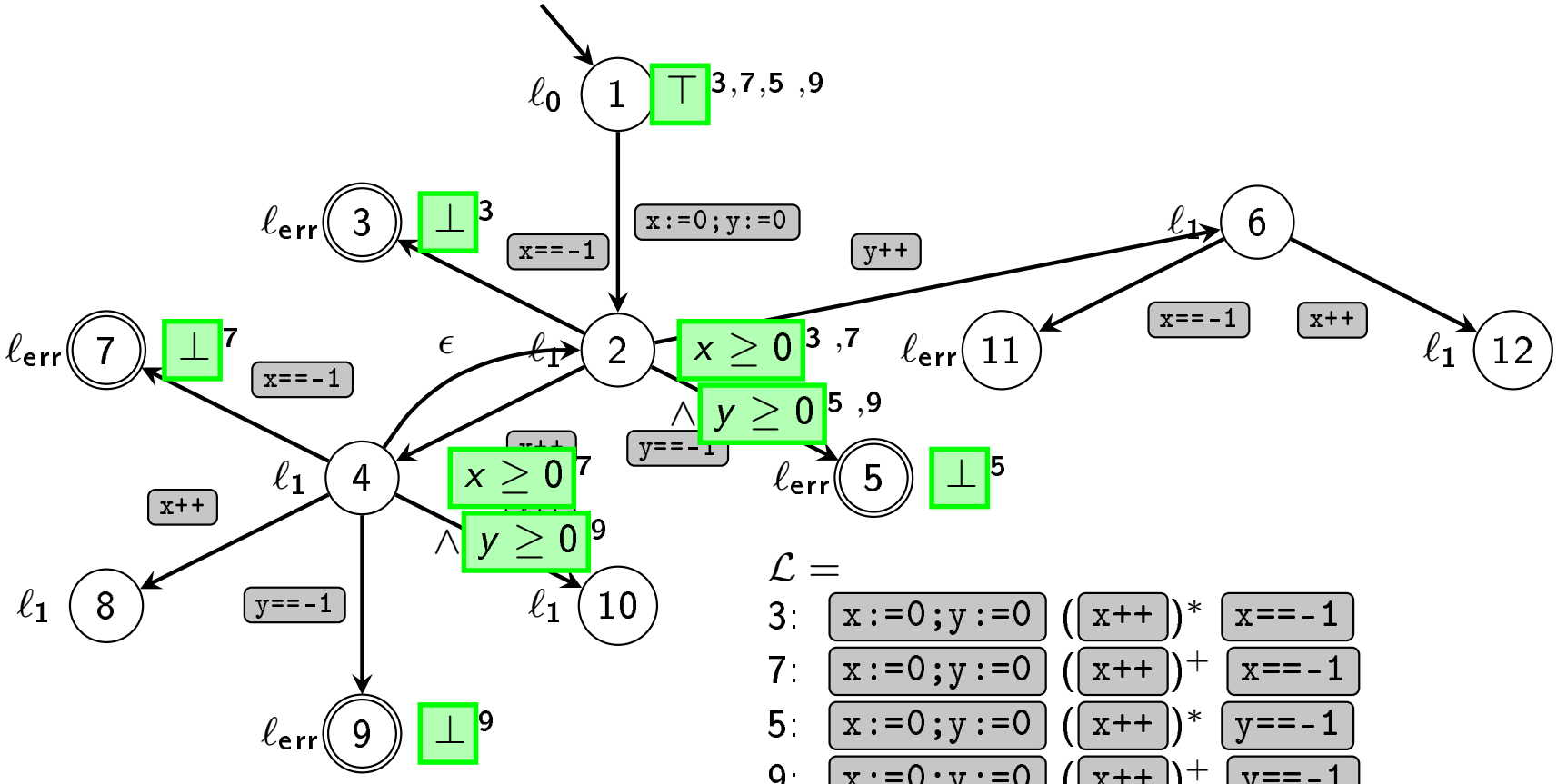
3: x:=0;y:=0 (x++)* x==-1

7: x:=0;y:=0 (x++)+ x==-1

5: x:=0;y:=0 (x++)* y==-1

9: x:=0;y:=0 (x++)+ y==-1

Unwindings als Automaten



$\mathcal{L} =$

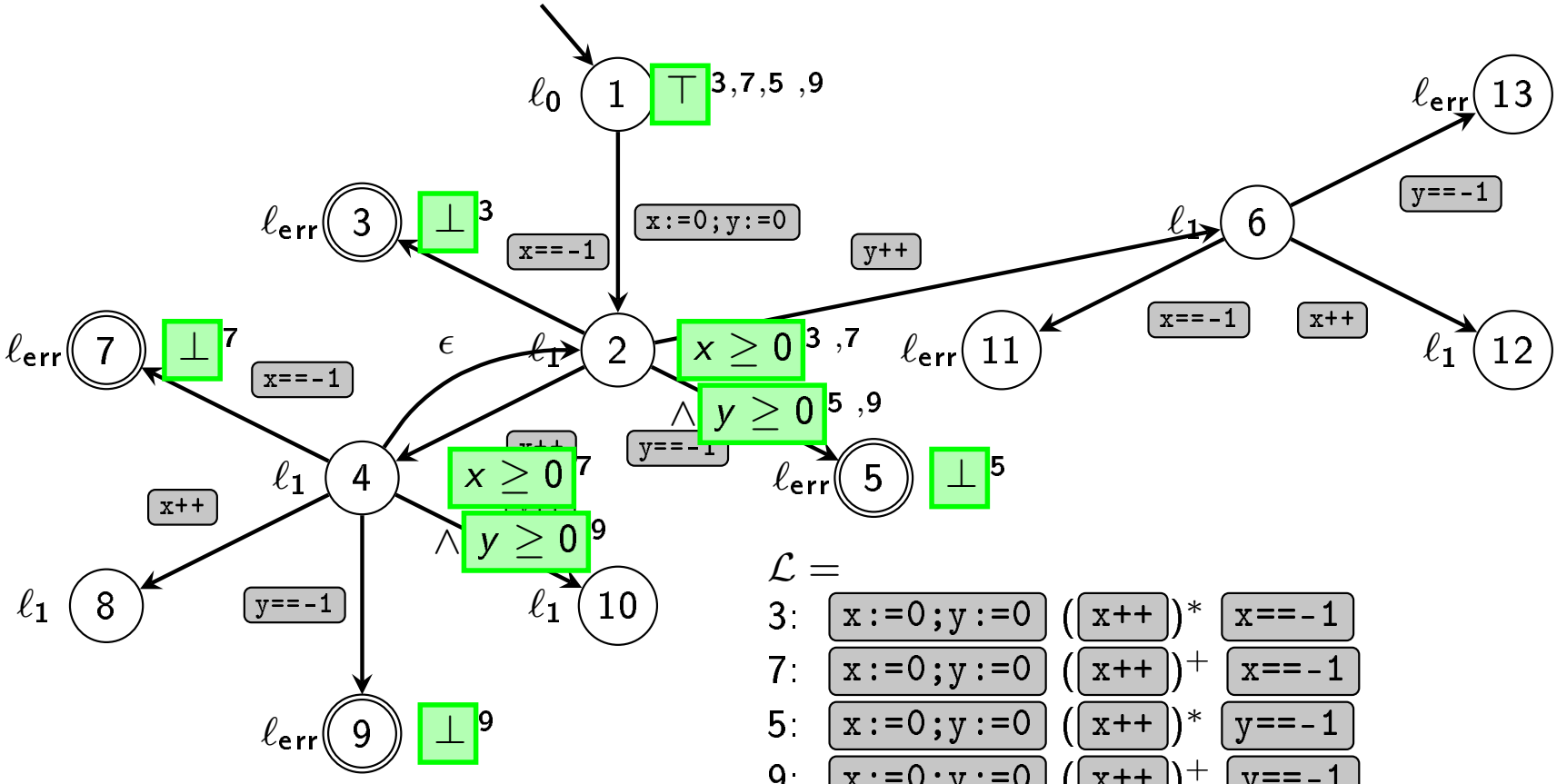
3: x:=0;y:=0 (x++)* x==-1

7: x:=0;y:=0 (x++)+ x==-1

5: x:=0;y:=0 (x++)* y==-1

9: x:=0;y:=0 (x++)+ y==-1

Unwindings als Automaten



$\mathcal{L} =$

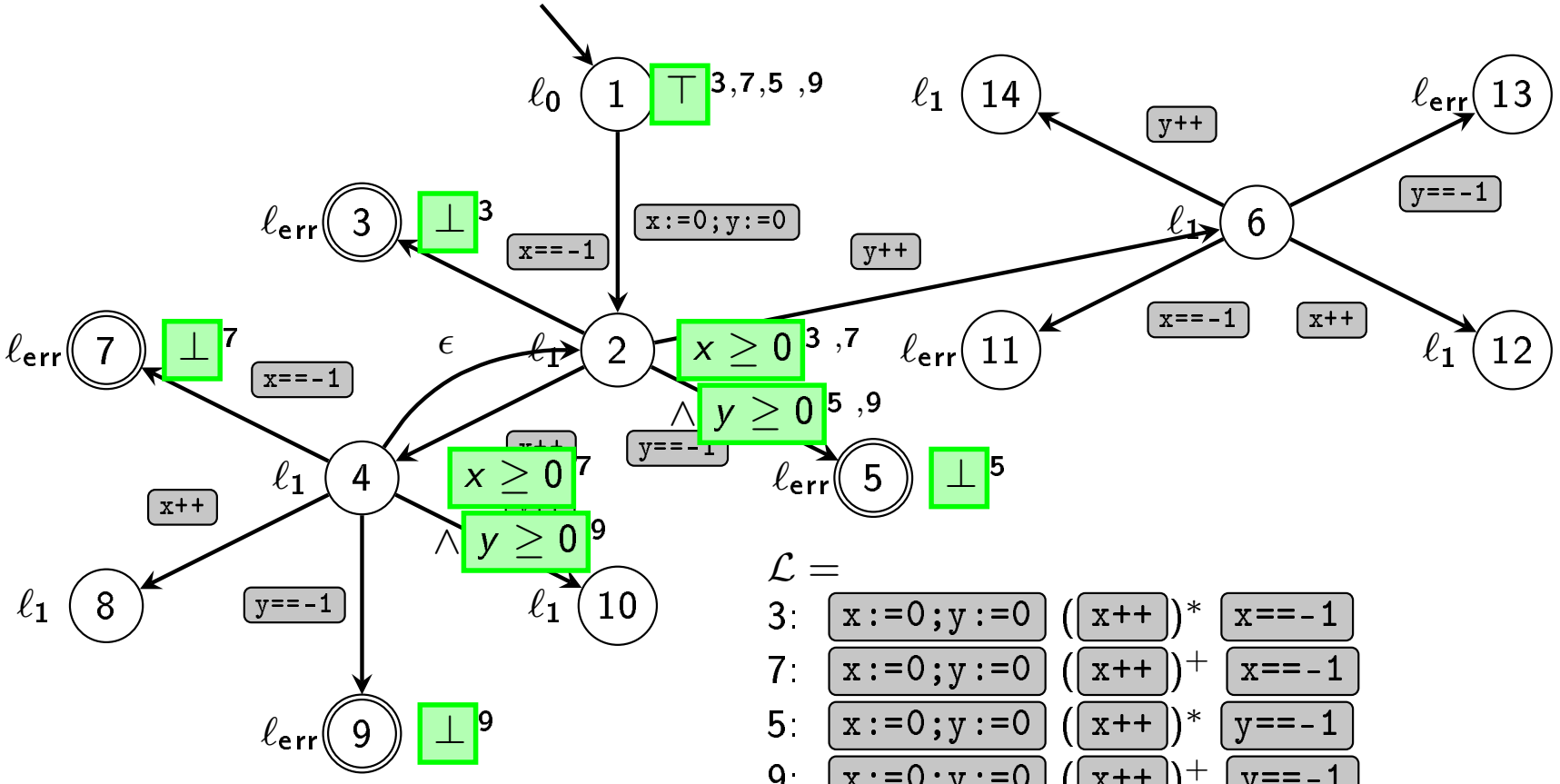
3: `x:=0;y:=0` (`x++`)* `x==-1`

7: `x:=0;y:=0` (`x++`)+ `x==-1`

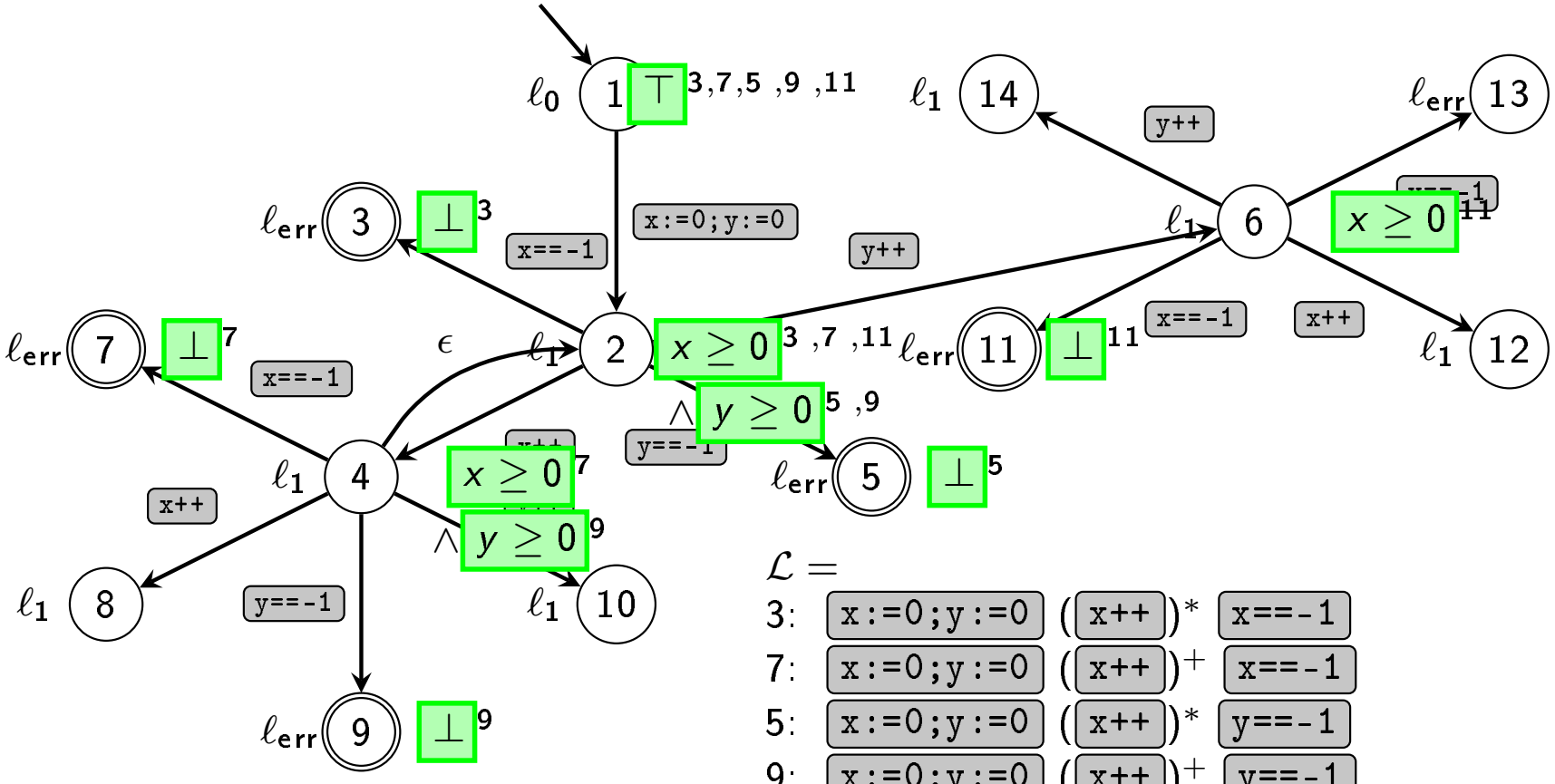
5: `x:=0;y:=0` (`x++`)* `y==-1`

9: `x:=0;y:=0` (`x++`)+ `y==-1`

Unwindings als Automaten



Unwindings als Automaten



$\mathcal{L} =$

3: x:=0;y:=0 (x++)* x==-1

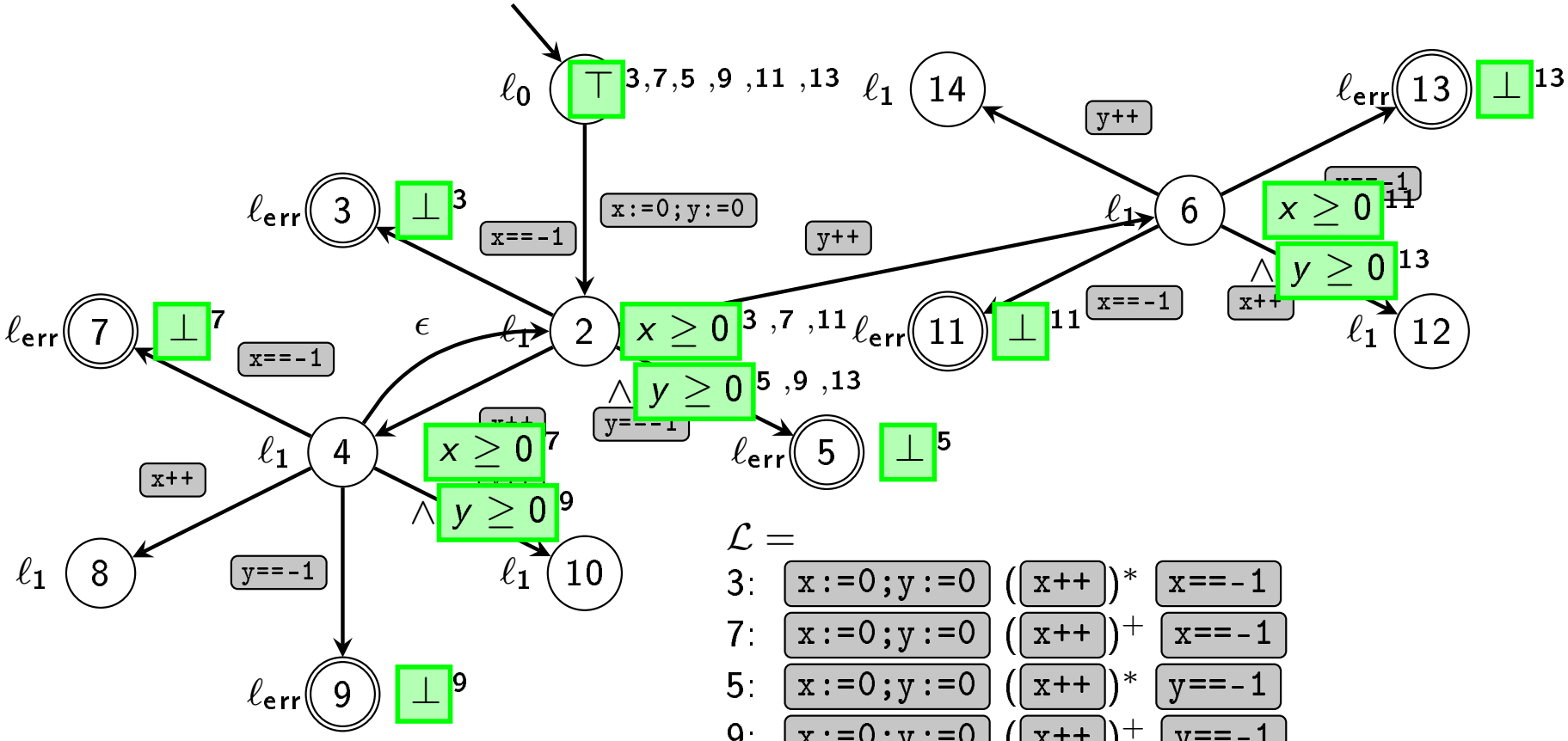
7: x:=0;y:=0 (x++)+ x==-1

5: x:=0;y:=0 (x++)* y==-1

9: x:=0;y:=0 (x++)+ y==-1

11: x:=0;y:=0 (x++)* y++ x==-1

Unwindings als Automaten



$\mathcal{L} =$

3: x:=0;y:=0 (x++)* x==-1

7: x:=0;y:=0 (x++)+ x==-1

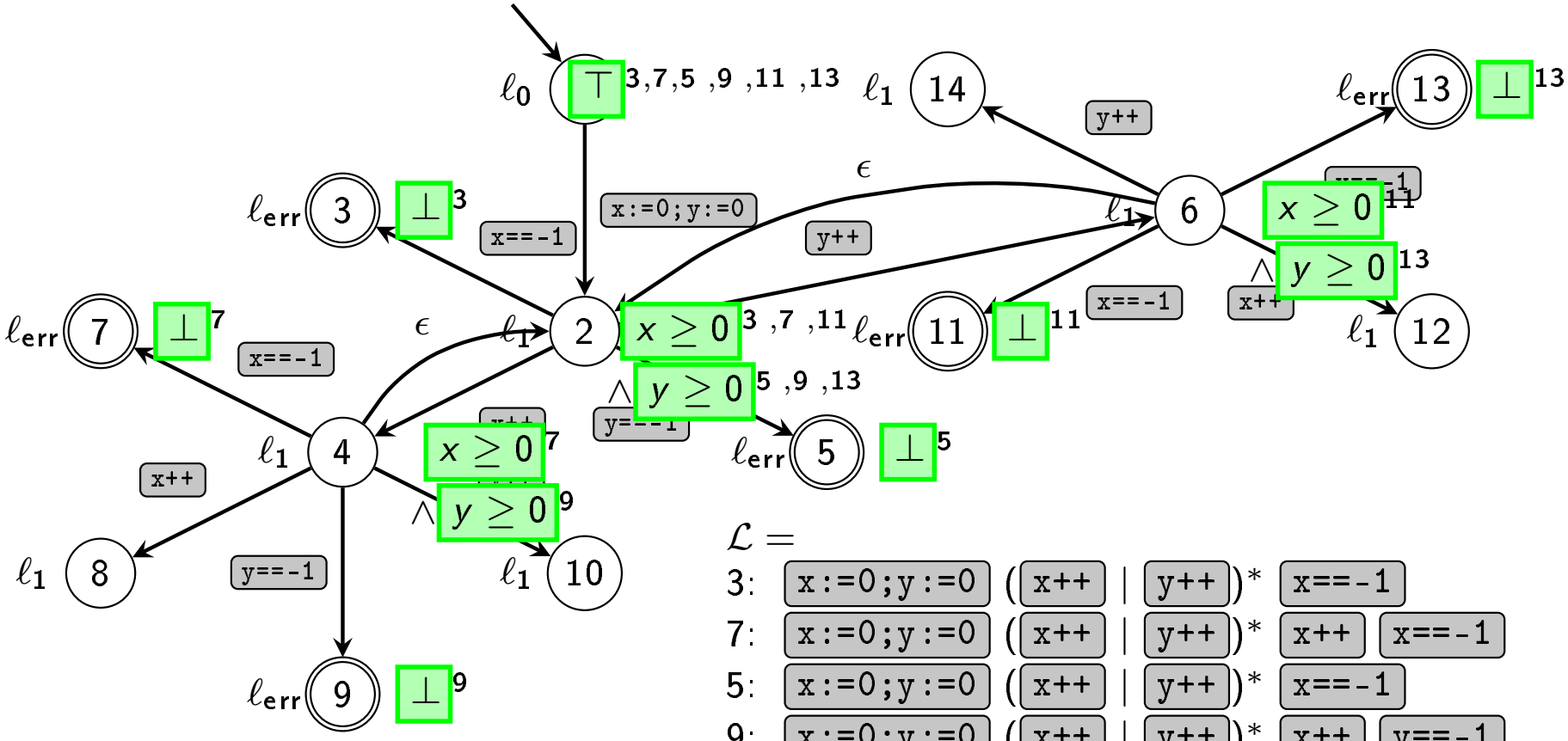
5: x:=0;y:=0 (x++)* y==-1

9: x:=0;y:=0 (x++)+ y==-1

11: x:=0;y:=0 (x++)* y++ x==-1

13: x:=0;y:=0 (x++)* y++ y==-1

Unwindings als Automaten



$\mathcal{L} =$

3: x:=0;y:=0 (x++ | y++)* x==-1

7: x:=0;y:=0 (x++ | y++)* x++ x==-1

5: x:=0;y:=0 (x++ | y++)* x==-1

9: x:=0;y:=0 (x++ | y++)* x++ y==-1

11: x:=0;y:=0 (x++ | y++)* y++ x==-1

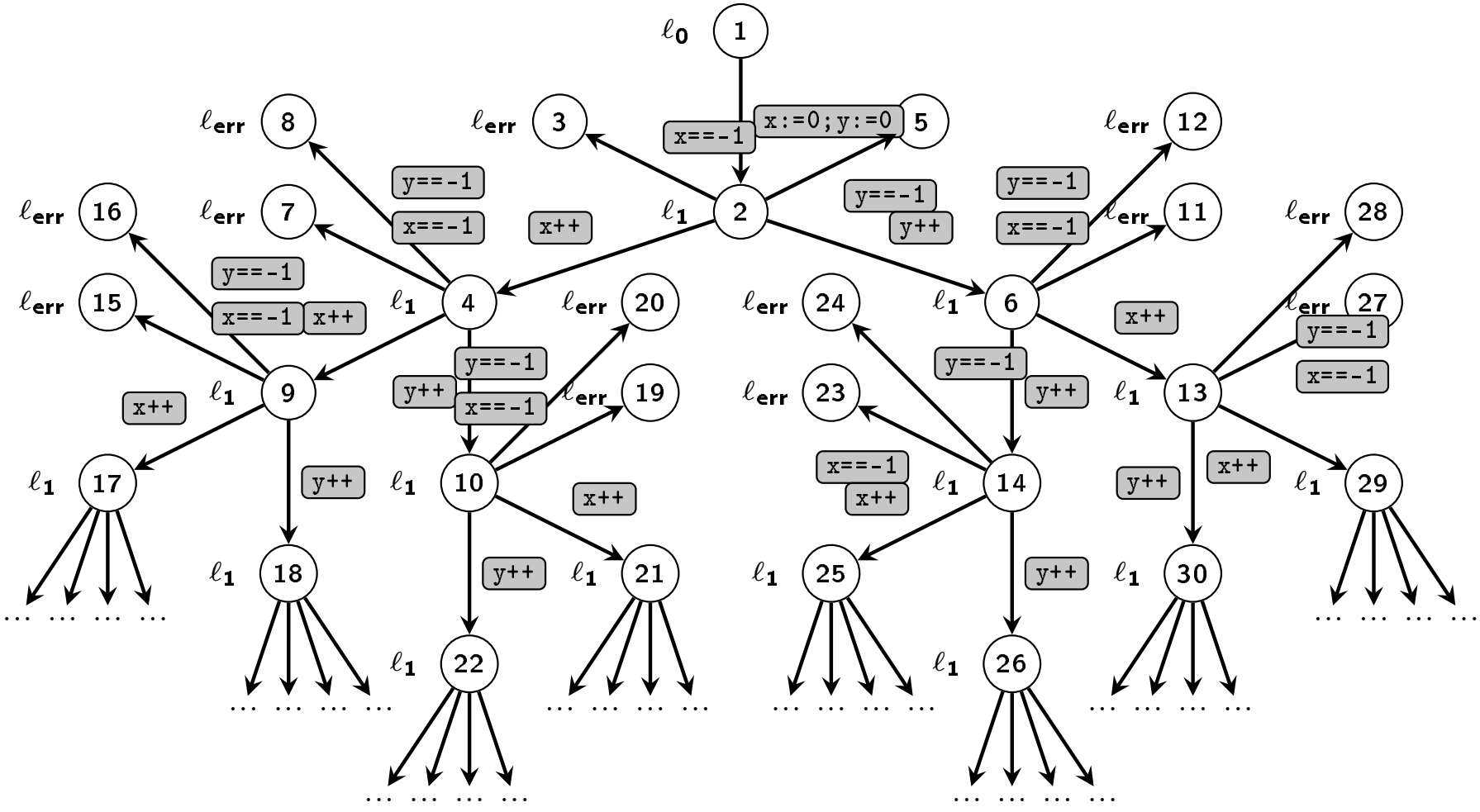
13: x:=0;y:=0 (x++ | y++)* y++ y==-1

Trace Abstraction auf Unwindings

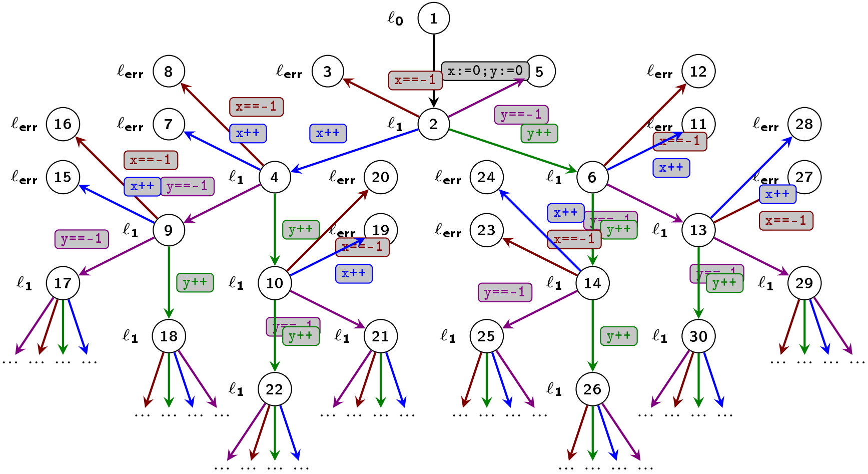
Die Unwindings von IMPACT entsprechen teilweisen Abwicklungen des Kontrollflussgraphen.

- Stelle den Kontrollflussgraphen als Unwinding dar.
- Streiche für jeden Iterationsschritt der Trace abstraction die Error locations, die als infeasible erkannt wurden.

