Morphing Graph Drawings in the Presence of Point Obstacles

SOFSEM 2024

Oksana Firman Tim Hegemann Boris Klemz Felix Klesen
Marie Diana Sieper Alexander Wolff **Johannes Zink**

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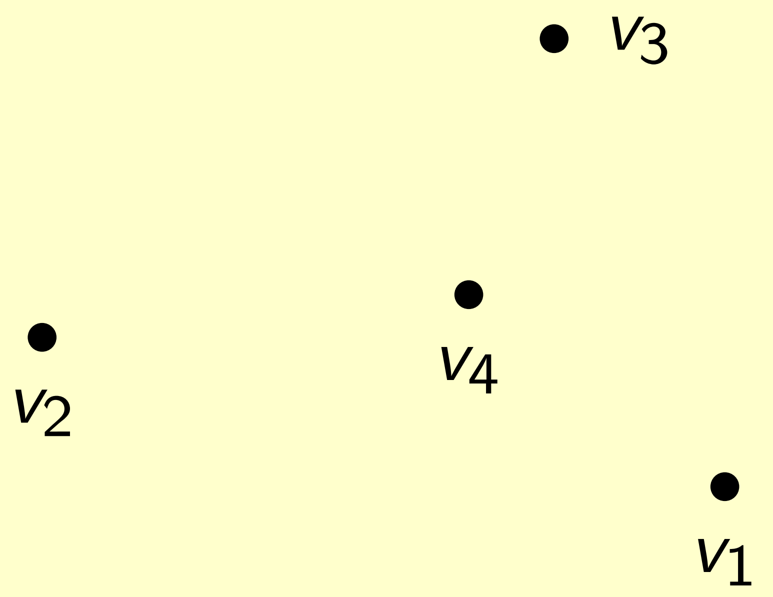

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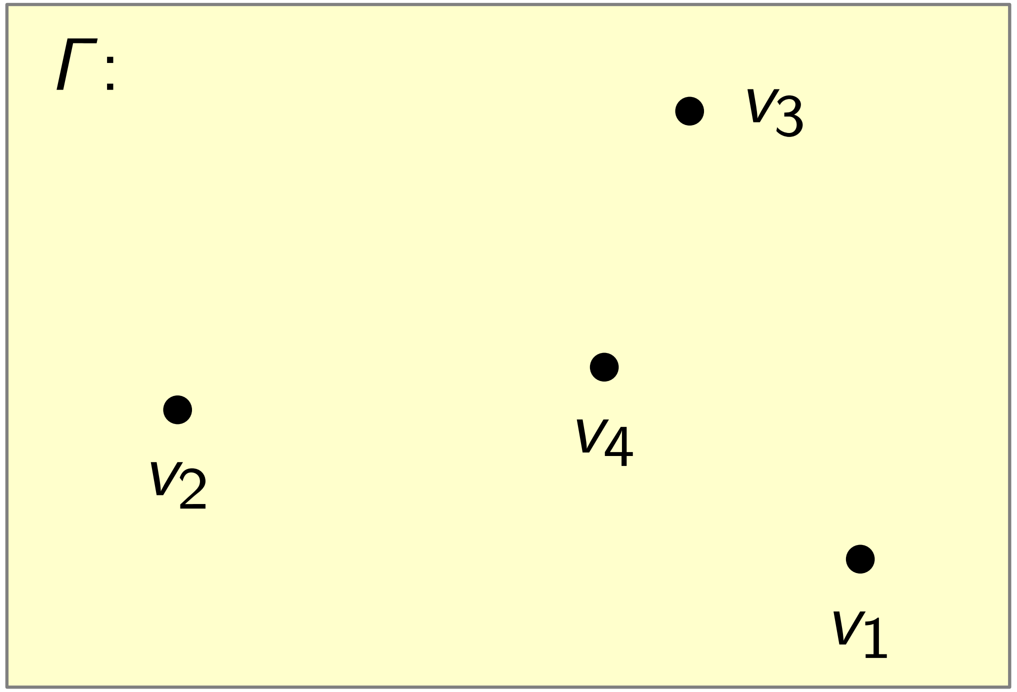

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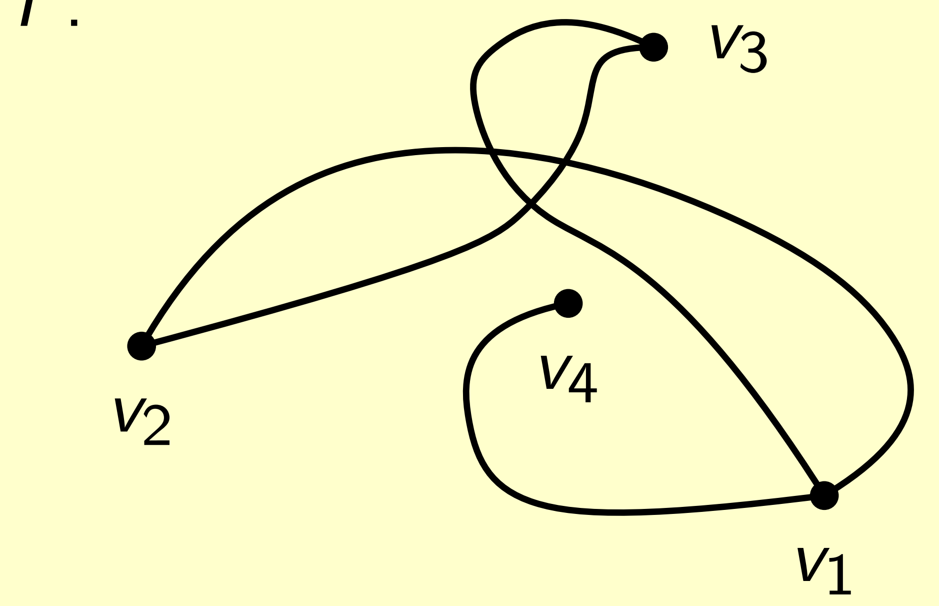

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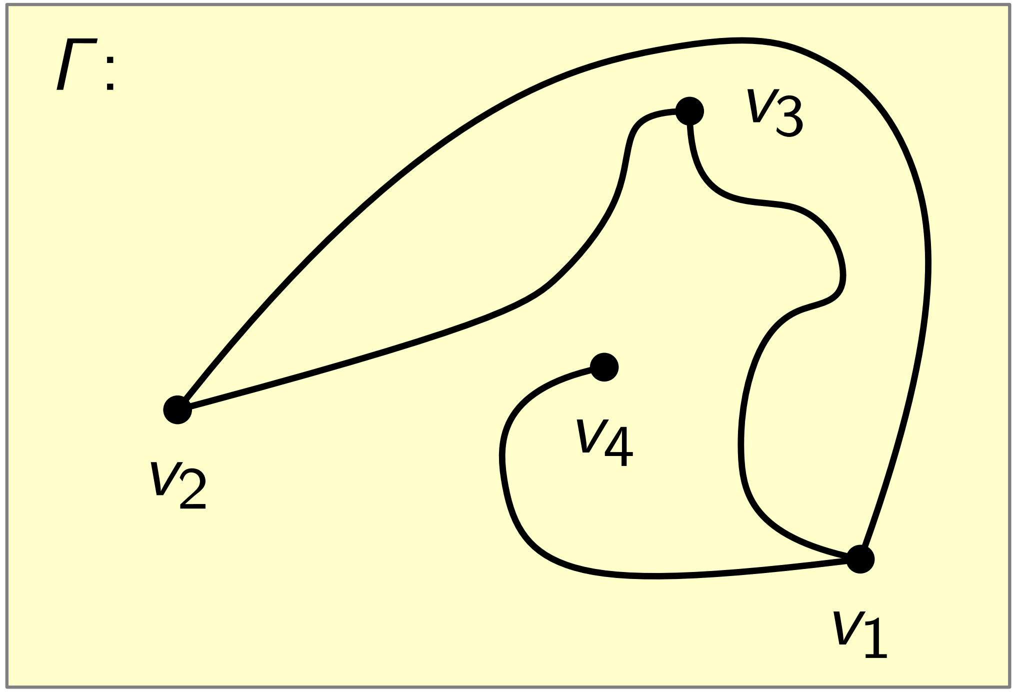

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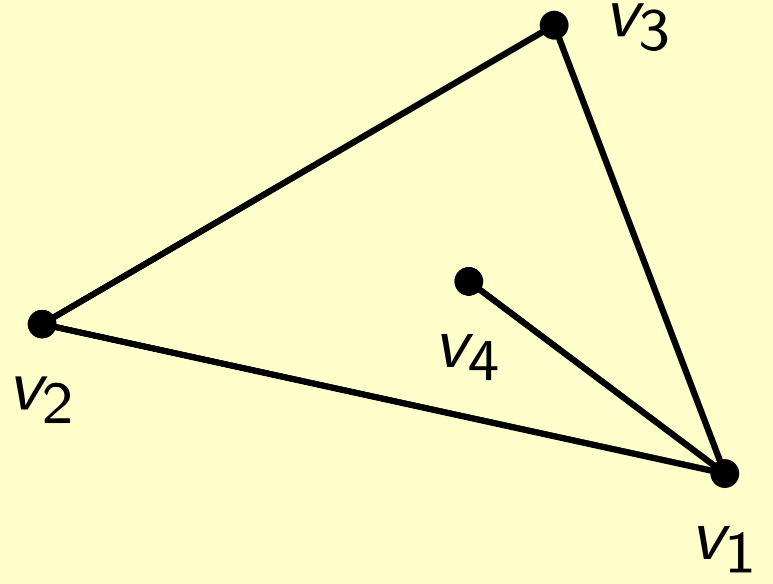

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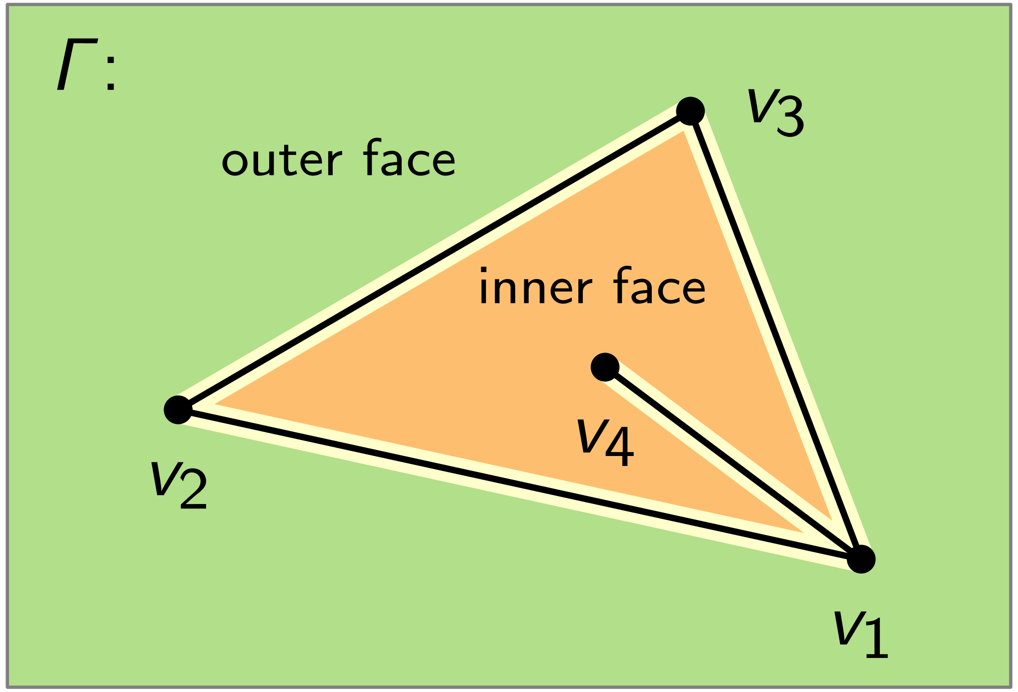

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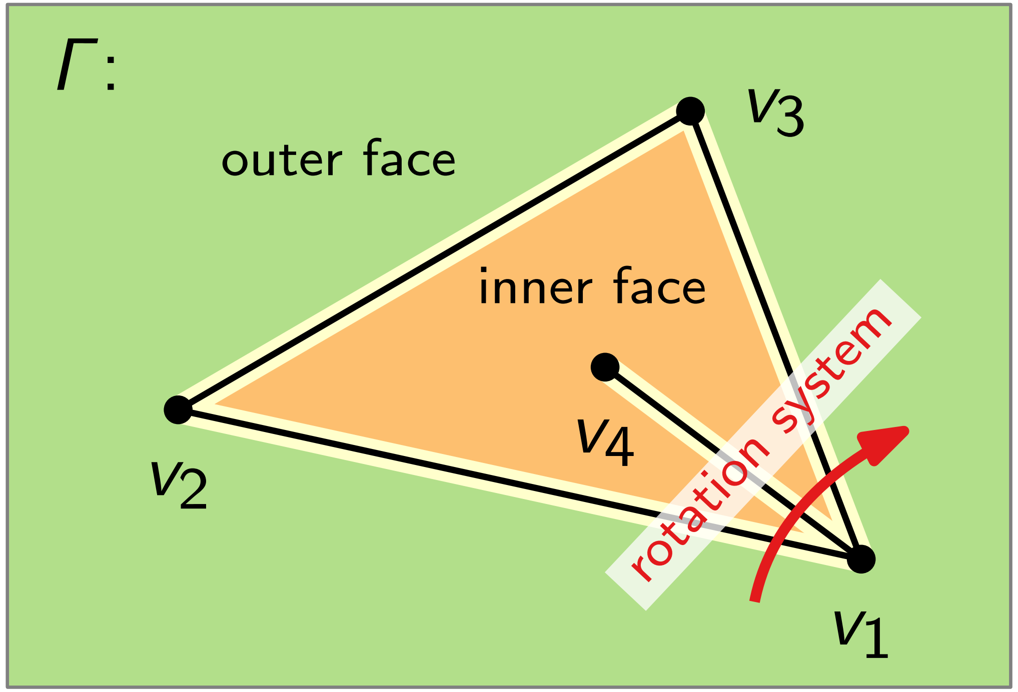

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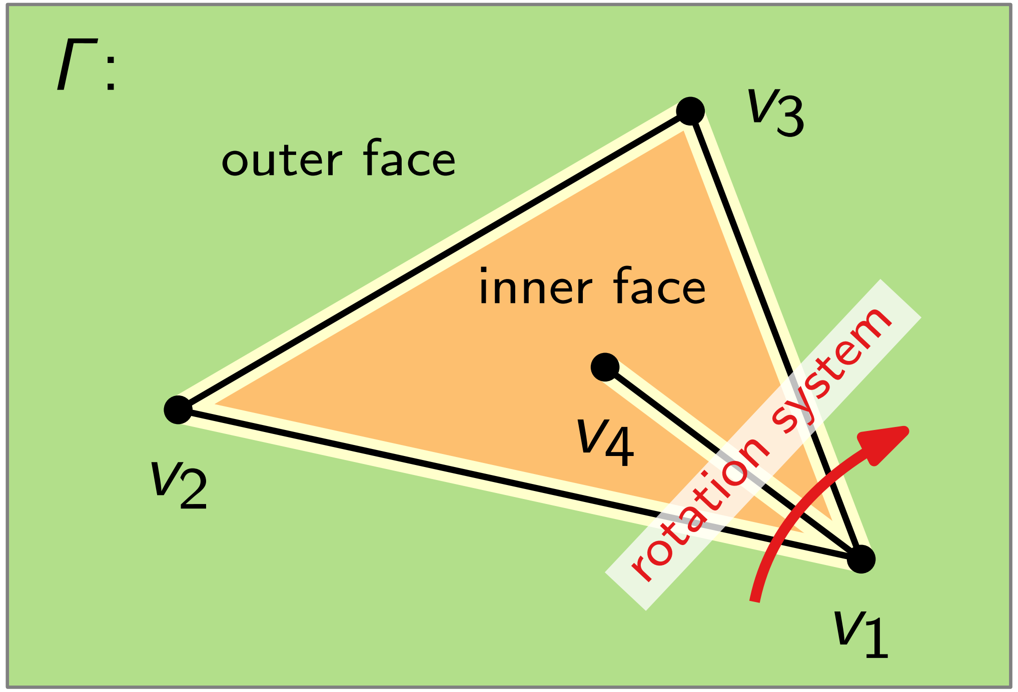

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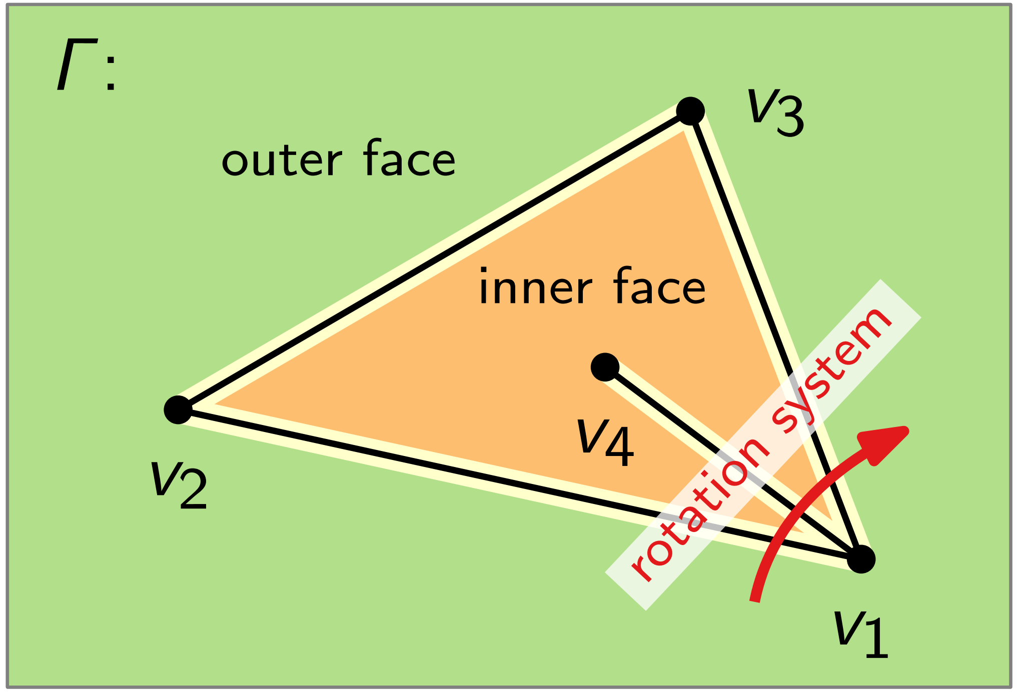

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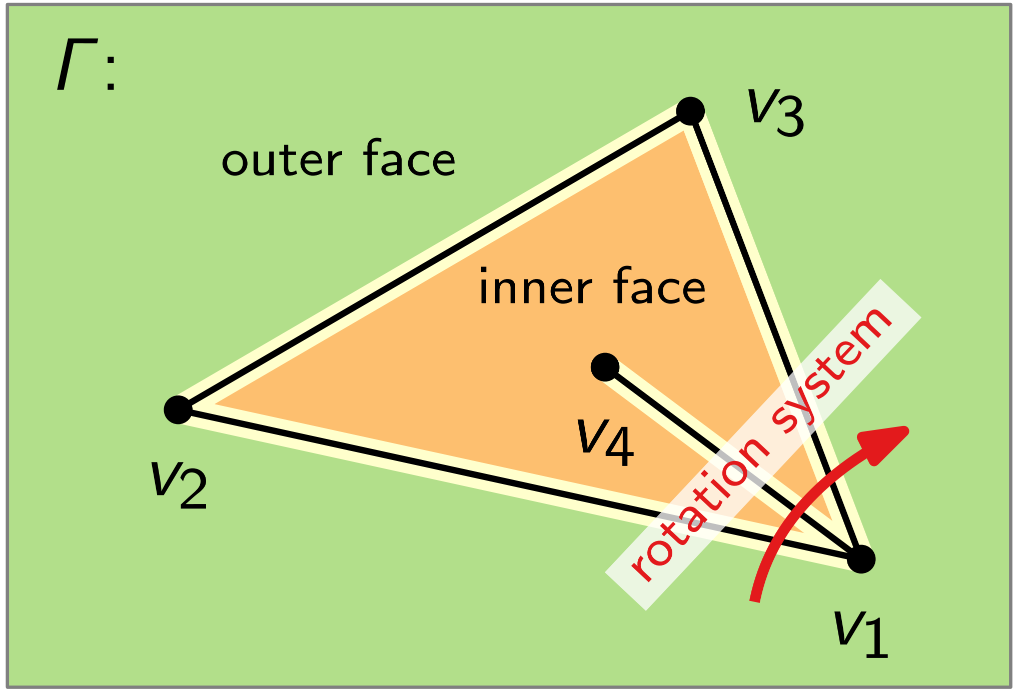