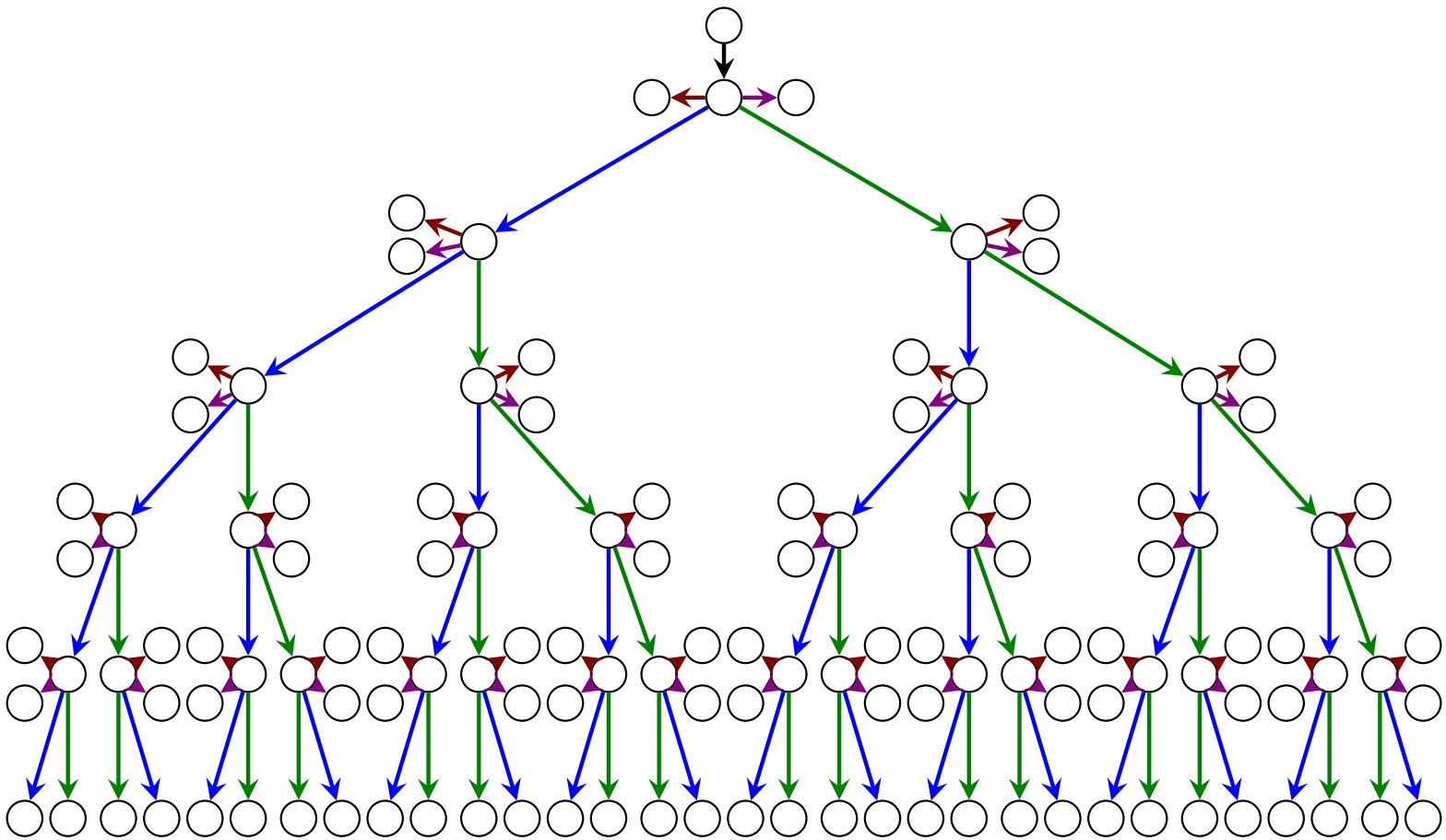
Trace Abstraction auf Unwindings



Trace Abstraction auf Unwindings

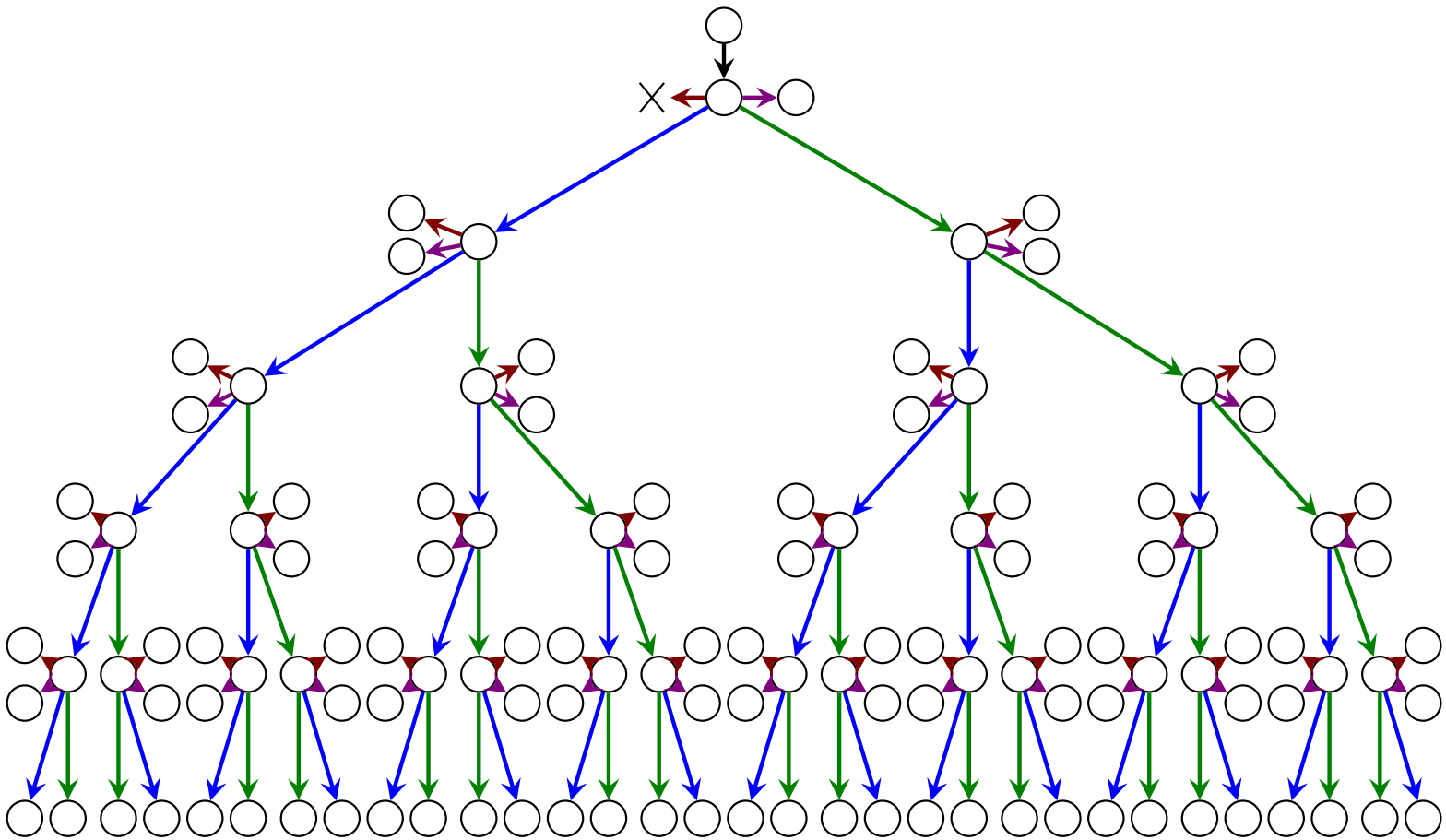


$\cup \mathcal{L}(A_I) =$
$\emptyset$



$\cup \mathcal{L}(A_I) =$

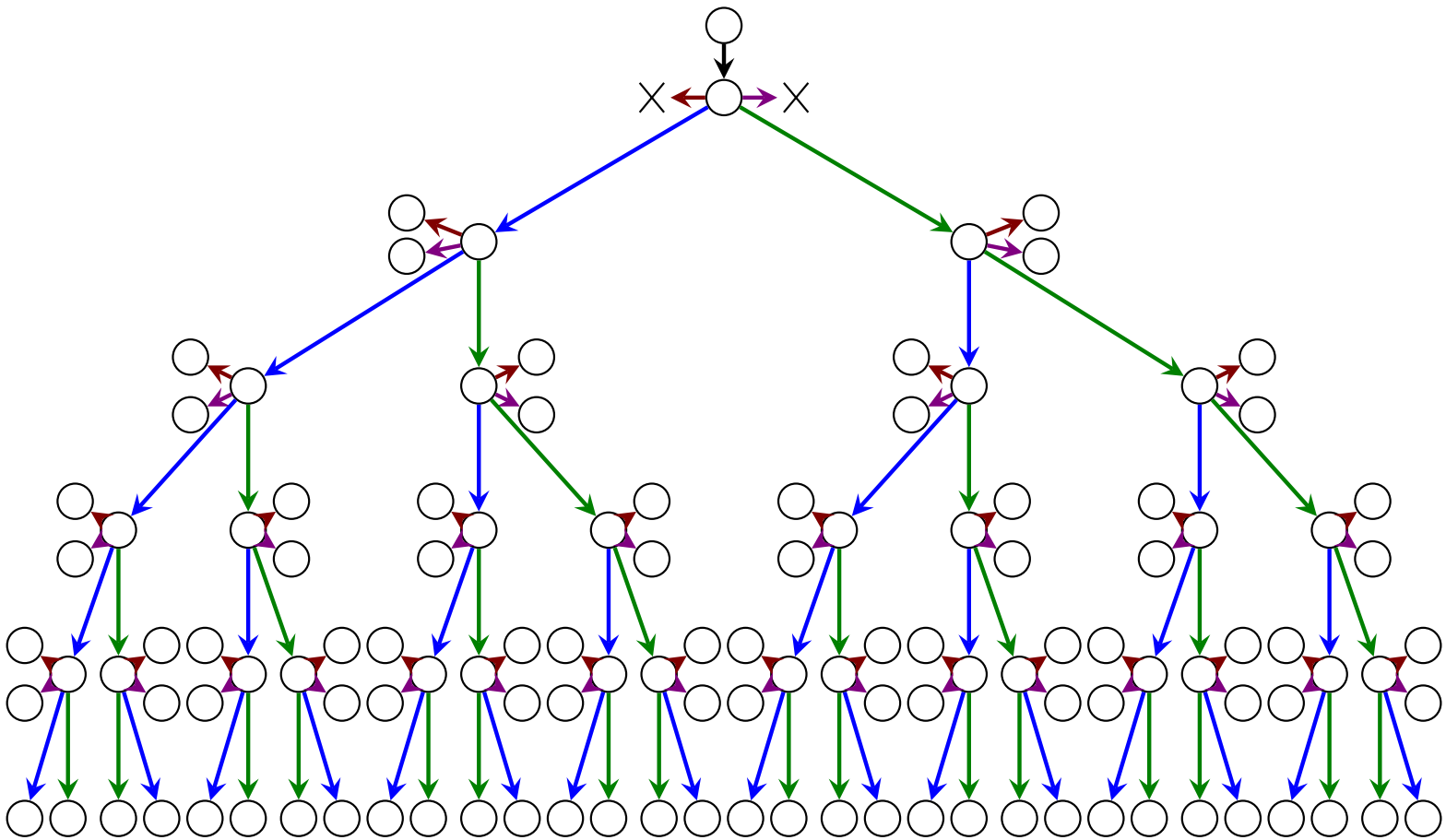
1: init x==-1



$\cup\mathcal{L}(A_I) =$

1: init x==-1

2: init y==-1

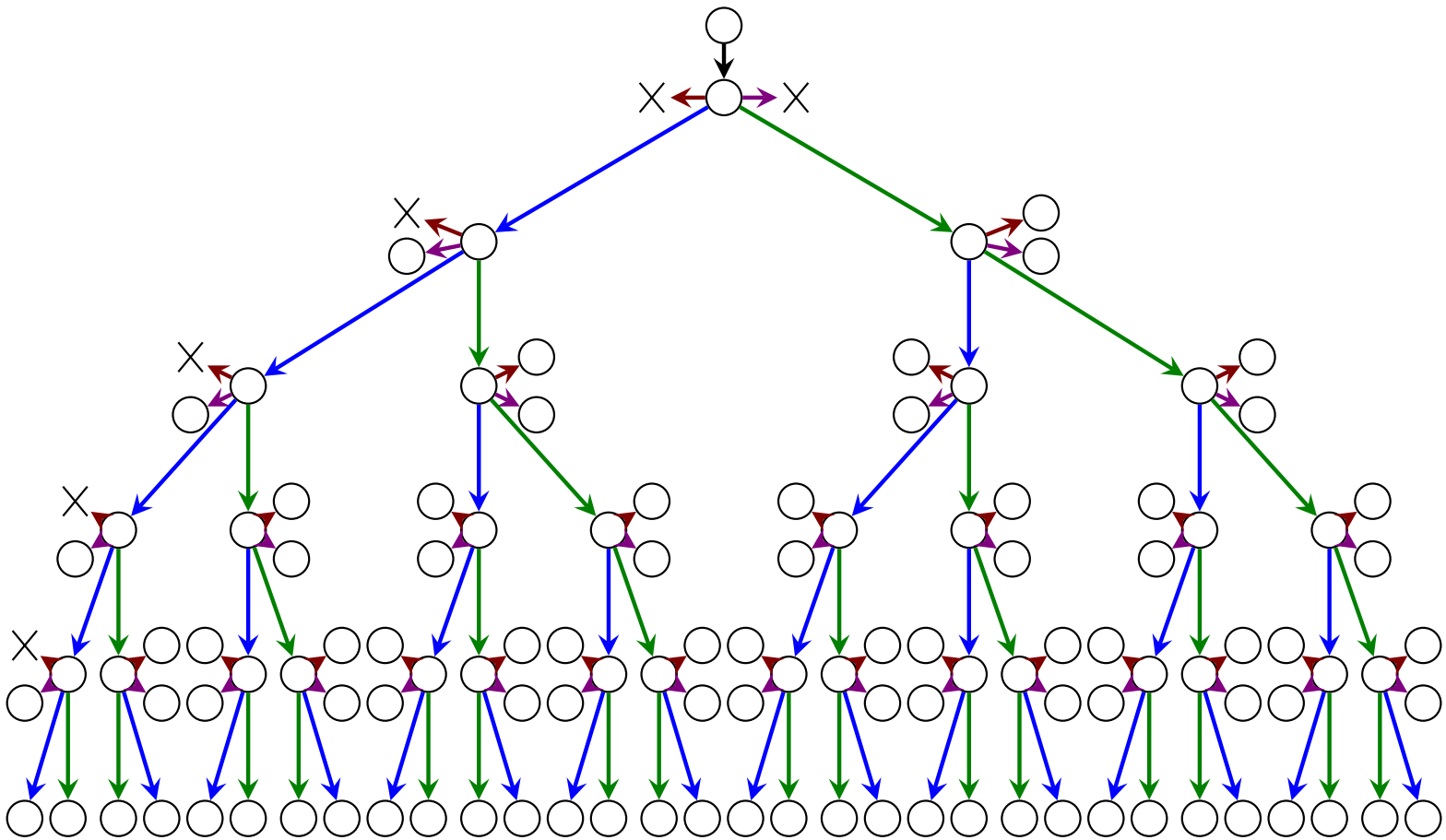


$\cup \mathcal{L}(A_I) =$

1: init x==-1

2: init y==-1

3: init (x++)$^+$ x==-1



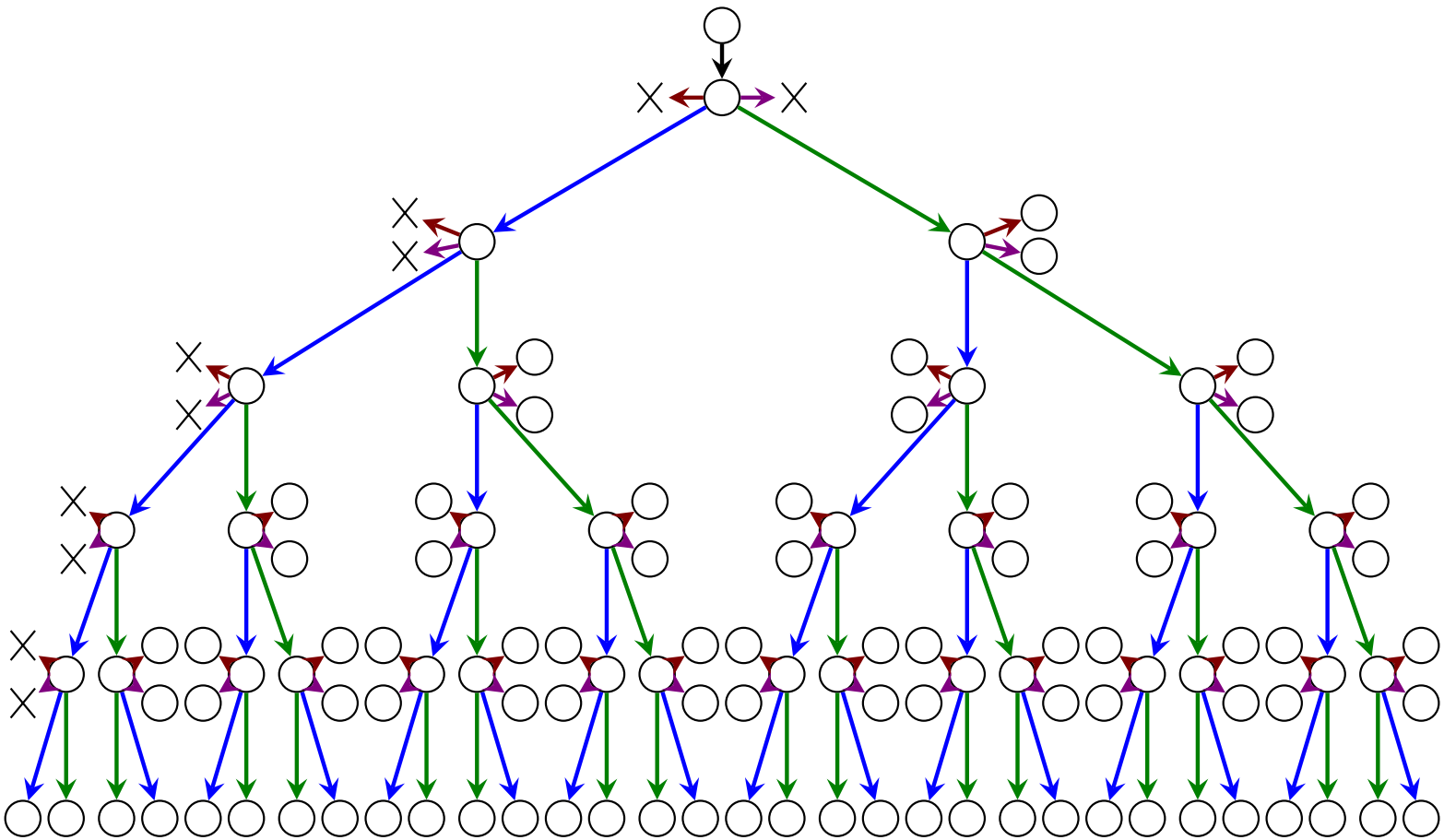
$\cup \mathcal{L}(A_I) =$

1: init x==-1

2: init y==-1

3: init (x++)$^+$ x==-1

4: init (x++)$^+$ y==-1



$\cup \mathcal{L}(A_I) =$

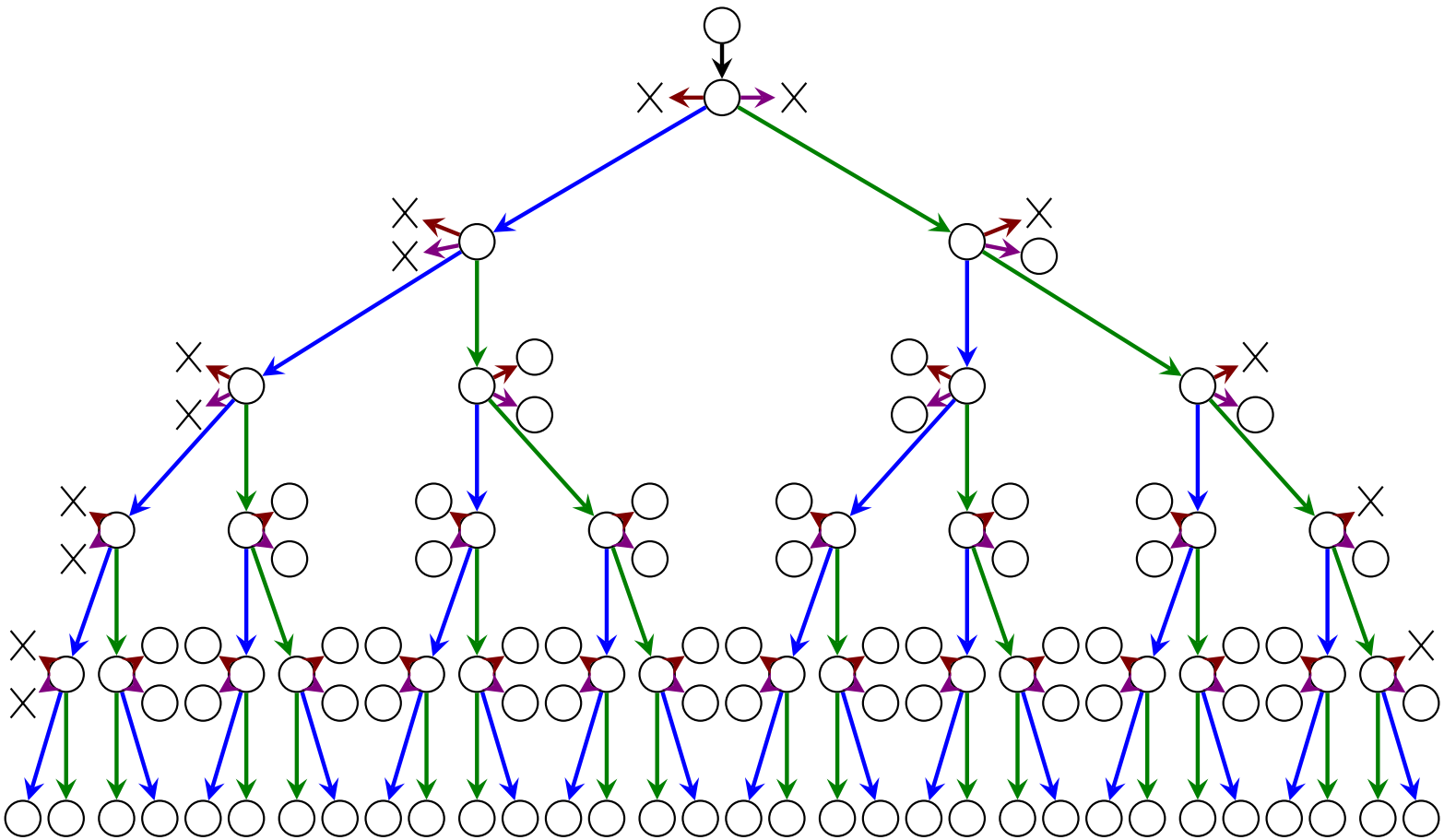
1: init x==-1

2: init y==-1

3: init (x++)$^+$ x==-1

4: init (x++)$^+$ y==-1

5: init (y++)$^+$ x==-1



$\cup \mathcal{L}(A_I) =$

1: init x==-1

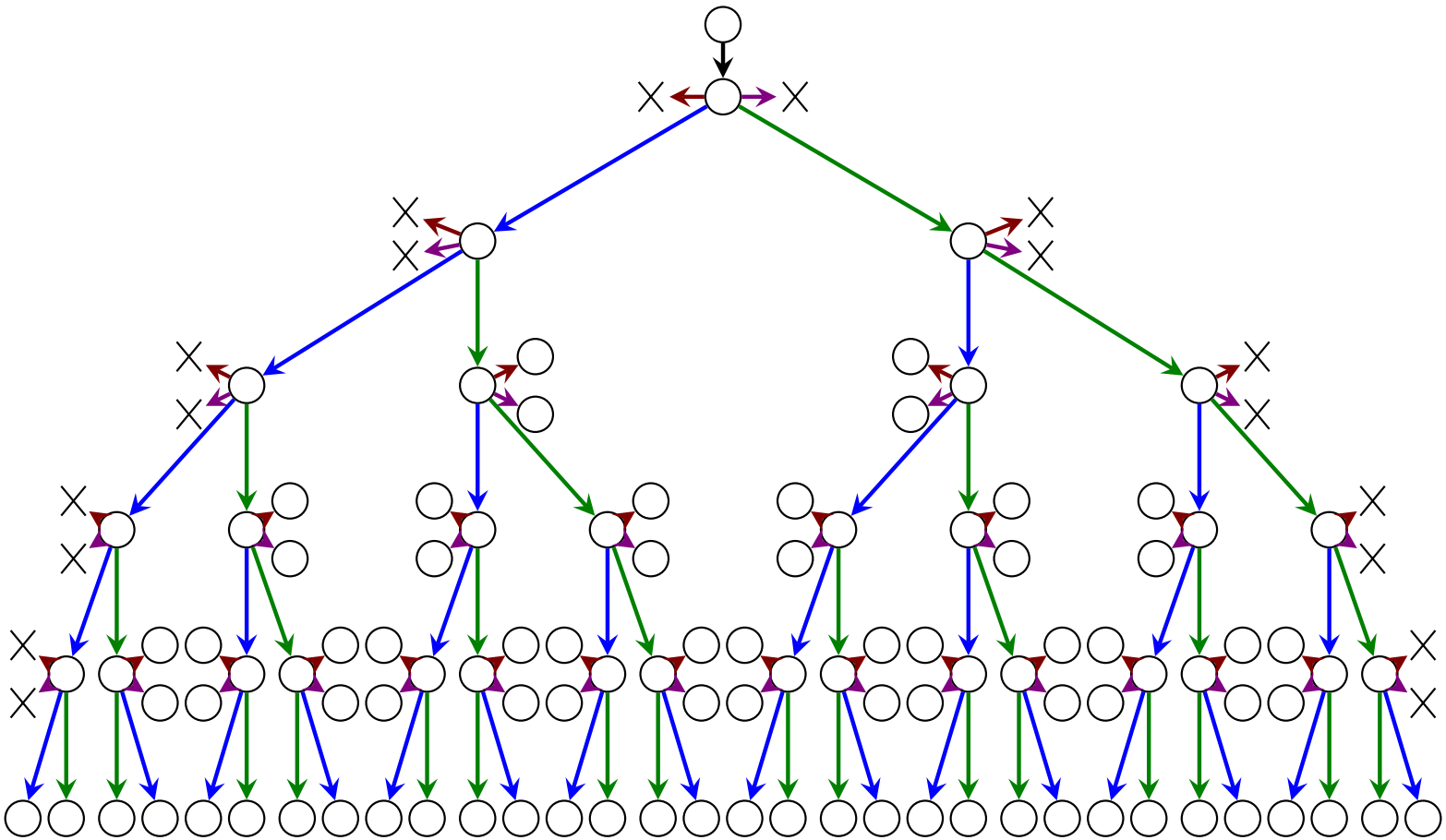
2: init y==-1

3: init (x++)$^+$ x==-1

4: init (x++)$^+$ y==-1

5: init (y++)$^+$ x==-1

6: init (y++)$^+$ y==-1



$\cup \mathcal{L}(A_I) =$

1: init x==-1

2: init y==-1

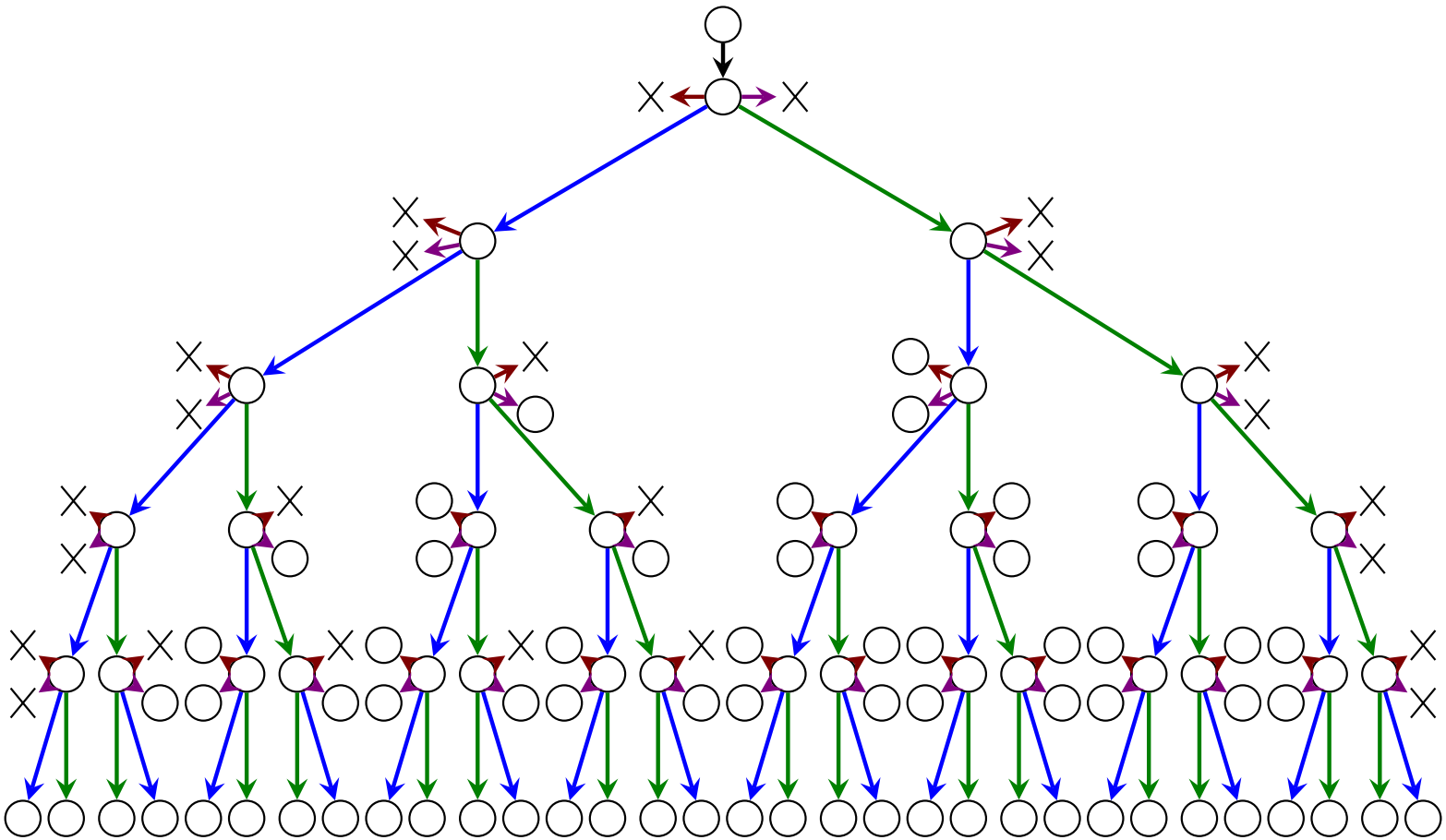
3: init (x++)$^+$ x==-1

4: init (x++)$^+$ y==-1

5: init (y++)$^+$ x==-1

6: init (y++)$^+$ y==-1

7: init ((x++)$^+$ (y++)$^+$)$^+$ x==-1



$\cup \mathcal{L}(A_I) =$

1: init x==-1

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3: init (x++)$^+$ x==-1

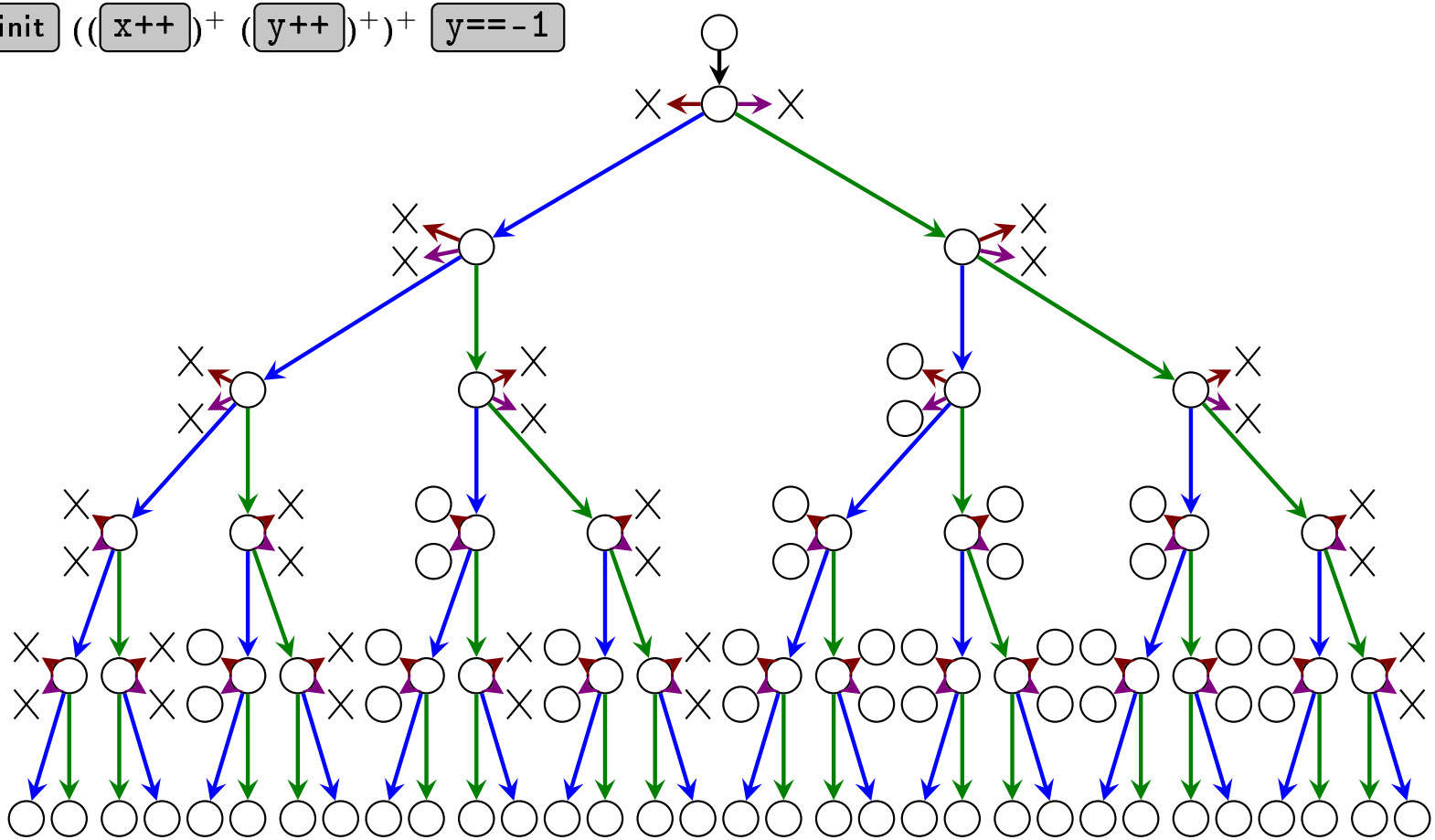
4: init (x++)$^+$ y==-1

5: init (y++)$^+$ x==-1

6: init (y++)$^+$ y==-1

7: init ((x++)$^+$ (y++)$^+$)$^+$ x==-1

8: init ((x++)$^+$ (y++)$^+$)$^+$ y==-1



$\cup \mathcal{L}(A_I) =$

1: init x==-1

2: init y==-1

3: init (x++)$^+$ x==-1

4: init (x++)$^+$ y==-1

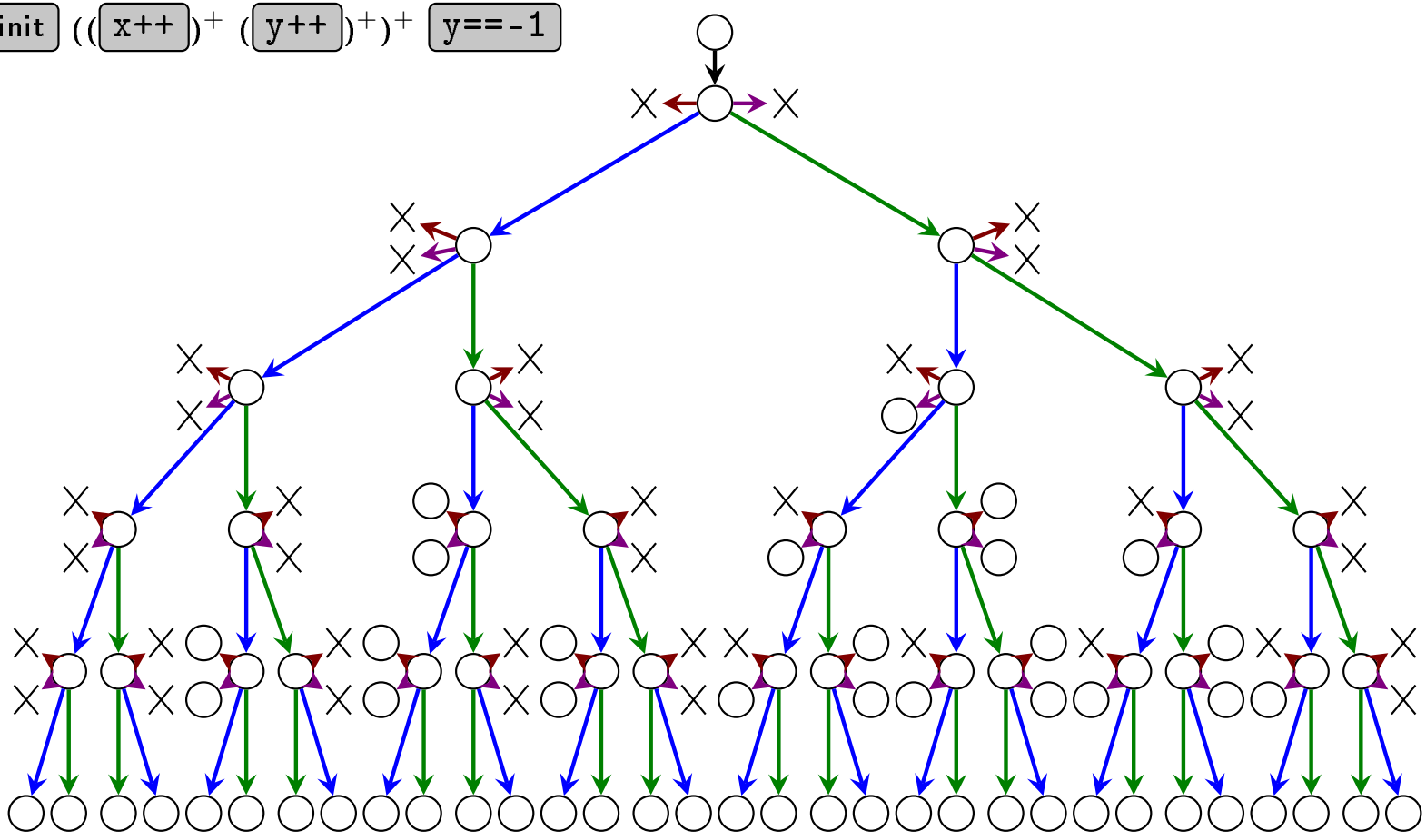
5: init (y++)$^+$ x==-1

6: init (y++)$^+$ y==-1

7: init ((x++)$^+$ (y++)$^+$)$^+$ x==-1

8: init ((x++)$^+$ (y++)$^+$)$^+$ y==-1

9: init ((y++)$^+$ (x++)$^+$)$^+$ x==-1



$\cup \mathcal{L}(A_I) =$

1: init x==-1

2: init y==-1

3: init (x++)$^+$ x==-1

4: init (x++)$^+$ y==-1

5: init (y++)$^+$ x==-1

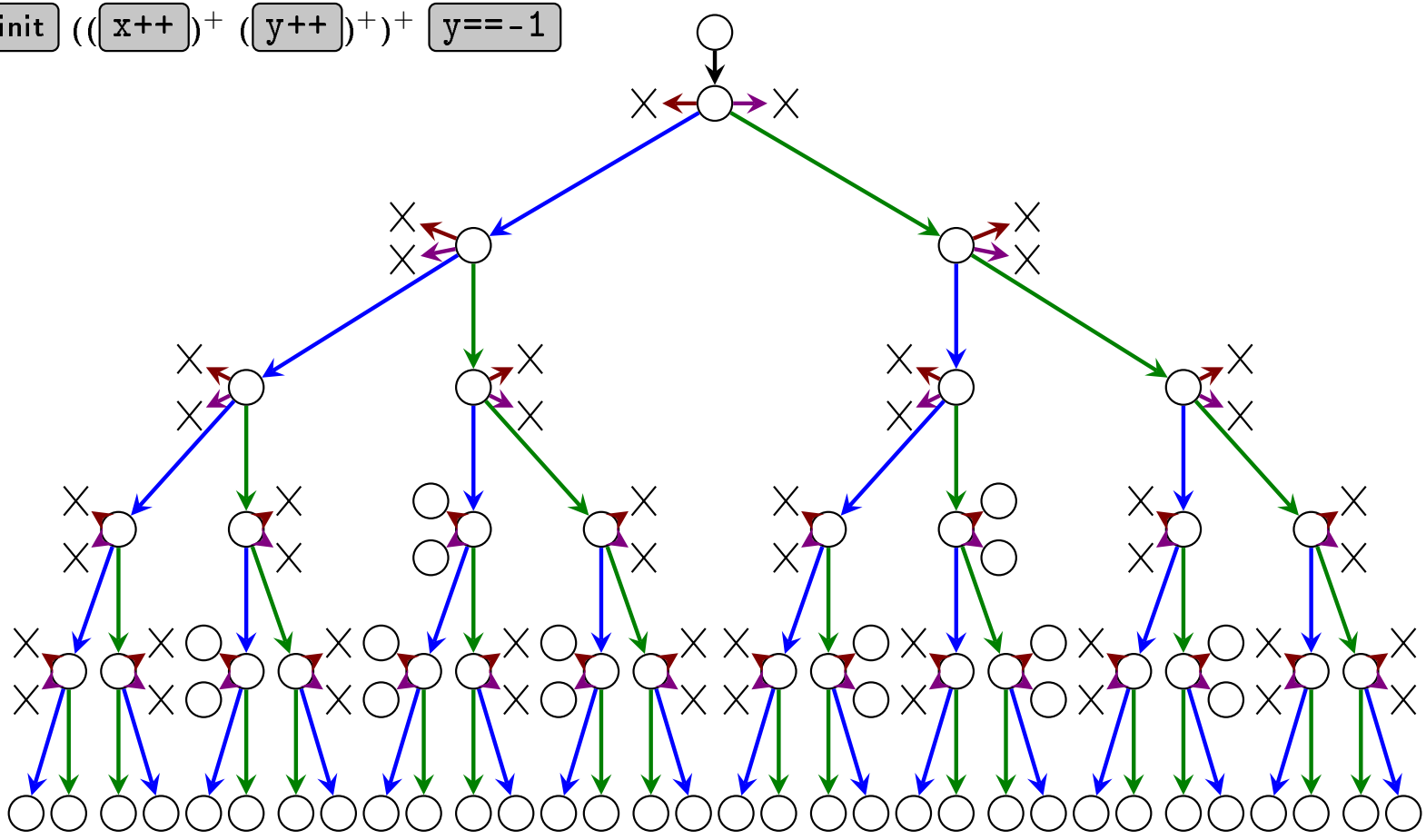
6: init (y++)$^+$ y==-1

7: init ((x++)$^+$ (y++)$^+$)$^+$ x==-1

8: init ((x++)$^+$ (y++)$^+$)$^+$ y==-1

9: init ((y++)$^+$ (x++)$^+$)$^+$ x==-1

10: init ((y++)$^+$ (x++)$^+$)$^+$ y==-1



$\cup \mathcal{L}(A_I) =$

1: init x==-1

2: init y==-1

3: init (x++)$^+$ x==-1

4: init (x++)$^+$ y==-1

5: init (y++)$^+$ x==-1

6: init (y++)$^+$ y==-1

7: init ((x++)$^+$ (y++)$^+$)$^+$ x==-1

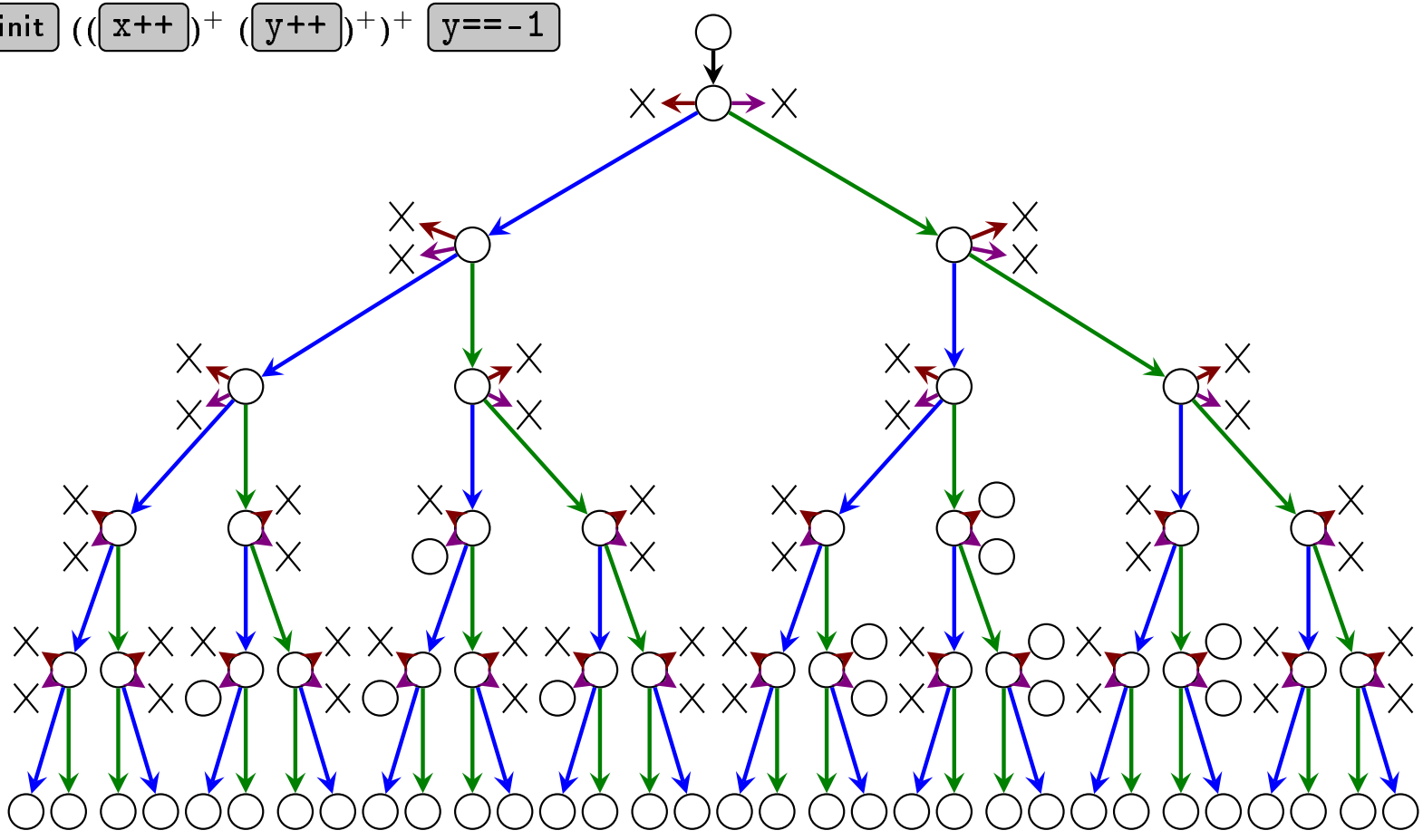
8: init ((x++)$^+$ (y++)$^+$)$^+$ y==-1

9: init ((y++)$^+$ (x++)$^+$)$^+$ x==-1

10: init ((y++)$^+$ (x++)$^+$)$^+$ y==-1

11: init ((x++)$^+$ ((y++)$^+$ (x++)$^+$)$^+$)$^+$ x==-1

init (((x++)$^+$ ((y++)$^+$)$^+$ (x++)$^+$)$^+$ x==-1



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5: init (y++)$^+$ x==-1

6: init (y++)$^+$ y==-1

7: init ((x++)$^+$ (y++)$^+$)$^+$ x==-1

8: init ((x++)$^+$ (y++)$^+$)$^+$ y==-1

9: init ((y++)$^+$ (x++)$^+$)$^+$ x==-1