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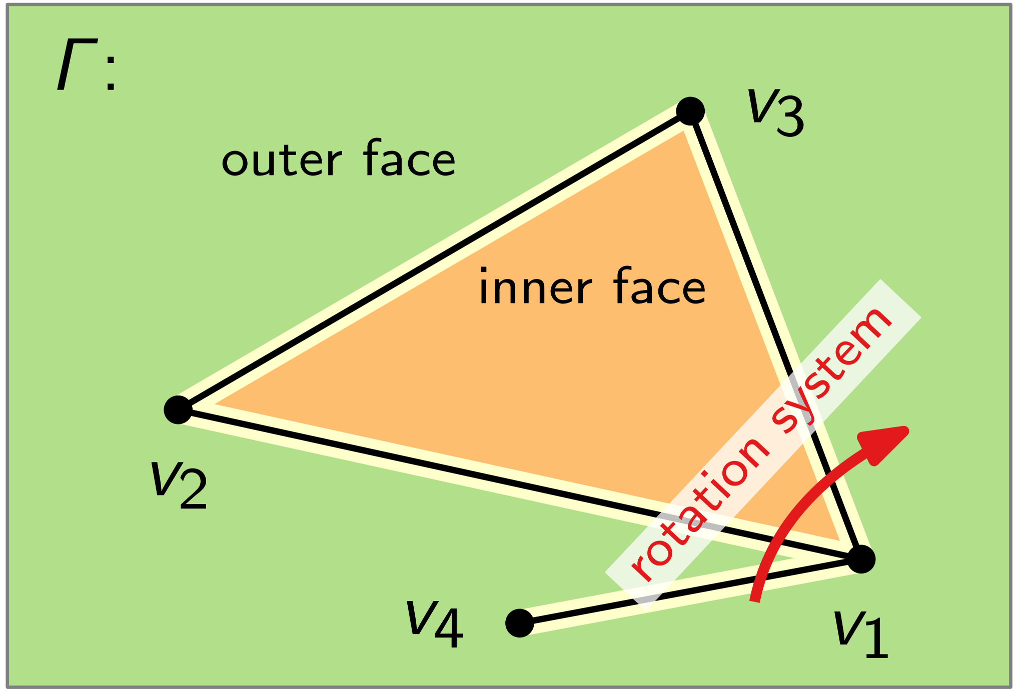

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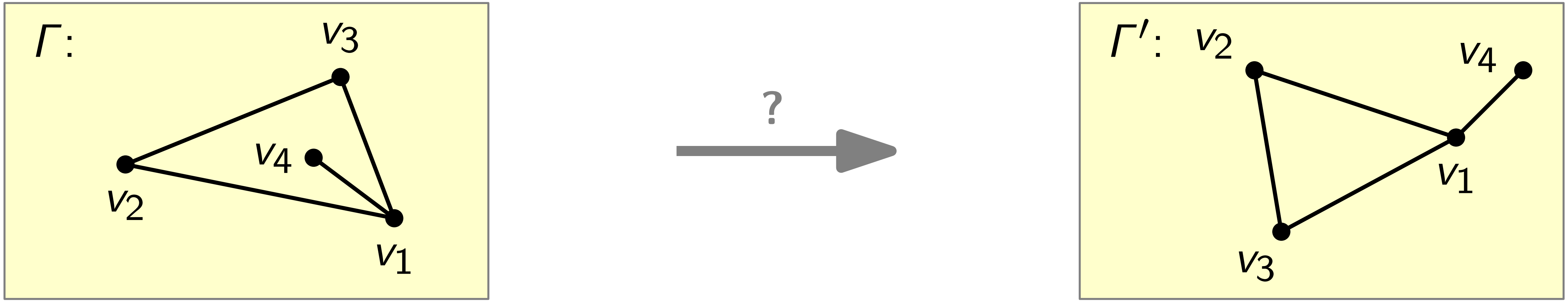

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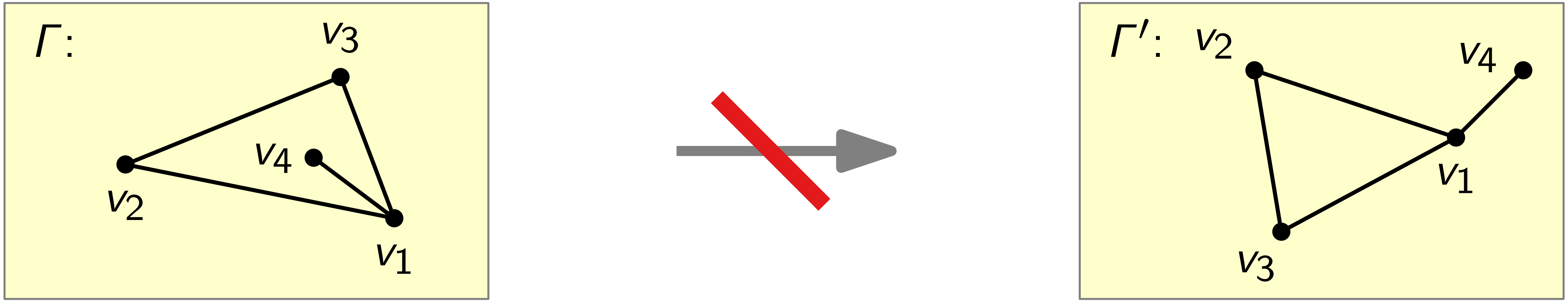

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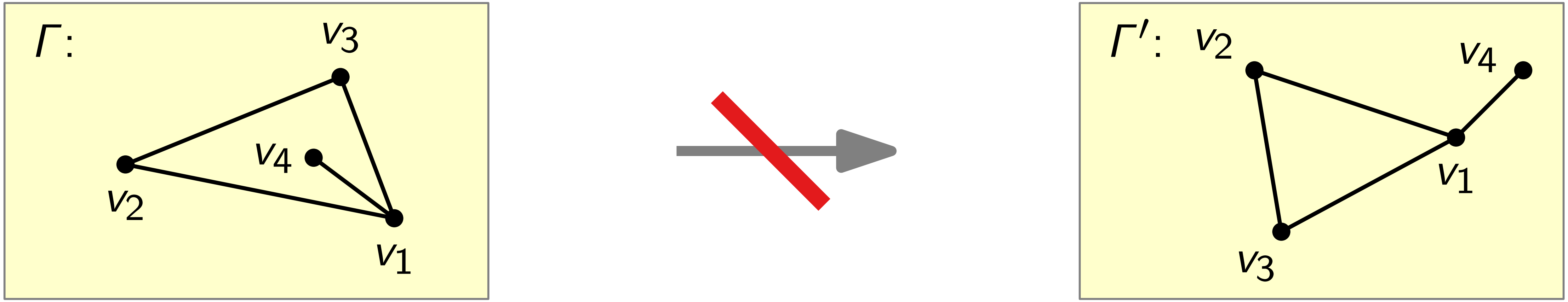

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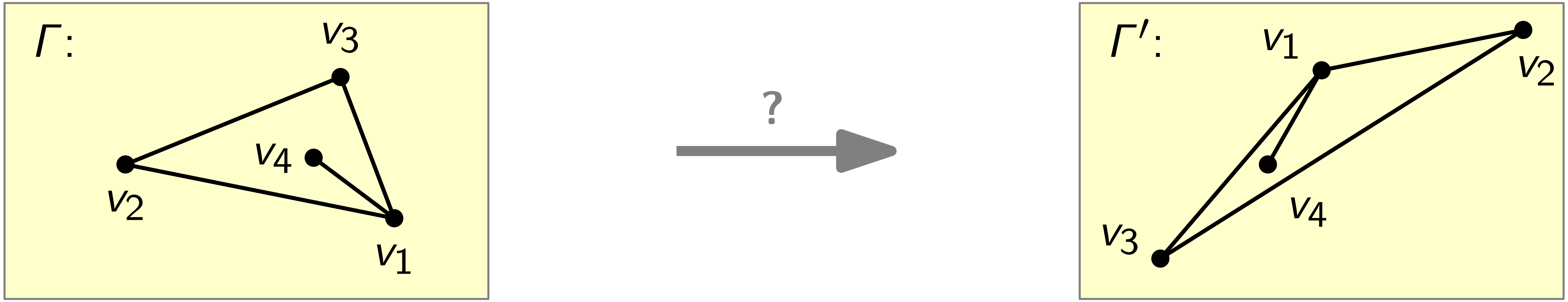

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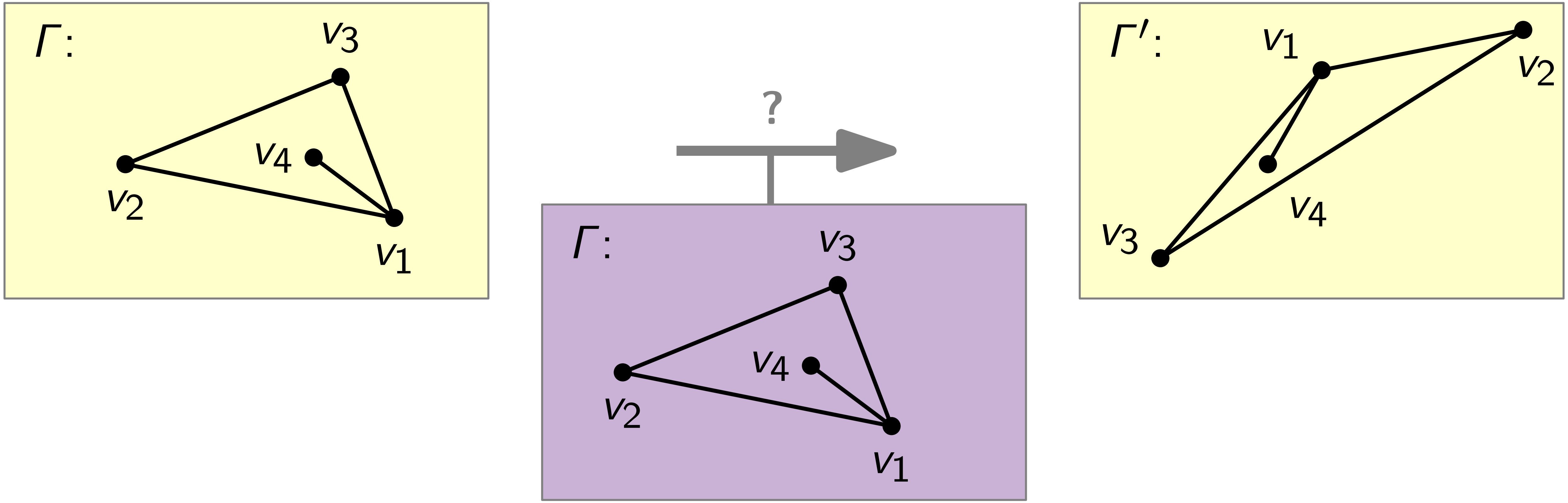

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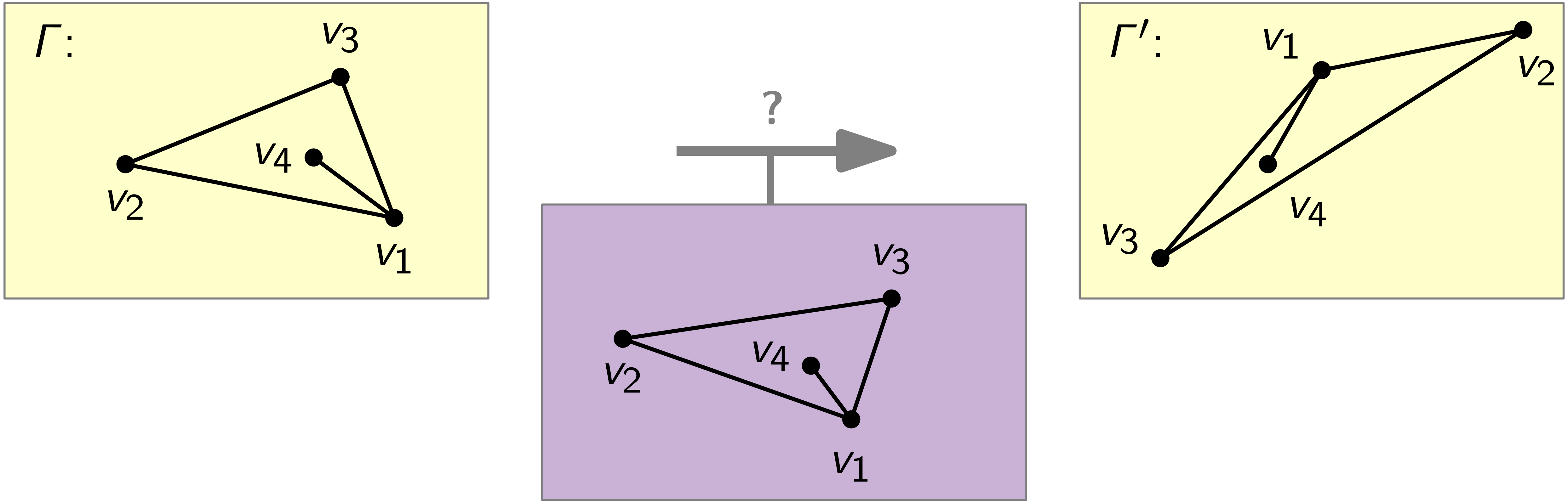

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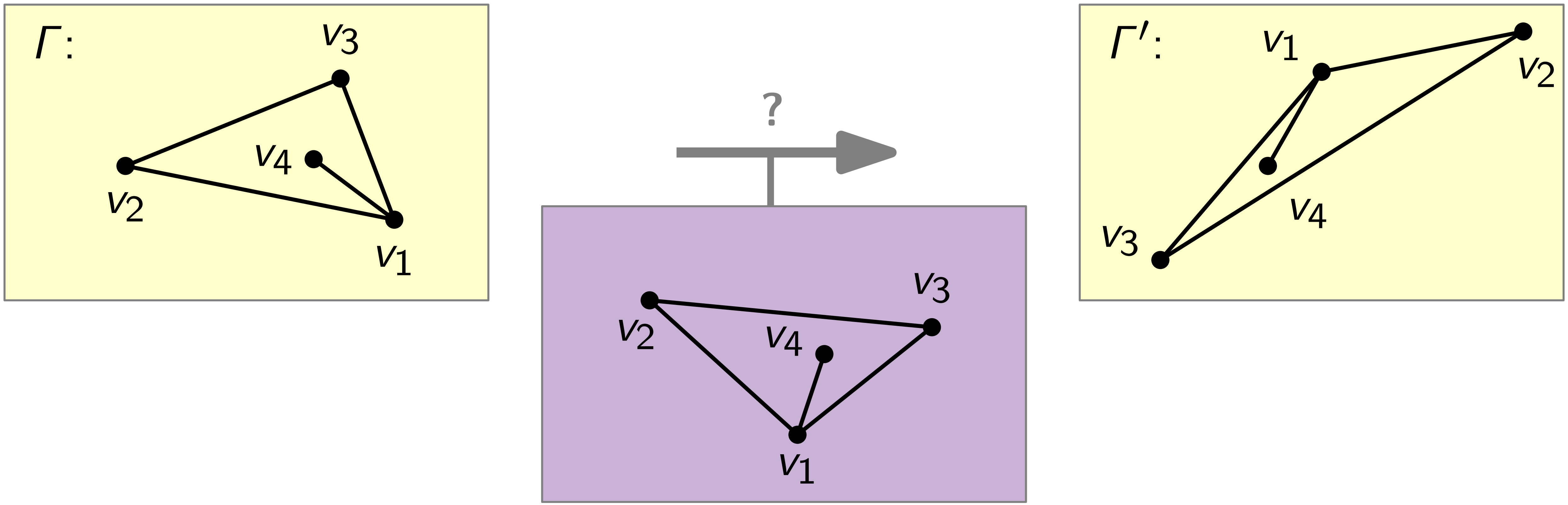

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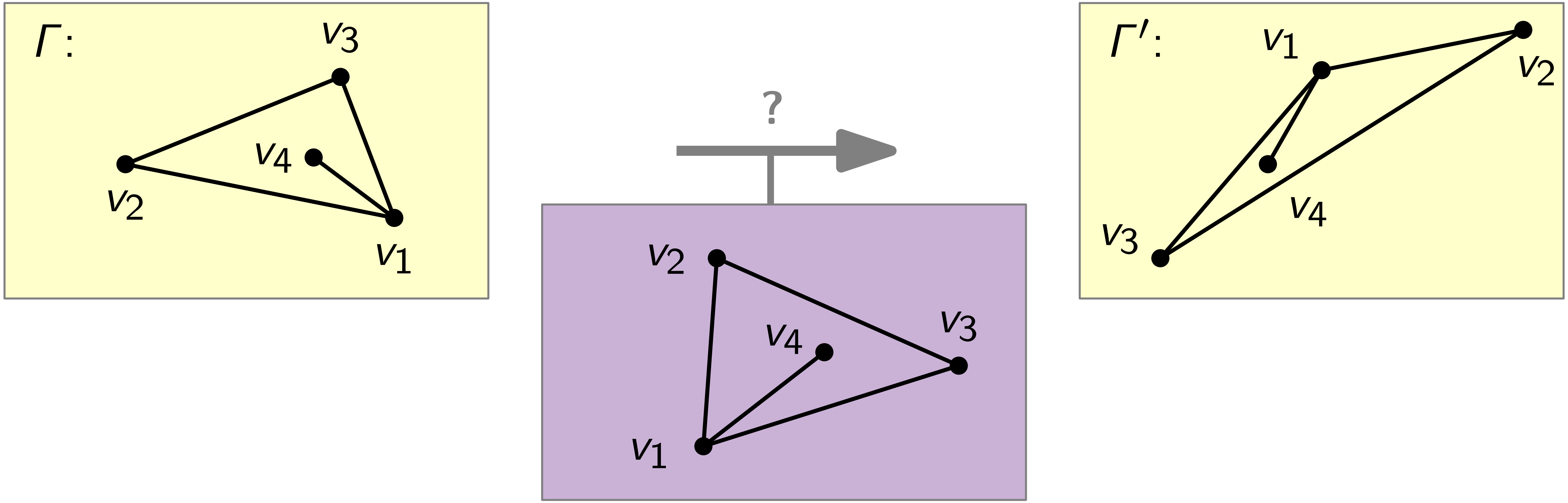