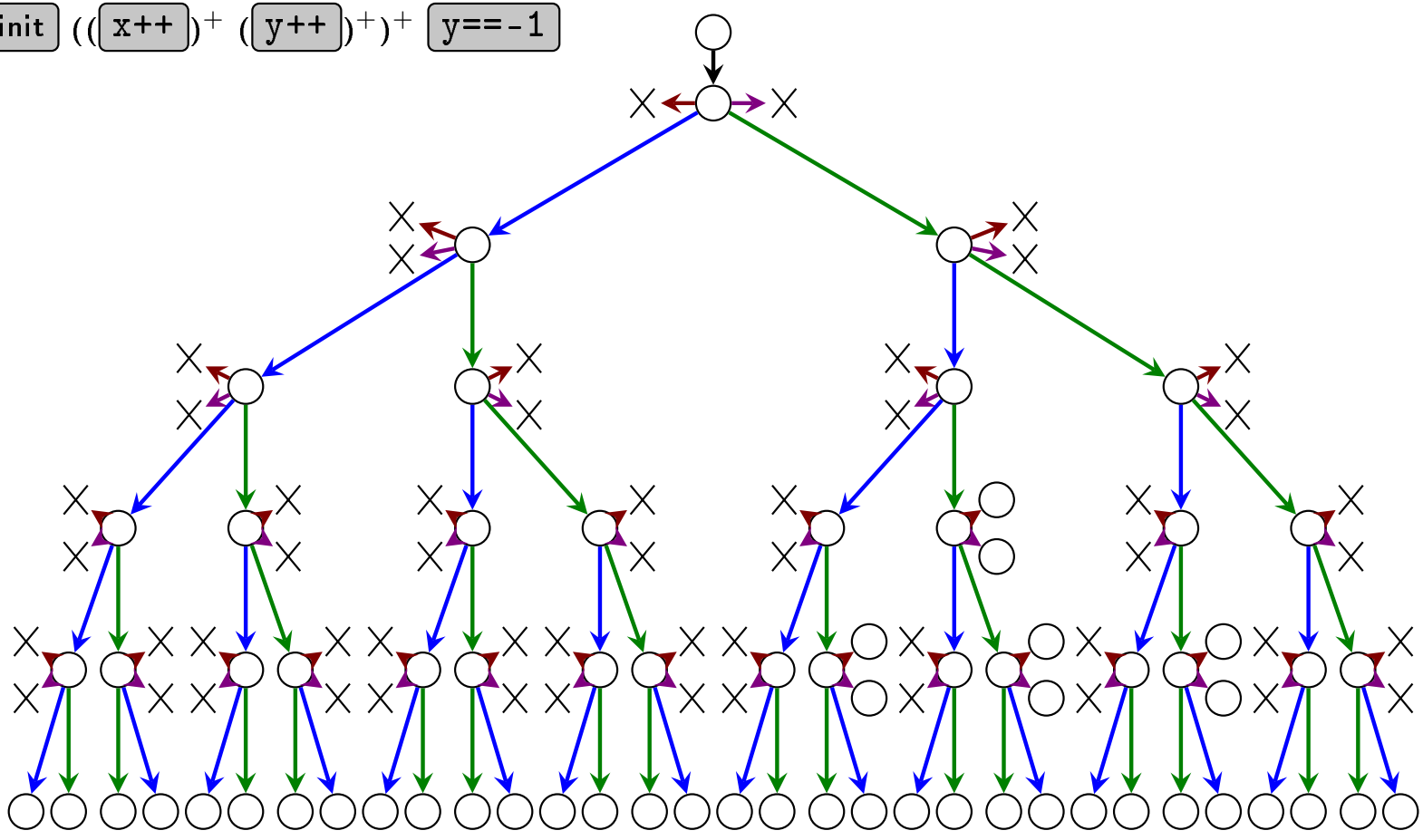
10: init ((y++)$^+$ (x++)$^+$)$^+$ y==-1

11: init ((x++)$^+$ ((y++)$^+$ (x++)$^+$)$^+$)$^+$ x==-1

init (((x++)$^+$ ((y++)$^+$)$^+$ (x++)$^+$)$^+$ x==-1

12: init ((x++)$^+$ ((y++)$^+$ (x++)$^+$)$^+$)$^+$ y==-1

init (((x++)$^+$ ((y++)$^+$)$^+$ (x++)$^+$)$^+$ y==-1



$\cup \mathcal{L}(A_I) =$

1: init x==-1

2: init y==-1

3: init (x++)$^+$ x==-1

4: init (x++)$^+$ y==-1

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6: init (y++)$^+$ y==-1

7: init ((x++)$^+$ (y++)$^+$)$^+$ x==-1

8: init ((x++)$^+$ (y++)$^+$)$^+$ y==-1

9: init ((y++)$^+$ (x++)$^+$)$^+$ x==-1

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11: init ((x++)$^+$ ((y++)$^+$ (x++)$^+$)$^+$)$^+$ x==-1

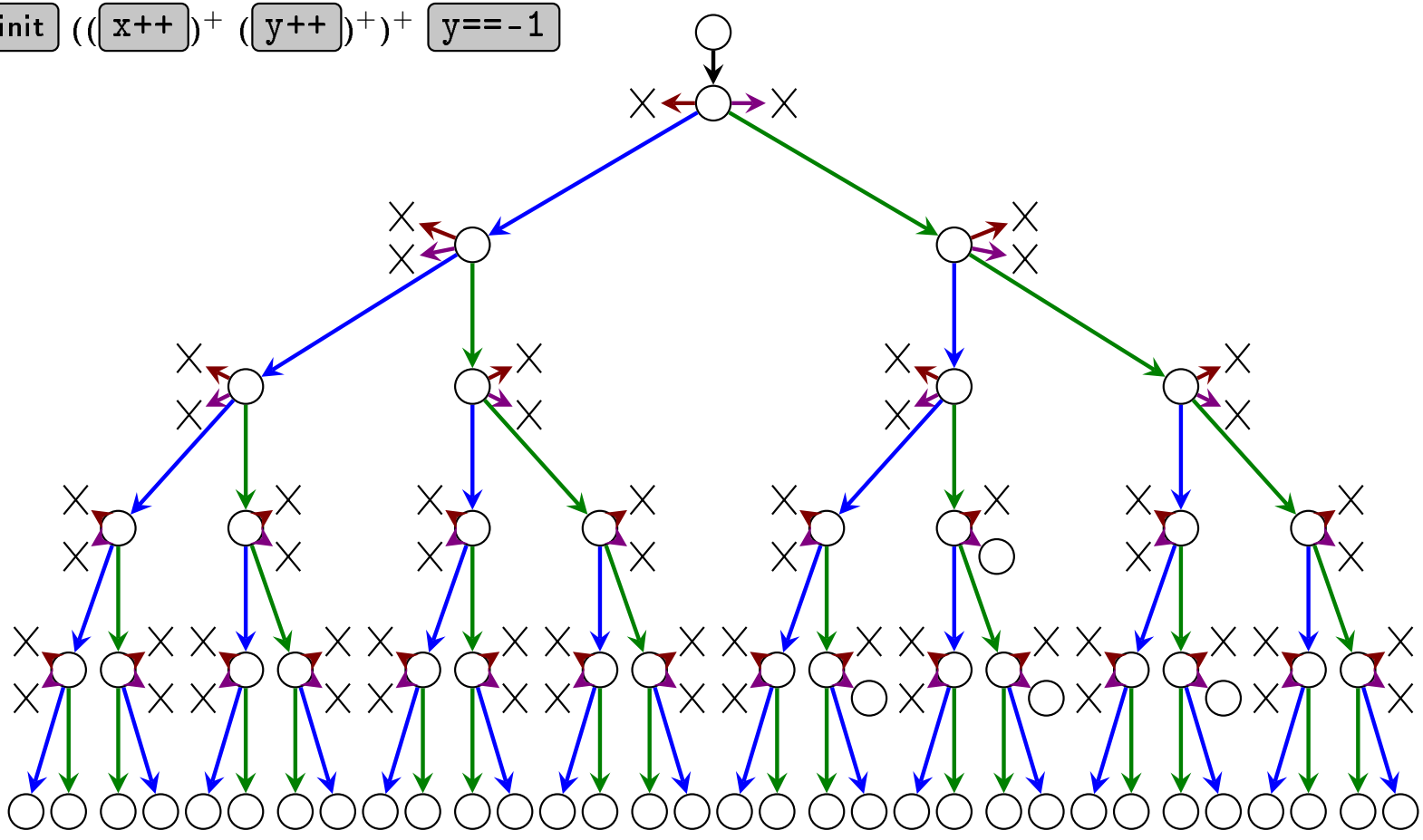
init (((x++)$^+$ ((y++)$^+$)$^+$ (x++)$^+$)$^+$ x==-1

12: init ((x++)$^+$ ((y++)$^+$ (x++)$^+$)$^+$)$^+$ y==-1

init (((x++)$^+$ ((y++)$^+$)$^+$ (x++)$^+$)$^+$ y==-1

13: init ((y++)$^+$ ((x++)$^+$ (y++)$^+$)$^+$)$^+$ x==-1

init (((y++)$^+$ ((x++)$^+$)$^+$ (y++)$^+$)$^+$ x==-1



$\cup \mathcal{L}(A_I) =$

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5: init (y++)$^+$ x==-1

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7: init ((x++)$^+$ (y++)$^+$)$^+$ x==-1

8: init ((x++)$^+$ (y++)$^+$)$^+$ y==-1

9: init ((y++)$^+$ (x++)$^+$)$^+$ x==-1

10: init ((y++)$^+$ (x++)$^+$)$^+$ y==-1

11: init ((x++)$^+$ ((y++)$^+$ (x++)$^+$)$^+$)$^+$ x==-1

init (((x++)$^+$ ((y++)$^+$)$^+$ (x++)$^+$)$^+$ x==-1

12: init ((x++)$^+$ ((y++)$^+$ (x++)$^+$)$^+$)$^+$ y==-1

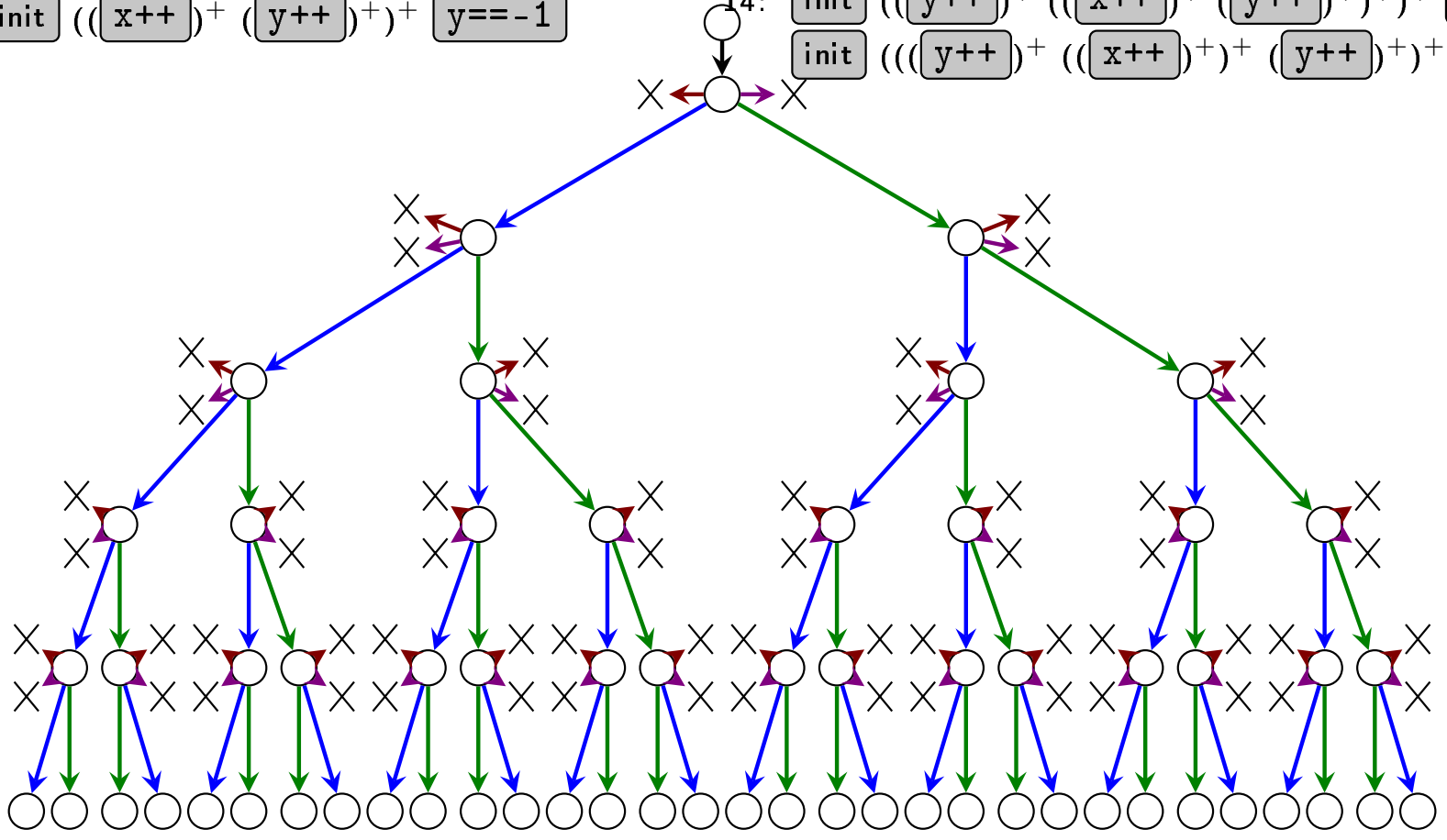
init (((x++)$^+$ ((y++)$^+$)$^+$ (x++)$^+$)$^+$ y==-1

13: init ((y++)$^+$ ((x++)$^+$ (y++)$^+$)$^+$)$^+$ x==-1

init (((y++)$^+$ ((x++)$^+$)$^+$ (y++)$^+$)$^+$ x==-1

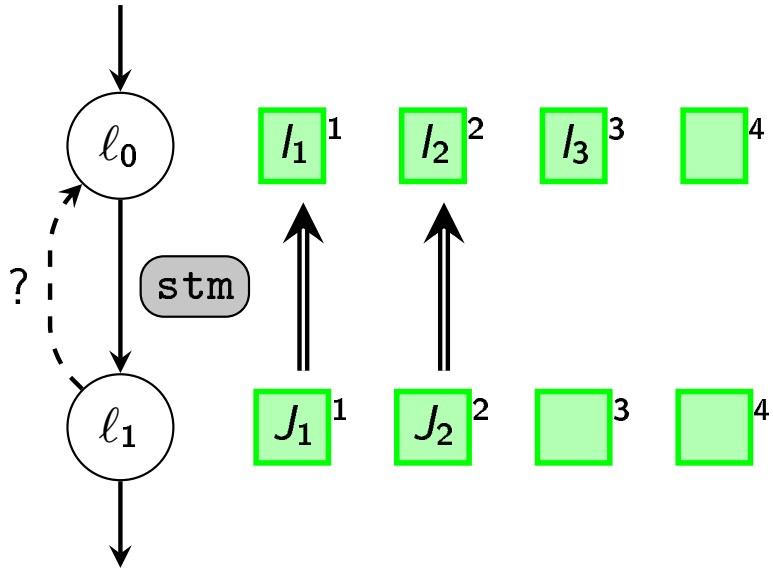
14: init ((y++)$^+$ ((x++)$^+$ (y++)$^+$)$^+$)$^+$ y==-1

init (((y++)$^+$ ((x++)$^+$)$^+$ (y++)$^+$)$^+$ y==-1



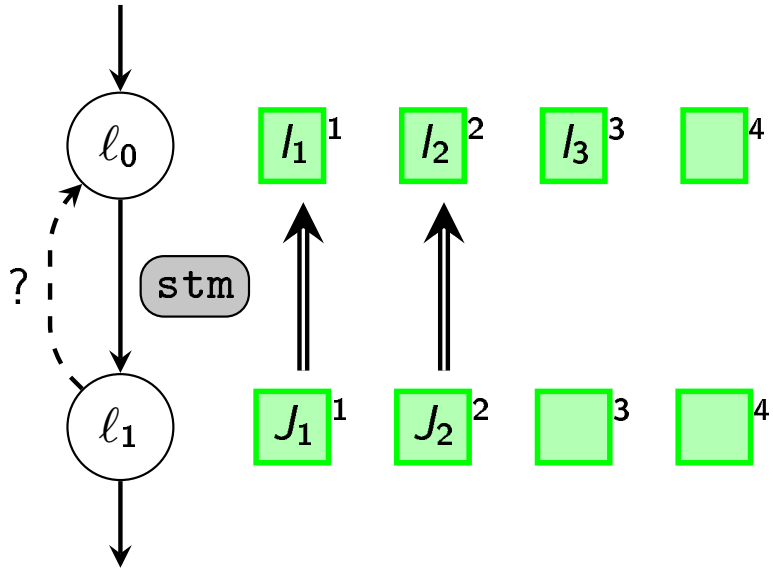
IMPACT-Variation 1

Idee: Implikations-Checks für Covering nur innerhalb einer Interpolantensequenz, bei nicht vorhandenen Interpolanten wird nichts überprüft

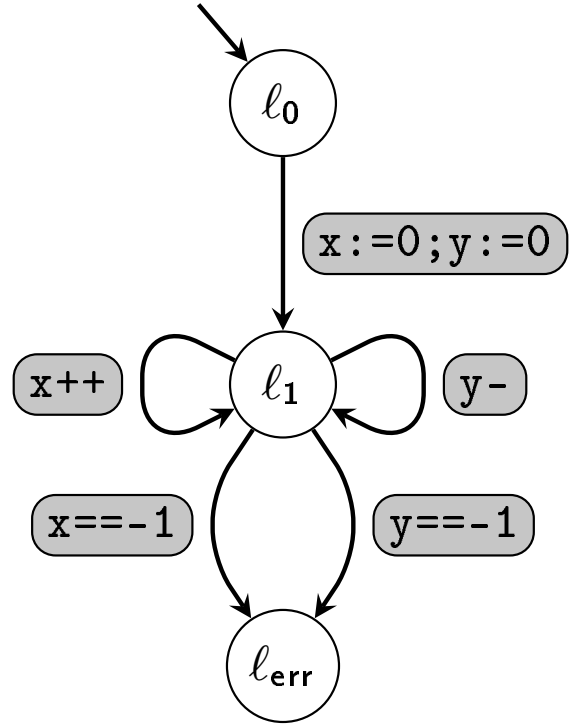


IMPACT-Variation 1

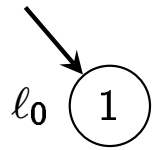
Idee: Implikations-Checks für Covering nur innerhalb einer Interpolantensequenz, bei nicht vorhandenen Interpolanten wird nichts überprüft



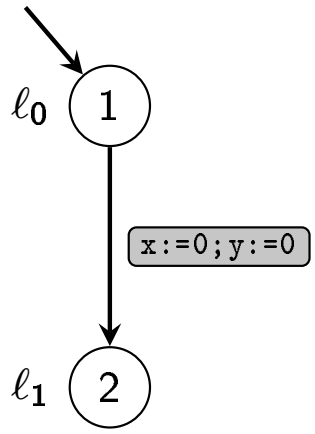
Beispiel für Inkorrektheit:



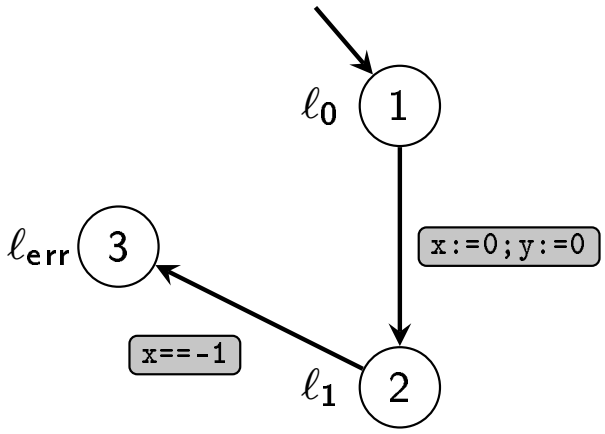
IMPACT-Variation 1



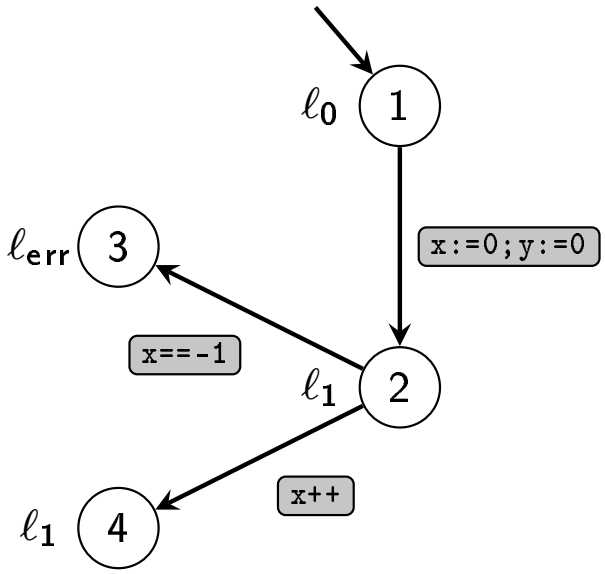
IMPACT-Variation 1



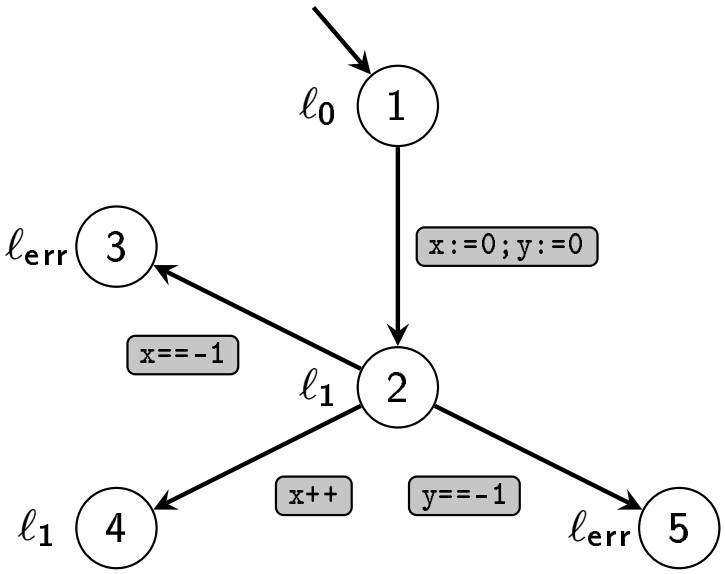
IMPACT-Variation 1



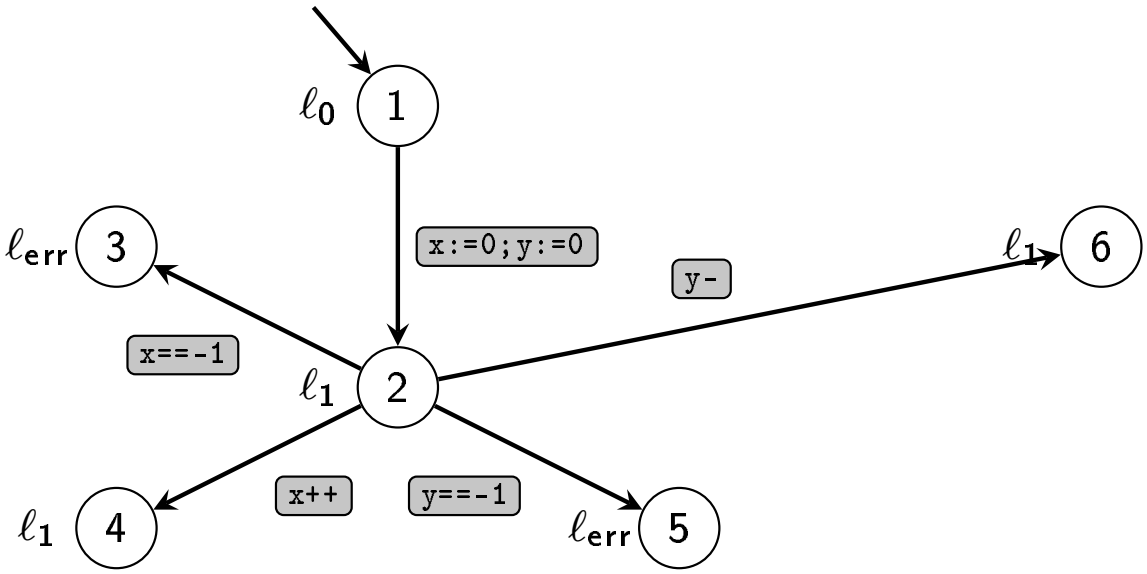
IMPACT-Variation 1



IMPACT-Variation 1



IMPACT-Variation 1



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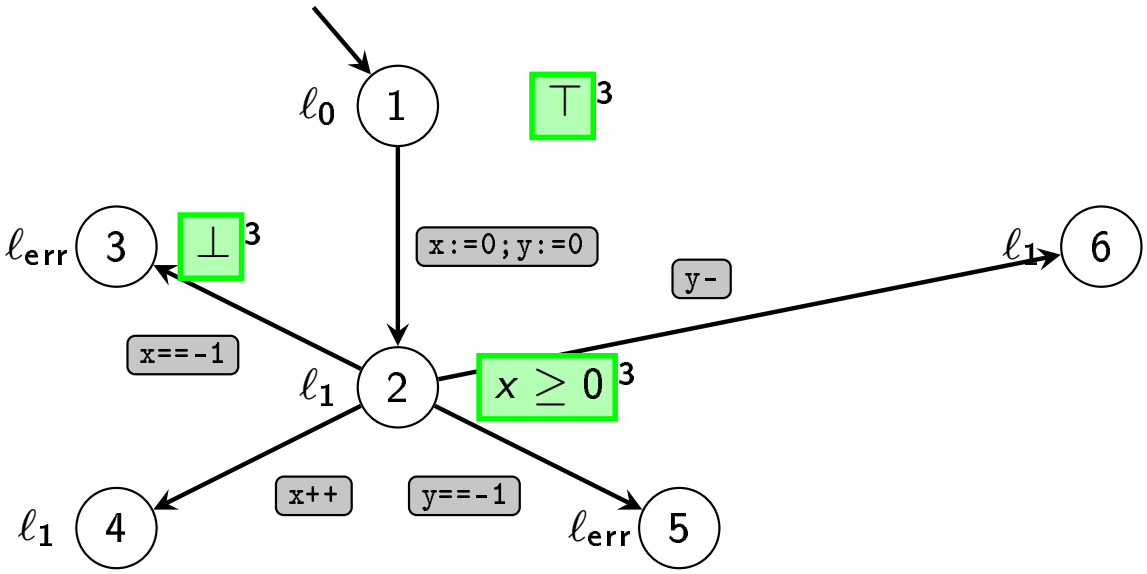
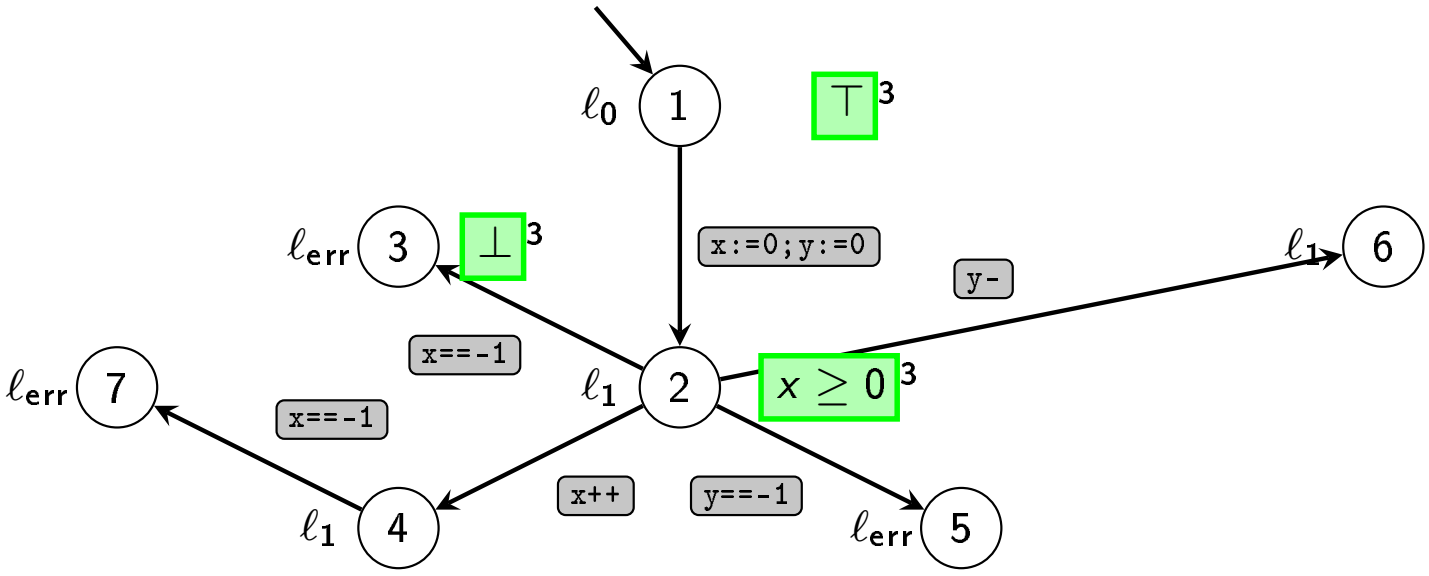
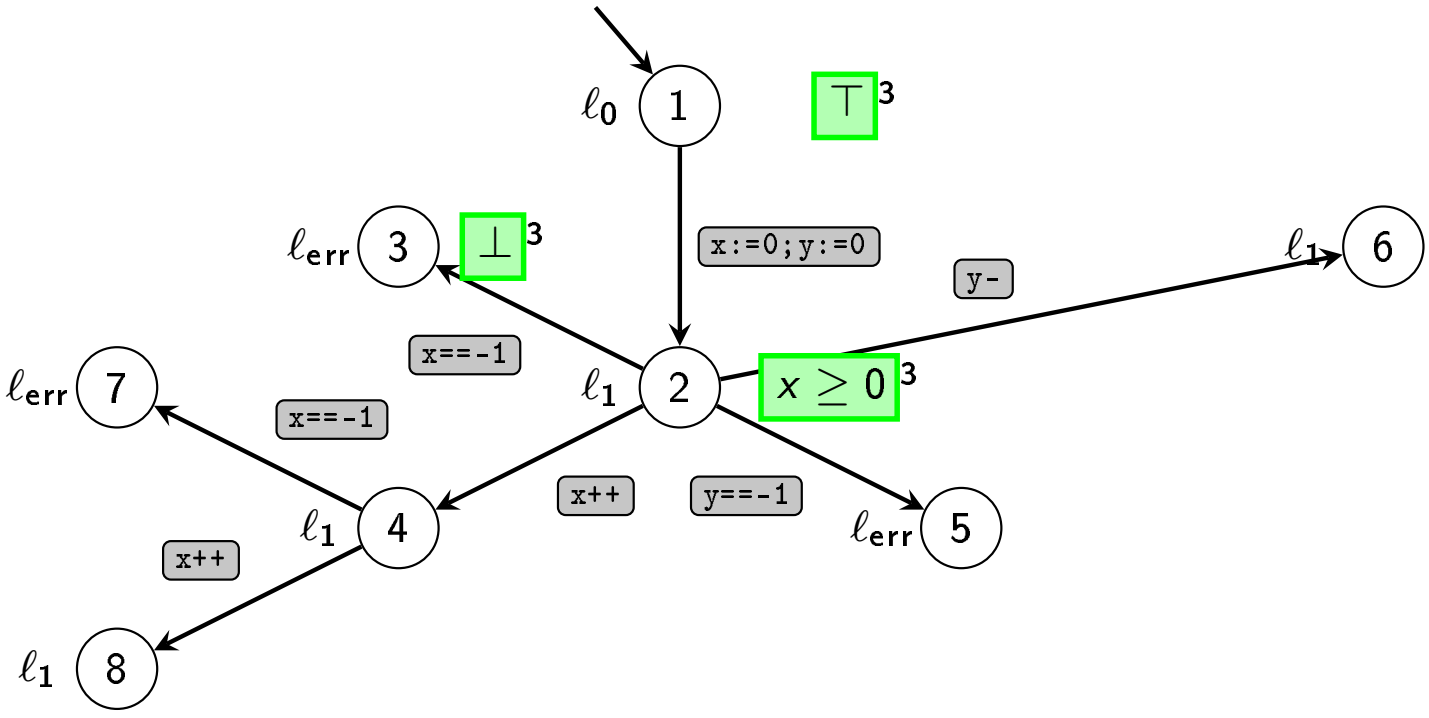


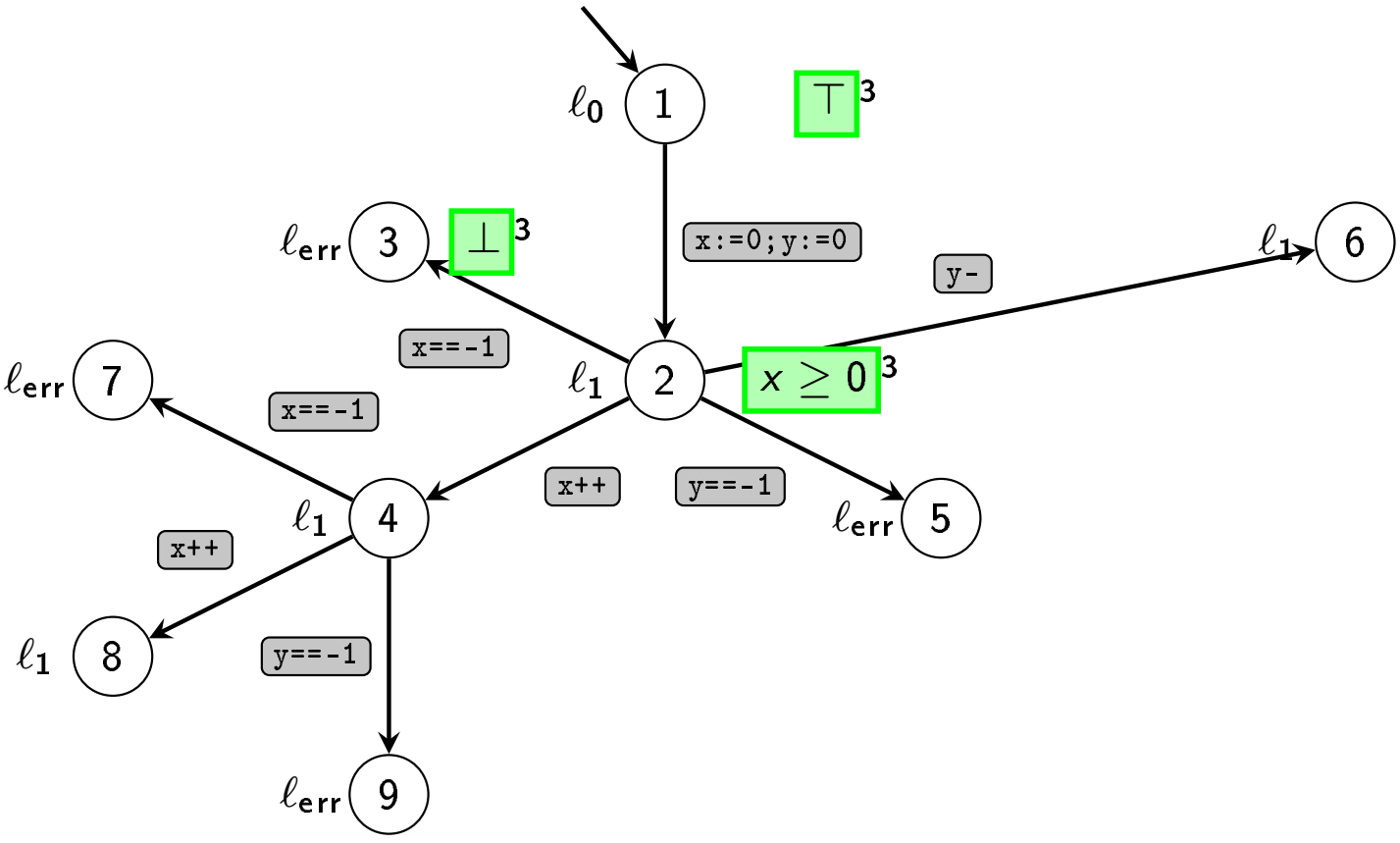
IMPACT-Variation 1



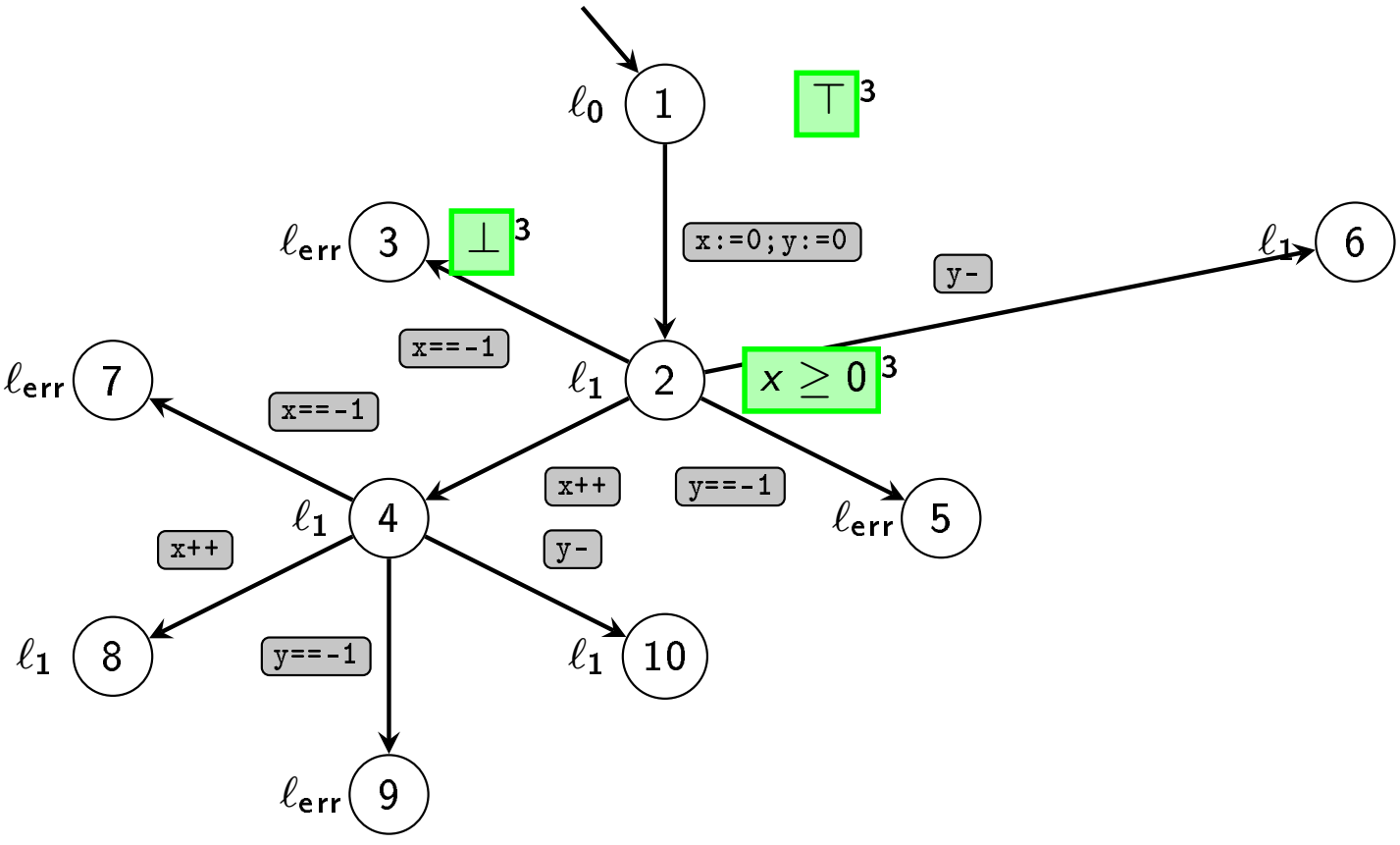
IMPACT-Variation 1



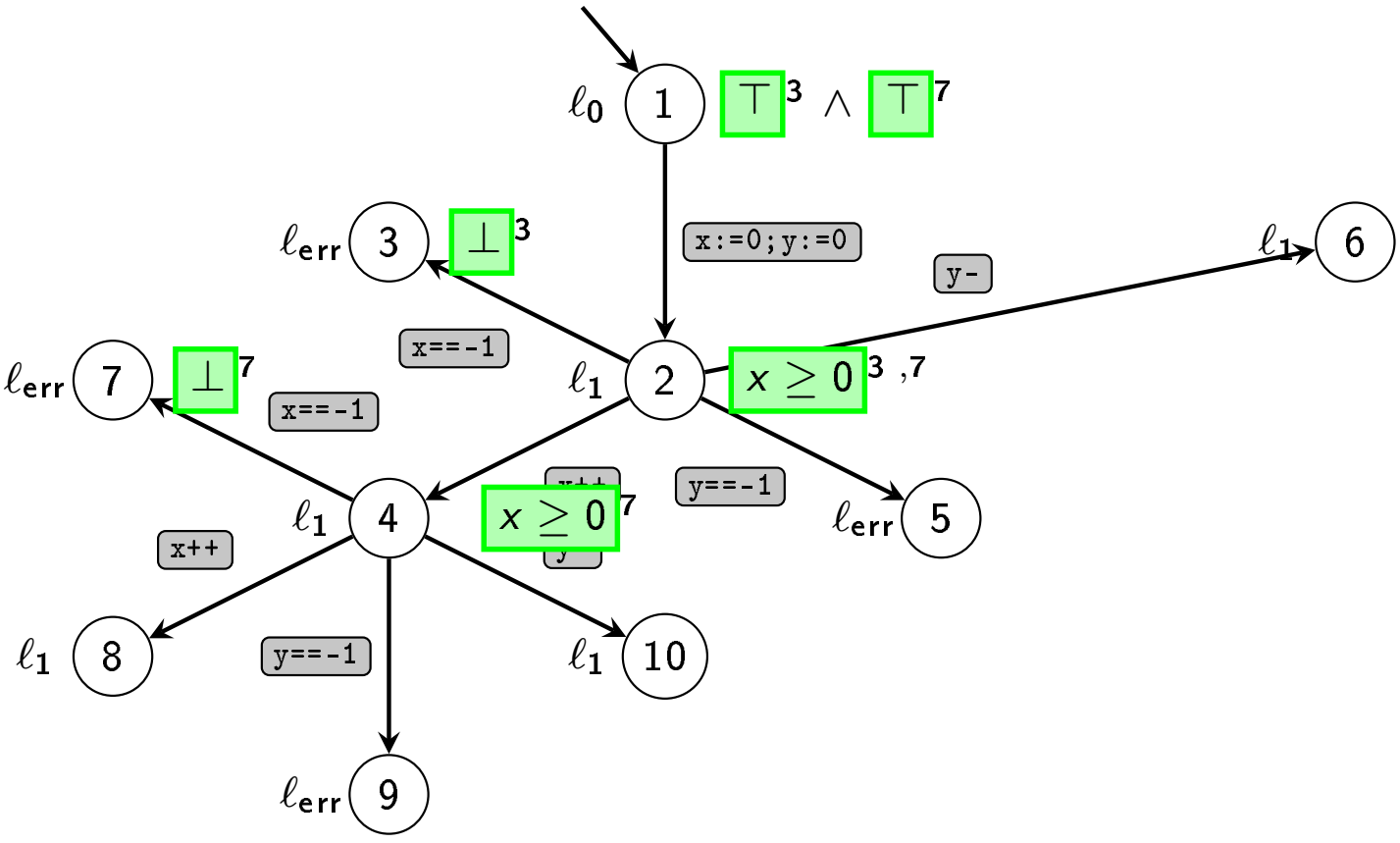
IMPACT-Variation 1



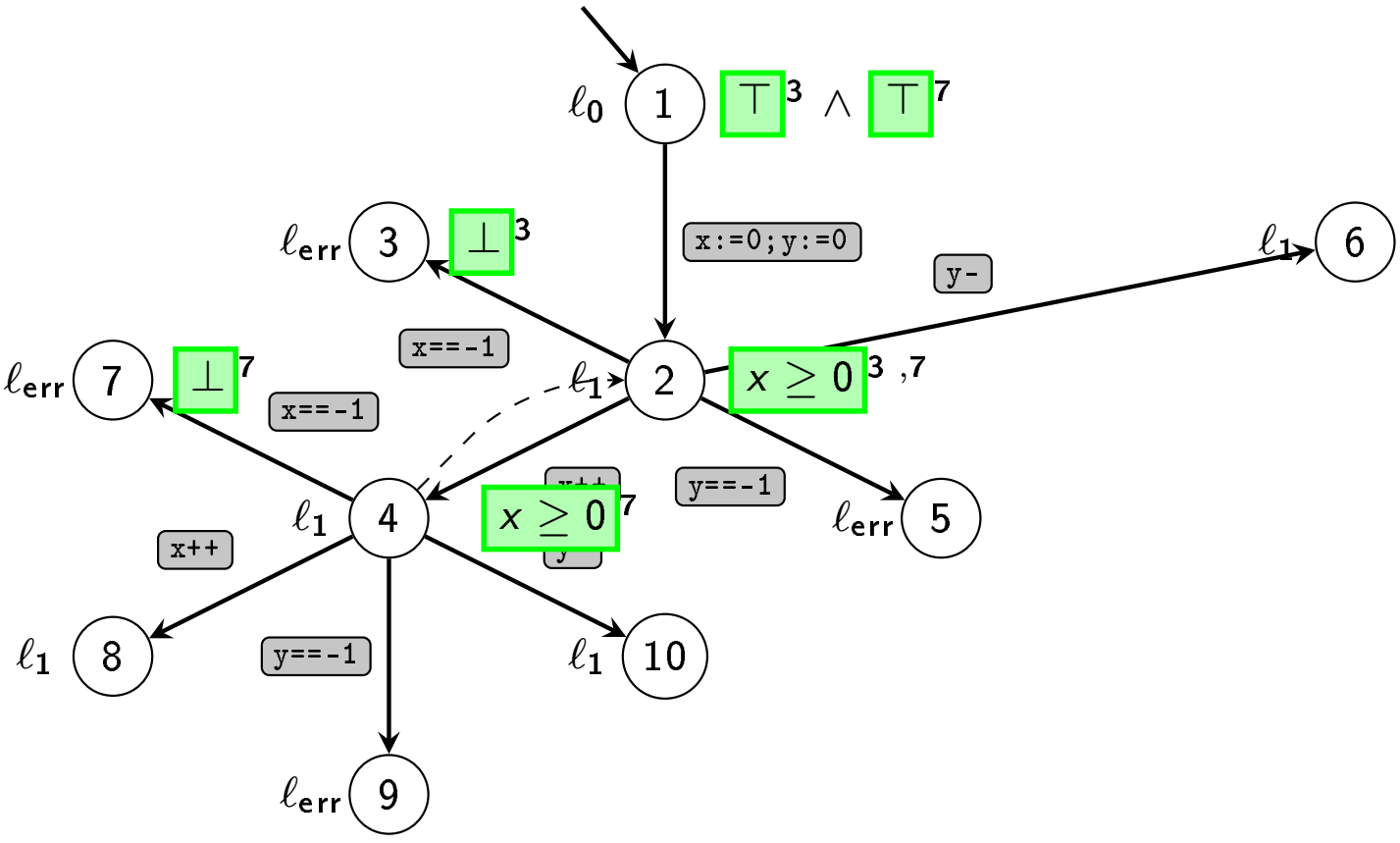
IMPACT-Variation 1



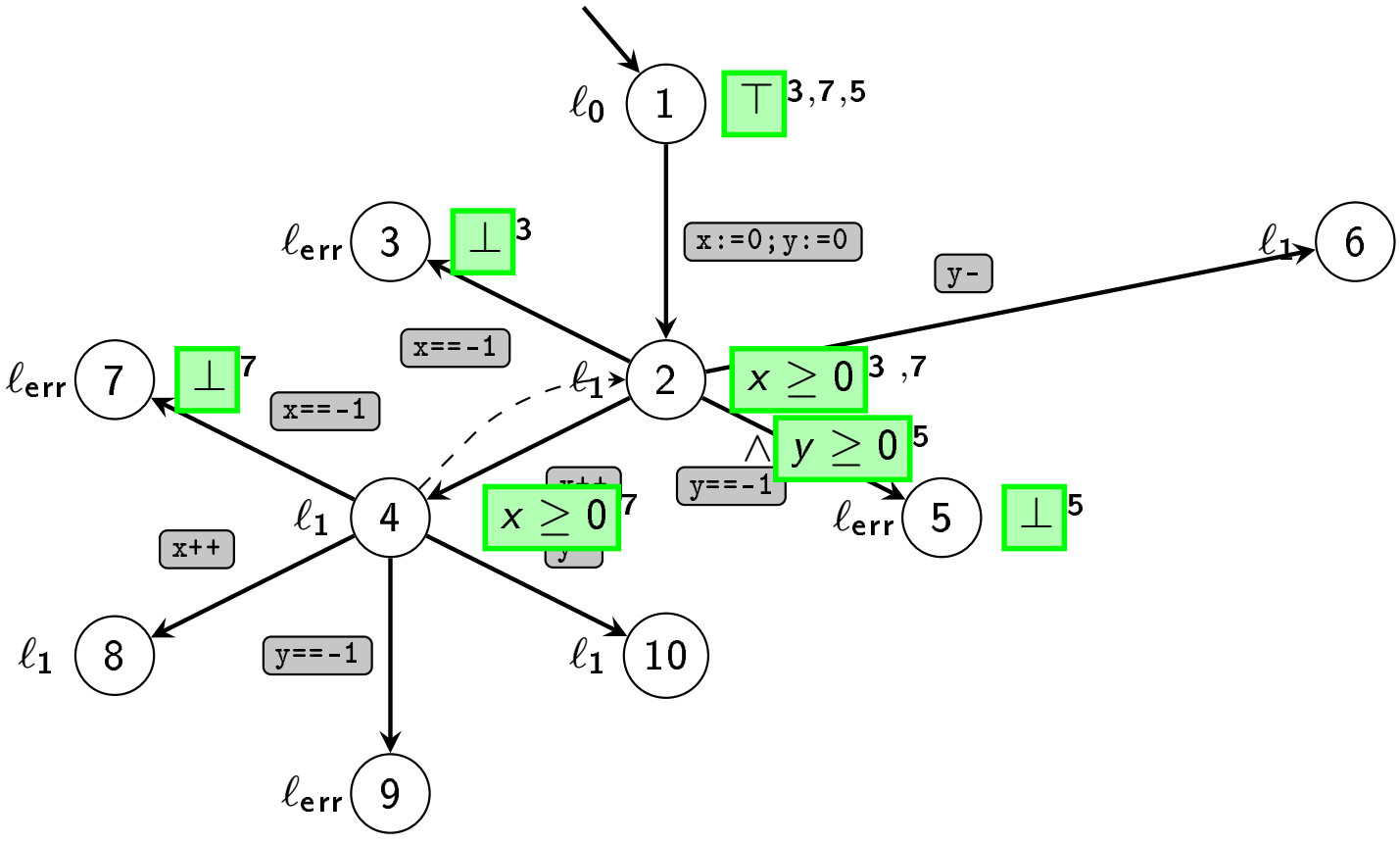
IMPACT-Variation 1



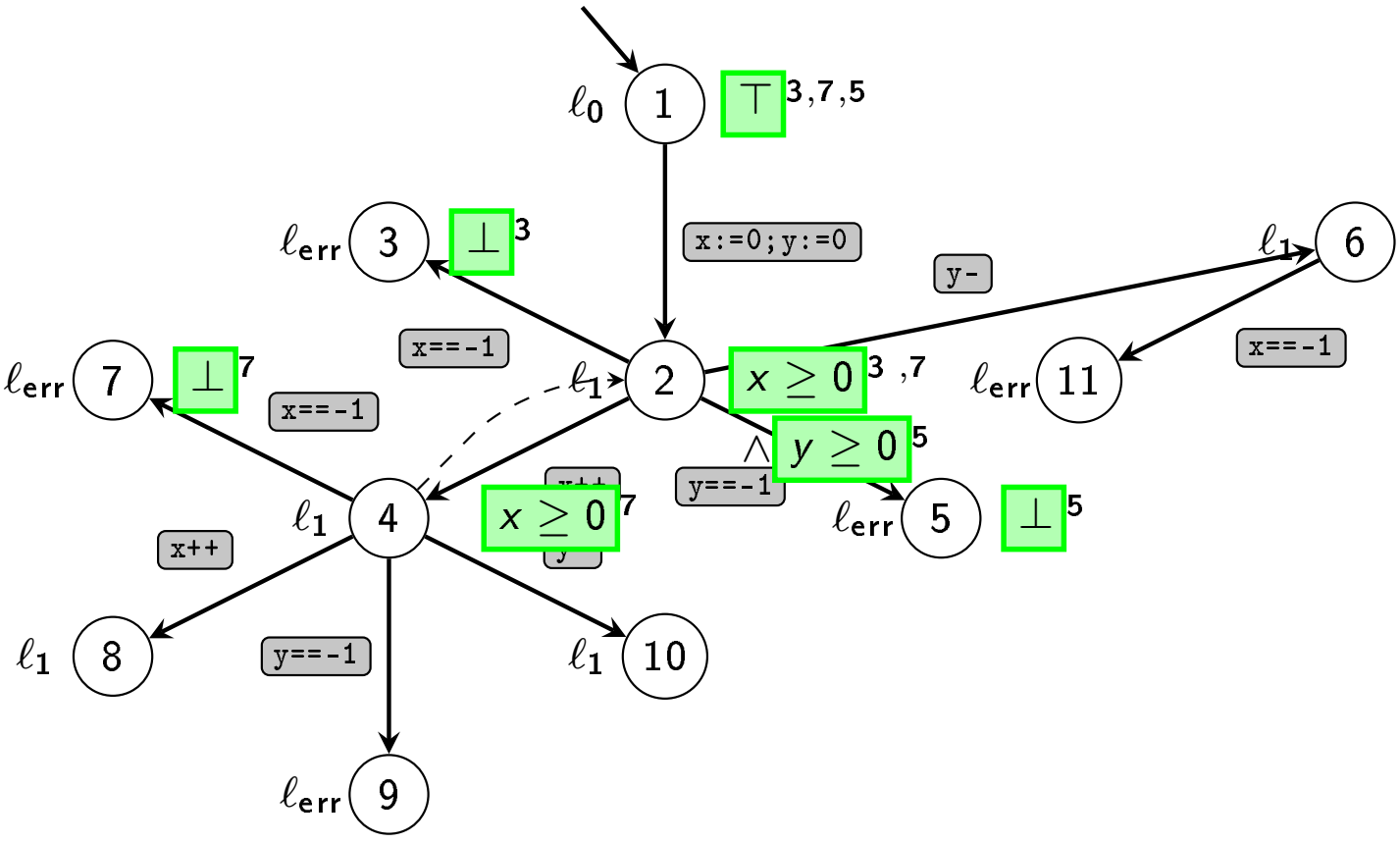
IMPACT-Variation 1



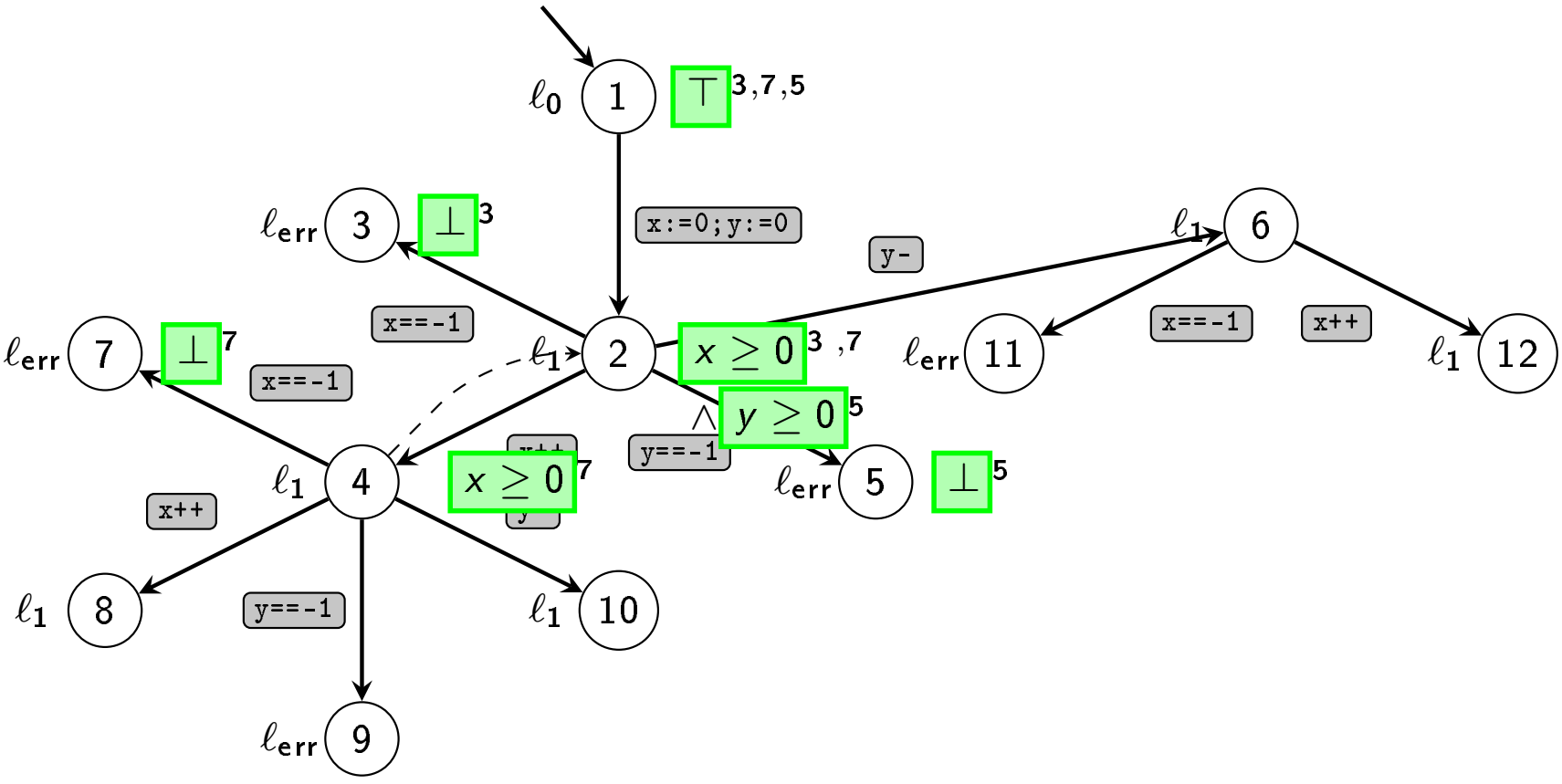
IMPACT-Variation 1



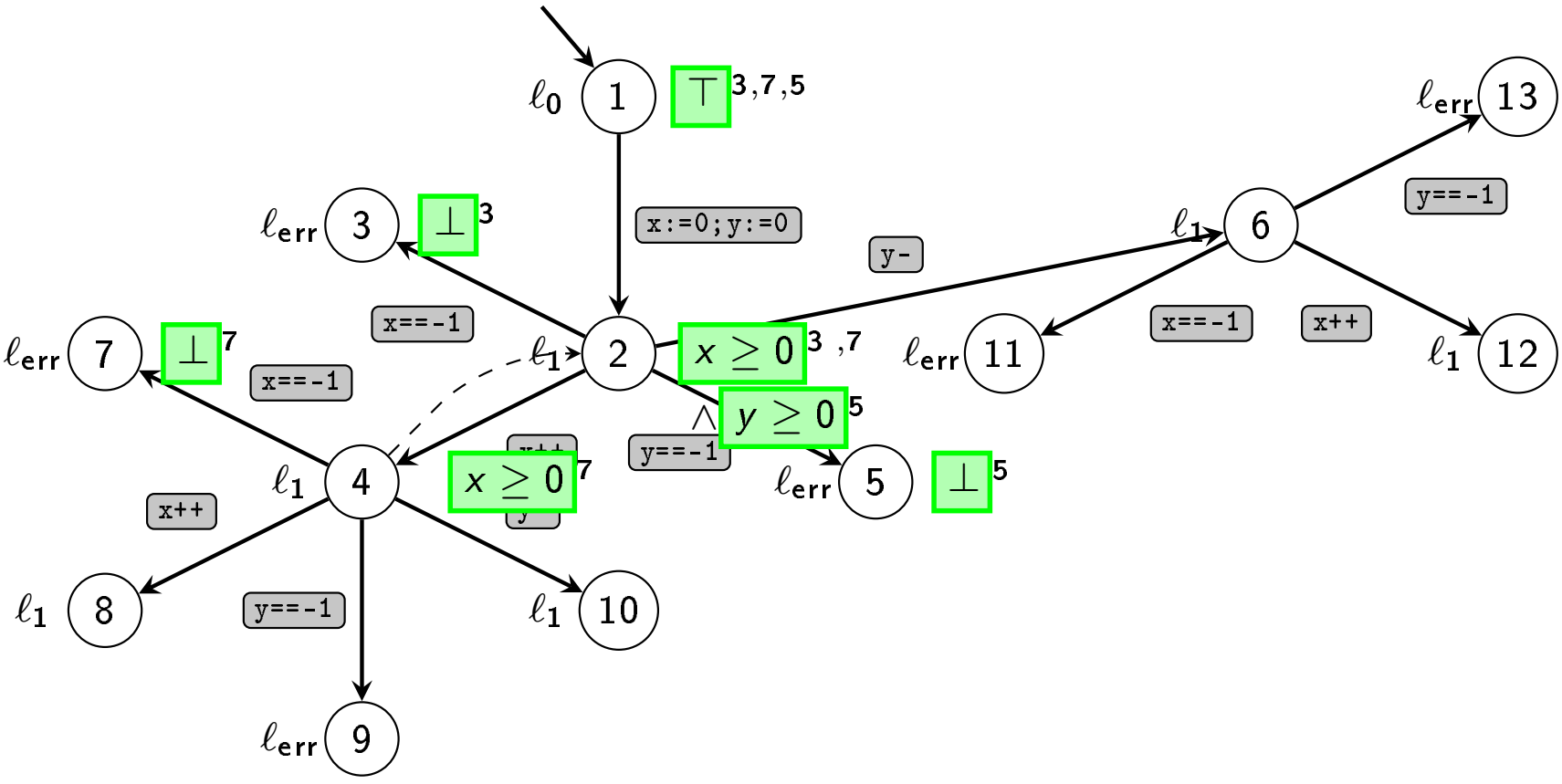
IMPACT-Variation 1



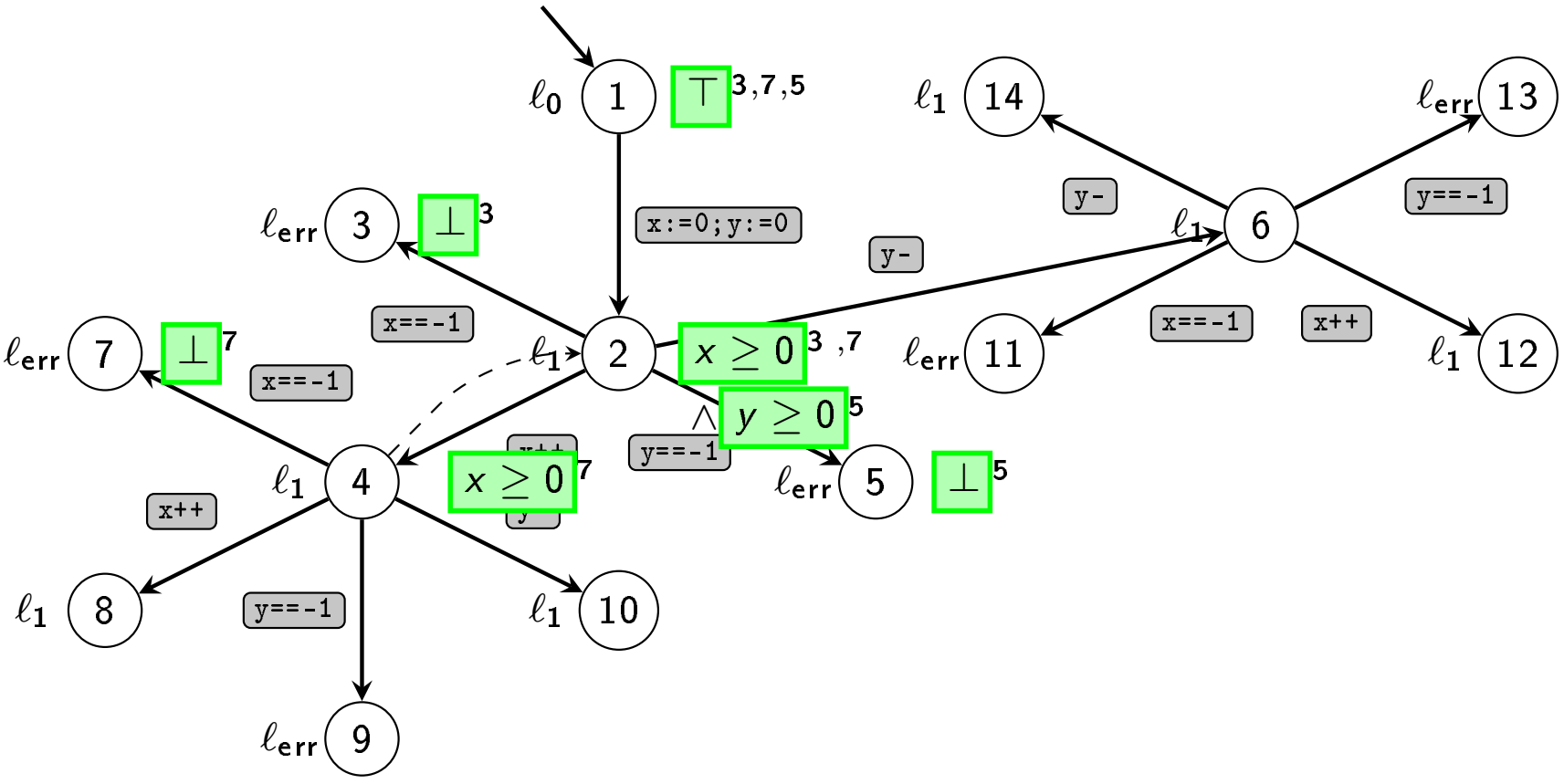
IMPACT-Variation 1



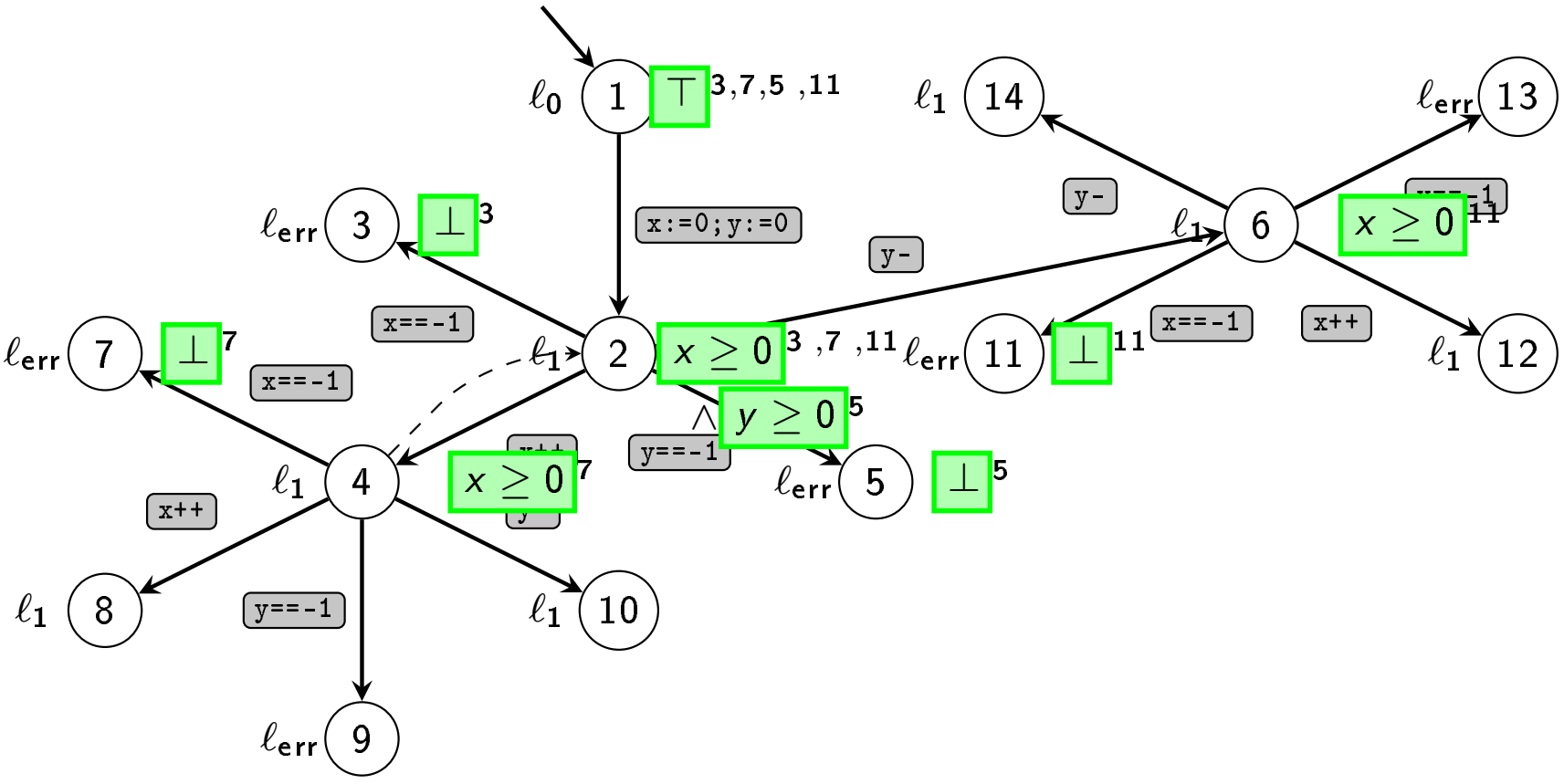
IMPACT-Variation 1



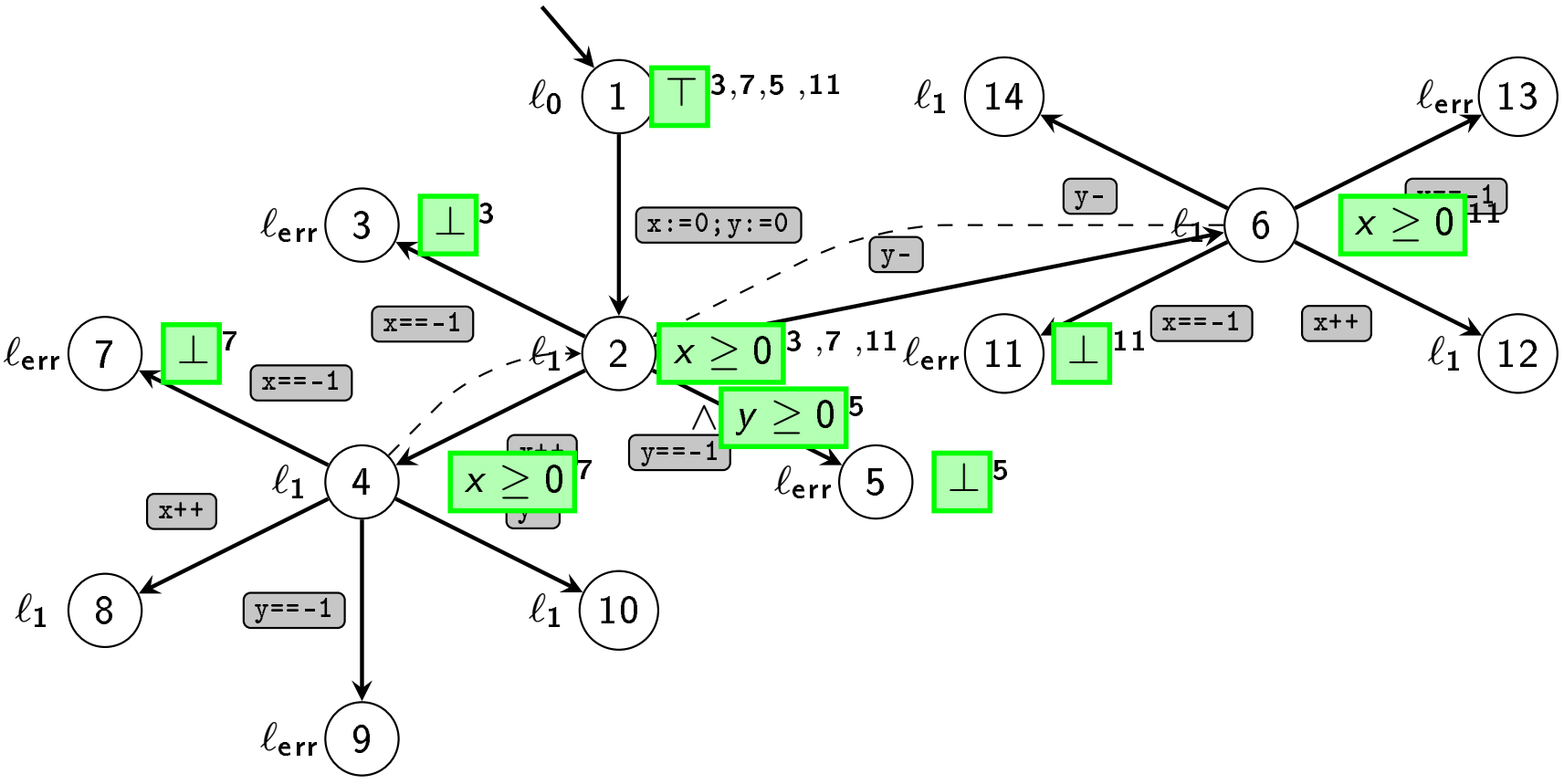
IMPACT-Variation 1



IMPACT-Variation 1

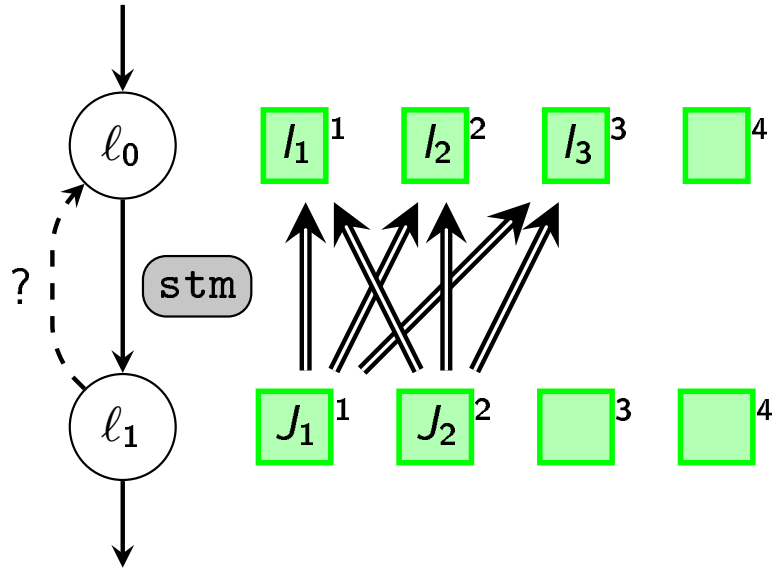


IMPACT-Variation 1



IMPACT-Variation 2

Idee: teste alle Implikationen zwischen Elementen beider Tupel



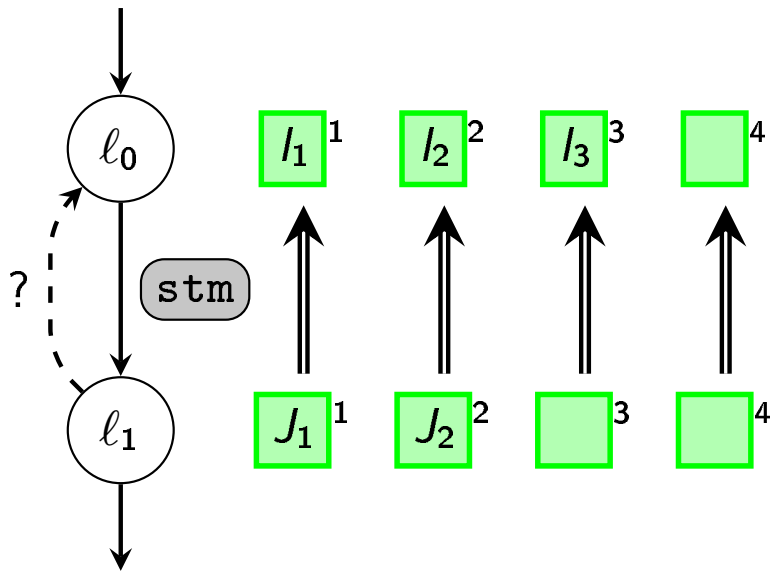
Fazit:

- Ist korrekt, da nur gecovert wird, wenn IMPACT auch covern würde
- Im Allgemeinen wird seltener gecovert, als bei IMPACT
- Keine große Ähnlichkeit zu Trace Abstraction
- Viele redundante Überprüfungen von Implikationen

IMPACT-Variation 3

Idee:

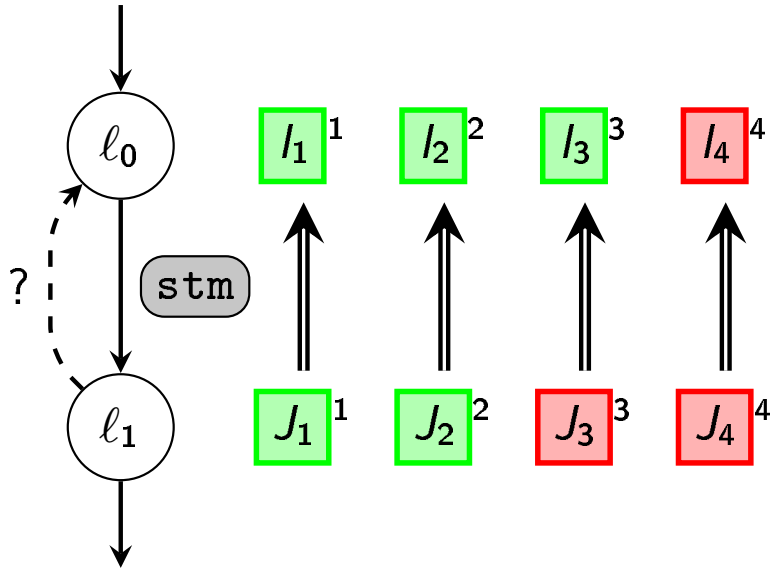
- Implikationsüberprüfung nur innerhalb der Interpolantensequenzen
- Ergänze fehlende Formeln mittels der Interpolantenautomaten aus der Trace Abstraction