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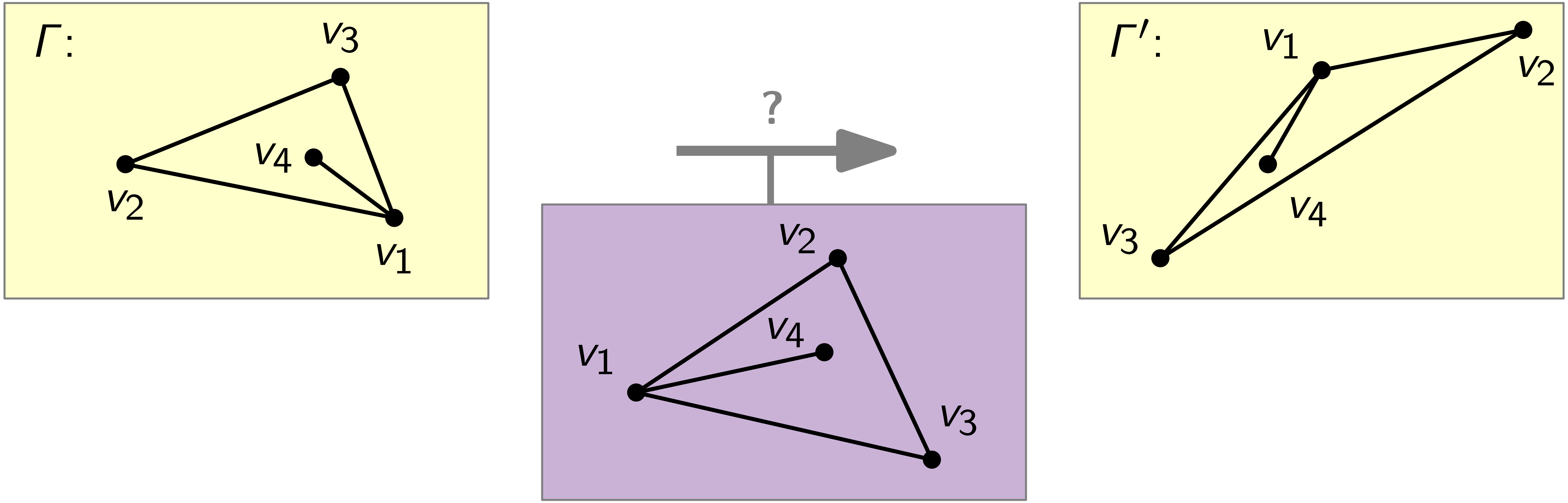

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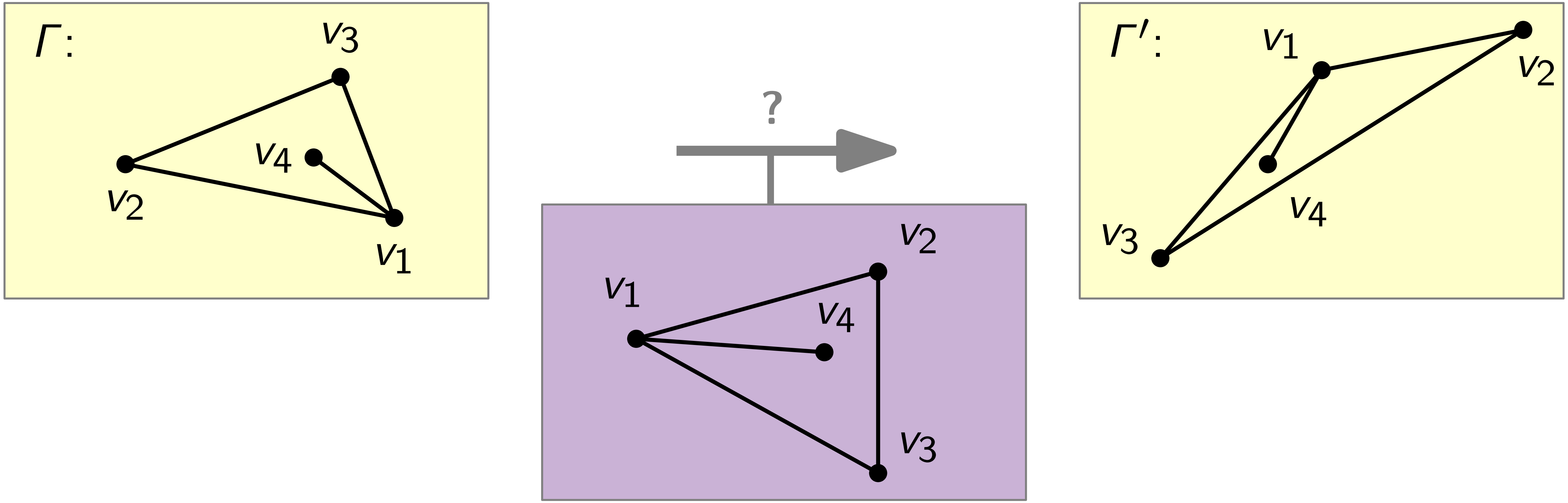

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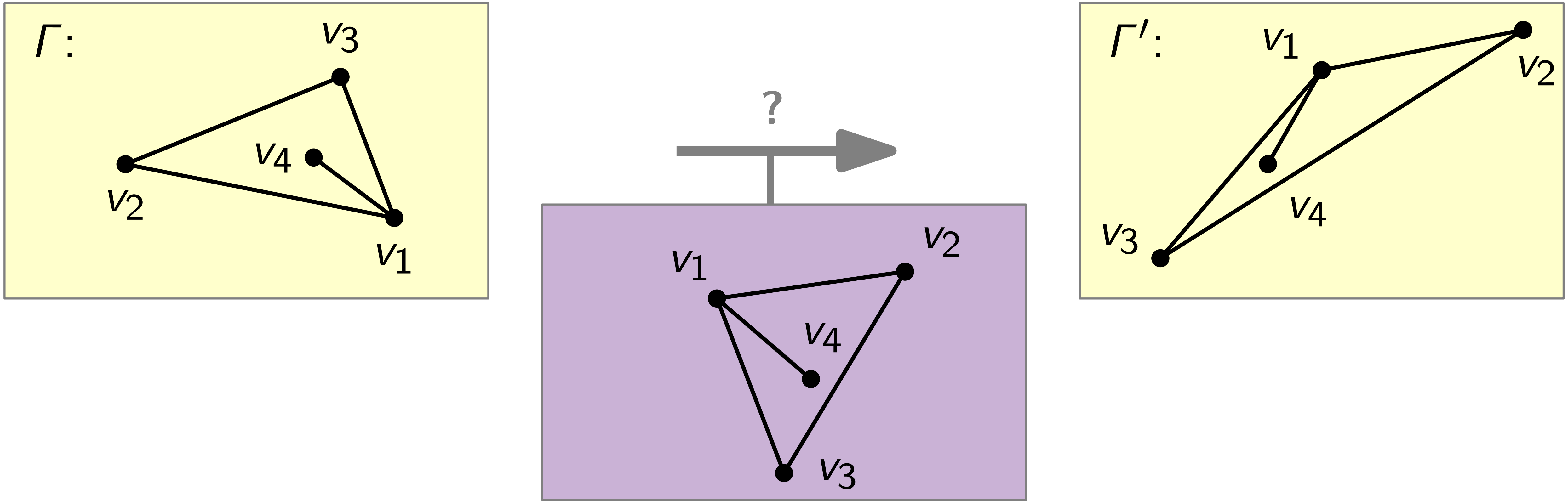

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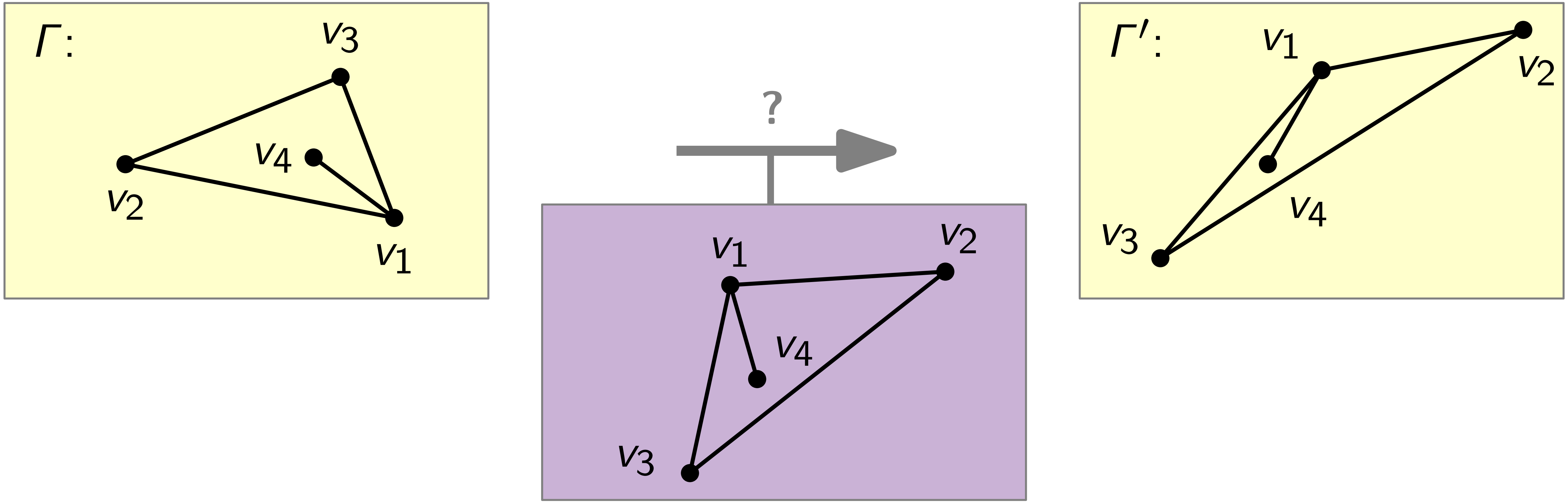

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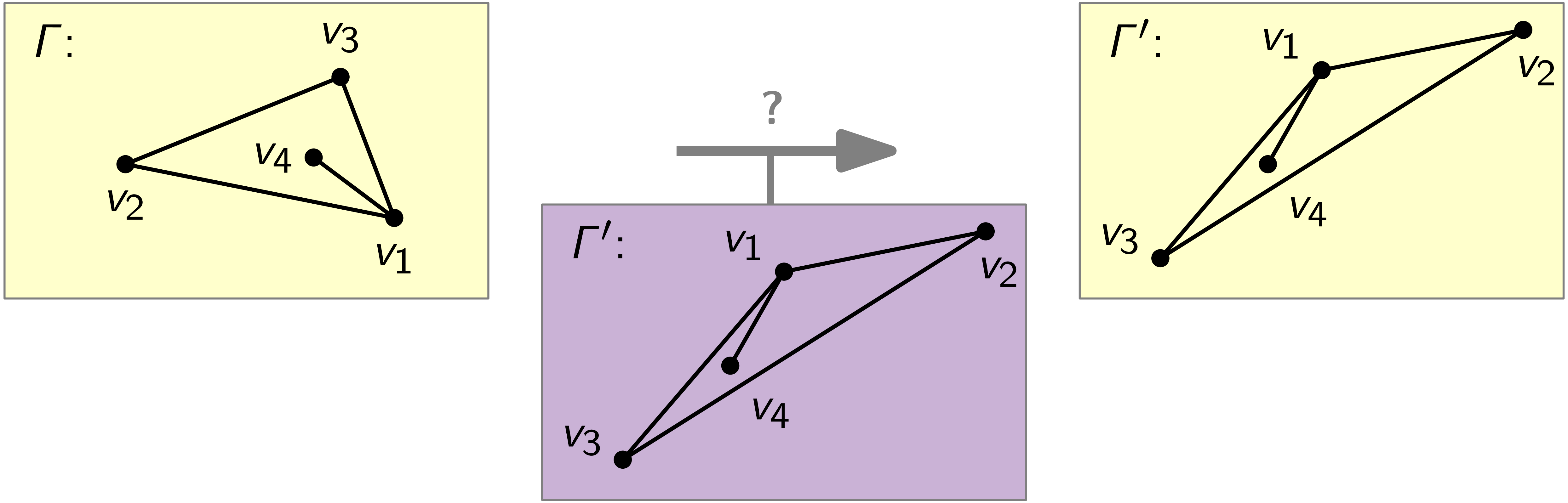

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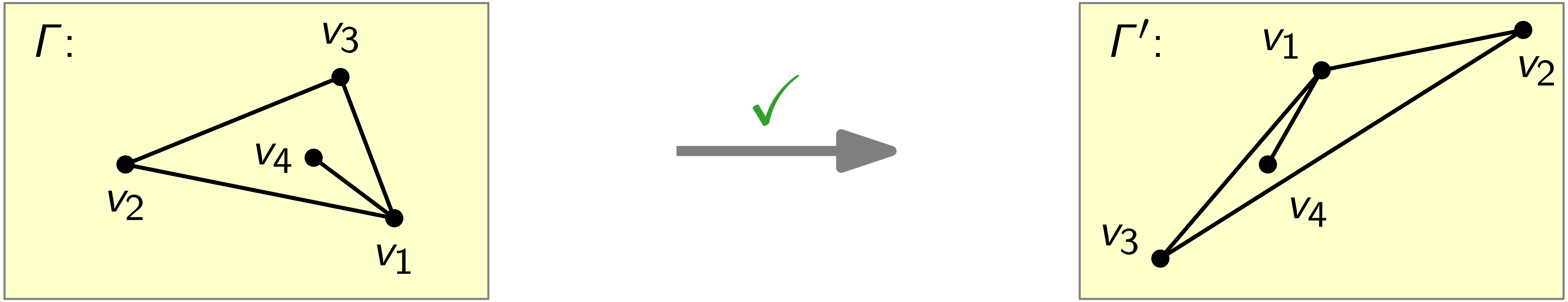

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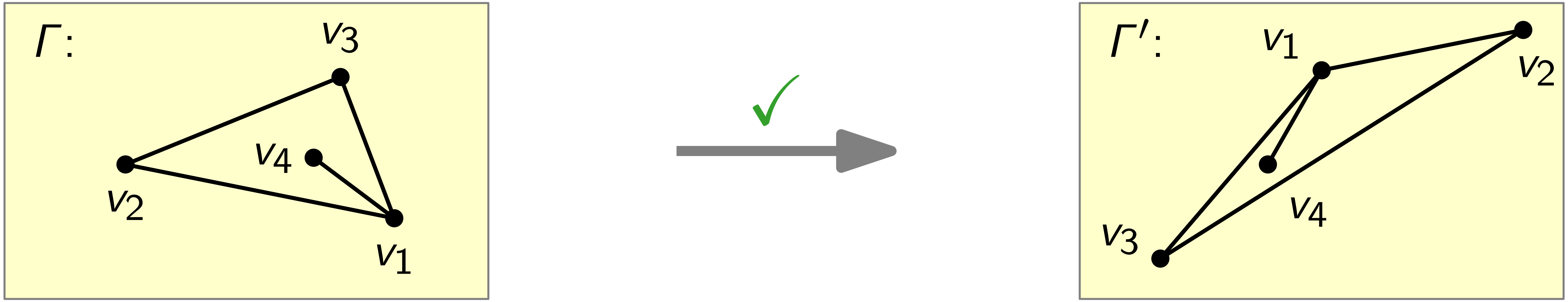

Theorem: It is sufficient that Γ and Γ' have the same planar embedding.

[Cairns 1944, Thomassen 1984]

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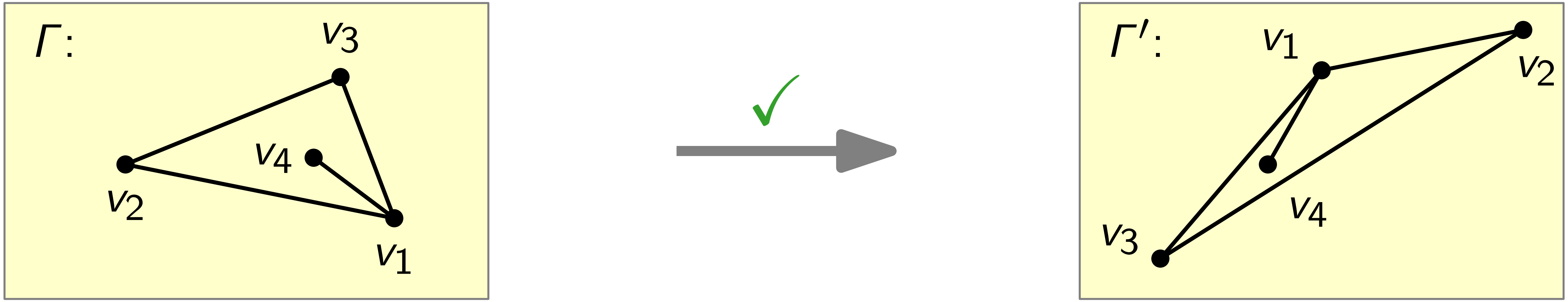

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Note: Checking if two planar drawings have the same planar embedding is in P.

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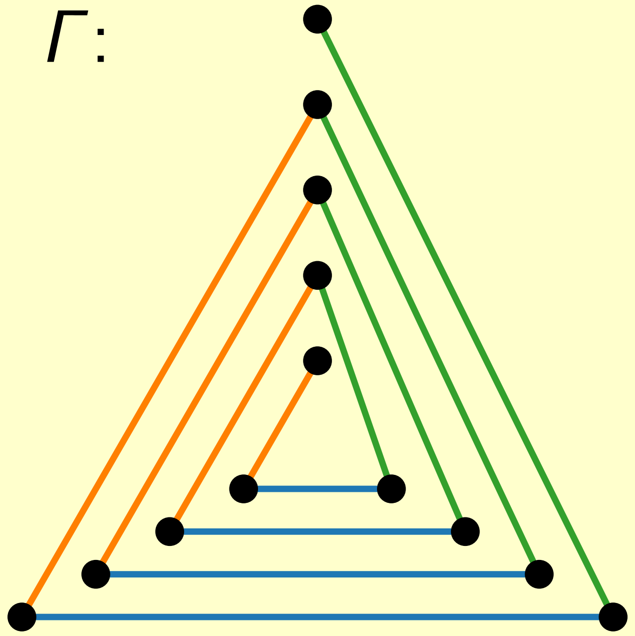

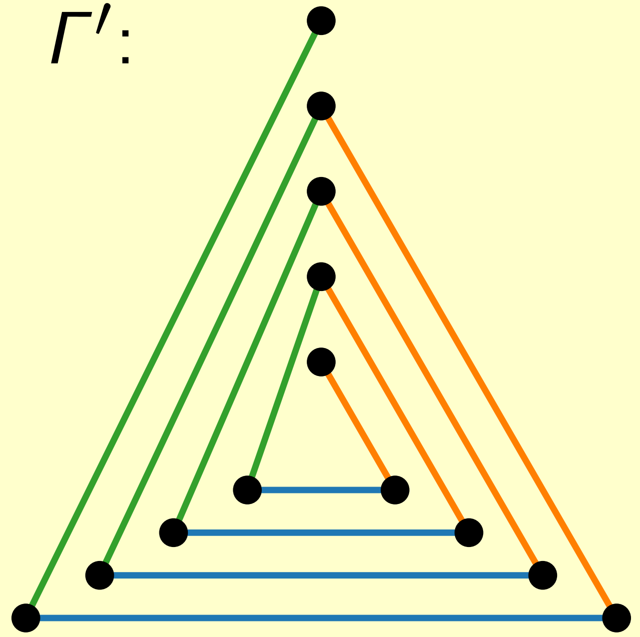

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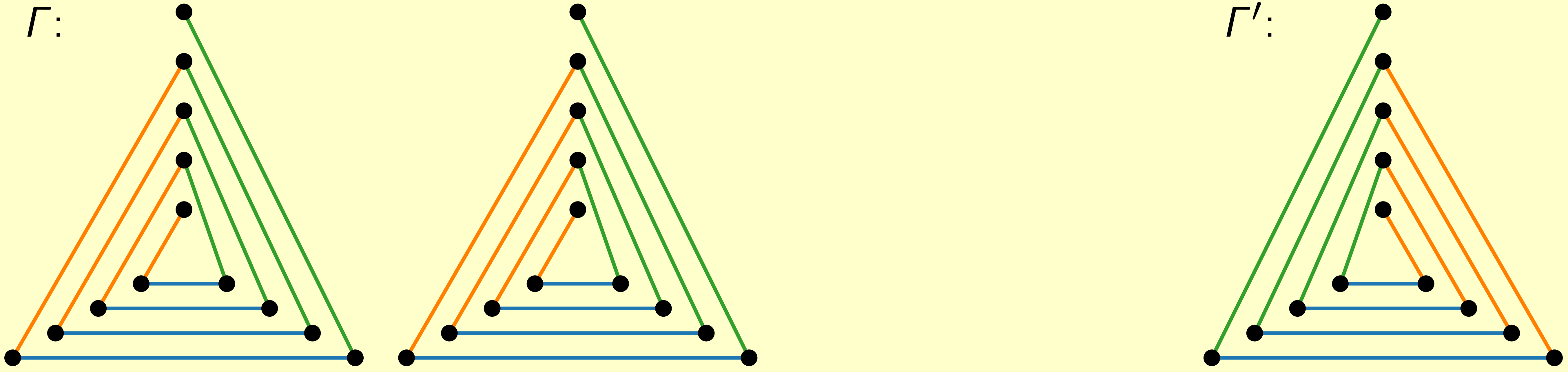