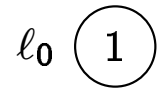


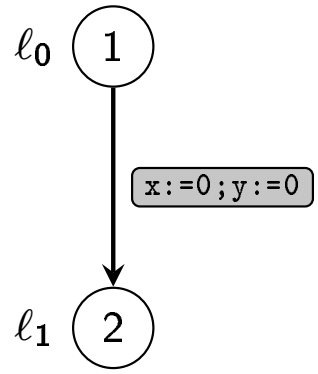
IMPACT-Variation 3

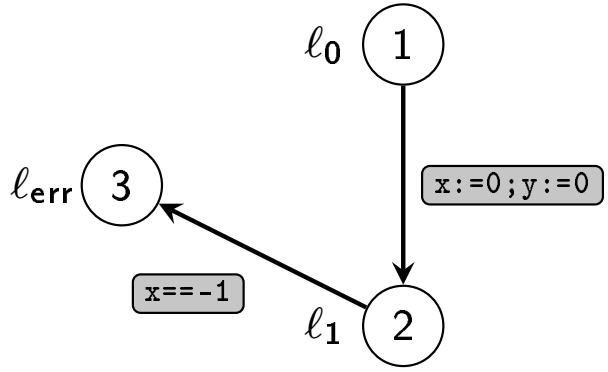
Idee:

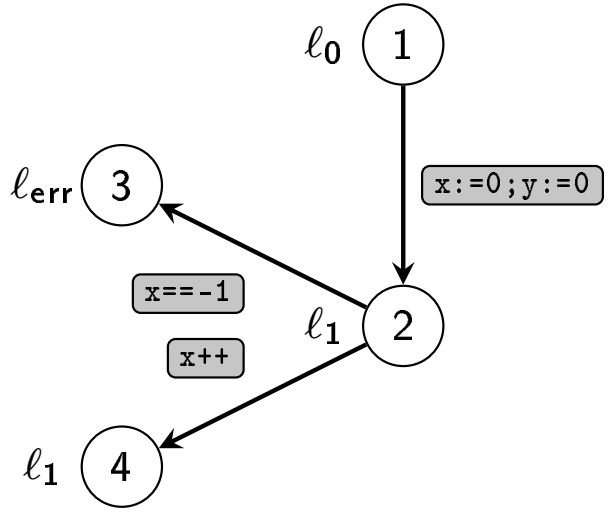
- Implikationsüberprüfung nur innerhalb der Interpolantensequenzen
- Ergänze fehlende Formeln mittels der Interpolantenautomaten aus der Trace Abstraction

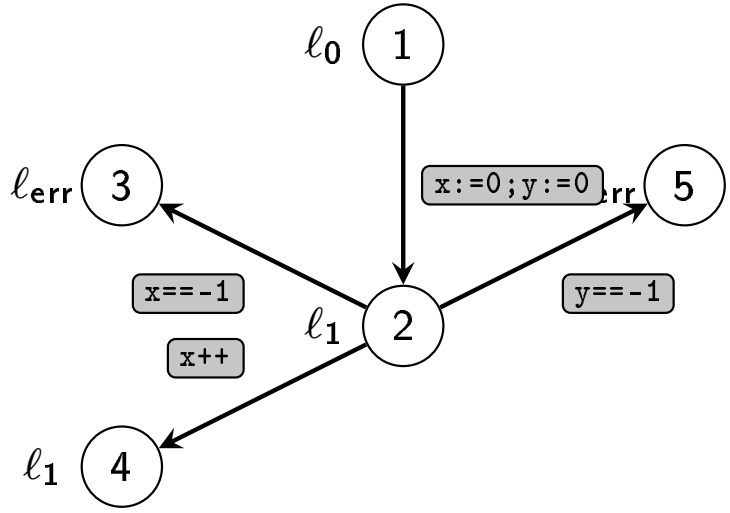


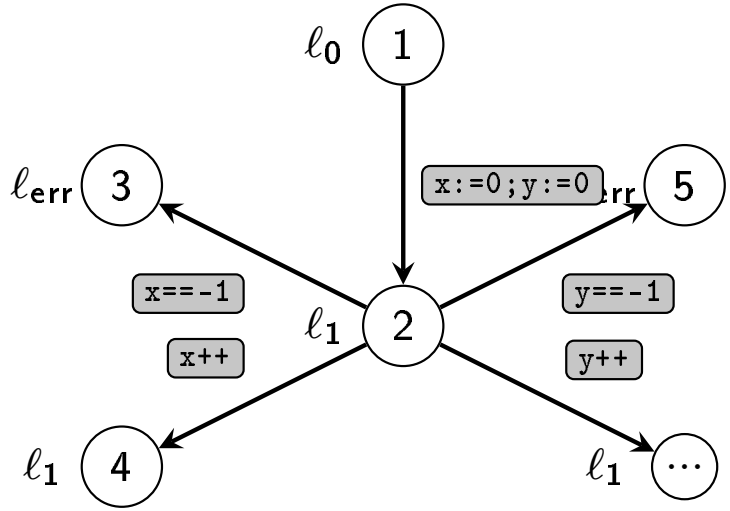

ℓ_0
1

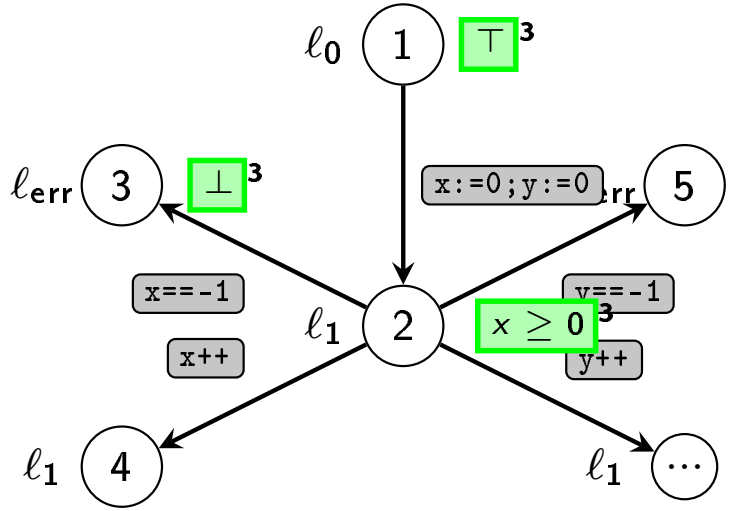

ℓ_0
1
x:=0;y:=0
ℓ_1
2

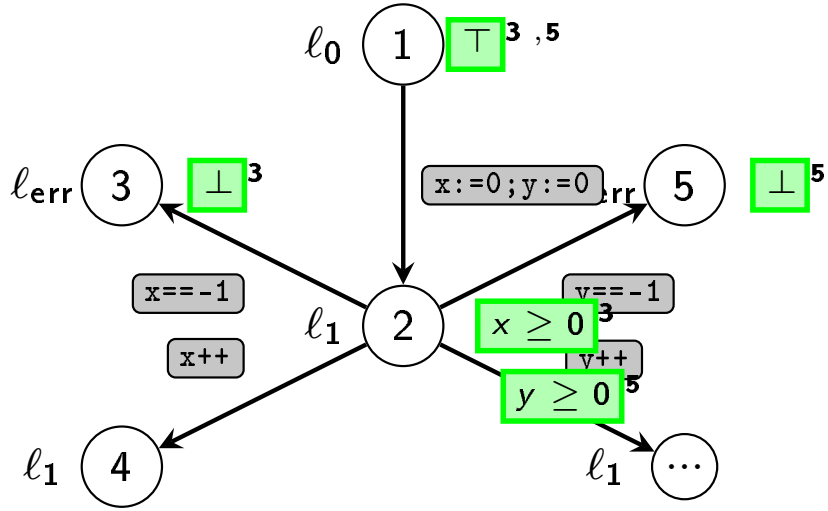

ℓ_0
1
x:=0;y:=0
ℓ_{err}
3
x==-1
ℓ_1
2

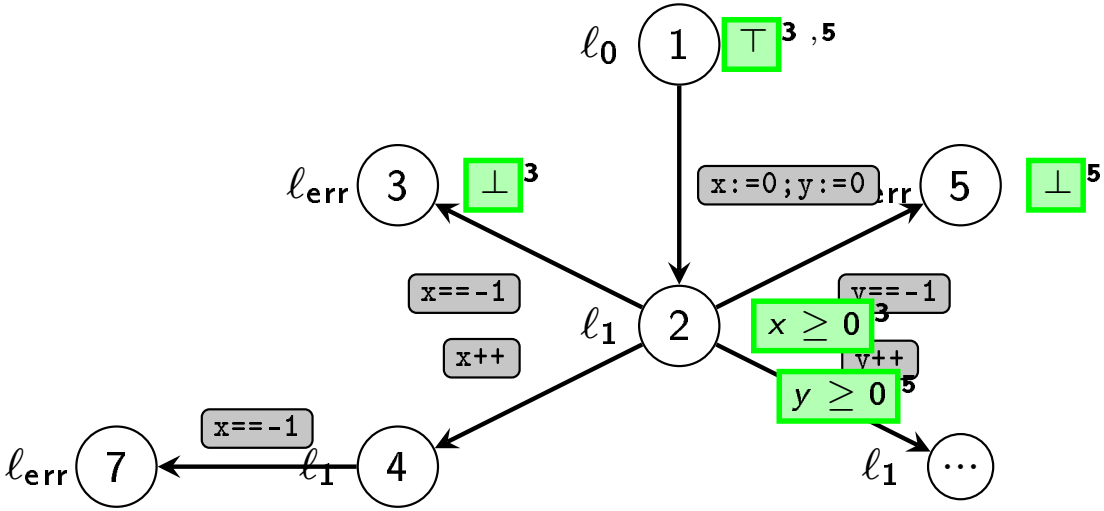

ℓ_0
1
x:=0;y:=0
ℓ_{err}
3
x==-1
ℓ_1
2
x++
ℓ_1
4

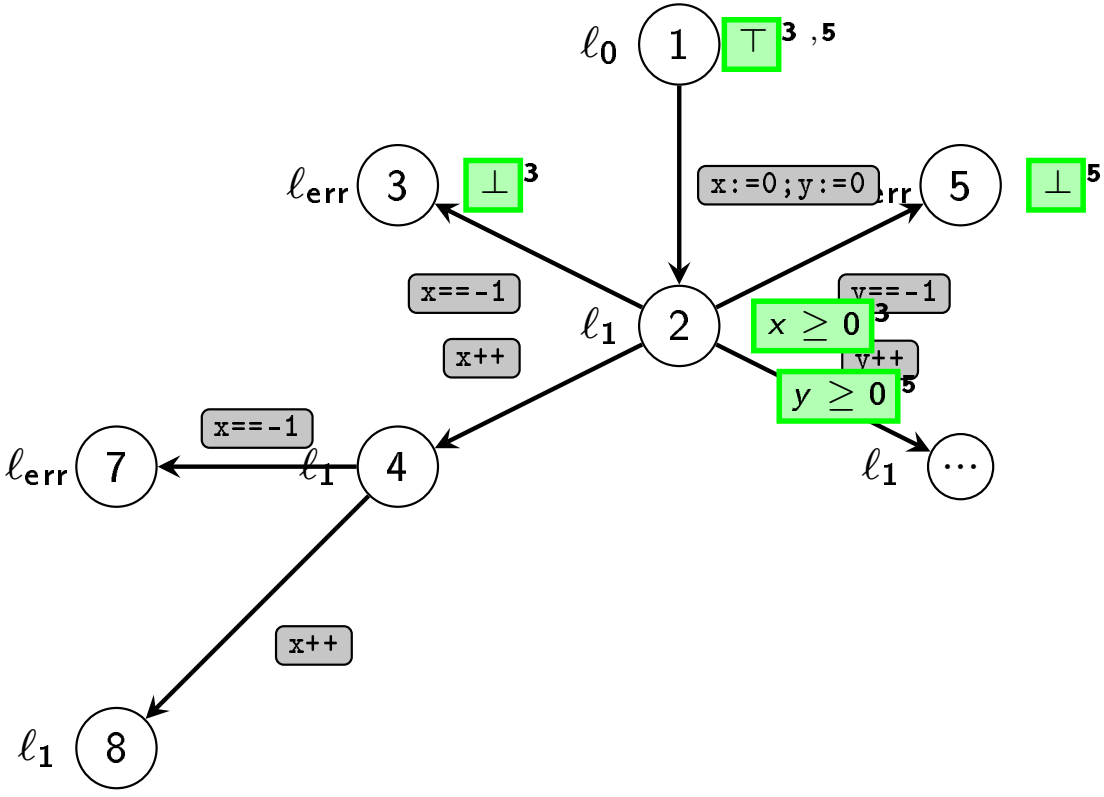

ℓ_0
1
ℓ_{err}
3
x:=0;y:=0
5
x==-1
y==-1
ℓ_1
2
x++
ℓ_1
4

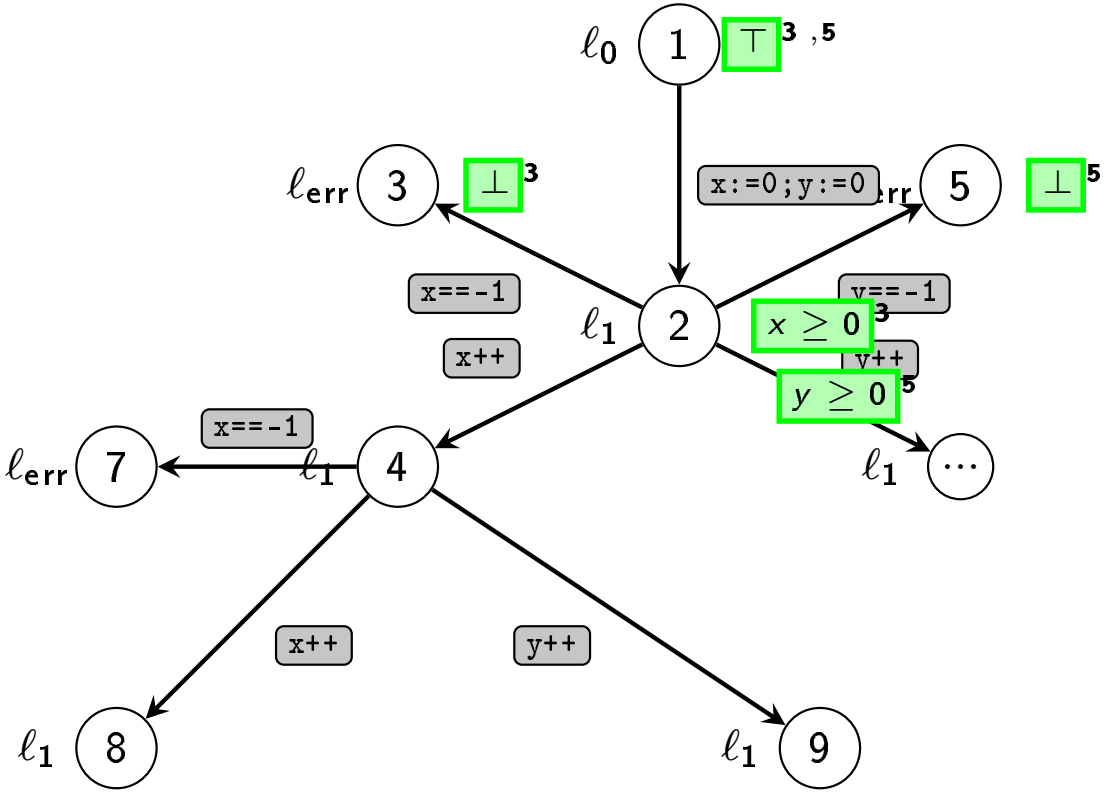

ℓ_0
1
x:=0;y:=0
ℓ_{err}
3
5
x==-1
y==-1
ℓ_1
2
x++
y++
ℓ_1
4
ℓ_1
...

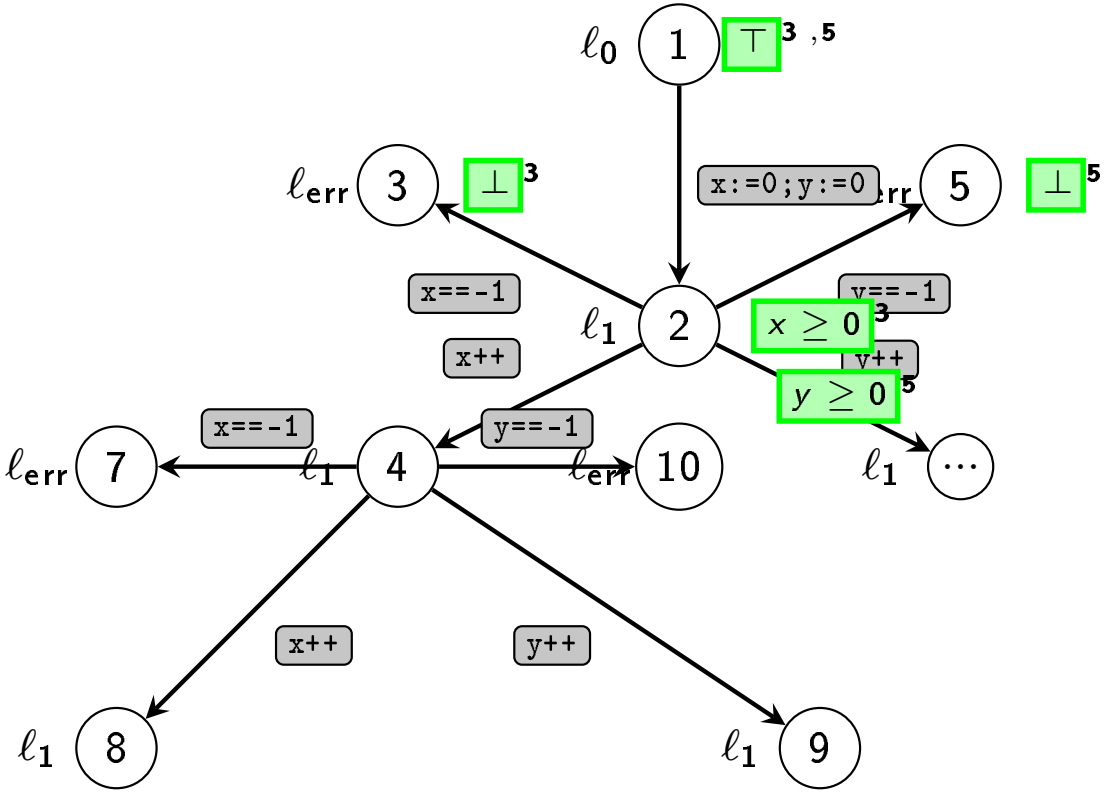

ℓ_0
1
$\top$
3
ℓ_{err}
3
$\bot$
3
x:=0;y:=0
5
x==-1
x++
ℓ_1
2
$x \geq 0$
3
y==-1
y++
ℓ_1
4
ℓ_1
...

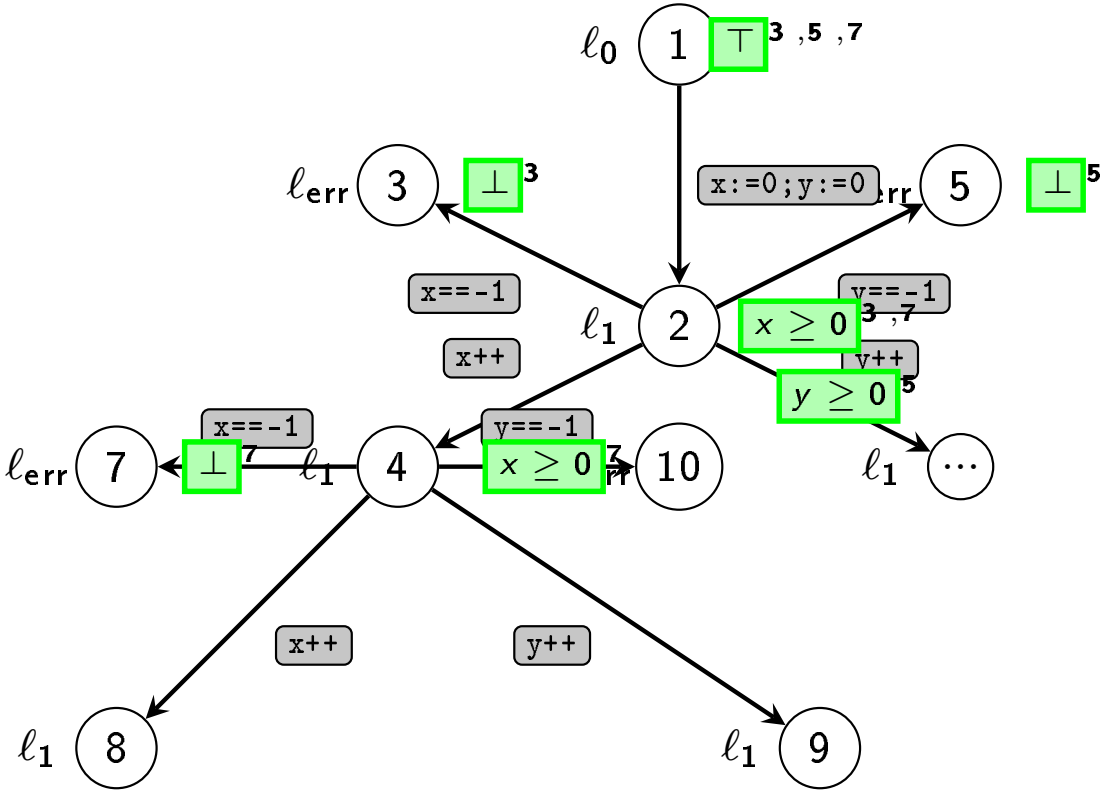

ℓ_0
1
$\top$ 3 ,5
ℓ_{err}
3
$\bot$ 3
x:=0;y:=0
5
$\bot$ 5
x==-1
x++
ℓ_1
2
y==-1
$x \geq 0$ 3
y++
$y \geq 0$ 5
ℓ_1
4
ℓ_1
...

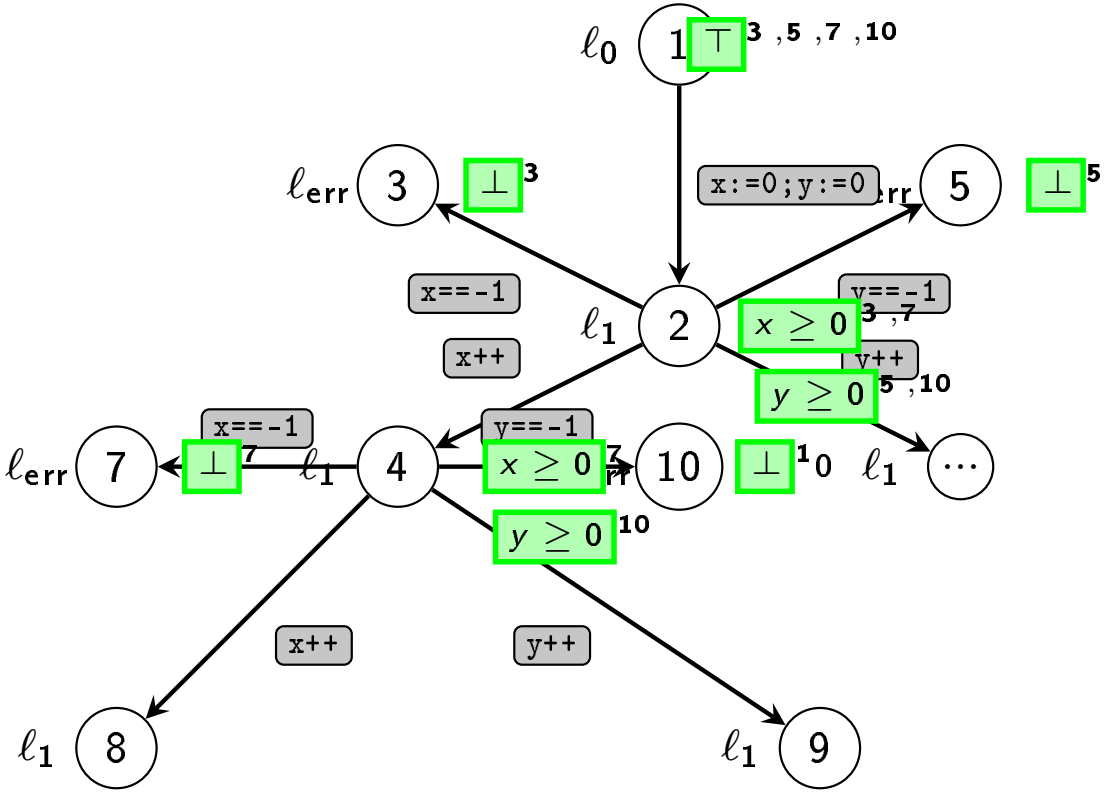

ℓ_0
1
$\top$ 3 ,5
ℓ_{err}
3
$\bot$ 3
x:=0;y:=0
5
$\bot$ 5
x==-1
ℓ_1
2
y==-1
$x \geq 0$ 3
x++
y++
$y \geq 0$ 5
x==-1
ℓ_{err}
7
ℓ_1
4
ℓ_1
...