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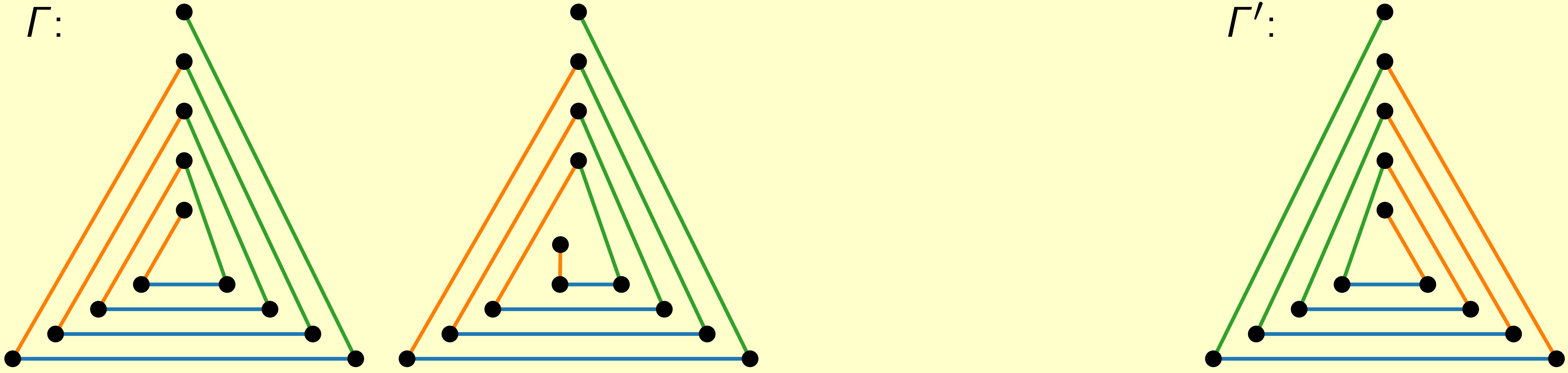

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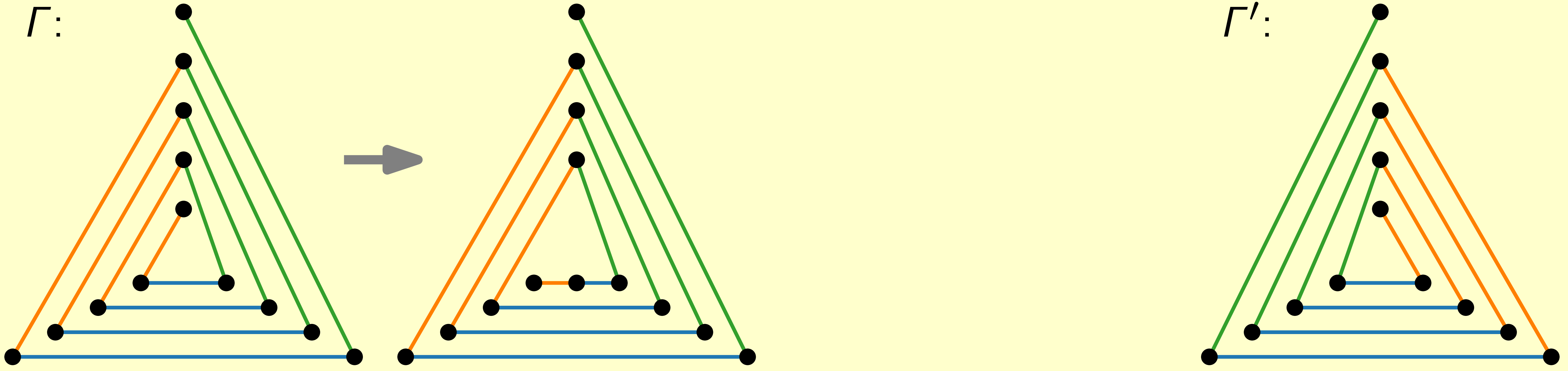

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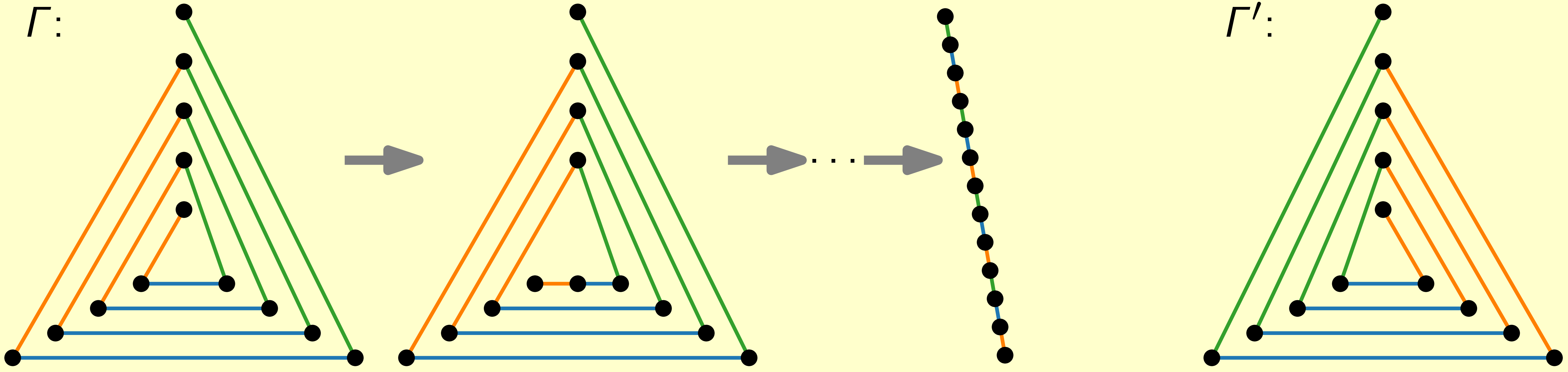

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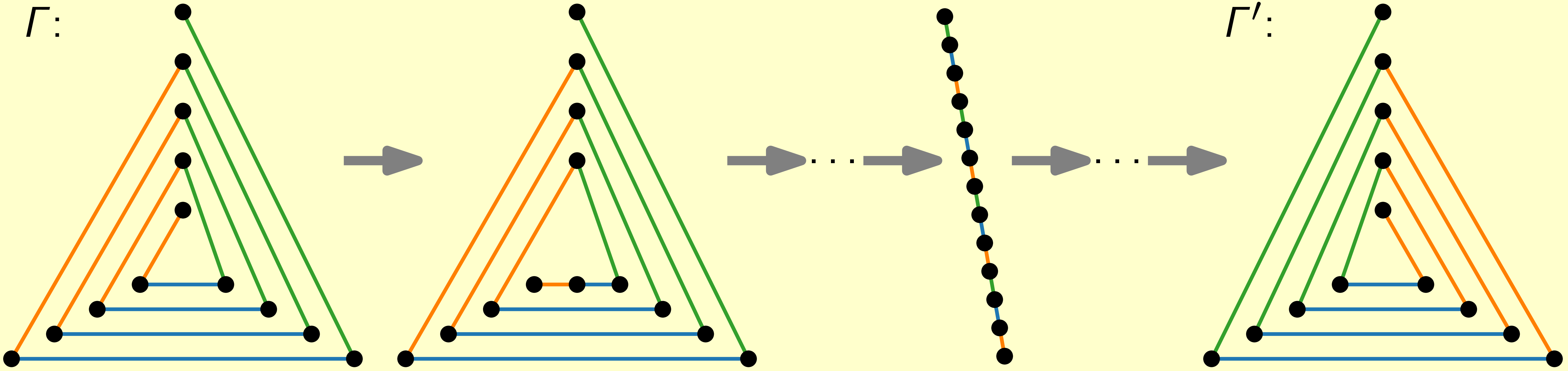

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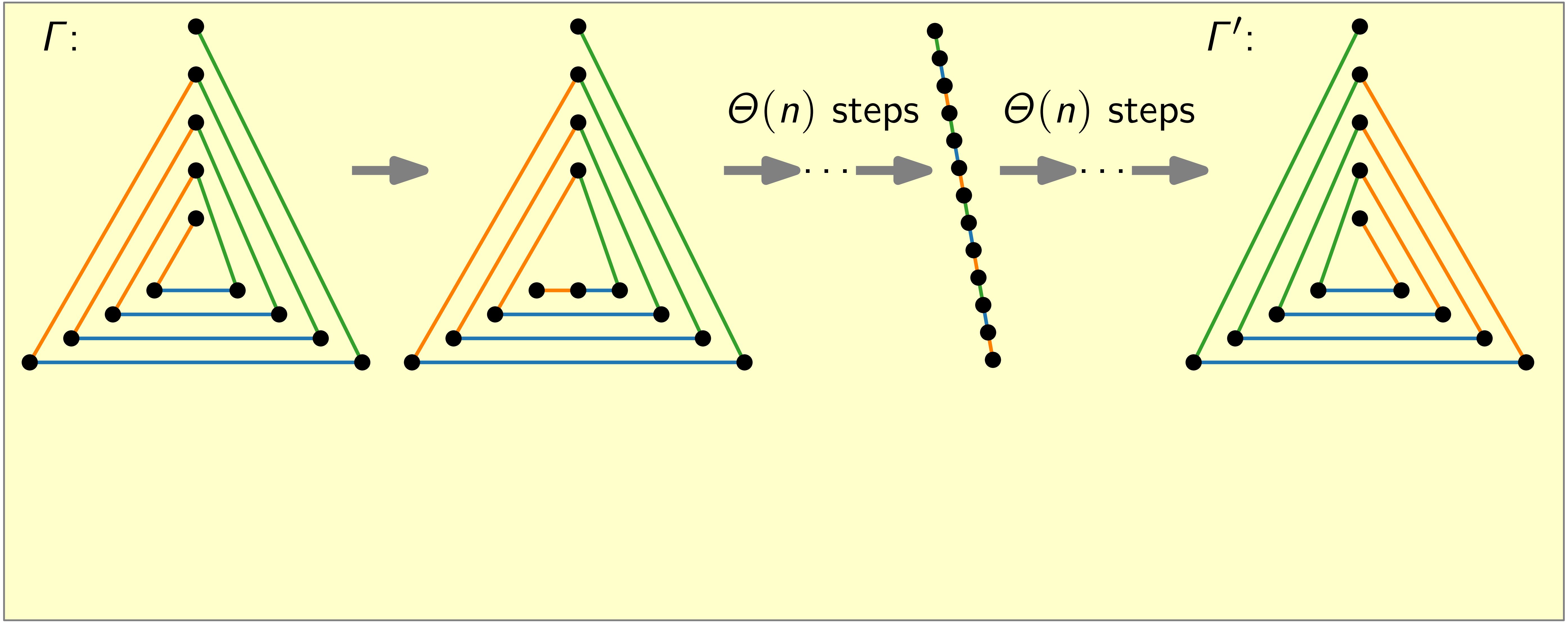

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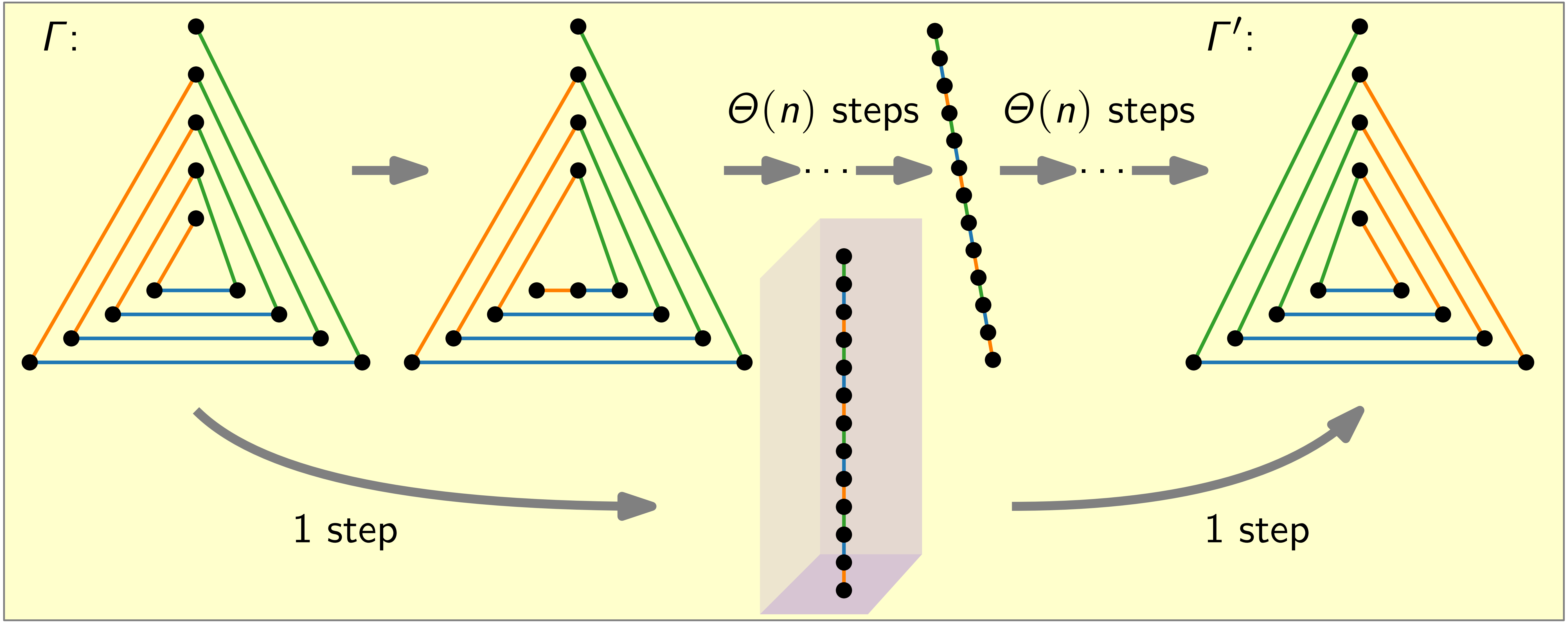

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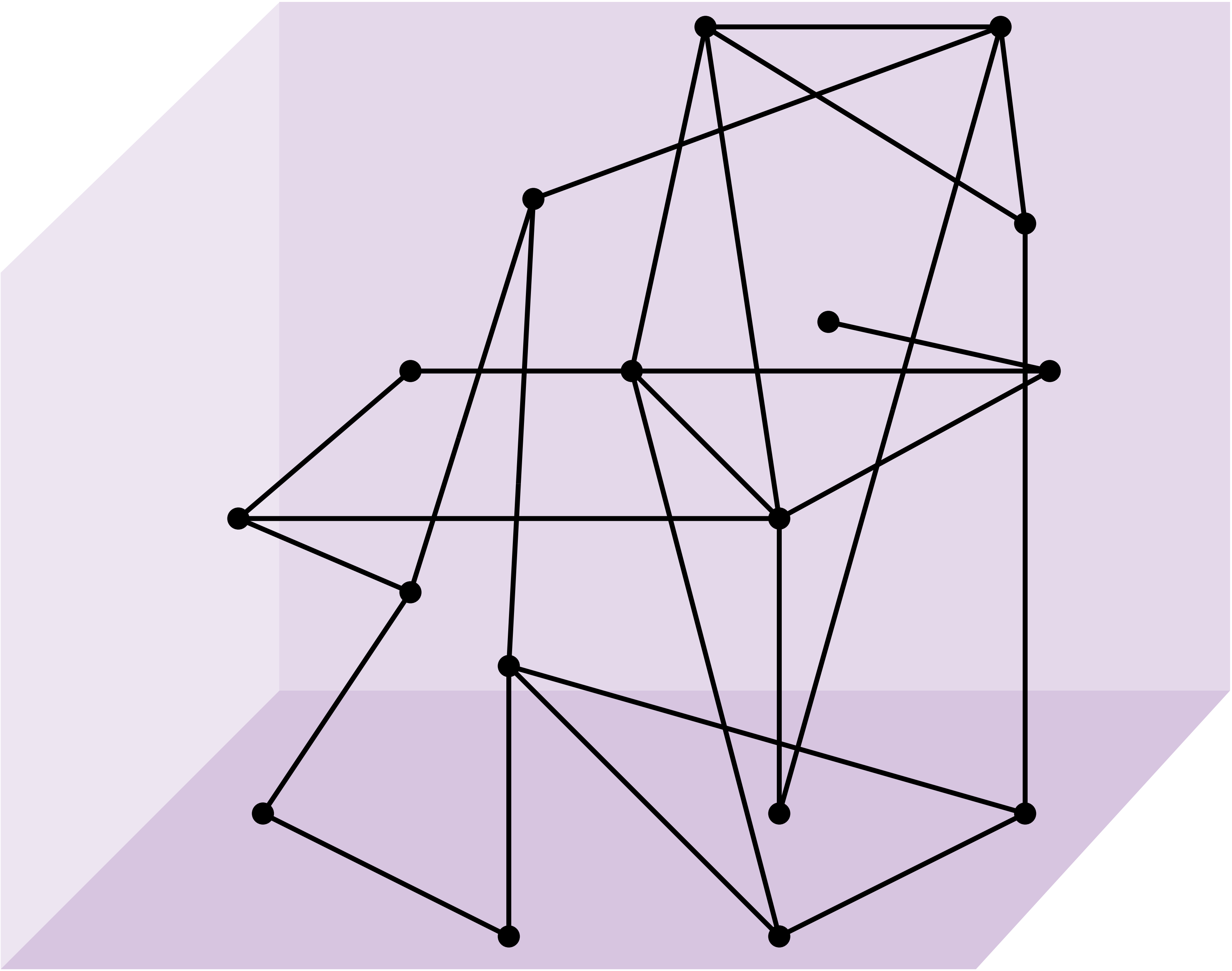

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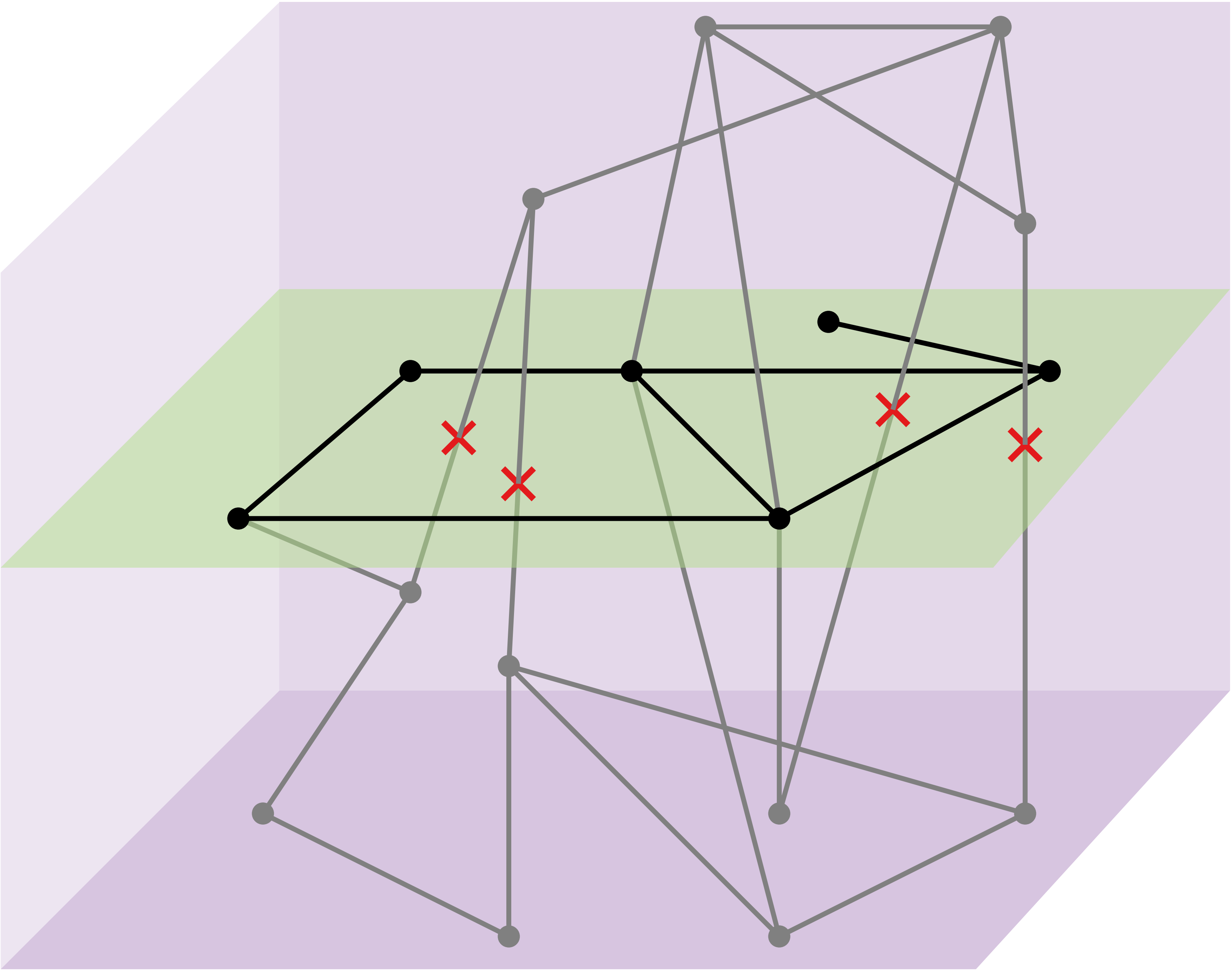

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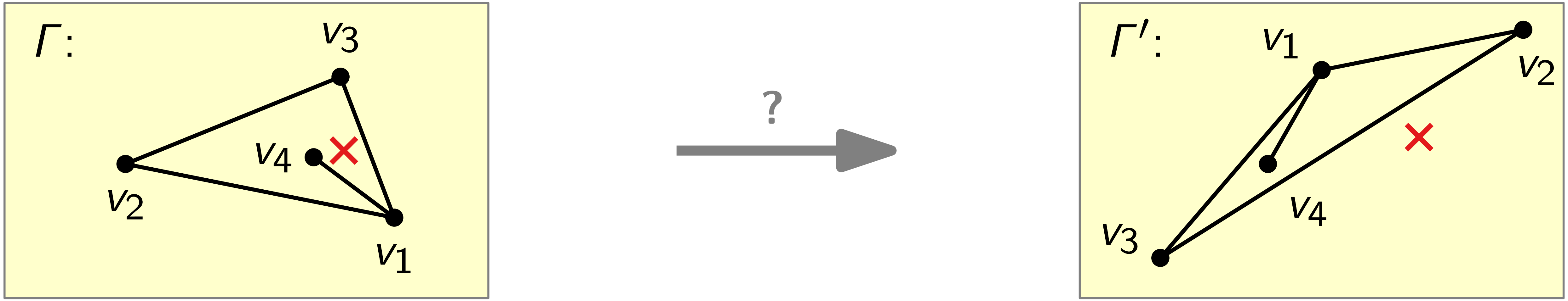

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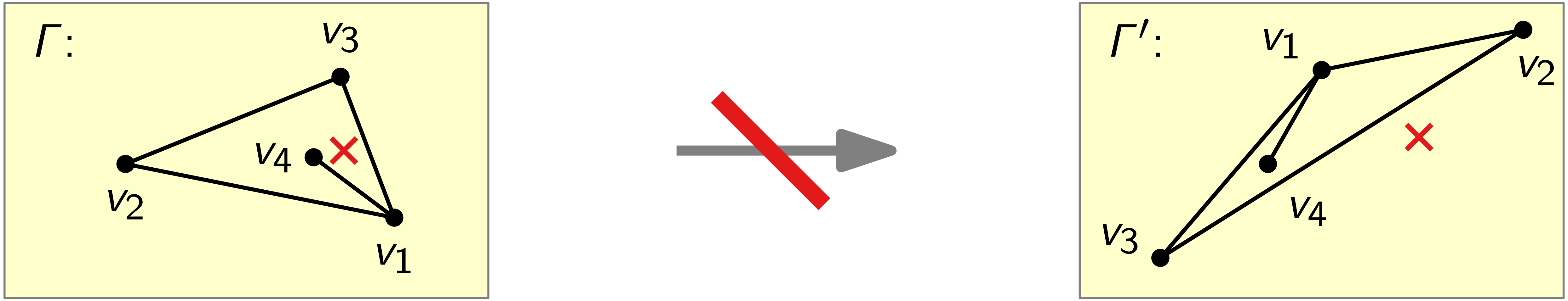

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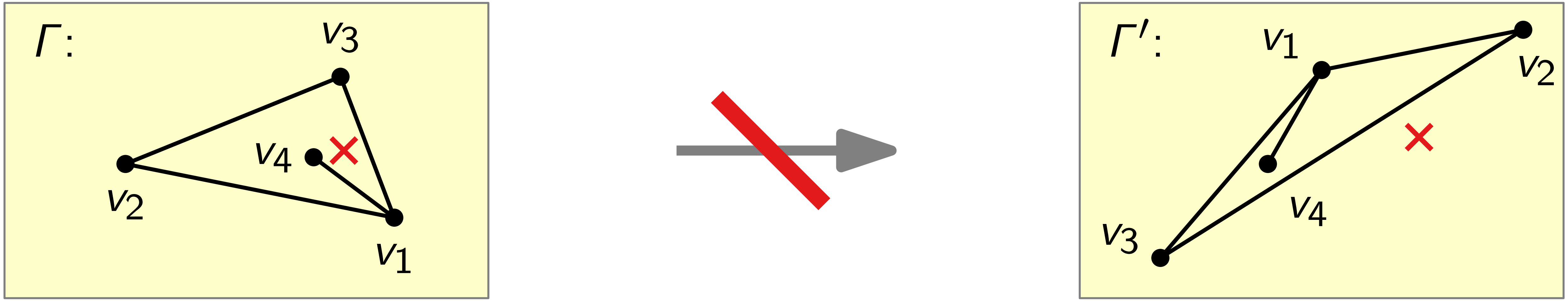

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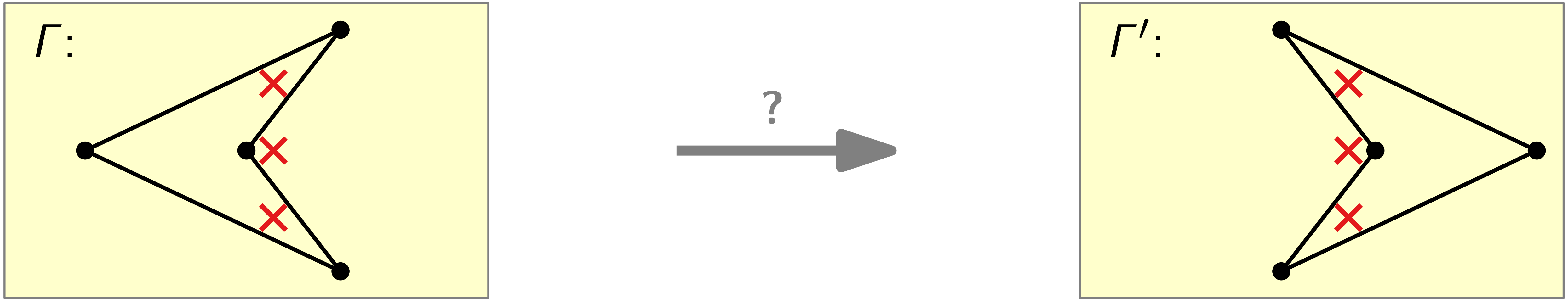

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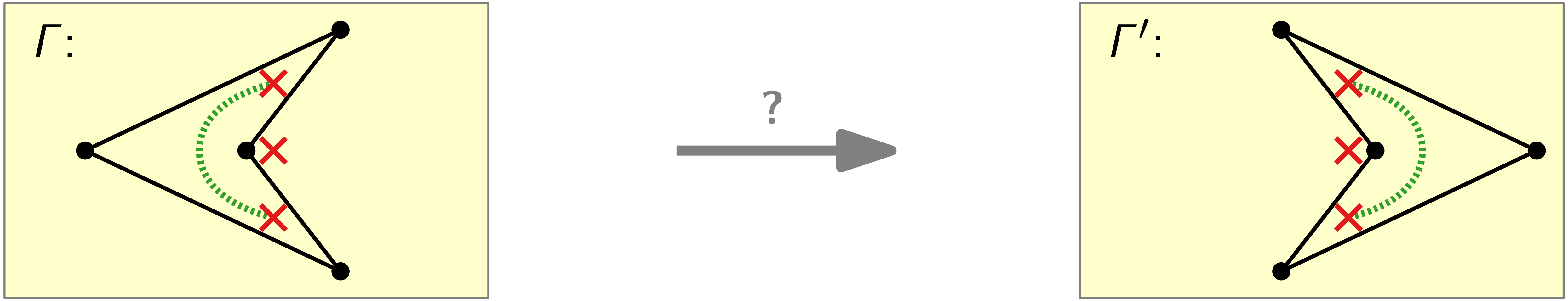

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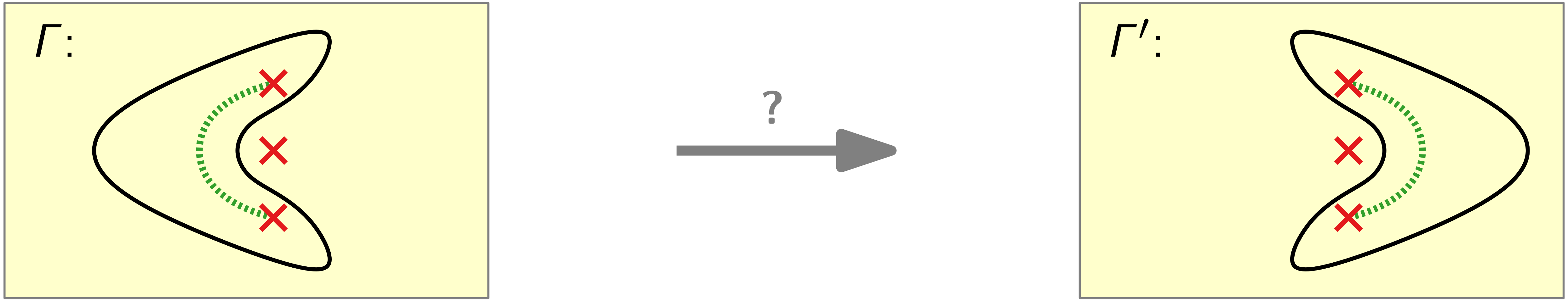

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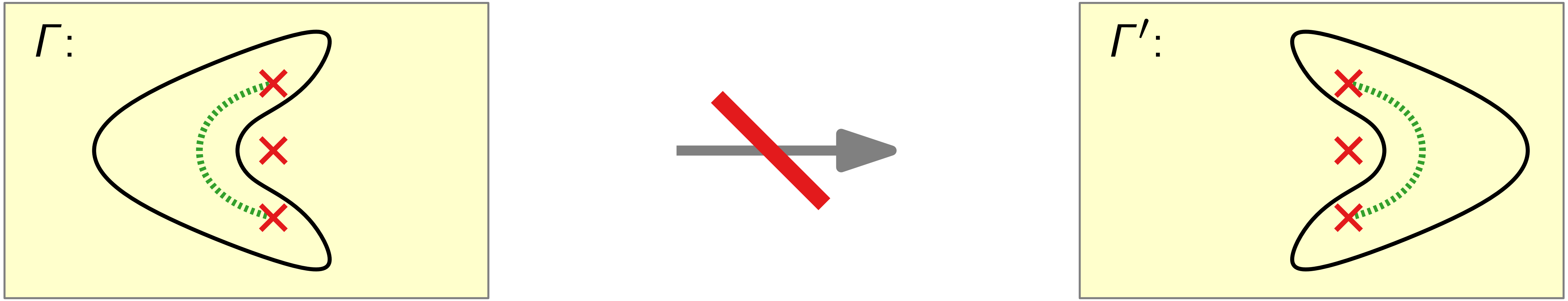

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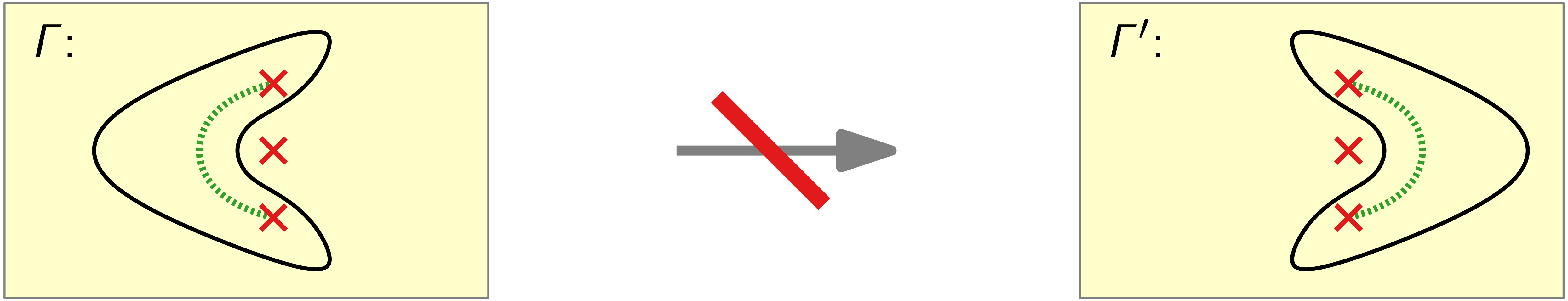

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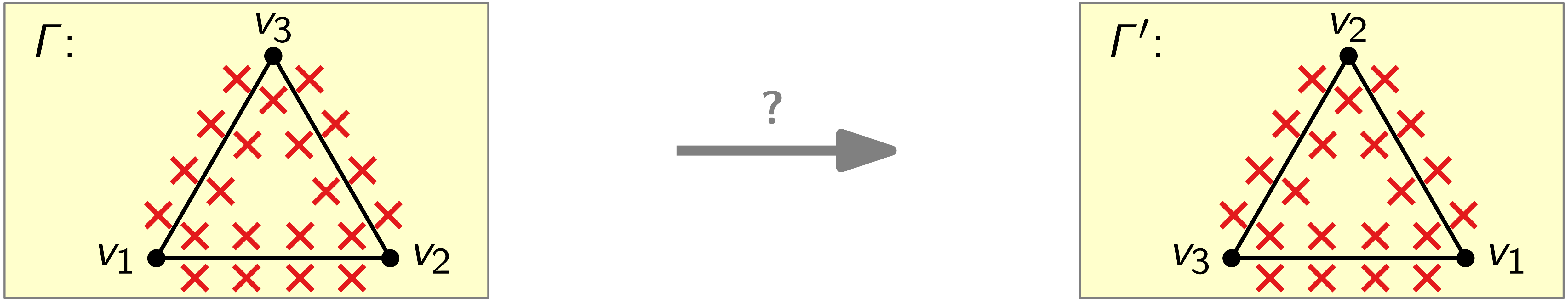

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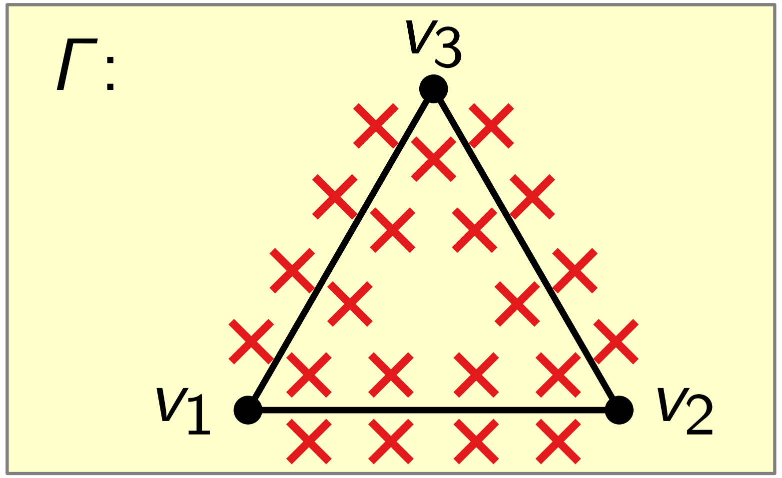

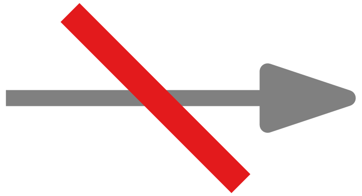

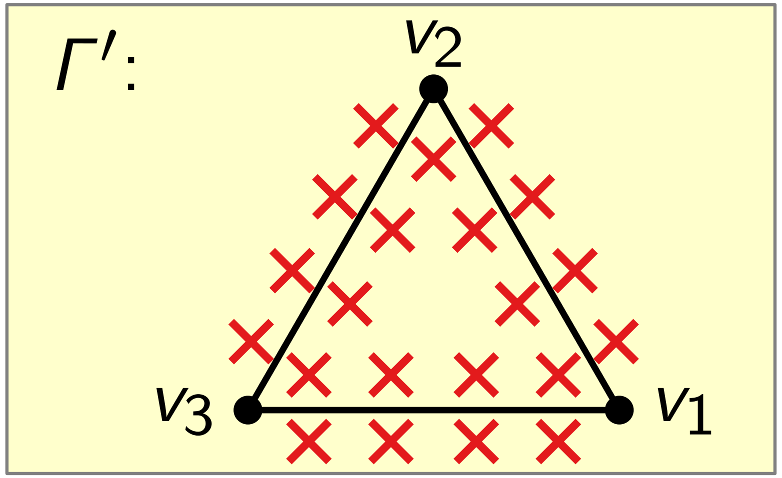

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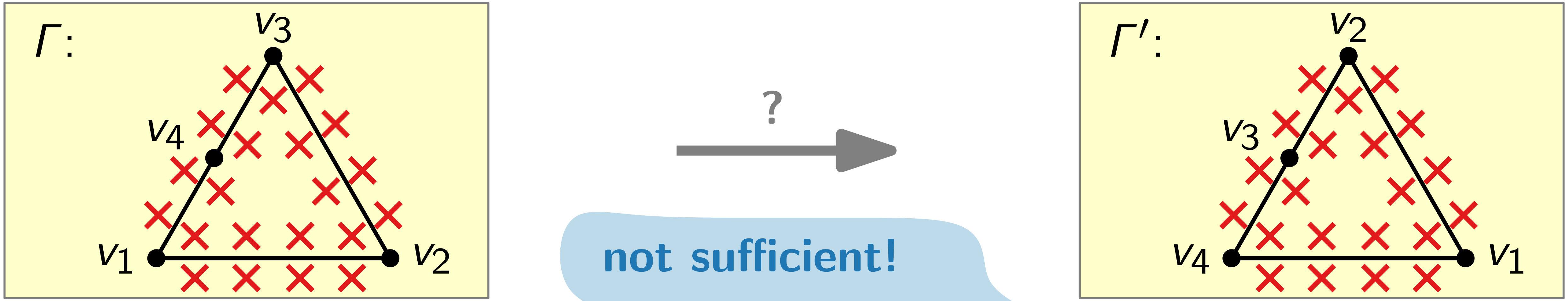