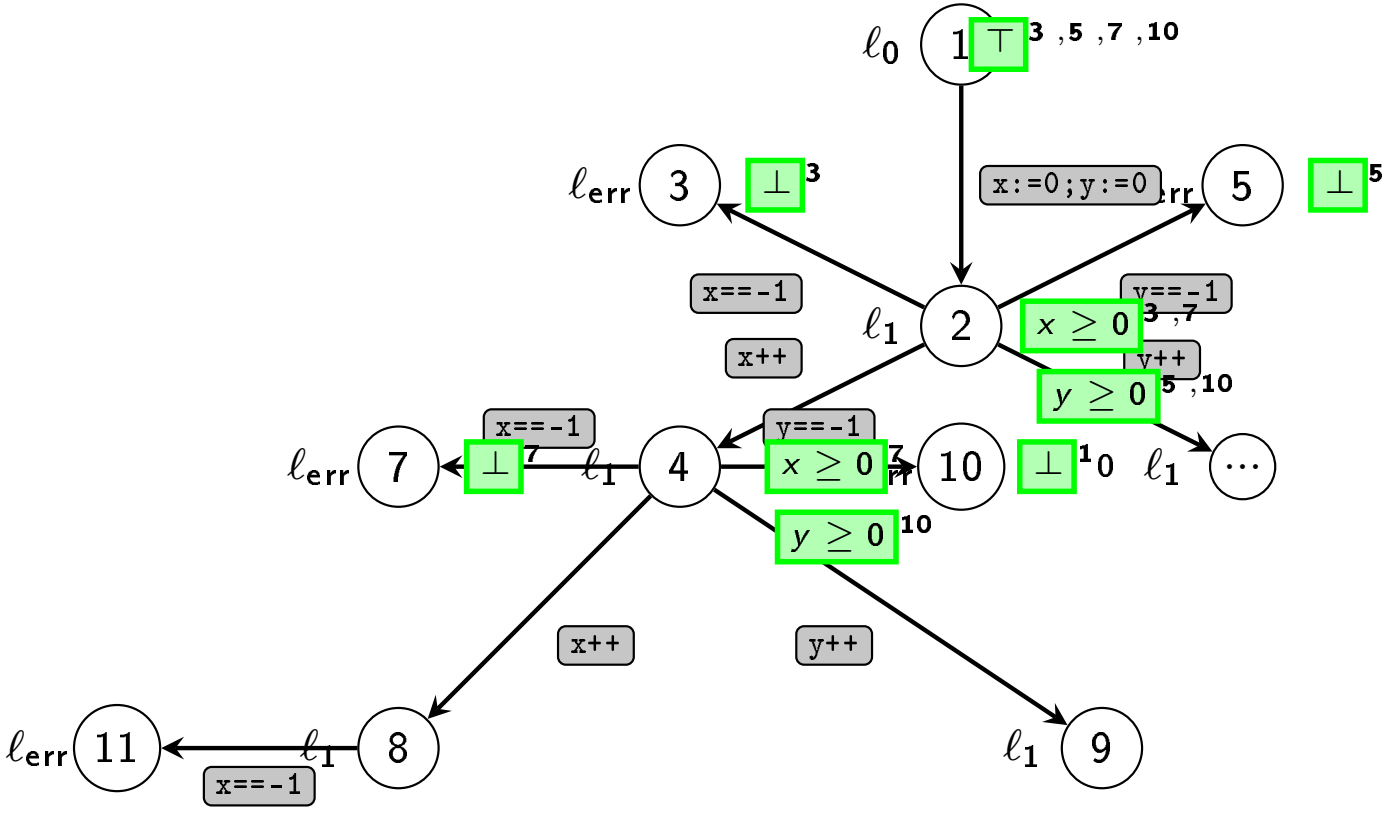

ℓ_0
1
$\top^{3,5}$
ℓ_{err}
3
$\bot^3$
x:=0;y:=0
5
$\bot^5$
x==-1
x++
ℓ_1
2
y==-1
$x \geq 0^3$
y++
$y \geq 0^5$
x==-1
ℓ_{err}
7
ℓ_1
4
ℓ_1
…
x++
ℓ_1
8

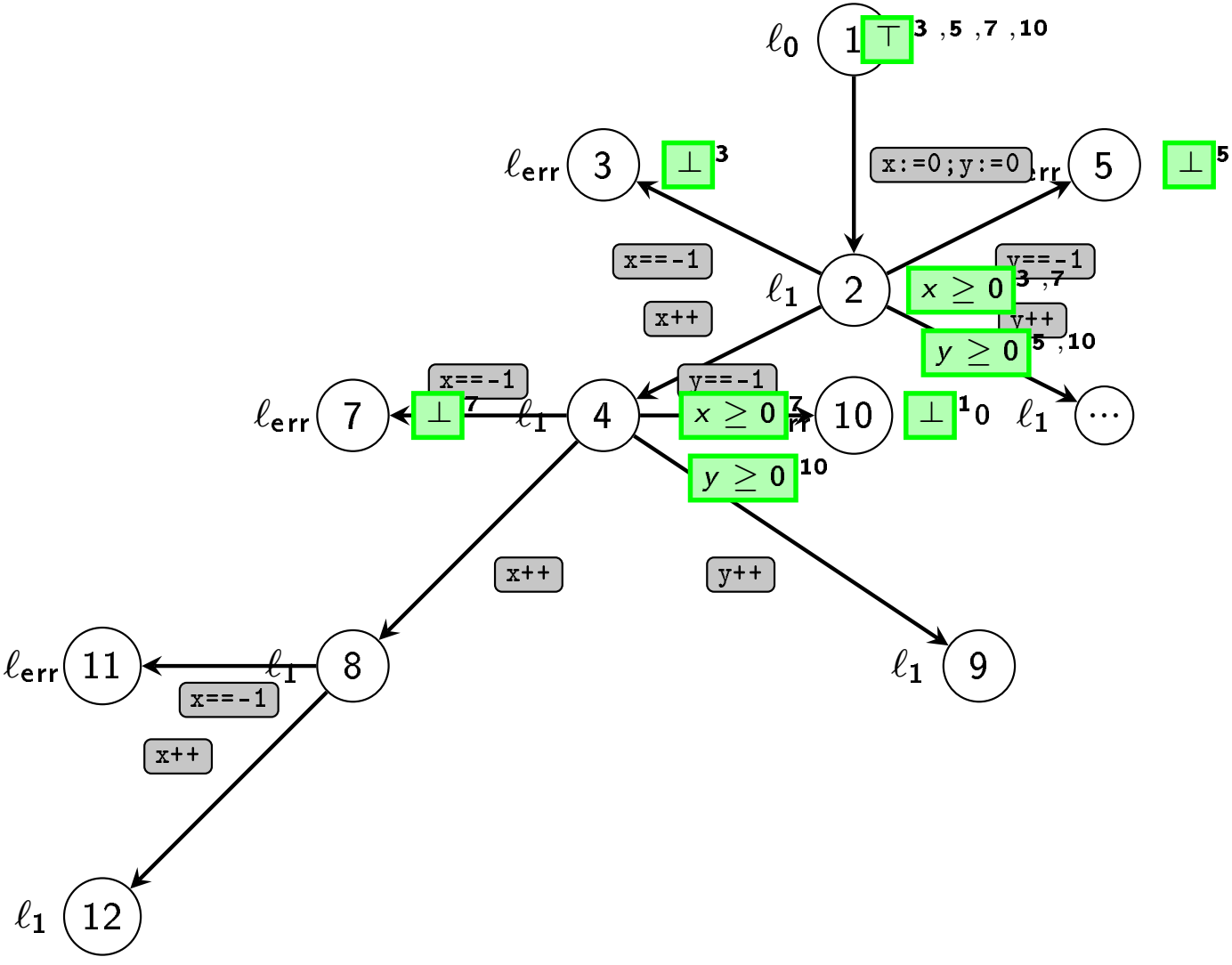

ℓ_0
1
$\top$ 3 ,5
ℓ_{err}
3
$\bot$ 3
x:=0;y:=0
5
$\bot$ 5
x==-1
ℓ_1
2
y==-1
$x \geq 0$ 3
x++
y++
$y \geq 0$ 5
x==-1
ℓ_{err}
7
ℓ_1
4
ℓ_1
…
x++
y++
ℓ_1
8
ℓ_1
9

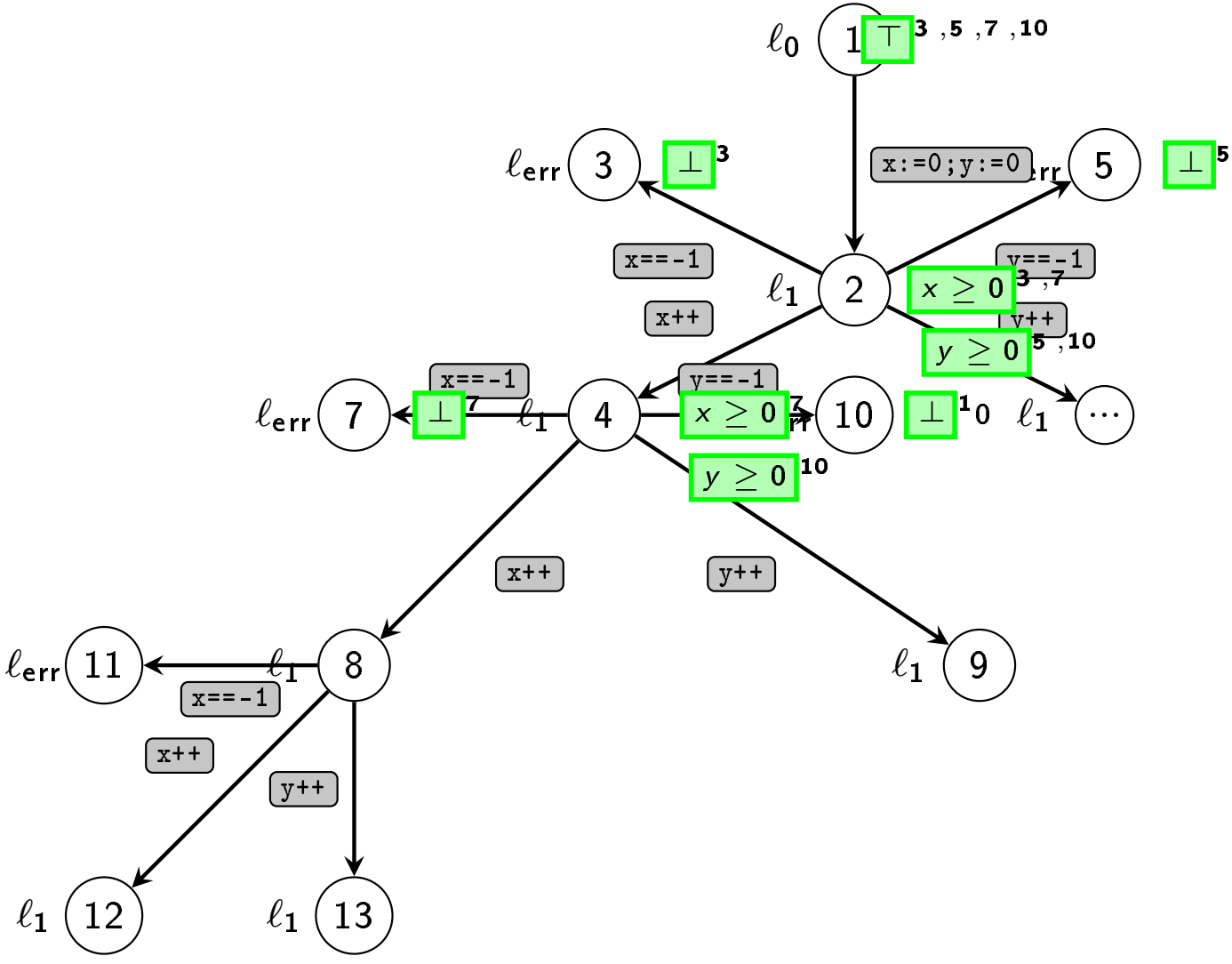

ℓ_0
1
$\top$ 3 ,5
ℓ_{err}
3
$\bot$ 3
x:=0;y:=0
5
$\bot$ 5
x==-1
ℓ_1
2
y==-1
$x \geq 0$ 3
x++
y++
$y \geq 0$ 5
x==-1
y==-1
ℓ_{err}
7
ℓ_1
4
ℓ_{err}
10
ℓ_1
...
x++
y++
ℓ_1
8
ℓ_1
9

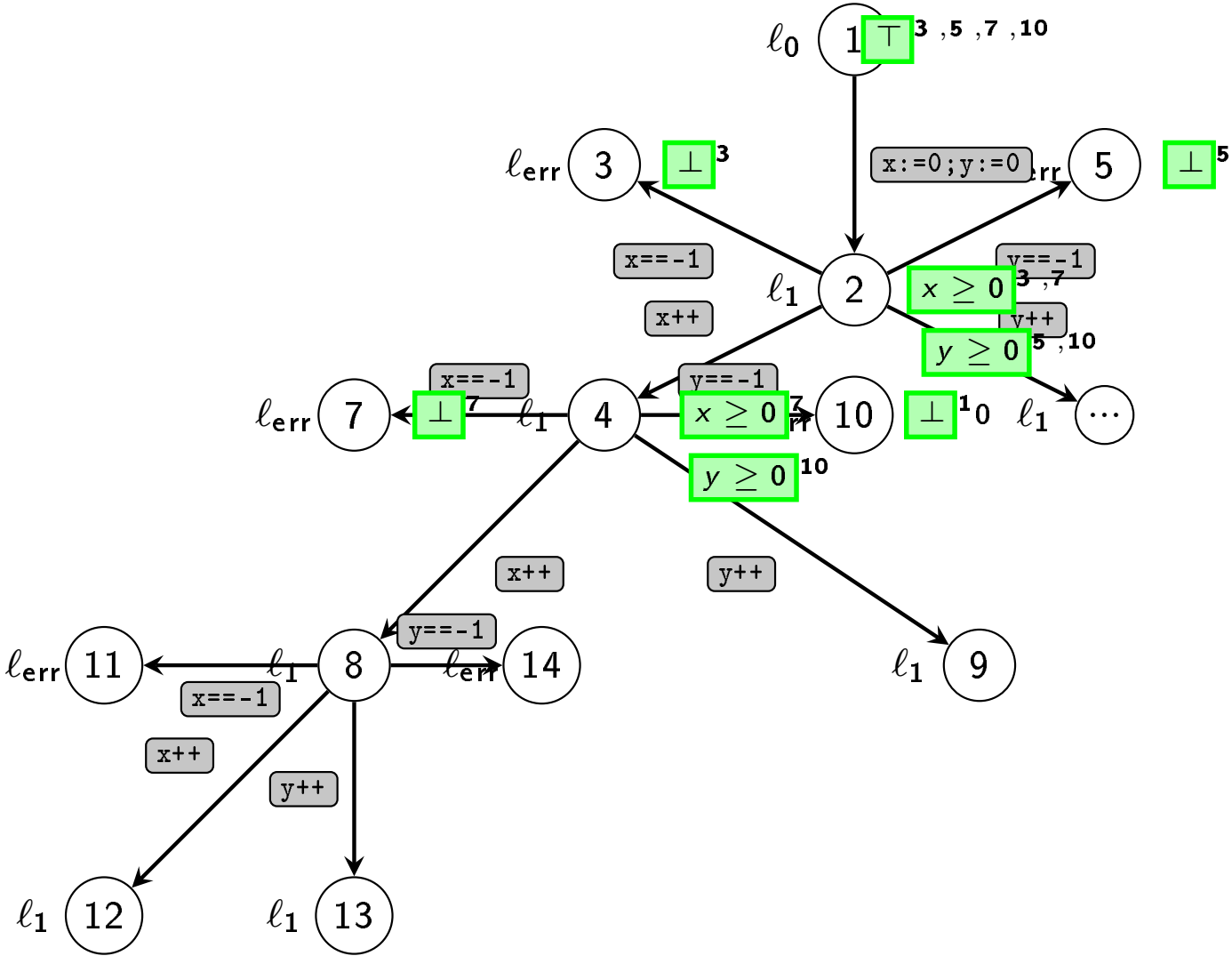

ℓ_0
1
$\top$
3 ,5 ,7
ℓ_{err}
3
$\bot$
3
x:=0;y:=0
5
$\bot$
5
x==-1
ℓ_1
2
y==-1
$x \geq 0$
3 ,7
x++
y++
$y \geq 0$
5
x==-1
y==-1
ℓ_{err}
7
$\bot$
7
ℓ_1
4
$x \geq 0$
7
10
ℓ_1
…
x++
y++
ℓ_1
8
ℓ_1
9

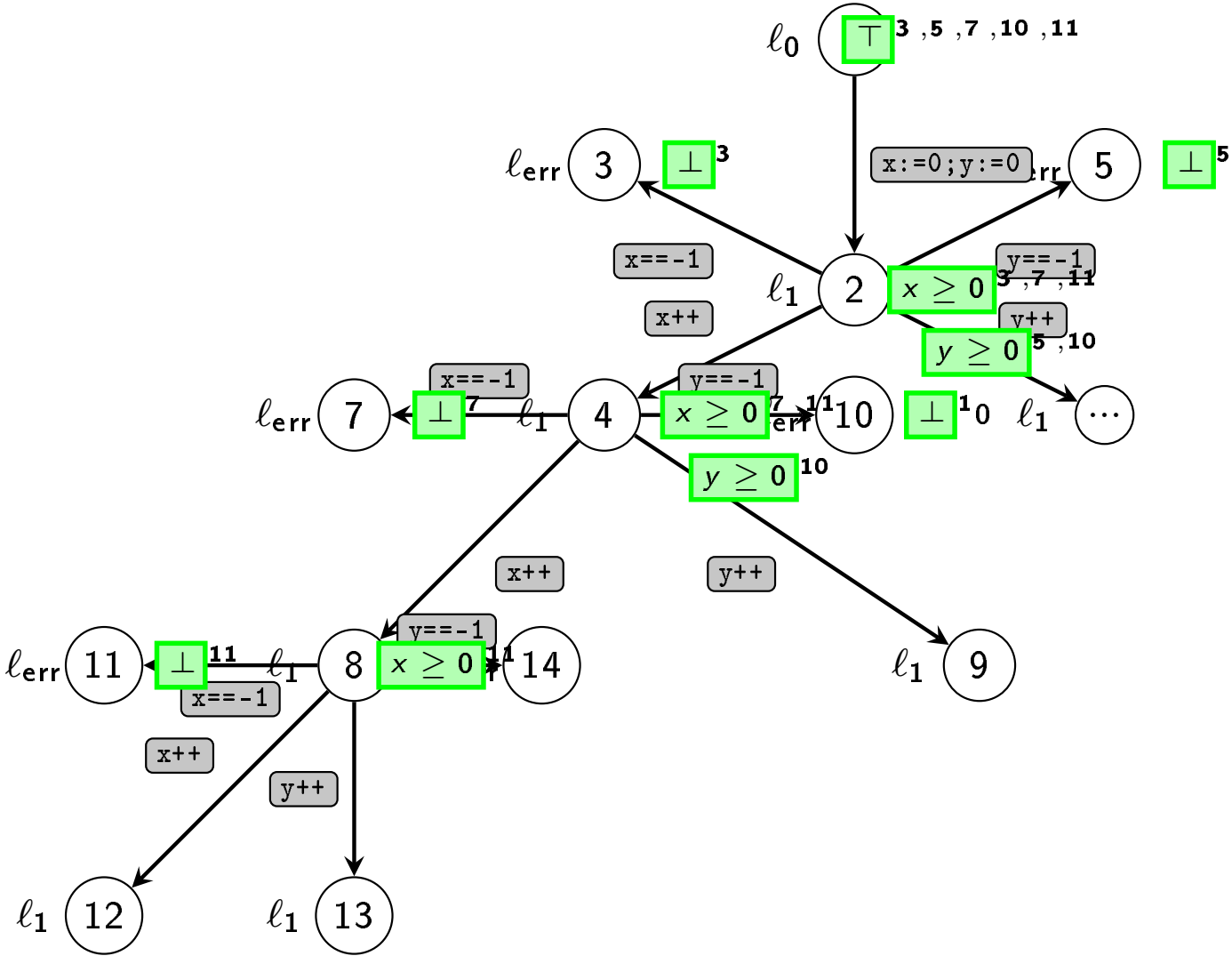

ℓ_0
1
$\top$
3 ,5 ,7 ,10
ℓ_{err}
3
$\bot$
3
x:=0;y:=0
5
$\bot$
5
x==-1
ℓ_1
2
$x \geq 0$
3 ,7
y==-1
x++
y++
5 ,10
$y \geq 0$
x==-1
y==-1
ℓ_{err}
7
$\bot$
7
ℓ_1
4
$x \geq 0$
7
10
$\bot$
10
ℓ_1
...
$y \geq 0$
10
x++
y++
ℓ_1
8
ℓ_1
9

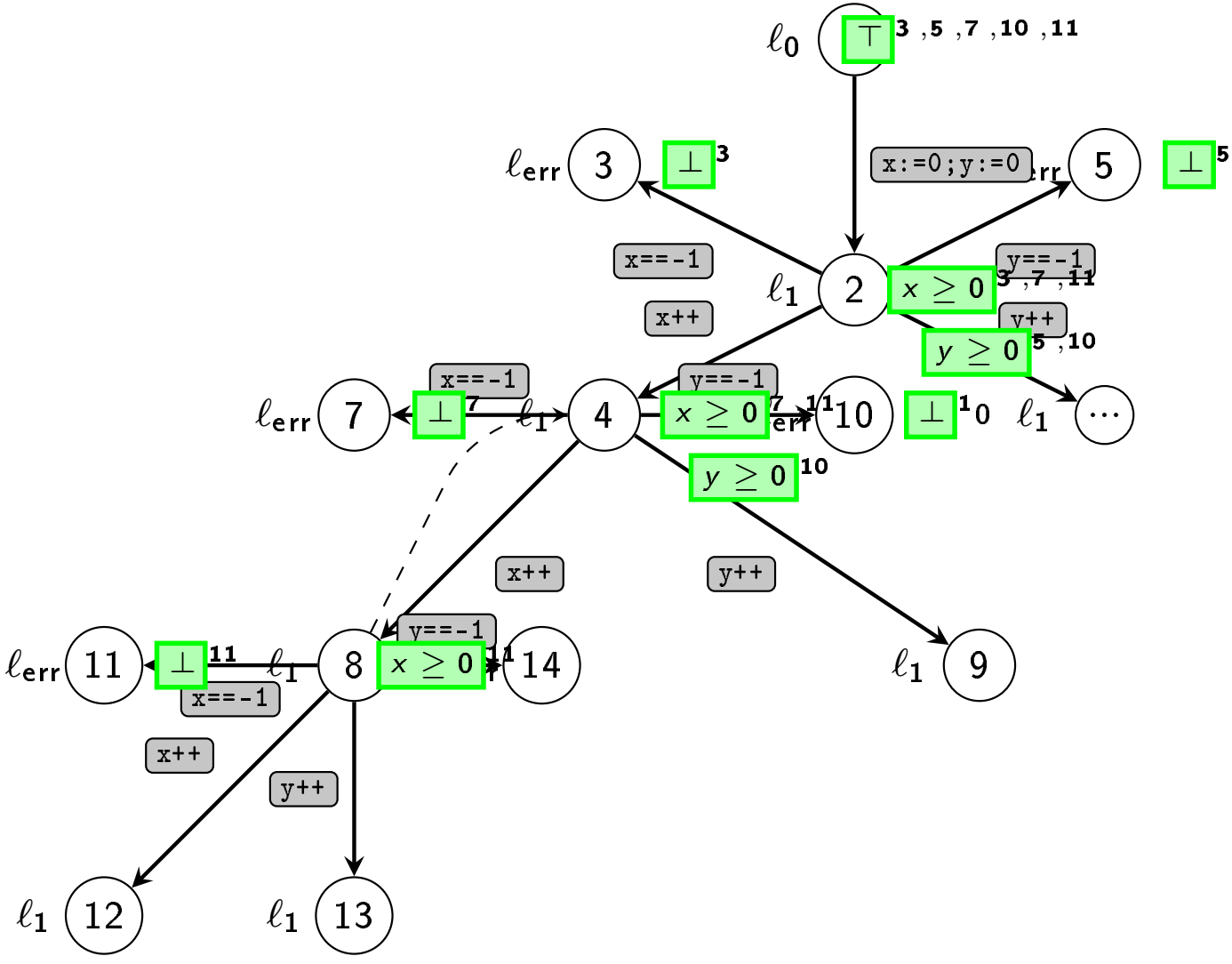

ℓ_0
1
$\top$
3 ,5 ,7 ,10
ℓ_{err}
3
$\bot$
3
x:=0;y:=0
5
$\bot$
5
x==-1
ℓ_1
2
y==-1
3 ,7
$x \geq 0$
x++
y++
5 ,10
$y \geq 0$
x==-1
y==-1
ℓ_{err}
7
$\bot$
7
ℓ_1
4
$x \geq 0$
7
10
$\bot$
10
ℓ_1
$\cdots$
$y \geq 0$
10
x++
y++
ℓ_{err}
11
ℓ_1
8
ℓ_1
9
x==-1

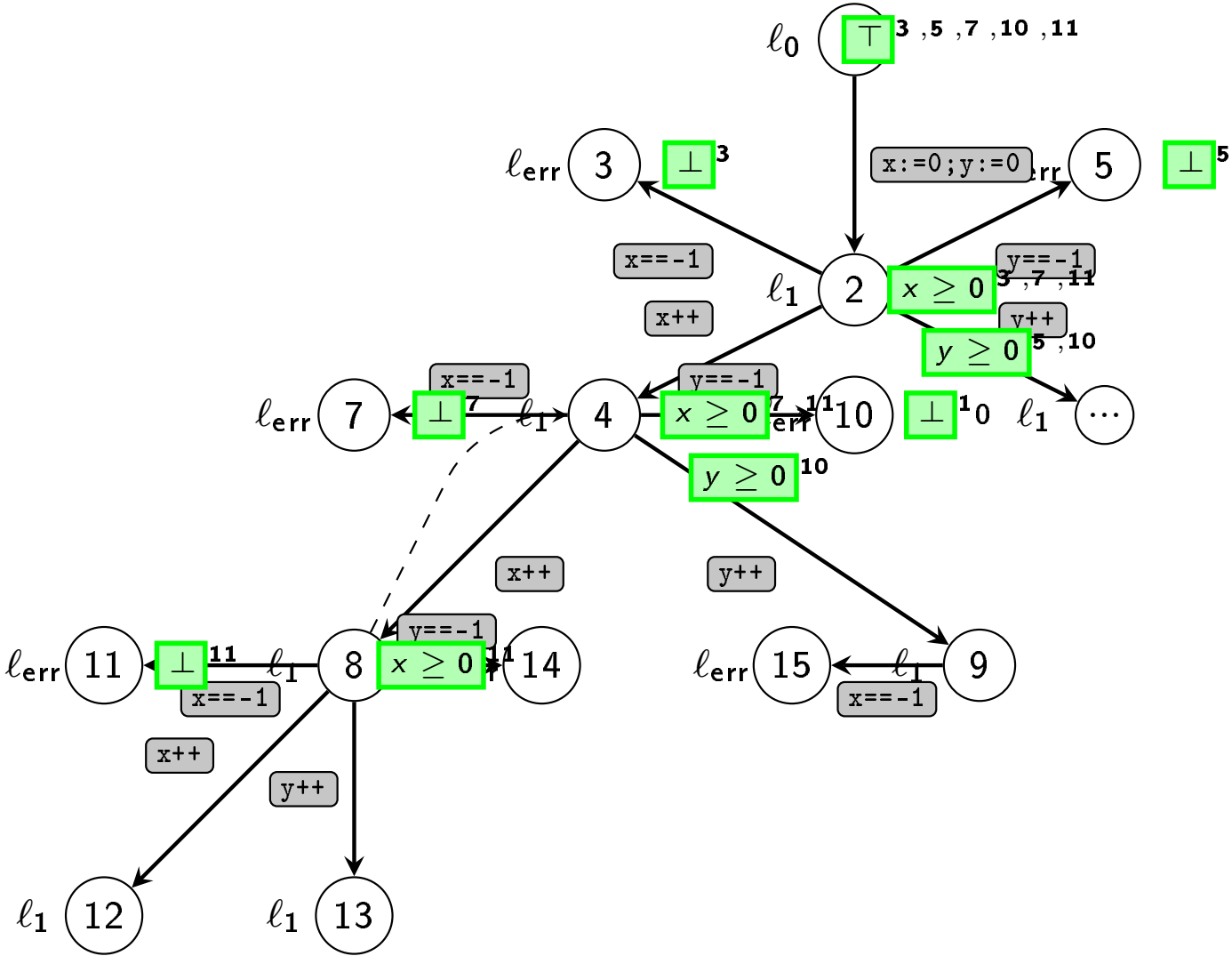

ℓ_0
1
$\top$ 3 ,5 ,7 ,10
ℓ_{err}
3
$\bot$ 3
x:=0;y:=0
5
$\bot$ 5
x==-1
ℓ_1
2
y==-1
$x \geq 0$ 3 ,7
x++
y++
$y \geq 0$ 5 ,10
x==-1
y==-1
ℓ_{err}
7
$\bot$ 7
ℓ_1
4
$x \geq 0$ 7
10
$\bot$ 10
ℓ_1
…
$y \geq 0$ 10
x++
y++
ℓ_{err}
11
ℓ_1
8
ℓ_1
9
x==-1
x++
ℓ_1
12

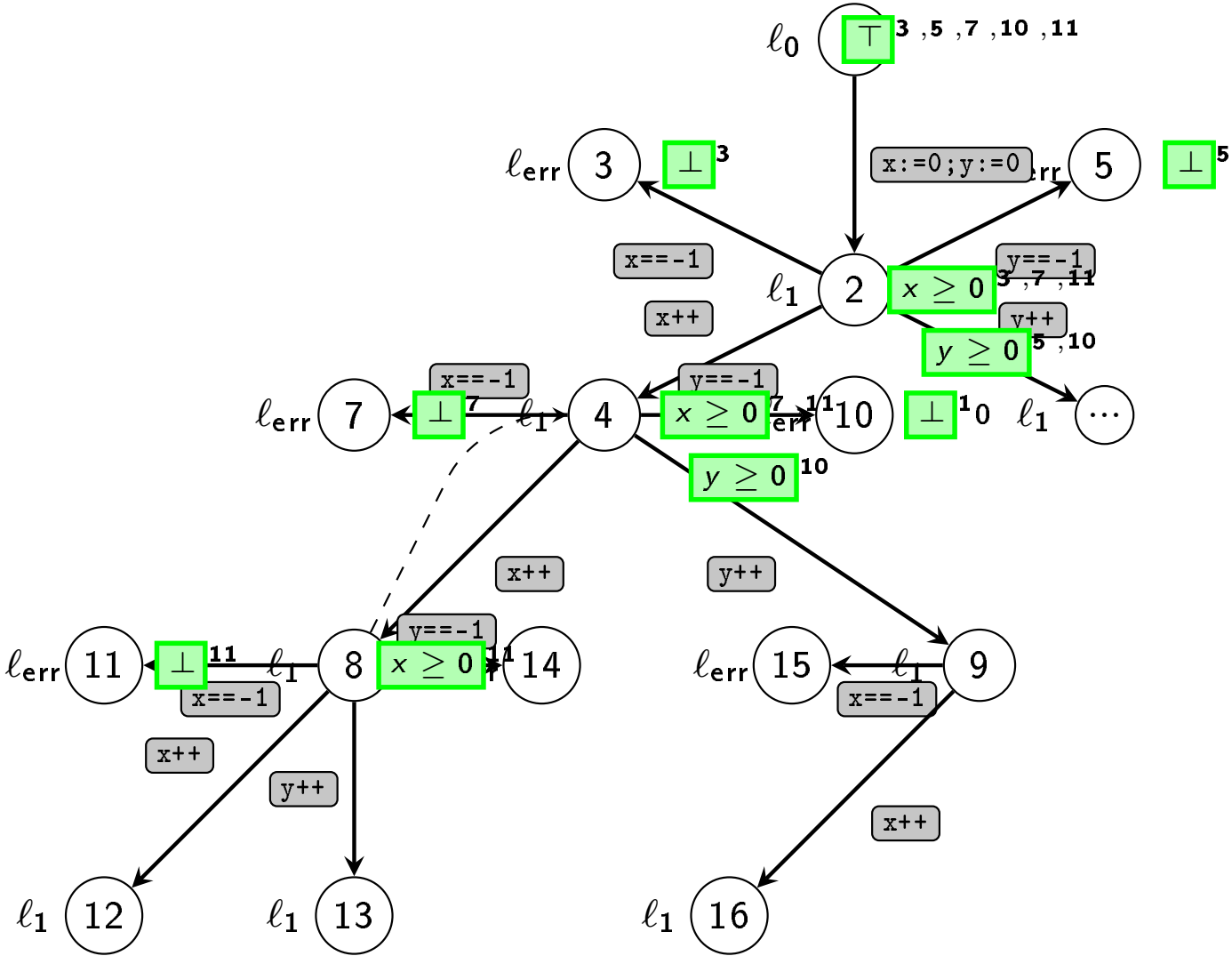

ℓ_0
1
$\top$
3 ,5 ,7 ,10
ℓ_{err}
3
$\bot$
3
x:=0;y:=0
5
$\bot$
5
x==-1
ℓ_1
2
$x \geq 0$
3 ,7
x++
y==-1
y++
5 ,10
$y \geq 0$
ℓ_{err}
7
x==-1
$\bot$
7
ℓ_1
4
y==-1
$x \geq 0$
7
10
$\bot$
10
ℓ_1
$\cdots$
$y \geq 0$
10
x++
y++
ℓ_{err}
11
ℓ_1
8
ℓ_1
9
x==-1
x++
y++
ℓ_1
12
ℓ_1
13

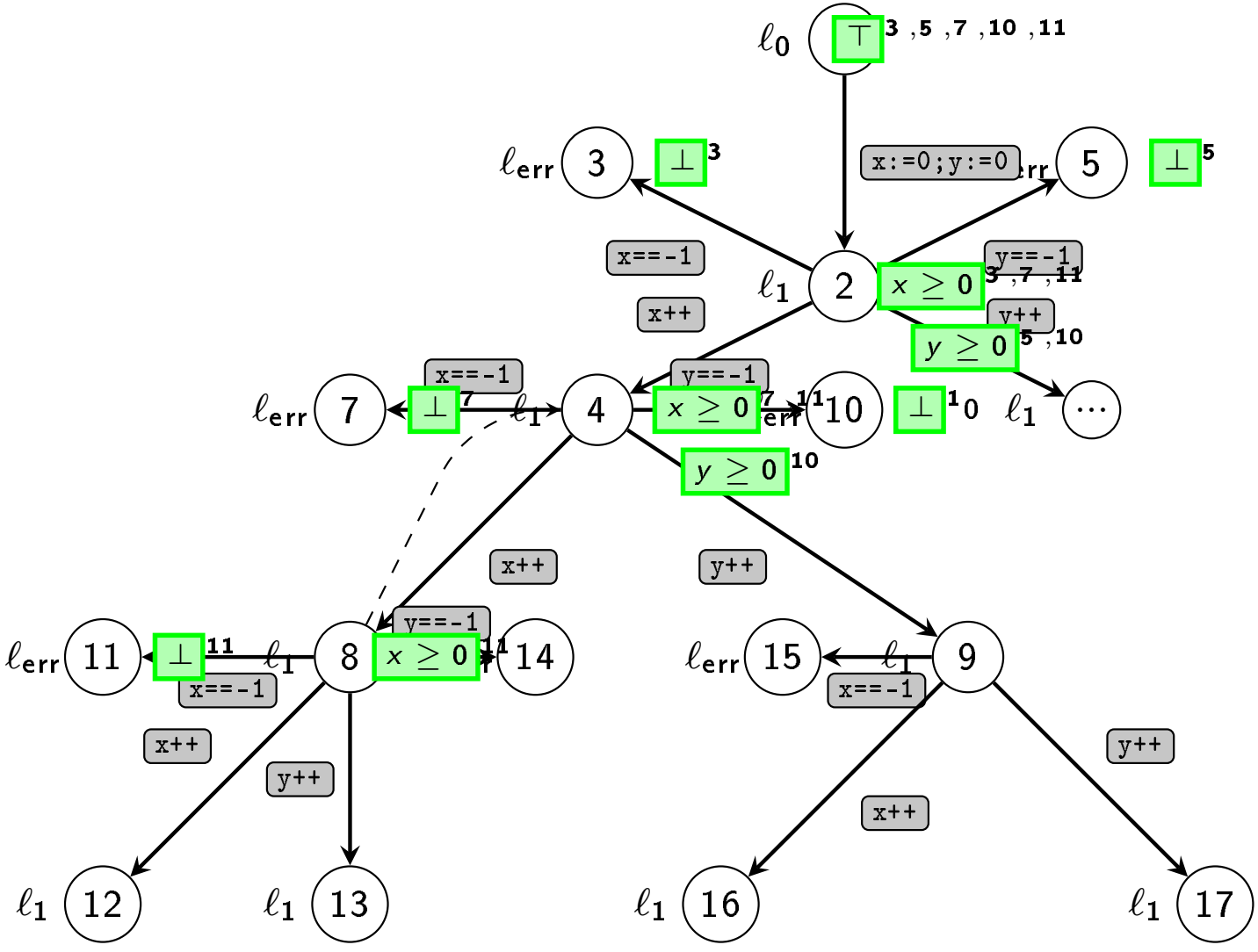

ℓ_0
1
$\top$
3 ,5 ,7 ,10
ℓ_{err}
3
$\bot$
3
x:=0;y:=0
5
$\bot$
5
x==-1
ℓ_1
2
$x \geq 0$
3 ,7
y==-1
x++
y++
5 ,10
$y \geq 0$
x==-1
y==-1
ℓ_{err}
7
$\bot$
7
ℓ_1
4
$x \geq 0$
7
10
$\bot$
10
ℓ_1
…
$y \geq 0$
10
x++
y++
y==-1
ℓ_{err}
11
ℓ_1
8
ℓ_{err}
14
ℓ_1
9
x==-1
x++
y++
ℓ_1
12
ℓ_1
13