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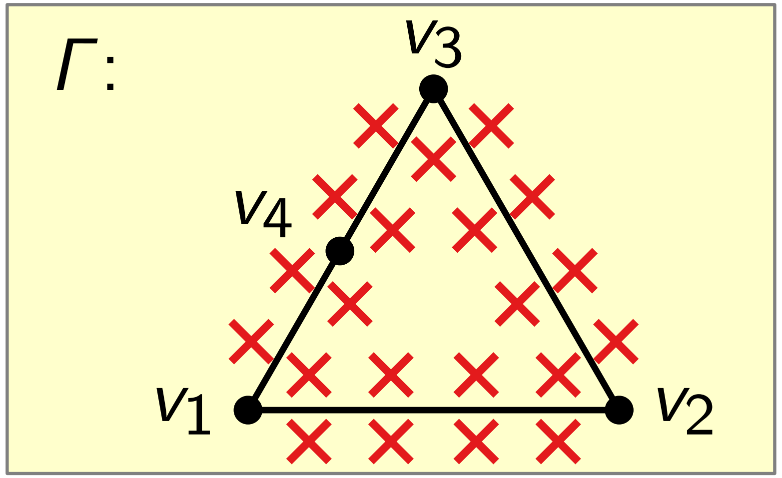

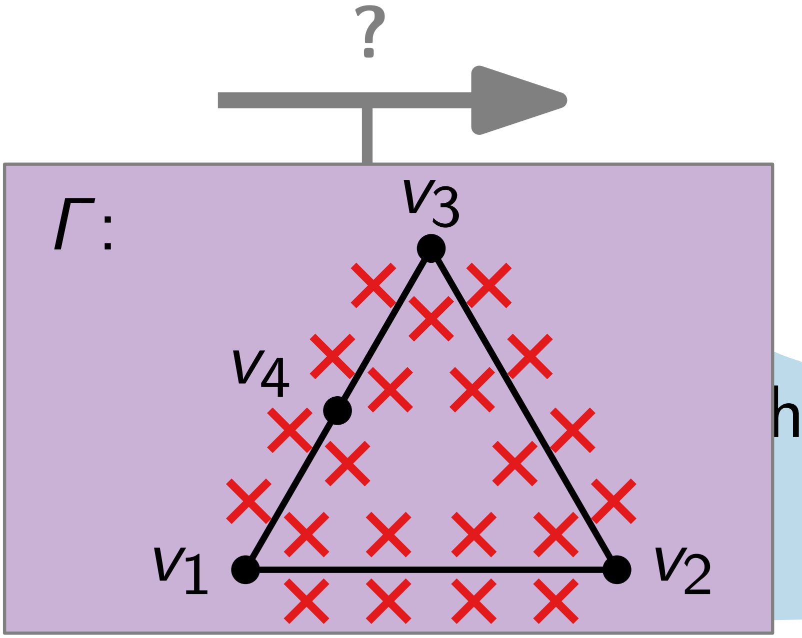

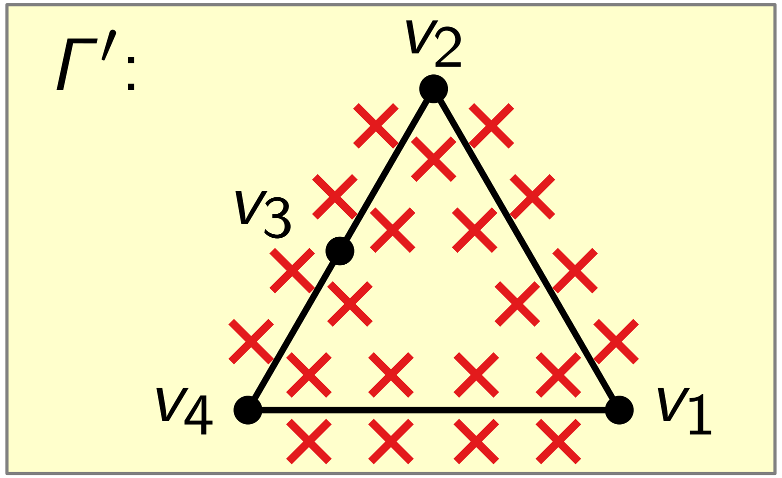

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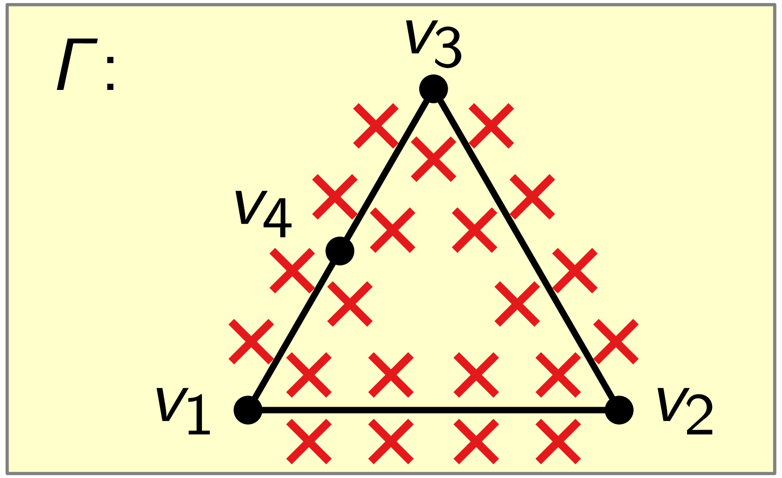

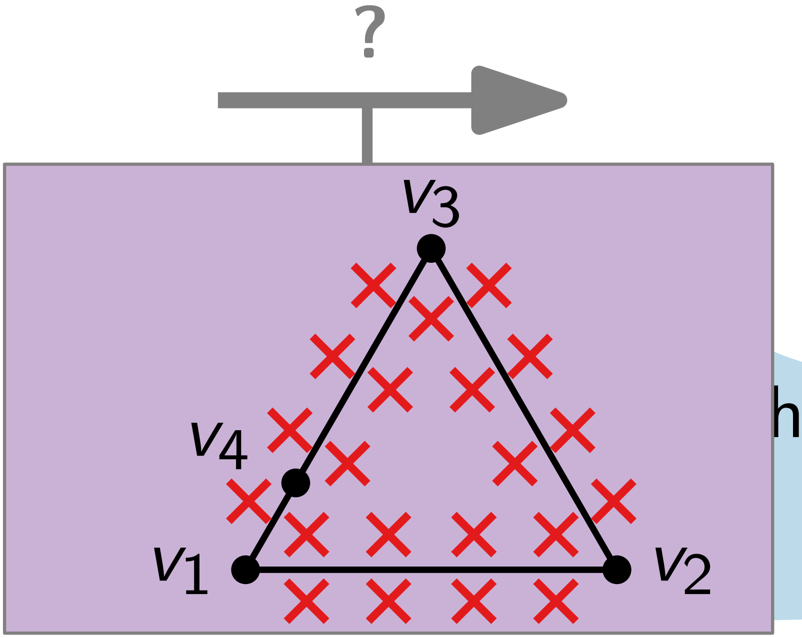

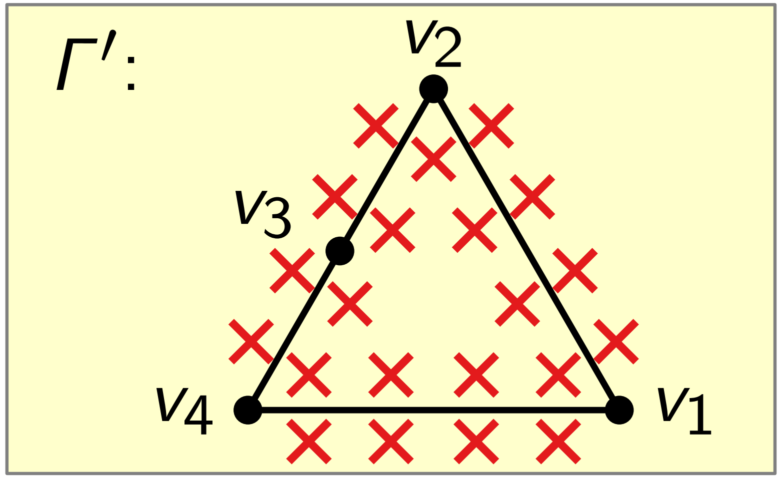

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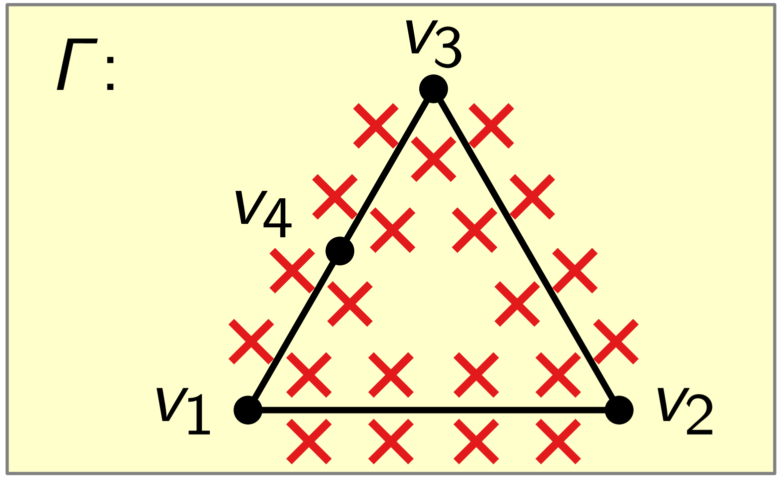

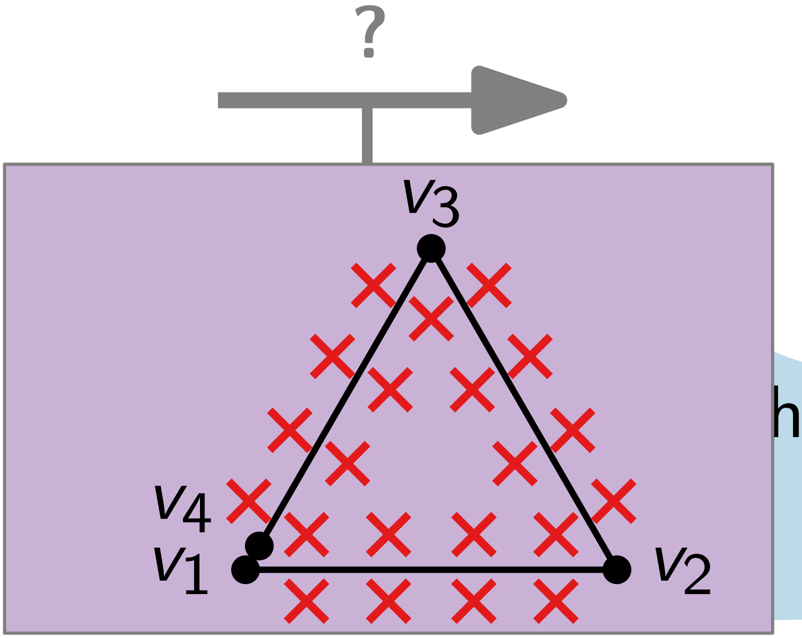

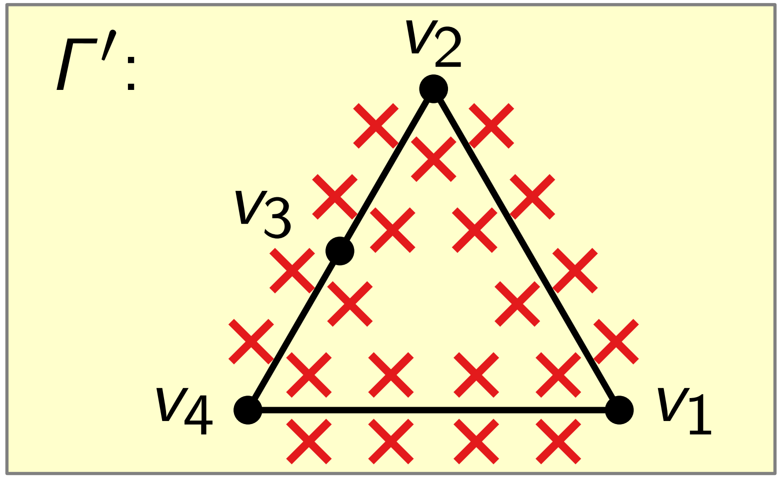

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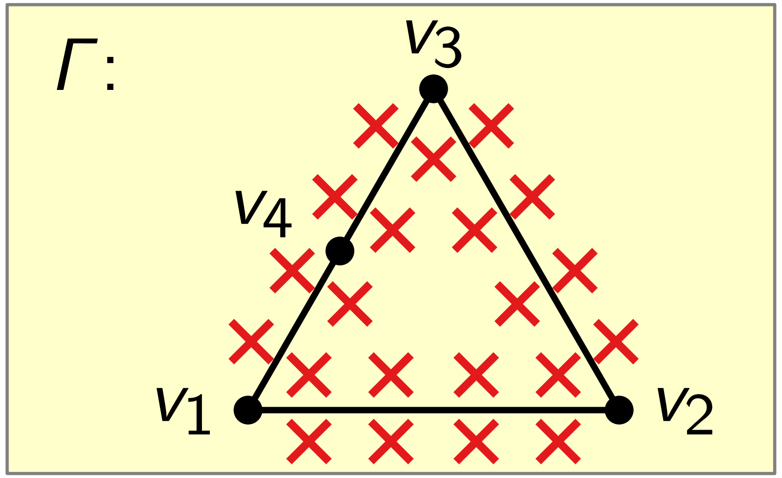

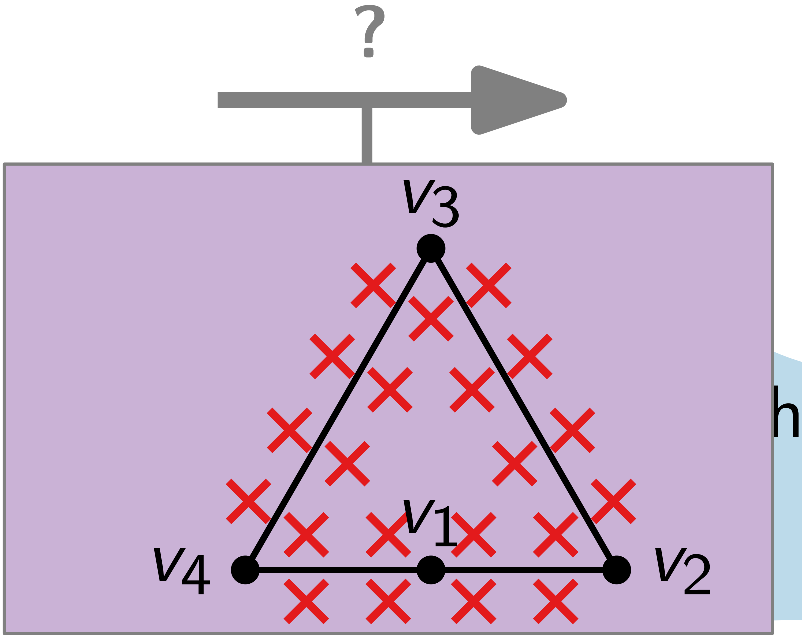

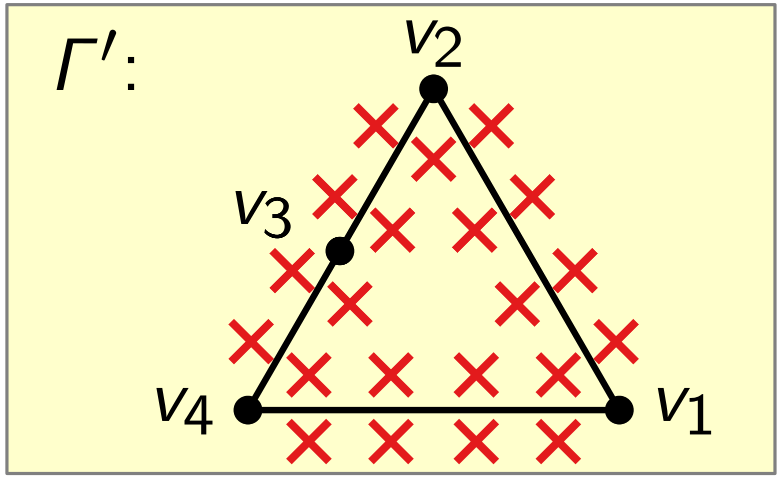

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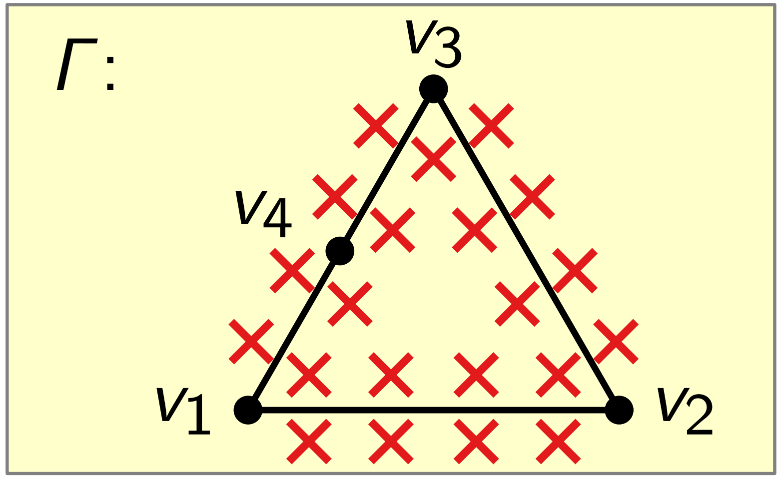

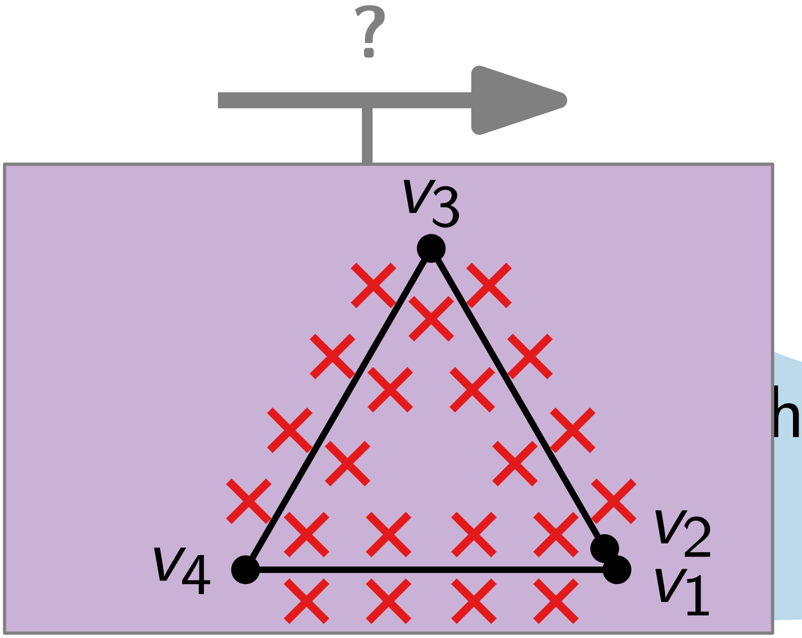

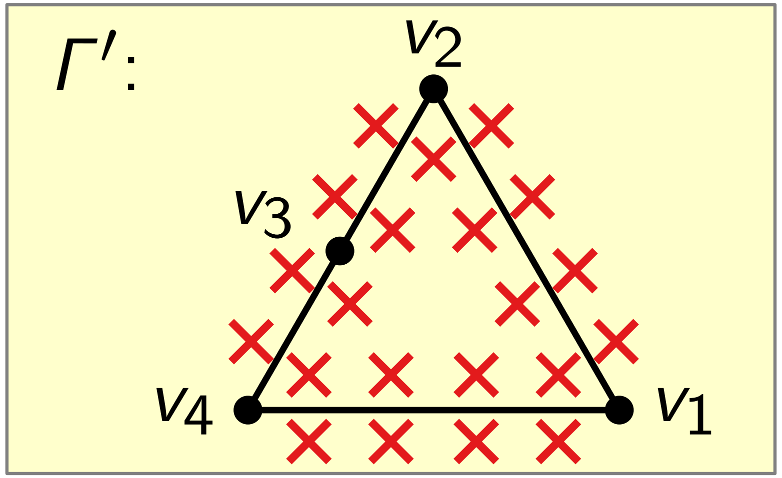

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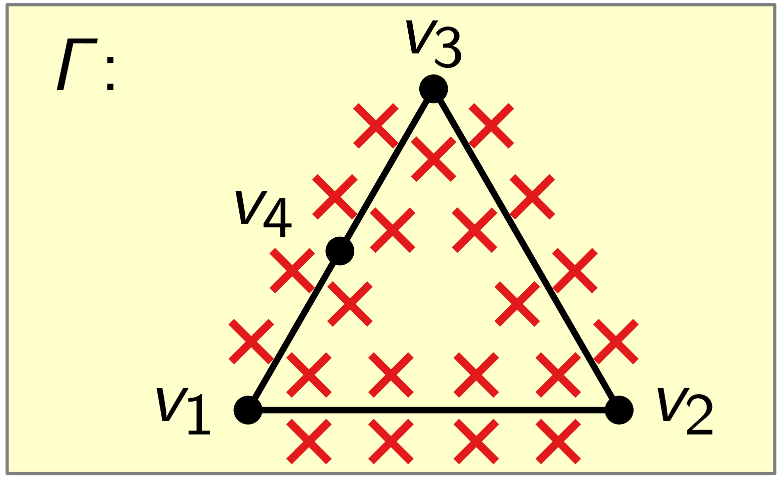

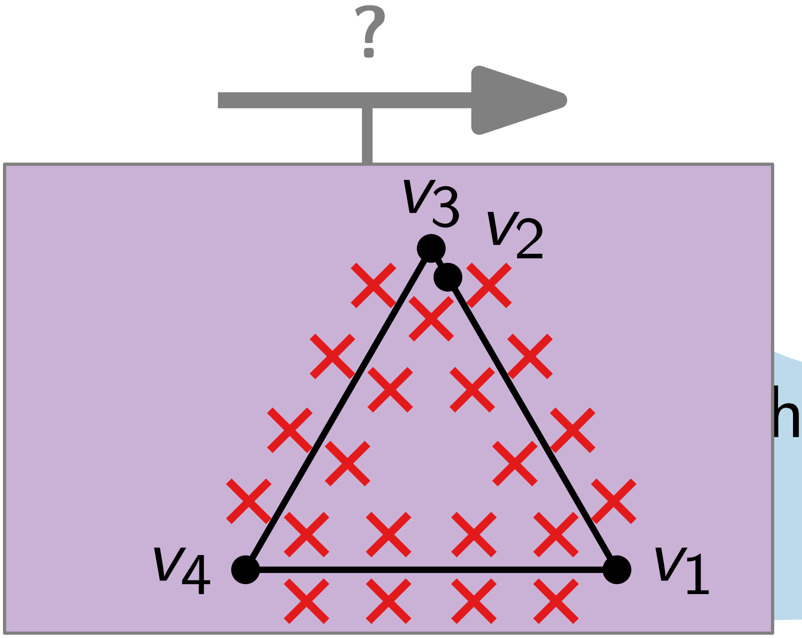

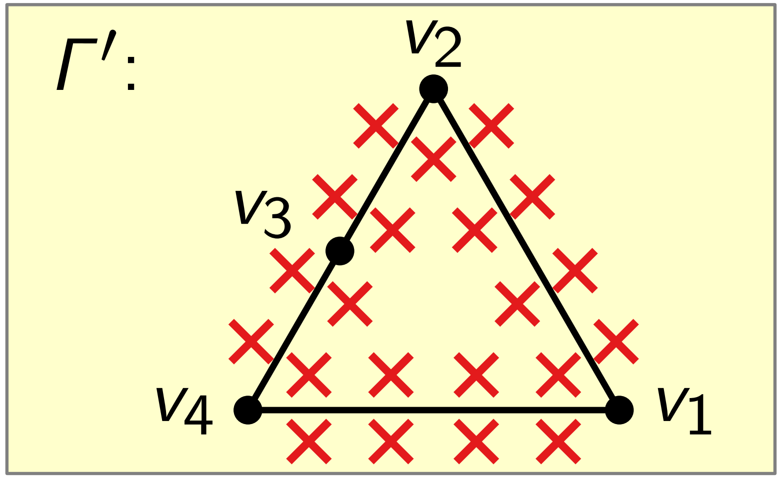

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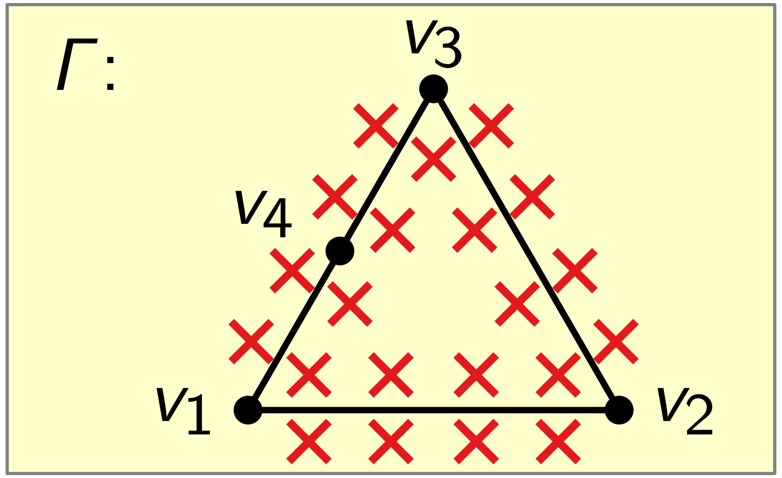

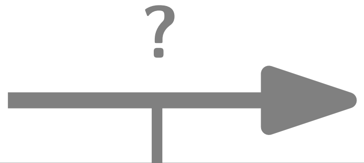

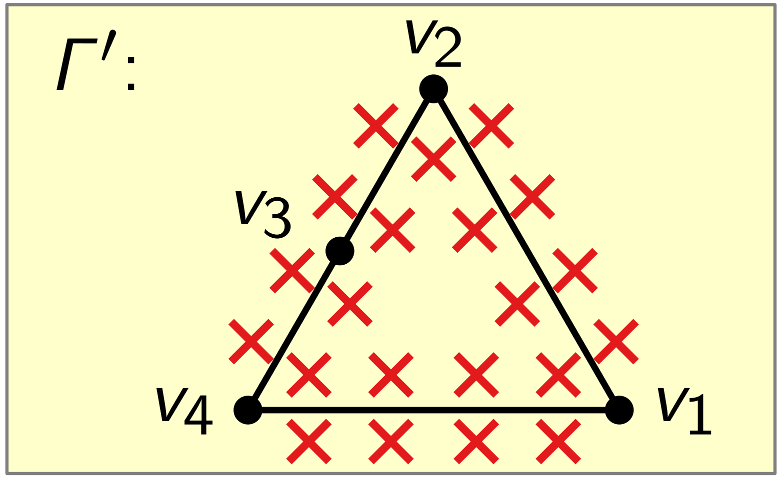

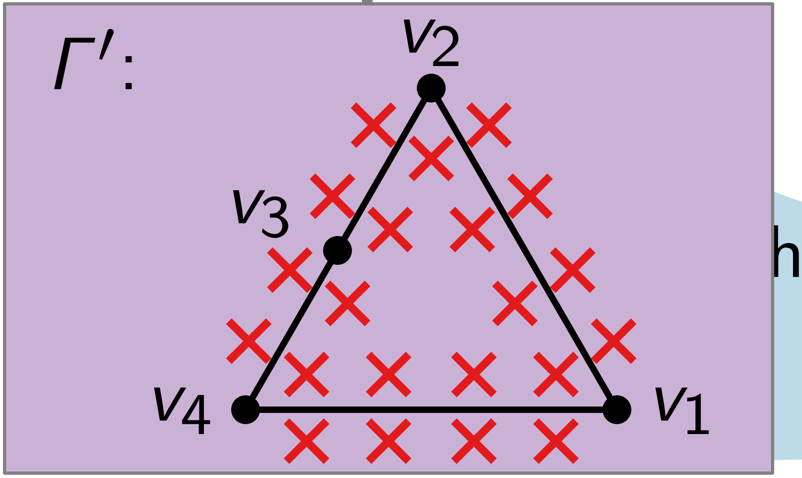

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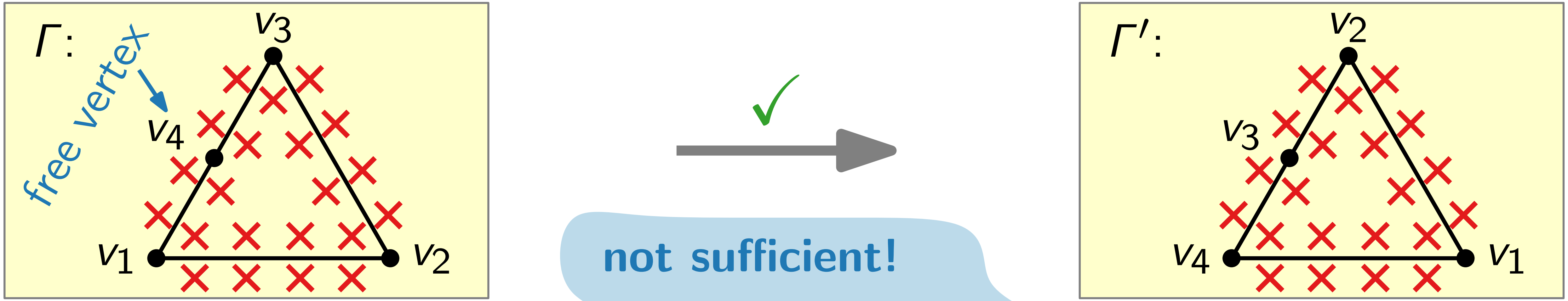

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Main Theorem: It is NP-hard to decide whether there exists an obstacle-avoiding planar straight-line morph in $\mathbb{R}^2$ between Γ and Γ'.

What a “typical” NP-hardness reduction in graph drawing looks like:

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- There is always an obstacle-avoiding continuous deformation from Γ to Γ'.

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The difficulty in this case:

- We need to construct two drawings Γ and Γ' based on I.
- Γ and Γ' need to exist regardless of whether I is a yes-instance or not.
- There is always an obstacle-avoiding continuous deformation from Γ to Γ'.
- There is an obstacle-avoiding planar straight-line morph iff I is a yes-instance.

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Main Theorem: It is NP-hard to decide whether there exists an obstacle-avoiding planar straight-line morph in $\mathbb{R}^2$ between Γ and Γ'.

Proof idea.

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Proof idea.

- Reduction from 3-SAT.
- We construct Γ and Γ' based on a given Boolean formula in CNF.
- Γ and Γ' are identical except for the positions of four vertices.

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Main Theorem: It is NP-hard to decide whether there exists an obstacle-avoiding planar straight-line morph in $\mathbb{R}^2$ between Γ and Γ'.

Proof idea.

- Reduction from 3-SAT.
- We construct Γ and Γ' based on a given Boolean formula in CNF.
- Γ and Γ' are identical except for the positions of four vertices.
- The obstacles are arranged to form a grid-like tunnel structure.

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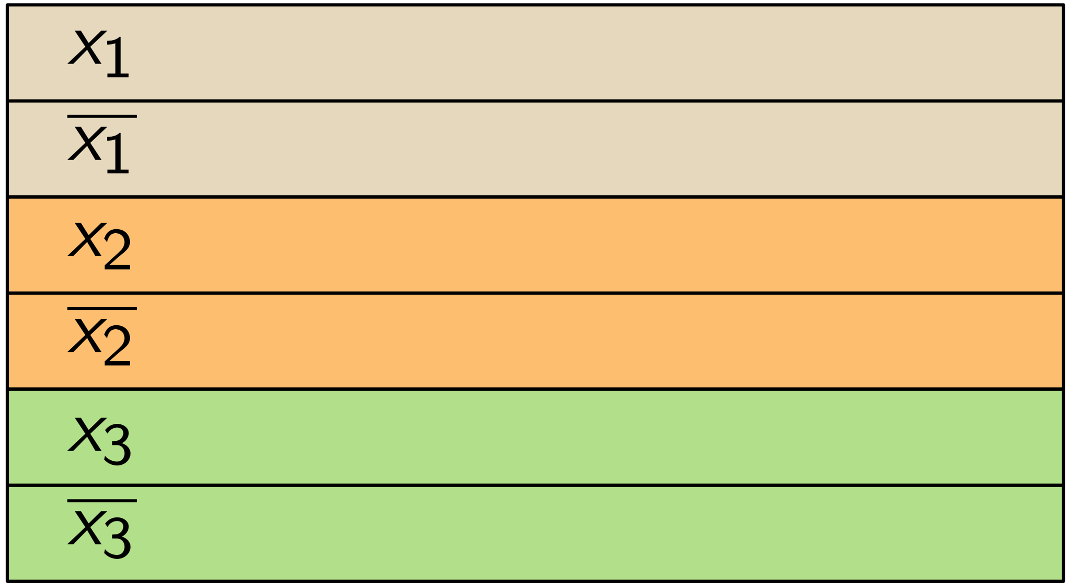
Main Theorem: It is NP-hard to decide whether there exists an obstacle-avoiding planar straight-line morph in $\mathbb{R}^2$ between Γ and Γ'.

Proof idea.

- Two rows for each variable (one per literal).



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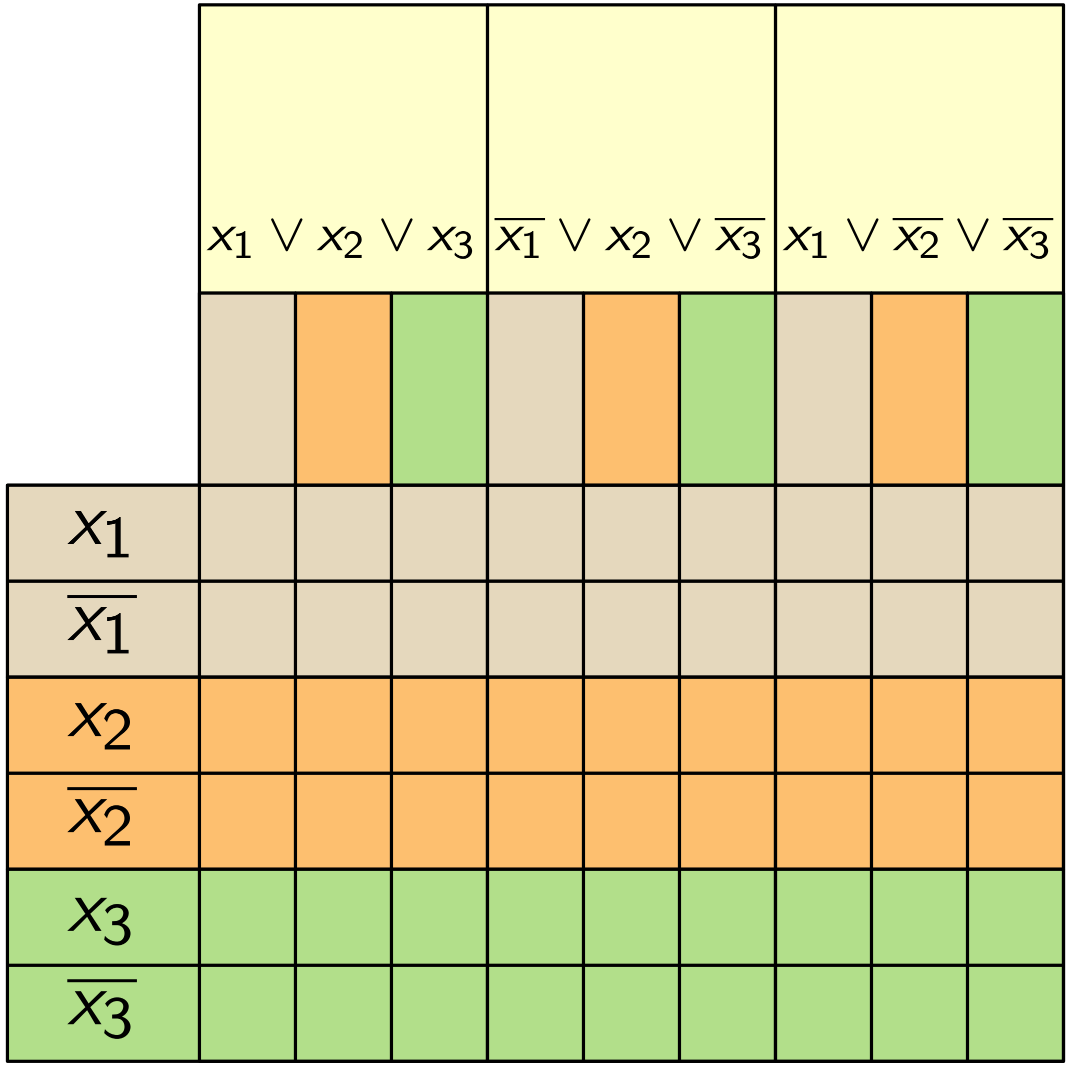
Proof idea.

- Two rows for each variable (one per literal).
- Three columns for each clause (one per literal).