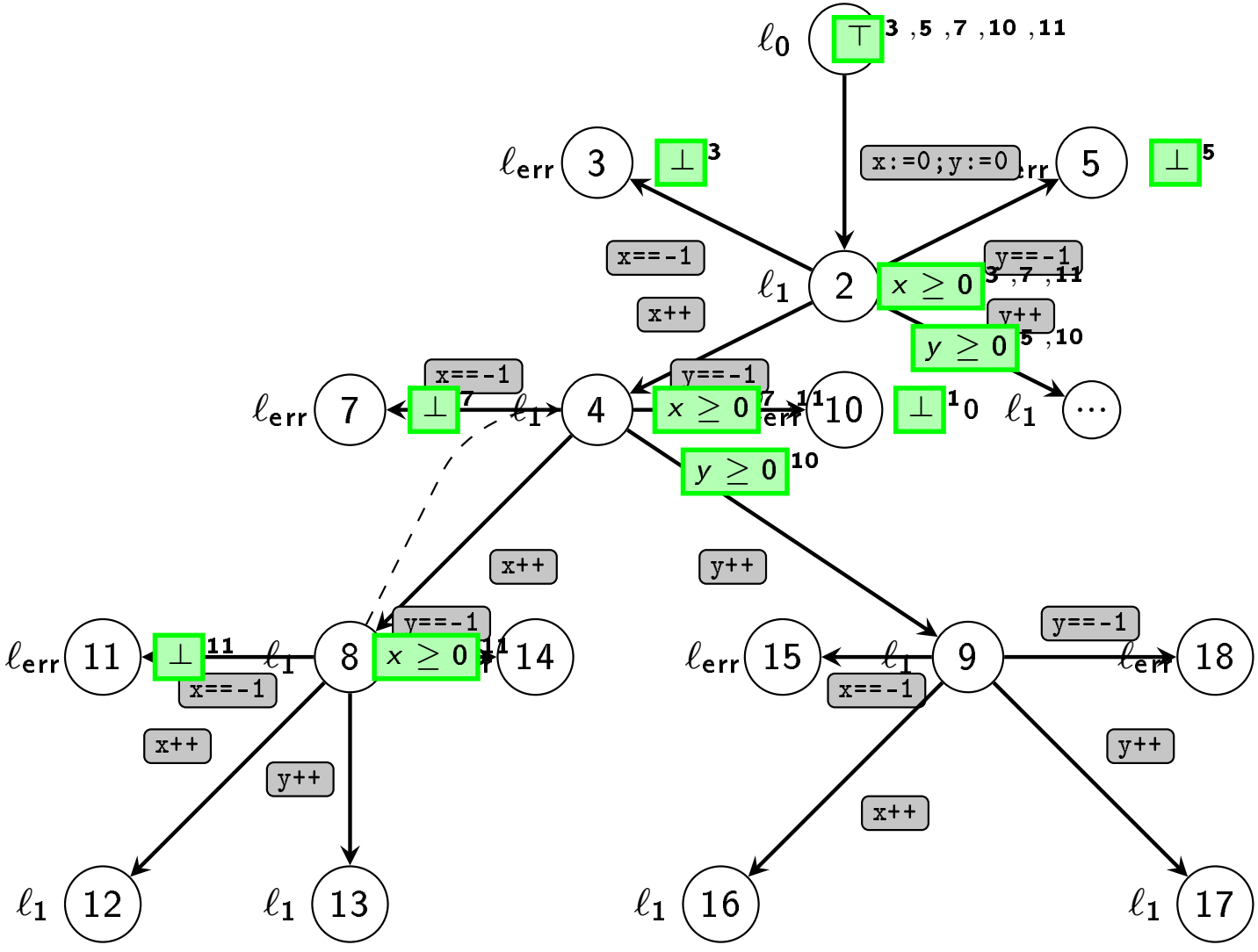

ℓ_0
$\top$ 3 ,5 ,7 ,10 ,11
ℓ_{err}
3
$\bot$ 3
x:=0;y:=0
5
$\bot$ 5
x==-1
ℓ_1
2
$x \geq 0$ 3 ,7 ,11
y==-1
x++
y++
$y \geq 0$ 5 ,10
x==-1
y==-1
ℓ_{err}
7
$\bot$ 7
ℓ_1
4
$x \geq 0$ 7 ,11
10
$\bot$ 10
ℓ_1
…
$y \geq 0$ 10
x++
y++
y==-1
ℓ_{err}
11
$\bot$ 11
ℓ_1
8
$x \geq 0$ 11
14
ℓ_1
9
x==-1
x++
y++
ℓ_1
12
ℓ_1
13

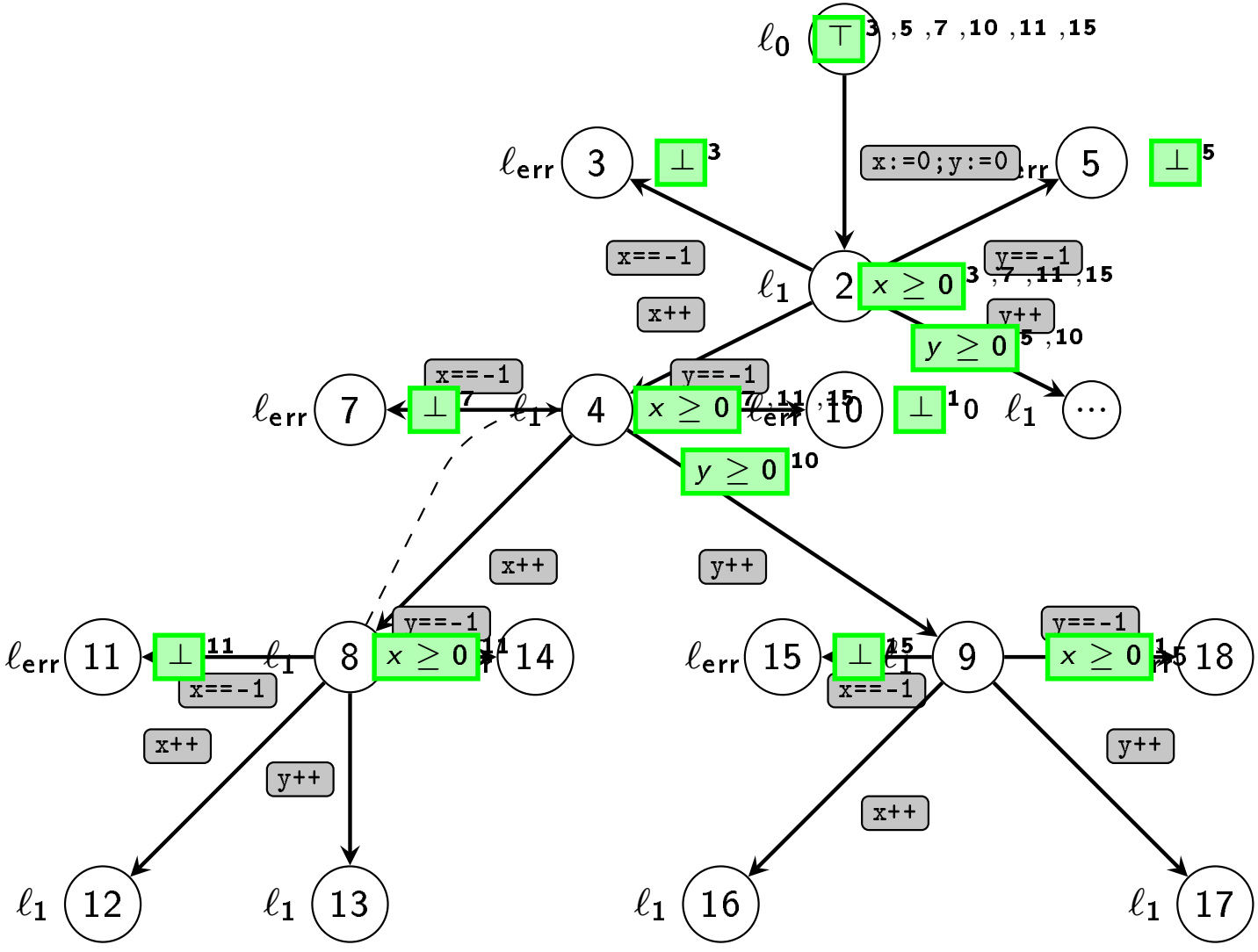

ℓ_0
$\top$ 3 ,5 ,7 ,10 ,11
ℓ_{err} 3 $\bot$ 3
x:=0;y:=0
5 $\bot$ 5
x==-1
ℓ_1 2 $x \geq 0$ 3 ,7 ,11
y==-1
x++
y++
$y \geq 0$ 5 ,10
x==-1
y==-1
ℓ_{err} 7 $\bot$ 7 ℓ_1 4 $x \geq 0$ 7 ,11 10 $\bot$ 10 ℓ_1 ...
$y \geq 0$ 10
x++
y++
y==-1
ℓ_{err} 11 $\bot$ 11 ℓ_1 8 $x \geq 0$ 11 14
ℓ_1 9
x==-1
x++
y++
ℓ_1 12
ℓ_1 13

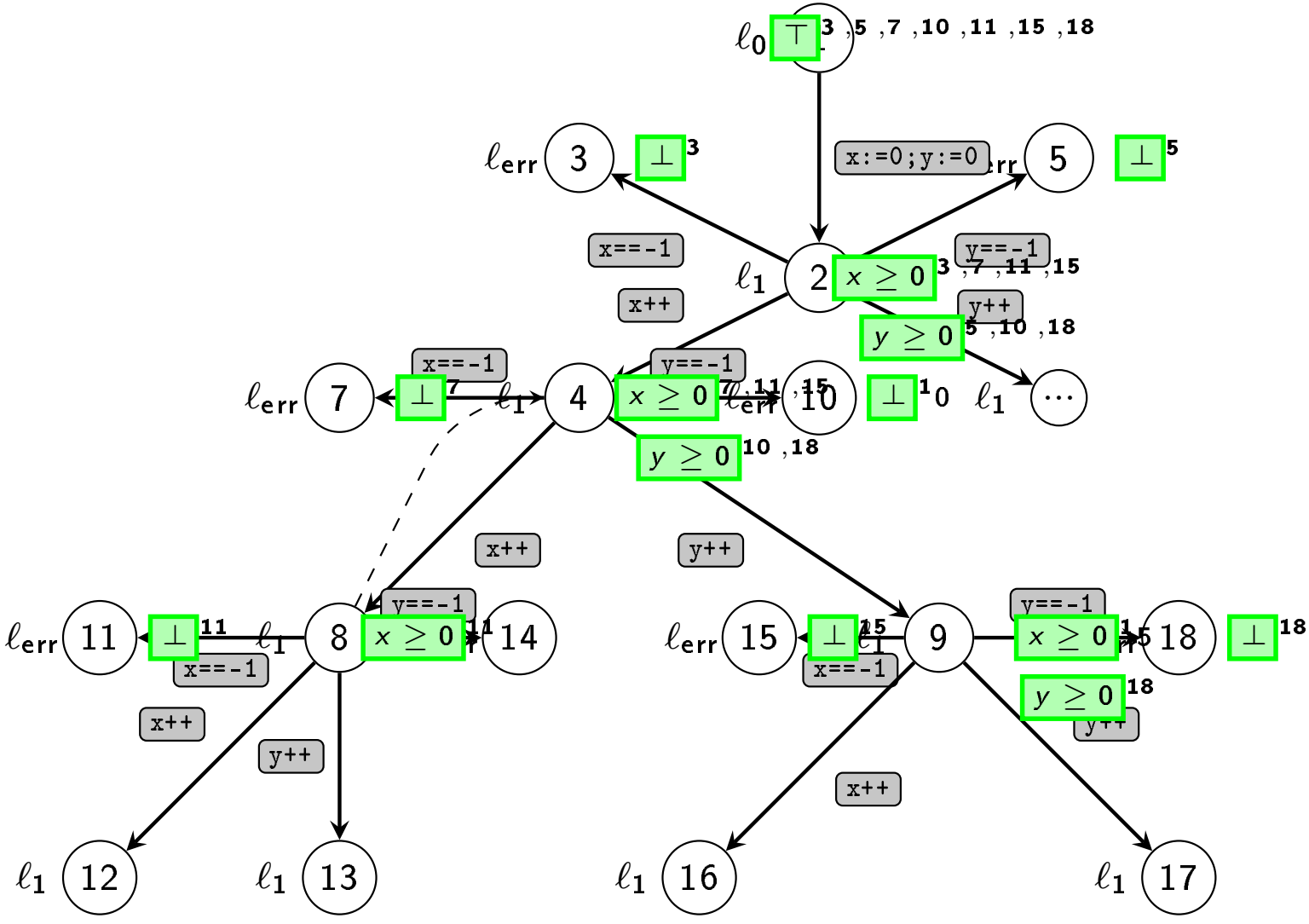

ℓ_0
$\top$ 3 ,5 ,7 ,10 ,11
ℓ_{err}
3
$\bot$ 3
x:=0;y:=0
5
$\bot$ 5
x==-1
ℓ_1
2
$x \geq 0$ 3 ,7 ,11
y==-1
x++
y++
$y \geq 0$ 5 ,10
ℓ_{err}
7
x==-1
$\bot$ 7
ℓ_1
4
y==-1
$x \geq 0$ 7 ,11
10
$\bot$ 10
ℓ_1
…
$y \geq 0$ 10
x++
y++
ℓ_{err}
11
$\bot$ 11
ℓ_1
8
y==-1
$x \geq 0$ 11
14
x==-1
ℓ_{err}
15
ℓ_1
9
x==-1
x++
y++
ℓ_1
12
ℓ_1
13

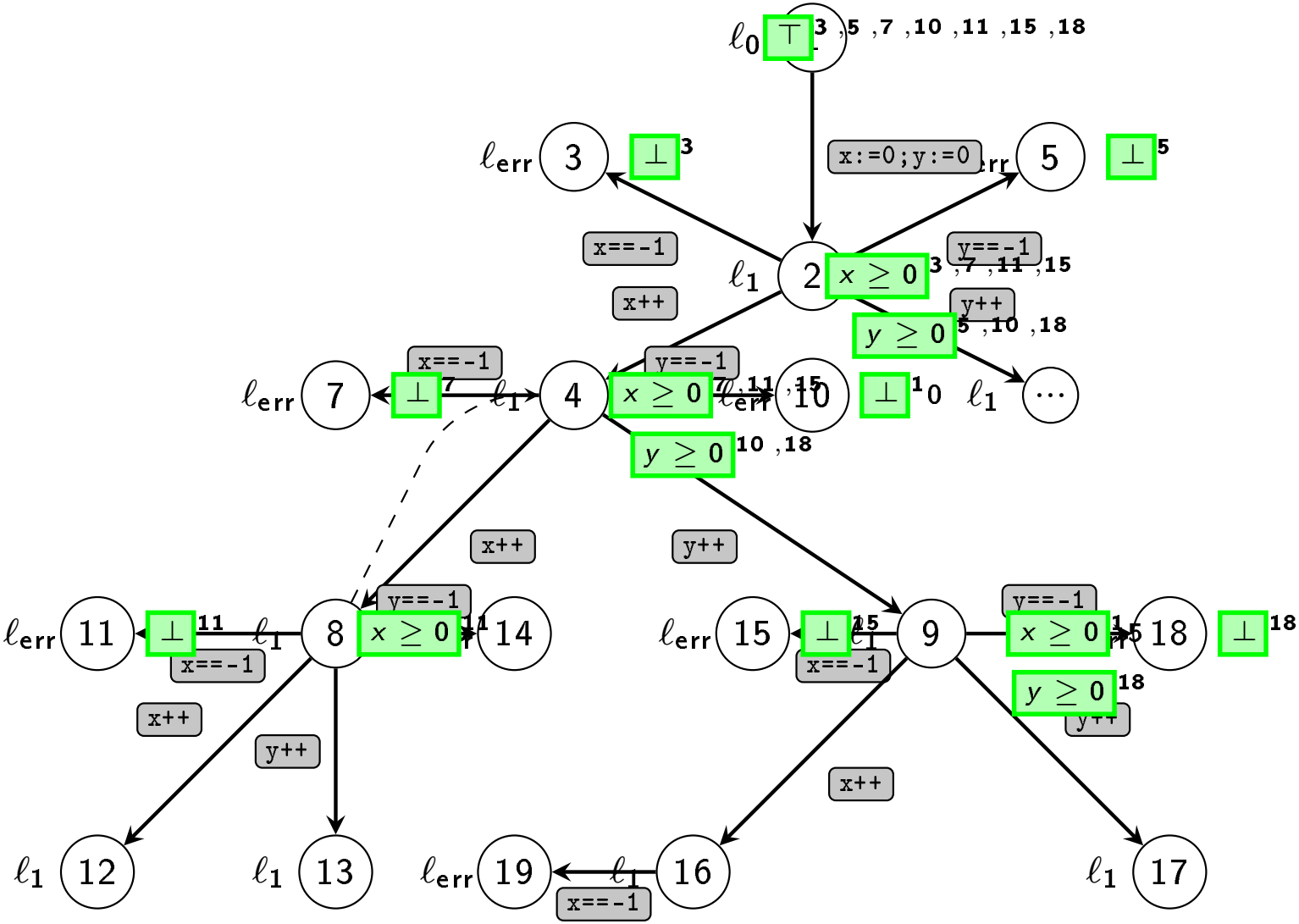

ℓ_0
$\top$
3 ,5 ,7 ,10 ,11
ℓ_{err}
3
$\bot$
3
x:=0;y:=0
5
$\bot$
5
x==-1
ℓ_1
2
$x \geq 0$
3 ,7 ,11
y==-1
x++
y++
$y \geq 0$
5 ,10
x==-1
y==-1
ℓ_{err}
7
$\bot$
7
ℓ_1
4
$x \geq 0$
7 ,11
10
$\bot$
10
ℓ_1
$\cdots$
$y \geq 0$
10
x++
y++
y==-1
ℓ_{err}
11
$\bot$
11
ℓ_1
8
$x \geq 0$
11
14
ℓ_{err}
15
ℓ_1
9
x==-1
x==-1
x++
y++
x++
ℓ_1
12
ℓ_1
13
ℓ_1
16

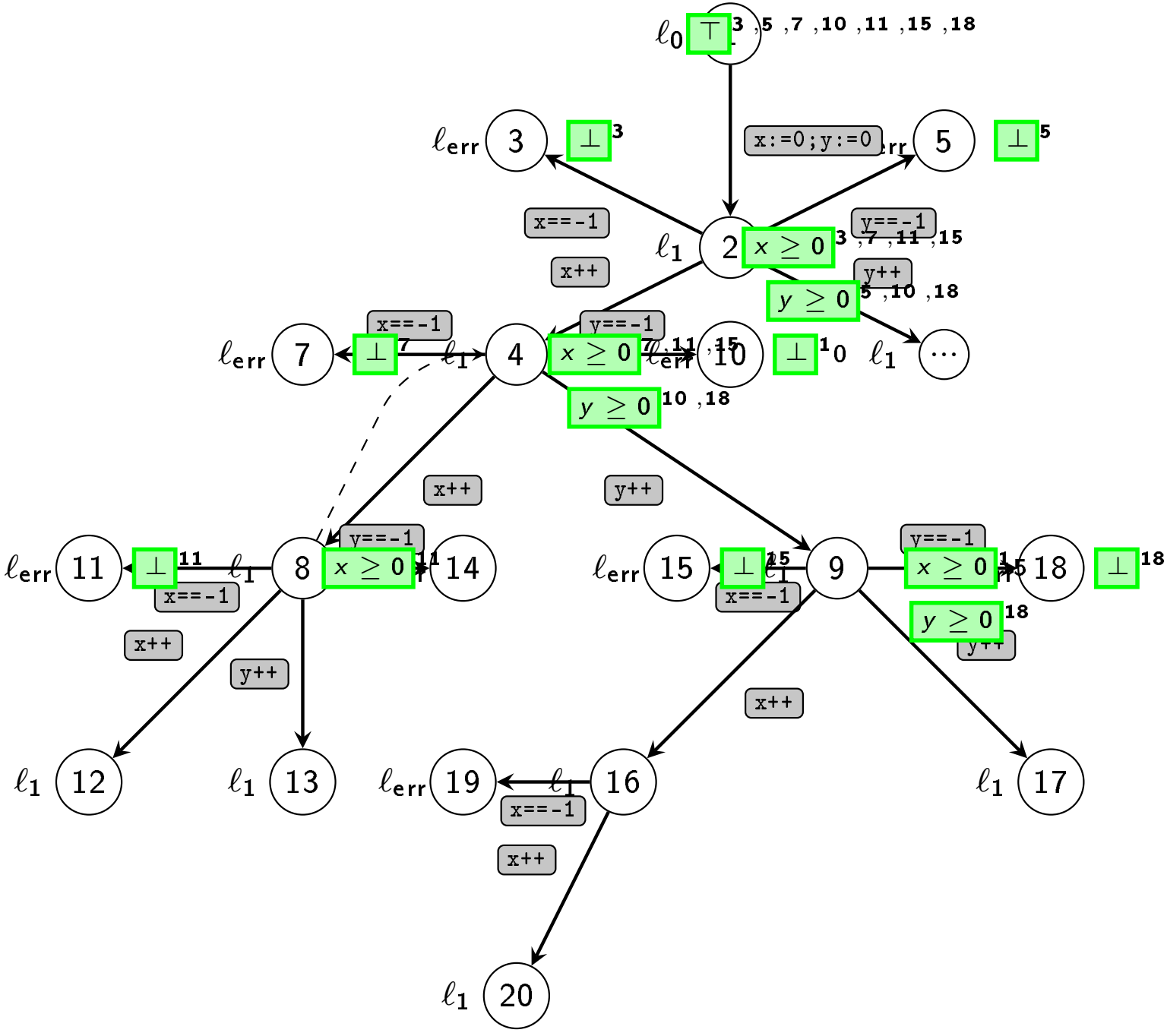

ℓ_0
$\top$ 3 ,5 ,7 ,10 ,11
ℓ_{err}
3
$\bot$ 3
x:=0;y:=0
5
$\bot$ 5
x==-1
ℓ_1
2
$x \geq 0$ 3 ,7 ,11
y==-1
x++
y++
$y \geq 0$ 5 ,10
ℓ_{err}
7
x==-1
$\bot$ 7
ℓ_1
4
y==-1
$x \geq 0$ 7 ,11
10
$\bot$ 10
ℓ_1
...
$y \geq 0$ 10
x++
y++
ℓ_{err}
11
$\bot$ 11
ℓ_1
8
y==-1
$x \geq 0$ 11
14
x==-1
ℓ_{err}
15
ℓ_1
9
x==-1
x++
y++
y++
x++
ℓ_1
12
ℓ_1
13
ℓ_1
16
ℓ_1
17

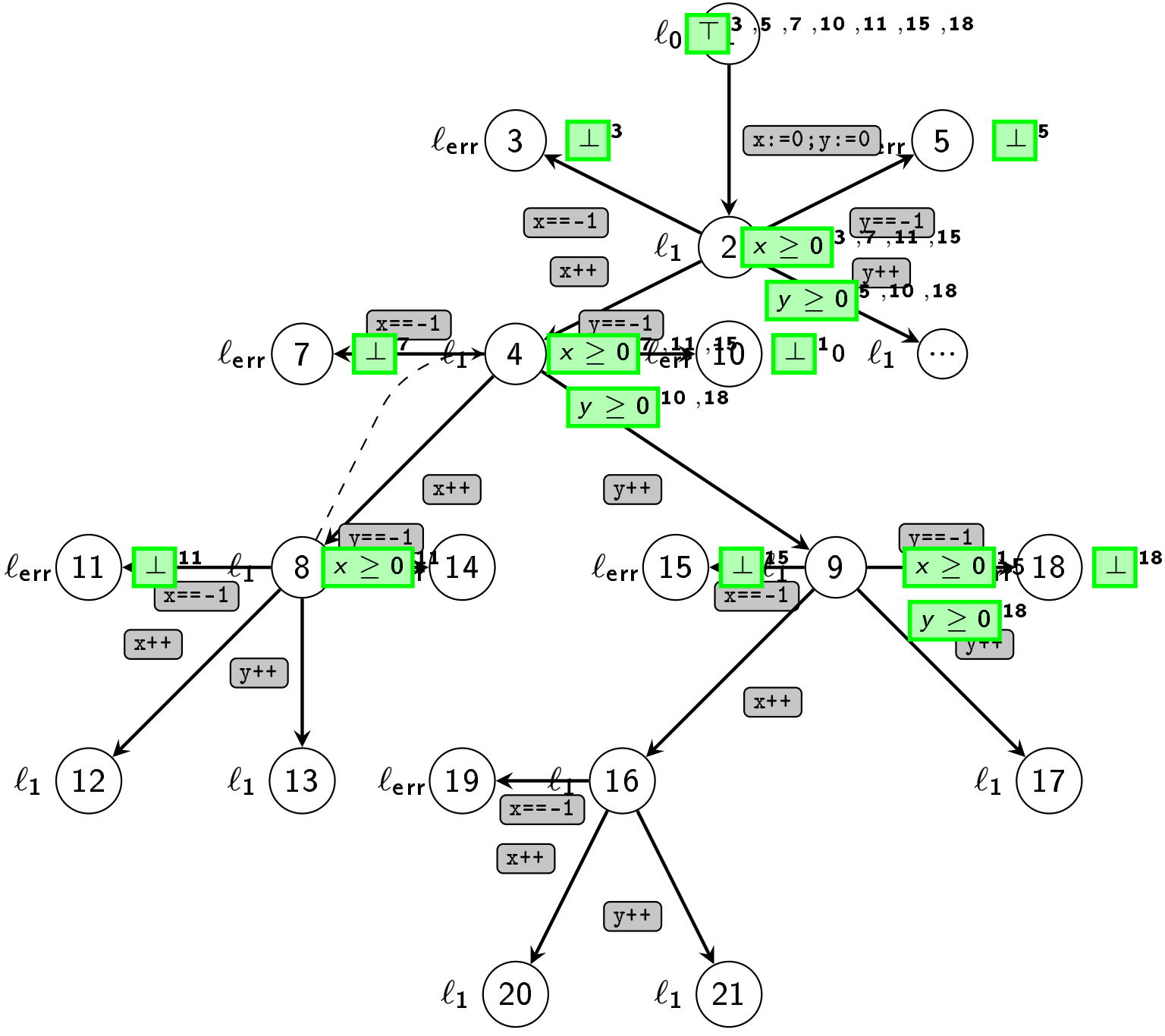

ℓ_0
$\top$ 3 ,5 ,7 ,10 ,11
ℓ_{err}
3
$\bot$ 3
x:=0;y:=0
5
$\bot$ 5
x==-1
y==-1
ℓ_1
2
$x \geq 0$ 3 ,7 ,11
x++
y++
$y \geq 0$ 5 ,10
x==-1
y==-1
ℓ_{err}
7
$\bot$ 7
ℓ_1
4
$x \geq 0$ 7 ,11
10
$\bot$ 10
ℓ_1
...
$y \geq 0$ 10
x++
y++
y==-1
ℓ_{err}
11
$\bot$ 11
ℓ_1
8
$x \geq 0$ 11
14
x==-1
x++
y++
ℓ_{err}
15
ℓ_1
9
y==-1
18
x==-1
y++
x++
ℓ_1
12
ℓ_1
13
ℓ_1
16
ℓ_1
17

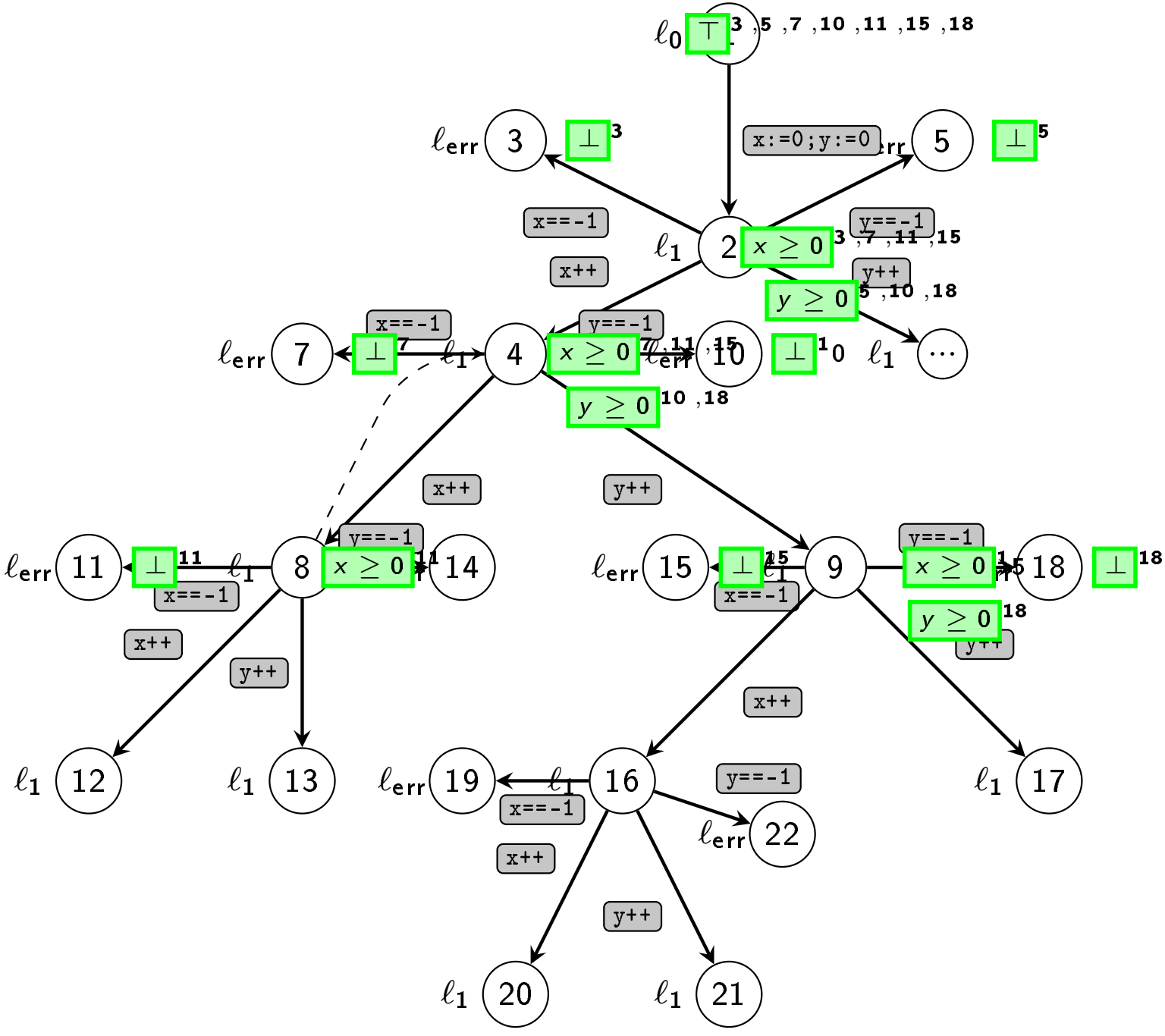

ℓ_0
$\top$
3 ,5 ,7 ,10 ,11 ,15
ℓ_{err}
3
$\bot$
3
x:=0;y:=0
5
$\bot$
5
x==-1
ℓ_1
2
$x \geq 0$
3 ,7 ,11 ,15
y==-1
x++
y++
$y \geq 0$
5 ,10
ℓ_{err}
7
x==-1
$\bot$
7
ℓ_1
4
$x \geq 0$
7 ,11 ,15
y==-1
ℓ_{err}
10
$\bot$
10
ℓ_1
$\cdots$
$y \geq 0$
10
x++
y++
ℓ_{err}
11
$\bot$
11
ℓ_1
8
$x \geq 0$
11
y==-1
14
x==-1
ℓ_{err}
15
$\bot$
15
ℓ_1
9
$x \geq 0$
15
y==-1
18
x==-1
x++
y++
y++
x++
ℓ_1
12
ℓ_1
13
ℓ_1
16
ℓ_1
17

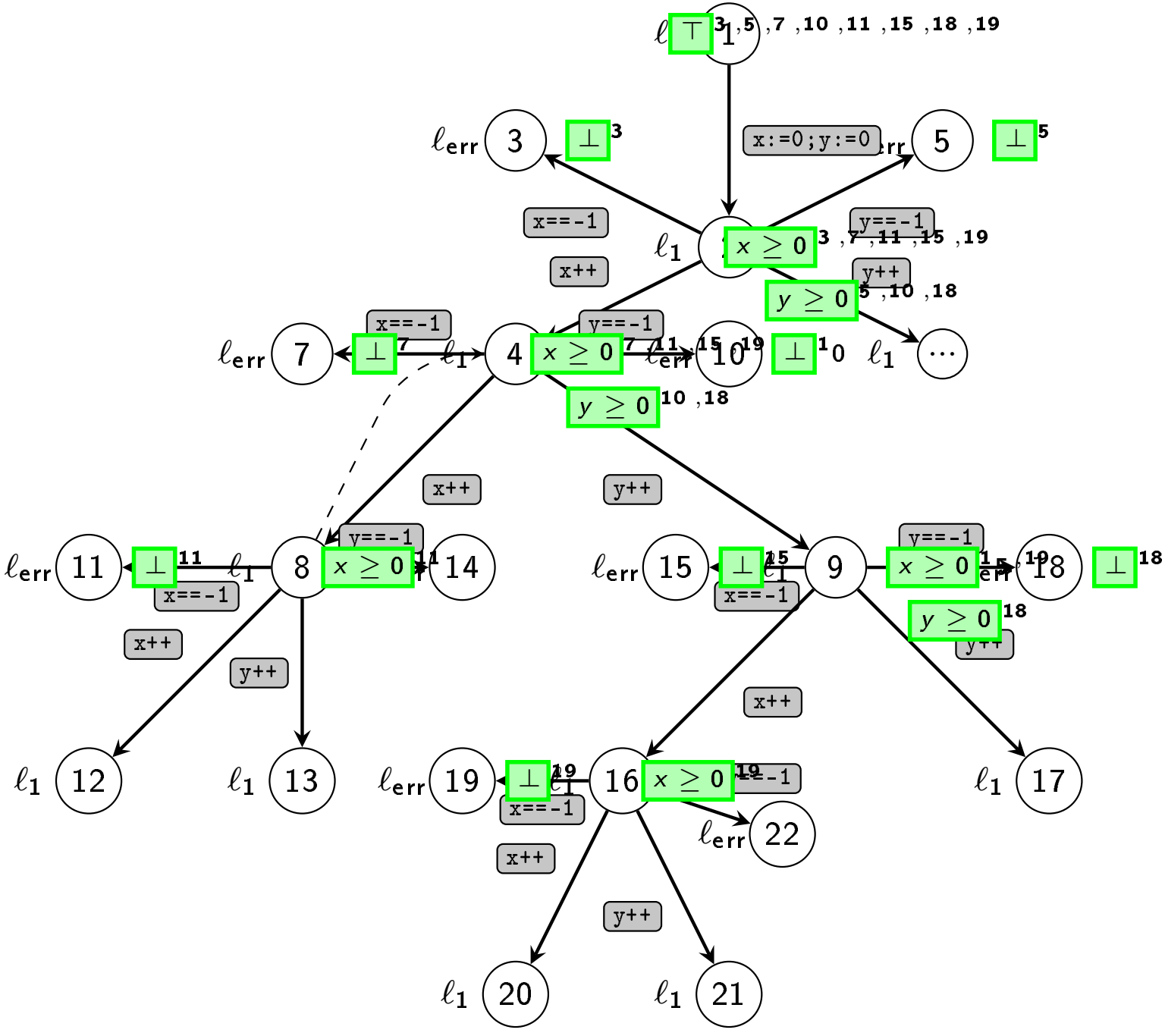

ℓ_0
$\top$
3 ,5 ,7 ,10 ,11 ,15 ,18
ℓ_{err}
3
$\bot$
3
x:=0;y:=0
5
$\bot$
5
x==-1
y==-1
ℓ_1
2
$x \geq 0$
3 ,7 ,11 ,15
x++
y++
$y \geq 0$
5 ,10 ,18
x==-1
y==-1
ℓ_{err}
7
$\bot$
7
ℓ_1
4
$x \geq 0$
7 ,11 ,15
ℓ_{err}
10
$\bot$
10
ℓ_1
$\cdots$
$y \geq 0$
10 ,18
x++
y++
y==-1
ℓ_{err}
11
$\bot$
11
ℓ_1
8
$x \geq 0$
11
14
x==-1
x++
y++
ℓ_1
12
ℓ_1
13
y==-1
ℓ_{err}
15
$\bot$
15
ℓ_1
9
$x \geq 0$
15
18
$\bot$
18
x==-1
$y \geq 0$
18
x++
ℓ_1
16
ℓ_1
17

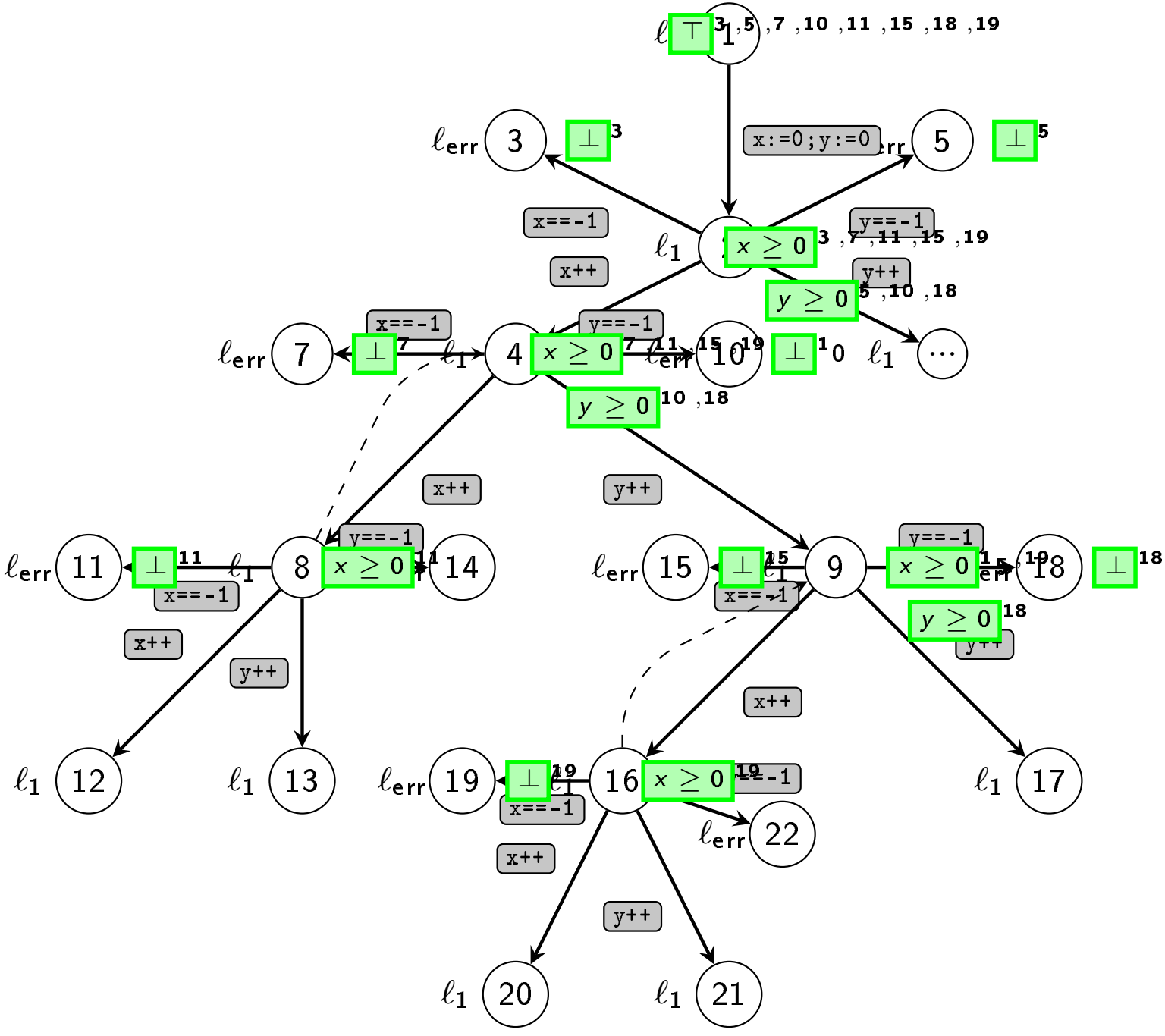

ℓ_0
$\top$
3 ,5 ,7 ,10 ,11 ,15 ,18
ℓ_{err}
3
$\bot$
3
x:=0;y:=0
5
$\bot$
5
x==-1
y==-1
ℓ_1
2
$x \geq 0$
3 ,7 ,11 ,15
x++
y++
$y \geq 0$
5 ,10 ,18
x==-1
y==-1
ℓ_{err}
7
$\bot$
7
ℓ_1
4
$x \geq 0$
7 ,11 ,15
ℓ_{err}
10
$\bot$
10
ℓ_1
$\cdots$
$y \geq 0$
10 ,18
x++
y++
y==-1
ℓ_{err}
11
$\bot$
11
ℓ_1
8
$x \geq 0$
11
14
x==-1
x++
y++
ℓ_{err}
15
$\bot$
15
ℓ_1
9
y==-1
$x \geq 0$
15
18
$\bot$
18
x==-1
$y \geq 0$
18
x++
ℓ_1
12
ℓ_1
13
ℓ_{err}
19
ℓ_1
16
x==-1
x++
ℓ_1
17

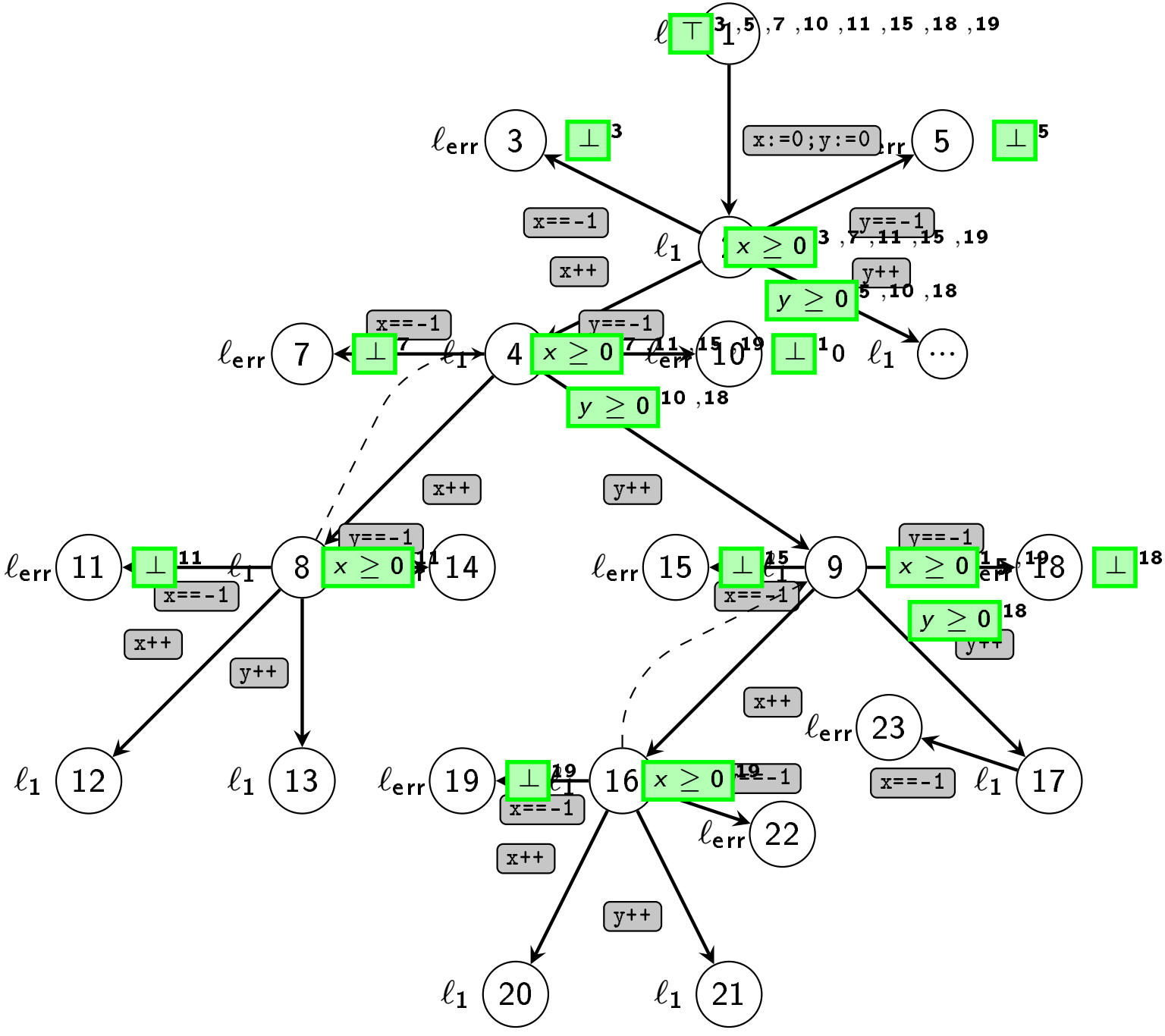

ℓ_0
$\top$
3 ,5 ,7 ,10 ,11 ,15 ,18
ℓ_{err}
3
$\bot$
3
x:=0;y:=0
5
$\bot$
5
x==-1
y==-1
ℓ_1
2
$x \geq 0$
3 ,7 ,11 ,15
x++
y++
$y \geq 0$
5 ,10 ,18
ℓ_{err}
7
x==-1
$\bot$
7
ℓ_1
4
y==-1
$x \geq 0$
7 ,11 ,15
ℓ_{err}
10
$\bot$
10
ℓ_1
...
$y \geq 0$
10 ,18
x++
y++
ℓ_{err}
11
$\bot$
11
ℓ_1
8
y==-1
$x \geq 0$
11
14
x==-1
x++
y++
ℓ_{err}
15
$\bot$
15
ℓ_1
9
y==-1
$x \geq 0$
15
18
$\bot$
18
x==-1
$y \geq 0$
18
x++
ℓ_1
12
ℓ_1
13
ℓ_{err}
19
ℓ_1
16
ℓ_1
17
x==-1
x++
ℓ_1
20

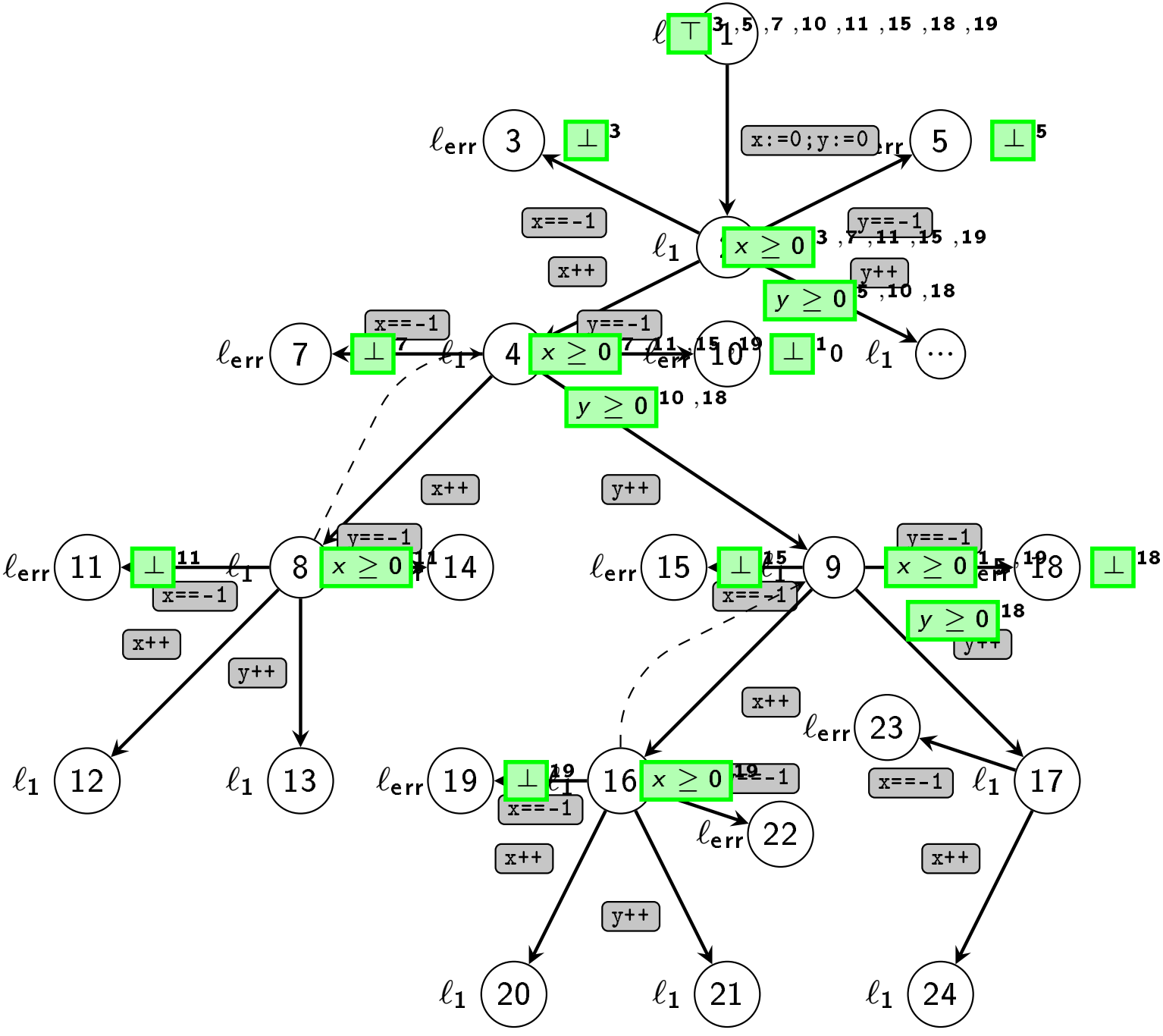

ℓ_0
$\top$
3 ,5 ,7 ,10 ,11 ,15 ,18
ℓ_{err}
3
$\bot$
3
x:=0;y:=0
5
$\bot$
5
x==-1
y==-1
ℓ_1
2
$x \geq 0$
3 ,7 ,11 ,15
x++
y++
$y \geq 0$
5 ,10 ,18
ℓ_{err}
7
x==-1
$\bot$
7
ℓ_1
4
y==-1
$x \geq 0$
7 ,11 ,15
ℓ_{err}
10
$\bot$
10
ℓ_1
$\cdots$
$y \geq 0$
10 ,18
x++
y++
ℓ_{err}
11
$\bot$
11
ℓ_1
8
y==-1
$x \geq 0$
11
14
x==-1
x++
y++
ℓ_1
12
ℓ_1
13
ℓ_{err}
15
$\bot$
15
ℓ_1
9
y==-1
$x \geq 0$
15
18
$\bot$
18
x==-1
$y \geq 0$
18
x++
ℓ_{err}
19
ℓ_1
16
ℓ_1
17
x==-1
x++
y++
ℓ_1
20
ℓ_1
21

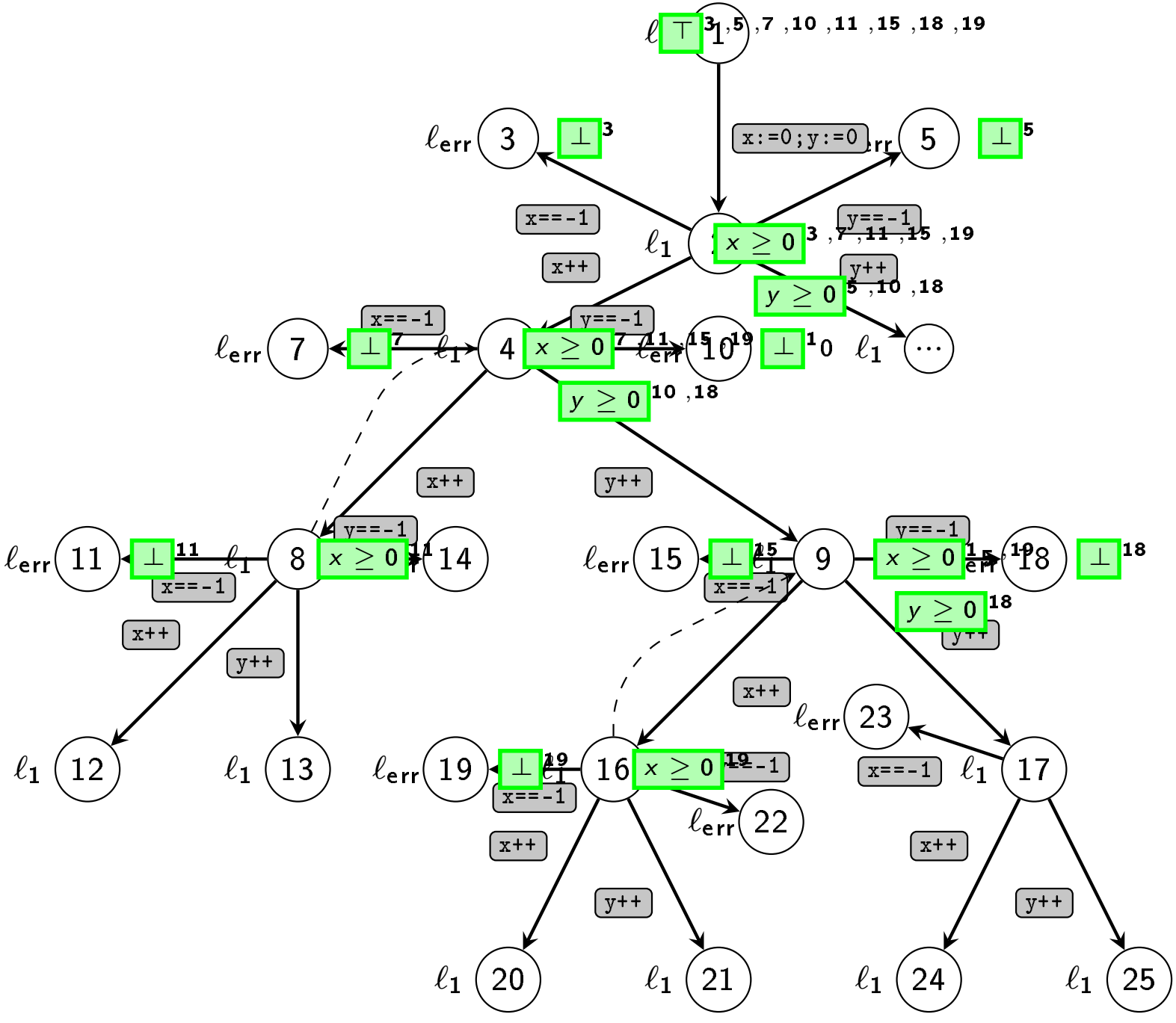

ℓ_0
$\top$
3 ,5 ,7 ,10 ,11 ,15 ,18
ℓ_{err}
3
$\bot$
3
x:=0;y:=0
5
$\bot$
5
x==-1
y==-1
ℓ_1
2
$x \geq 0$
3 ,7 ,11 ,15
x++
y++
$y \geq 0$
5 ,10 ,18
ℓ_{err}
7
x==-1
$\bot$
7
ℓ_1
4
y==-1
$x \geq 0$
7 ,11 ,15
ℓ_{err}
10
$\bot$
10
ℓ_1
$\cdots$
$y \geq 0$
10 ,18
x++
y++
ℓ_{err}
11
$\bot$
11
ℓ_1
8
y==-1
$x \geq 0$
11
14
x==-1
x++
y++
ℓ_1
12
ℓ_1
13
ℓ_{err}
15
$\bot$
15
ℓ_1
9
y==-1
$x \geq 0$
15
18
$\bot$
18
x==-1
$y \geq 0$
18
x++
ℓ_{err}
19
ℓ_1
16
y==-1
x==-1
ℓ_{err}
22
x++
y++
ℓ_1
17
ℓ_1
20
ℓ_1
21

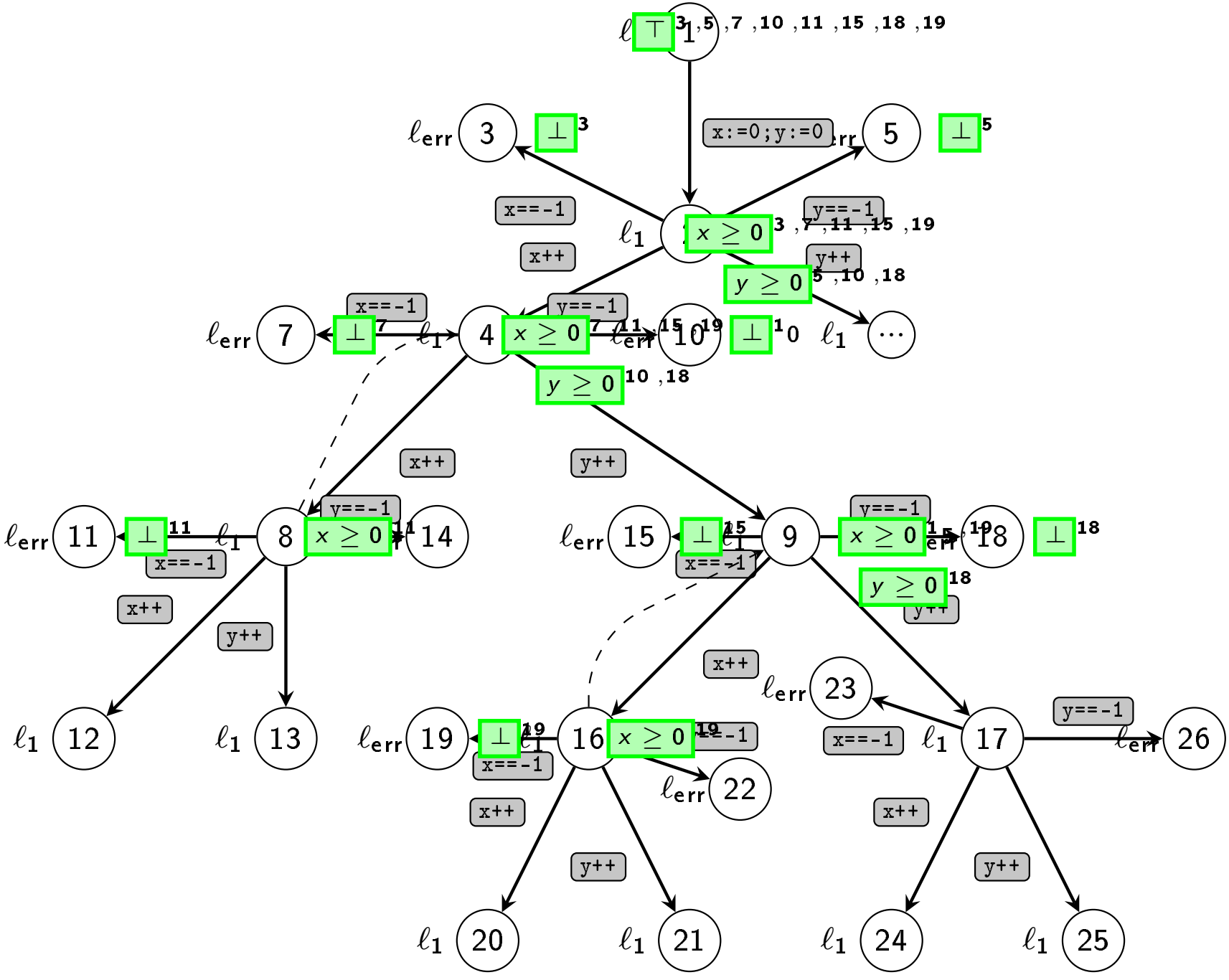

ℓ_{err}
3
$\bot$
x:=0;y:=0
5
$\bot$
ℓ_1
1
$\top$
x==-1
x++
y==-1
$x \geq 0$
y++
$y \geq 0$
ℓ_{err}
7
x==-1
$\bot$
ℓ_1
4
y==-1
$x \geq 0$
ℓ_{err}
10
$\bot$
ℓ_1
$\cdots$
$y \geq 0$
x++
y++
ℓ_{err}
11
$\bot$
ℓ_1
8
y==-1
$x \geq 0$
14
x==-1
x++
y++
ℓ_{err}
15
$\bot$
ℓ_1
9
y==-1
$x \geq 0$
18
$\bot$
x==-1
$y \geq 0$
y++
x++
ℓ_1
12
ℓ_1
13
ℓ_{err}
19
$\bot$
ℓ_1
16
$x \geq 0$
ℓ_1
17
x==-1
ℓ_{err}
22
x++
y++
ℓ_1
20
ℓ_1
21

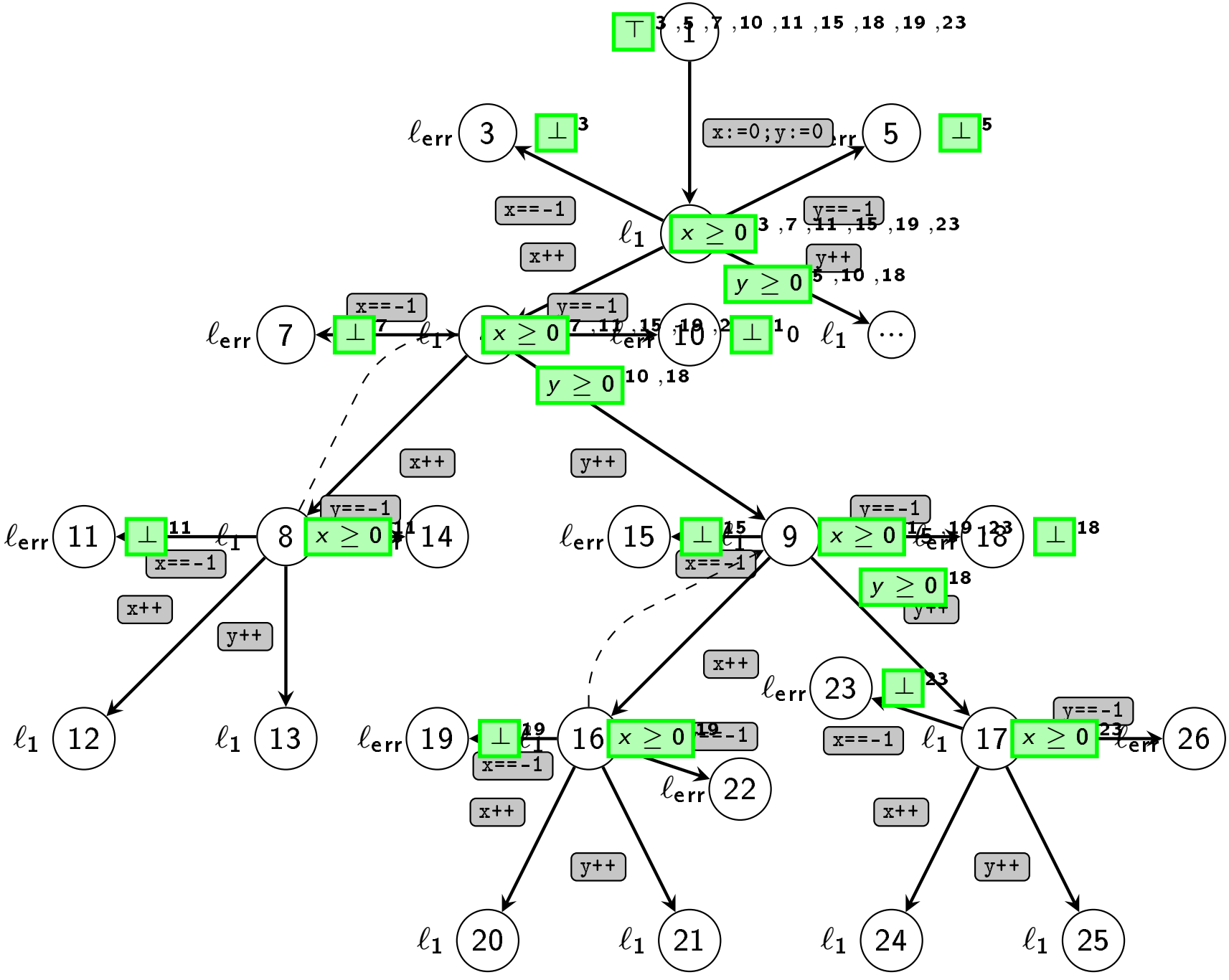

1
⊤
3,5,7,10,11,15,18,19
3
⊥
x:=0;y:=0
5
⊥
x==-1
x++
y==-1
y++
x ≥ 0
y ≥ 0
4
x ≥ 0
7
⊥
10
⊥
y ≥ 0
10,18
x==-1
y==-1
x++
y++
8
x ≥ 0
11
⊥
14
9
x ≥ 0
15
⊥
18
⊥
y ≥ 0
12
13
16
x ≥ 0
19
⊥
22
17
20
21

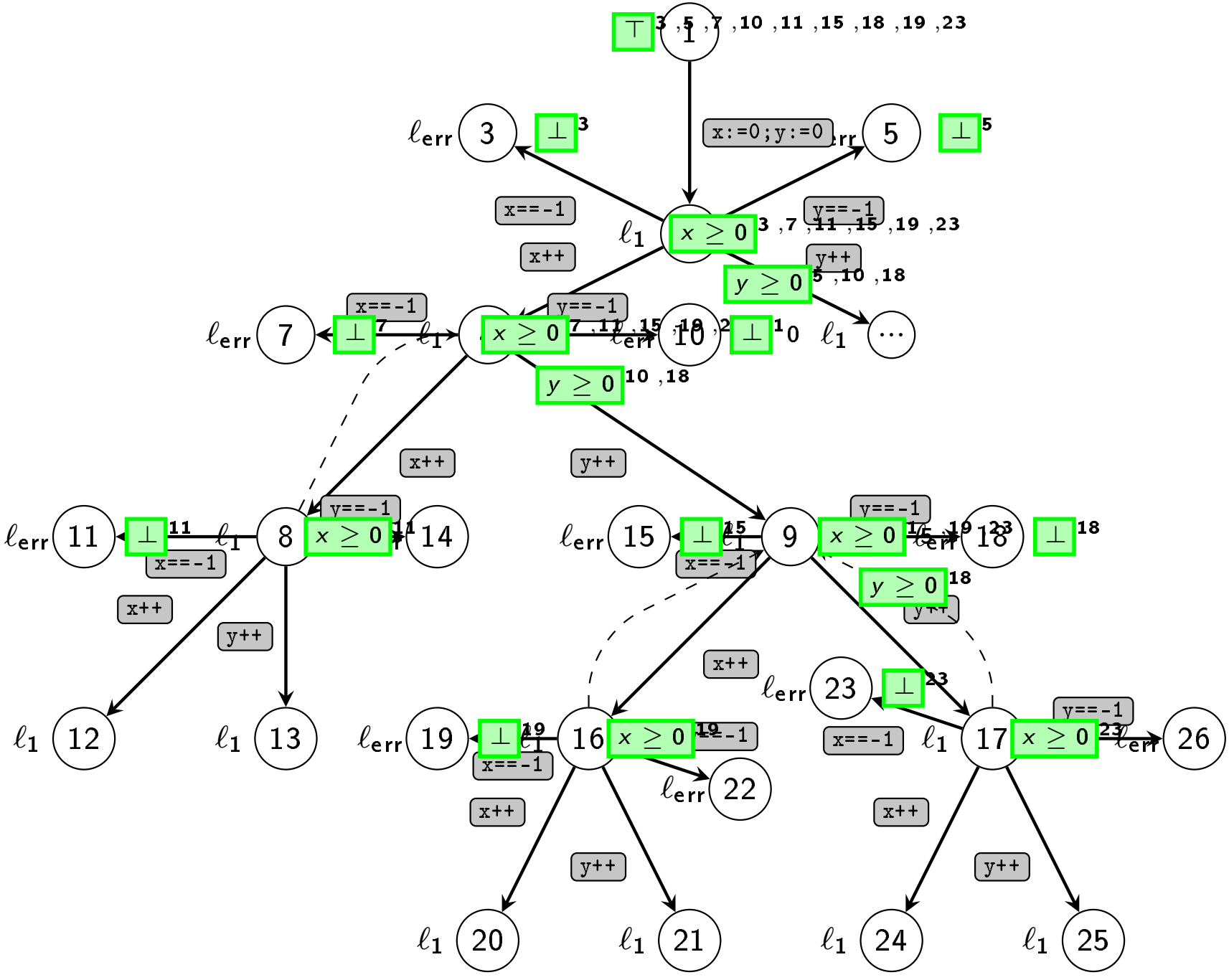

1
⊤
3,5,7,10,11,15,18,19
3
⊥
x:=0;y:=0
5
⊥
x==-1
x++
y==-1
y++
x ≥ 0
y ≥ 0
4
7
10
11
14
8
15
9
18
12
13
19
16
22
23
17
20
21
…


ℓ_{err}
$\top$
1
3,5,7,10,11,15,18,19
3
$\perp$
3
x:=0;y:=0
5
$\perp$
5
x==-1
x++
ℓ_1
$x \geq 0$
3,7,11,15,19
y==-1
y++
$y \geq 0$
5,10,18
7
$\perp$
7
4
$x \geq 0$
7,11,15,19
10
$\perp$
10
ℓ_1
...
$y \geq 0$
10,18
x++
y++
11
$\perp$
11
8
$x \geq 0$
11
14
x==-1
x++
y++
15
$\perp$
15
9
$x \geq 0$
15
18
$\perp$
18
x==-1
$y \geq 0$
18
x++
y++
12
13
19
$\perp$
19
16
$x \geq 0$
19
22
x==-1
x++
y++
23
x==-1
17
x++
20
21
24


1
$\top$
3,5,7,10,11,15,18,19
ℓ_{err}
3
$\bot$
3
x:=0;y:=0
5
$\bot$
5
ℓ_1
x==-1
x++
$x \geq 0$
3,7,11,15,19
y==-1
y++
$y \geq 0$
5,10,18
ℓ_{err}
7
$\bot$
7
ℓ_1
4
$x \geq 0$
7,11,15,19
ℓ_{err}
10
$\bot$
10
ℓ_1
$\cdots$
x==-1
y==-1
$y \geq 0$
10,18
x++
y++
ℓ_{err}
11
$\bot$
11
ℓ_1
8
$x \geq 0$
11
14
y==-1
x==-1
x++
y++
ℓ_{err}
15
$\bot$
15
ℓ_1
9
$x \geq 0$
15
18
$\bot$
18
y==-1
x==-1
$y \geq 0$
18
x++
ℓ_1
12
ℓ_1
13
ℓ_{err}
19
$\bot$
19
ℓ_1
16
$x \geq 0$
19
ℓ_{err}
22
x==-1
x++
y++
ℓ_1
20
ℓ_1
21
x++
ℓ_{err}
23
x==-1
ℓ_1
17
x++
y++
ℓ_1
24
ℓ_1
25


1
⊤
3,5,7,10,11,15,18,19
3
⊥
x:=0;y:=0
5
⊥
x==-1
x++
y==-1
x ≥ 0
3,7,11,15,19
y++
y ≥ 0
5,10,18
4
x ≥ 0
7,11,15,19
10
⊥
10
y ≥ 0
10,18
7
⊥
x==-1
y==-1
x++
y++
8
x ≥ 0
11
⊥
11
x==-1
y==-1
x++
y++
9
x ≥ 0
15
⊥
15
x==-1
y==-1
y ≥ 0
18
18
⊥
18
12
13
19
⊥
19
x==-1
16
x ≥ 0
19
x==-1
22
x++
y++
23
x==-1
17
y==-1
26
x++
y++
20
21
24
25


⊤
1
3 ,5 ,7 ,10 ,11 ,15 ,18 ,19 ,23
ℓ_{err}
3
⊥
3
x:=0;y:=0
5
⊥
5
x==-1
y==-1
ℓ_1
$x \geq 0$
3 ,7 ,11 ,15 ,19 ,23
x++
y++
$y \geq 0$
5 ,10 ,18
7
⊥
ℓ_1
$x \geq 0$
10
⊥
ℓ_1
…
$y \geq 0$
10 ,18
x++
y++
11
⊥
8
$x \geq 0$
14
15
⊥
9
$x \geq 0$
18
⊥
18
$y \geq 0$
18
12
13
19
⊥
16
$x \geq 0$
22
23
⊥
17
$x \geq 0$
26
20
21
24
25


⊤
1
3 ,5 ,7 ,10 ,11 ,15 ,18 ,19 ,23
ℓ_{err}
3
⊥
3
x:=0;y:=0
5
⊥
5
x==-1
y==-1
ℓ_1
$x \geq 0$
3 ,7 ,11 ,15 ,19 ,23
x++
y++
$y \geq 0$
5 ,10 ,18
7
⊥
ℓ_1
10
⊥
ℓ_1
…
$y \geq 0$
10 ,18
x++
y++
11
⊥
8
$x \geq 0$
14
15
⊥
9
$x \geq 0$
18
⊥
$y \geq 0$
18
12
13
19
⊥
16
$x \geq 0$
22
23
⊥
17
$x \geq 0$
26
20
21
24
25

IMPACT-Variation 3 - Vergleich

Mögliche Analogieen zwischen IMPACT-3 und Trace Abstraction:

- pro Refutation erkannte Sprachen
- Anzahl der Refutations

IMPACT-Variation 3 - Vergleich

Mögliche Analogieen zwischen IMPACT-3 und Trace Abstraction:

- pro Refutation erkannte Sprachen:
  kein offensichtlicherZusammenhang, keine Inklusion
- Anzahl der Refutations:
  nicht identisch, Unterschied möglicherweise konstanter Faktor

Fazit

- Ähnliche Verfahren, jedoch
  - Undwindings für IMPACT natürlicher
  - Automaten für Trace Abstraction natürlicher

  Unterschied in den Datenstrukturen macht Vergleich schwierig
- Hilfsmittel zur Analyse von Verfahren: (z.B. IMPACT-Varianten)
  - Unterapproximation der Sprache der Infeasible Traces
  - Unwindings mit Abbruchkriterium