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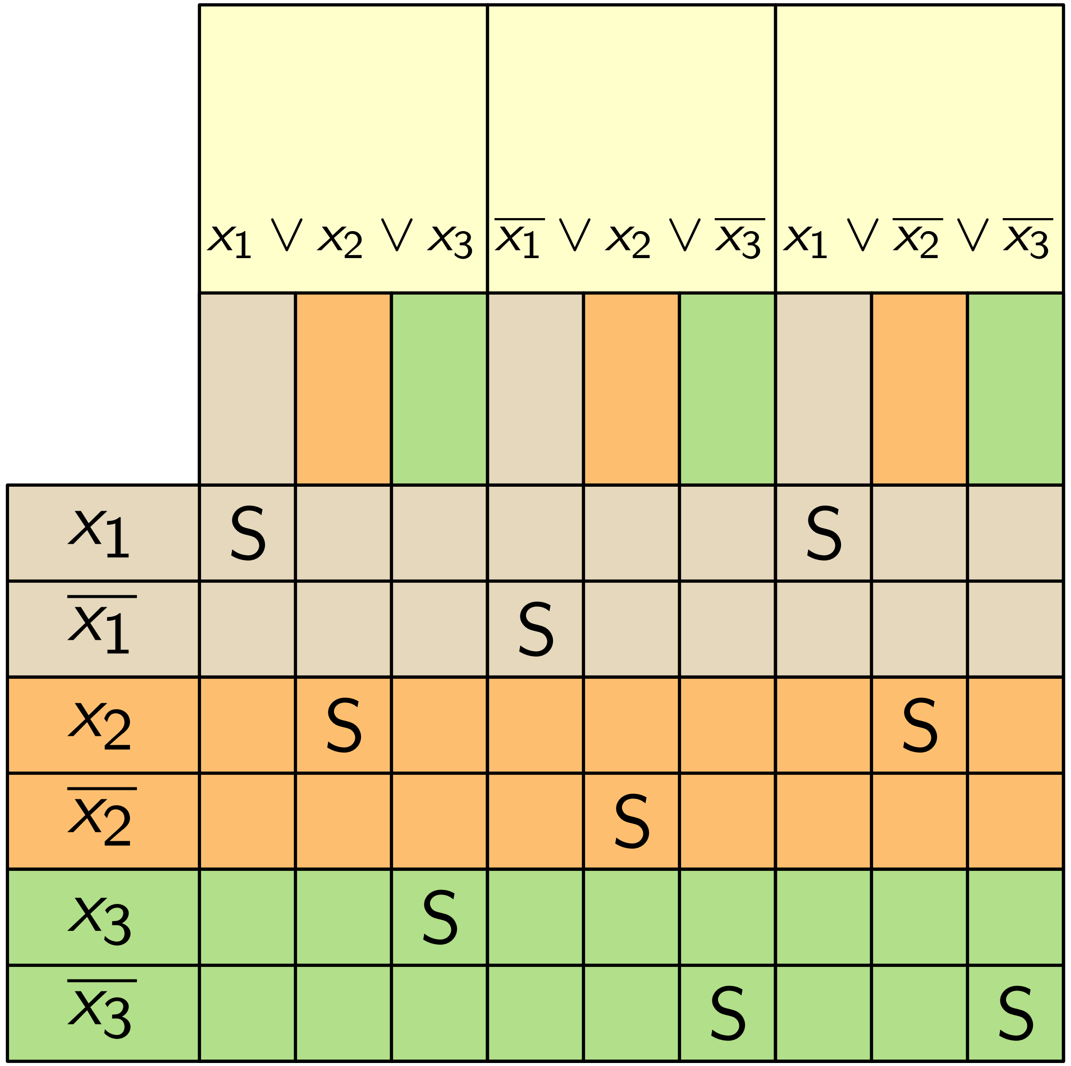
Proof idea.

- Two rows for each variable (one per literal).
- Three columns for each clause (one per literal).
- Split gadget if same literal in row & column;



	$x_1 \vee x_2 \vee x_3$			$\overline{x_1} \vee x_2 \vee \overline{x_3}$			$x_1 \vee \overline{x_2} \vee \overline{x_3}$		
	🟫	🟧	🟩	🟫	🟧	🟩	🟫	🟧	🟩
x_1	S						S		
$\overline{x_1}$				S					
x_2		S						S	
$\overline{x_2}$					S				
x_3			S						
$\overline{x_3}$						S			S

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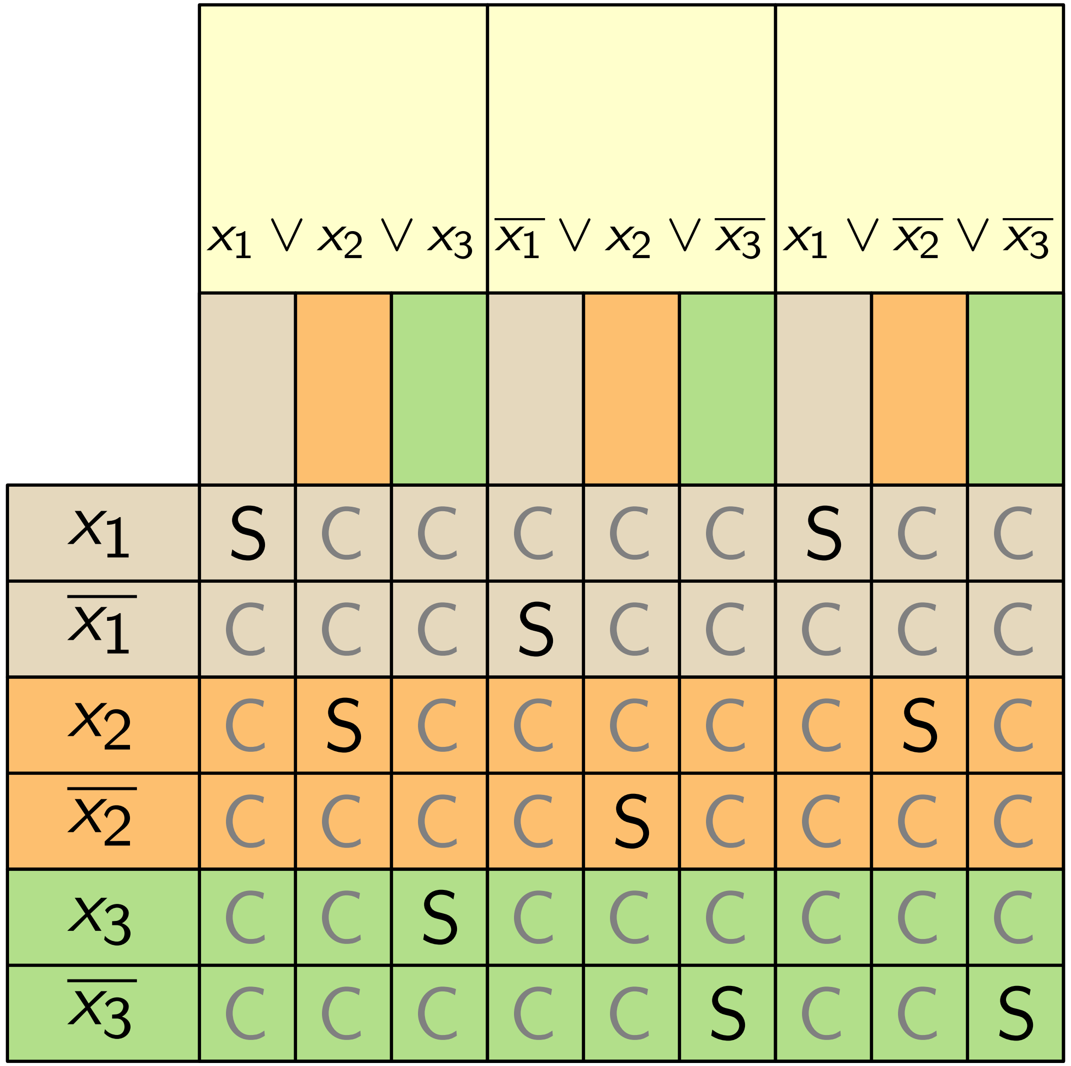
Proof idea.

- Two rows for each variable (one per literal).
- Three columns for each clause (one per literal).
- Split gadget if same literal in row & column; crossing gadget otherwise.



	$x_1 \vee x_2 \vee x_3$			$\overline{x_1} \vee x_2 \vee \overline{x_3}$			$x_1 \vee \overline{x_2} \vee \overline{x_3}$		
x_1	S	C	C	C	C	C	S	C	C
$\overline{x_1}$	C	C	C	S	C	C	C	C	C
x_2	C	S	C	C	C	C	C	S	C
$\overline{x_2}$	C	C	C	C	S	C	C	C	C
x_3	C	C	S	C	C	C	C	C	C
$\overline{x_3}$	C	C	C	C	C	S	C	C	S

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Proof idea.

- Two rows for each variable (one per literal).
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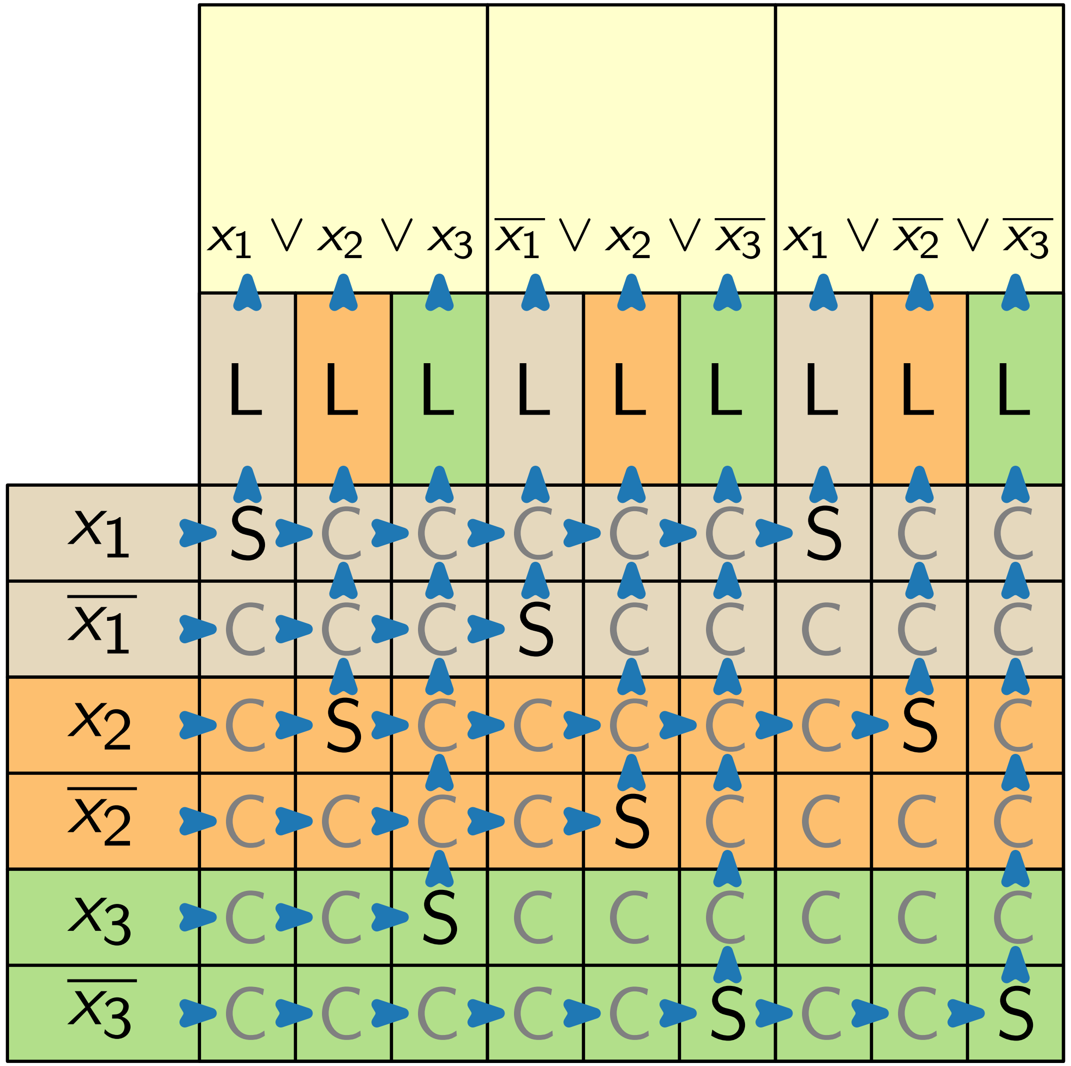
- Split gadget if same literal in row & column; crossing gadget otherwise.
- Free vertices can be passed from variable gadgets along rows and columns to literal gadgets.



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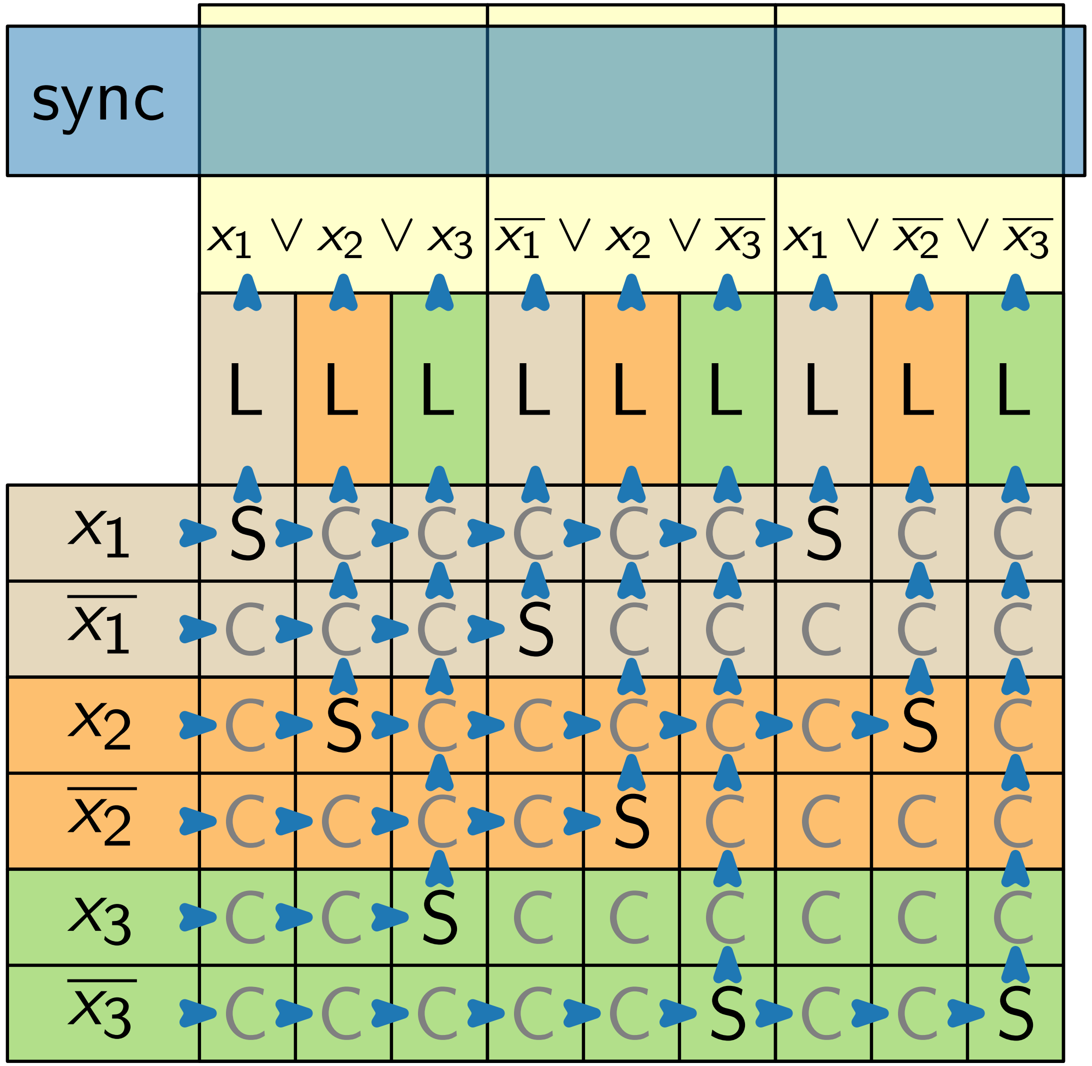
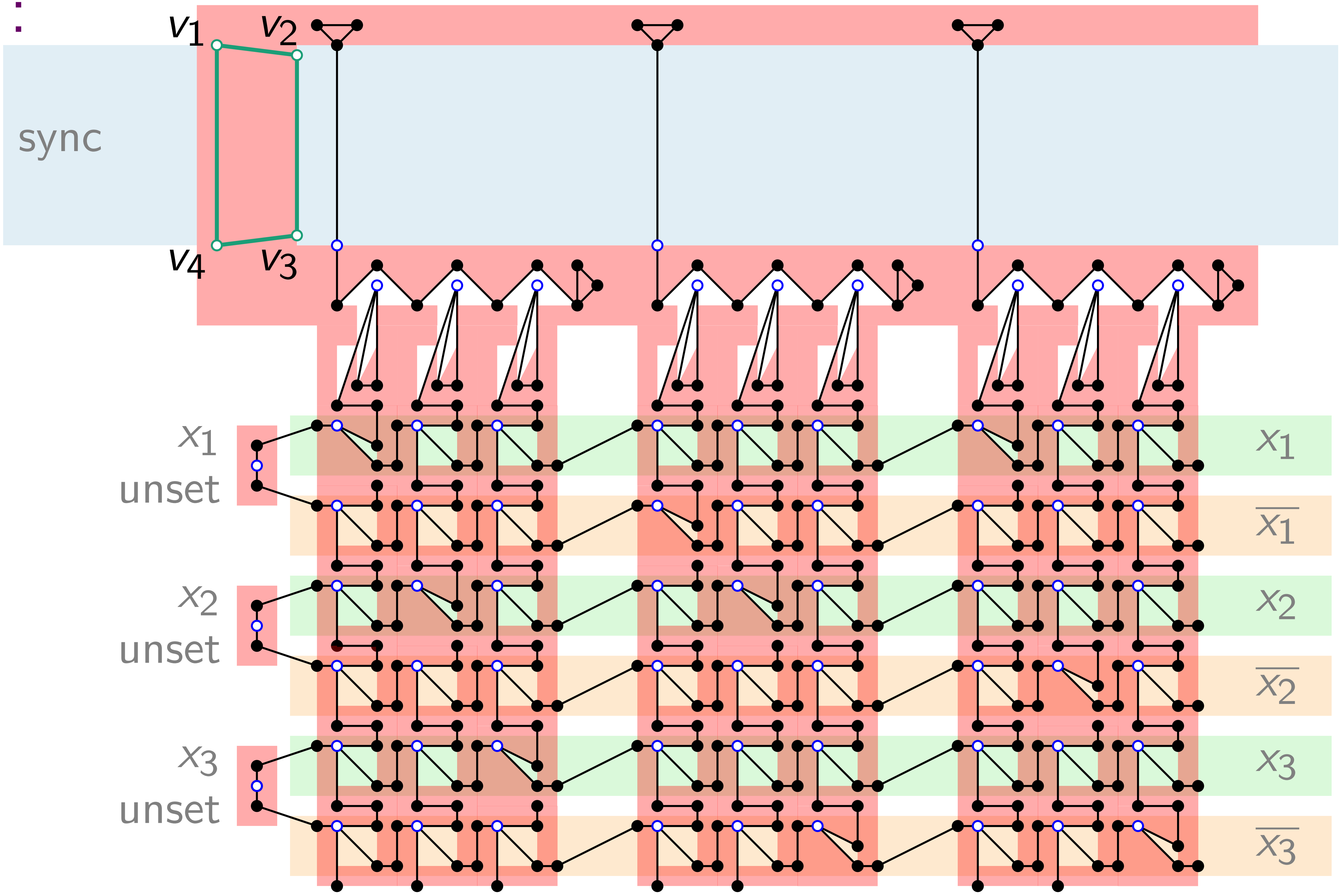
Proof idea.

- Two rows for each variable (one per literal).
- Three columns for each clause (one per literal).
- Split gadget if same literal in row & column; crossing gadget otherwise.
- Free vertices can be passed from variable gadgets along rows and columns to literal gadgets.
- Synchronization gadget assures consistent assignment of variables.

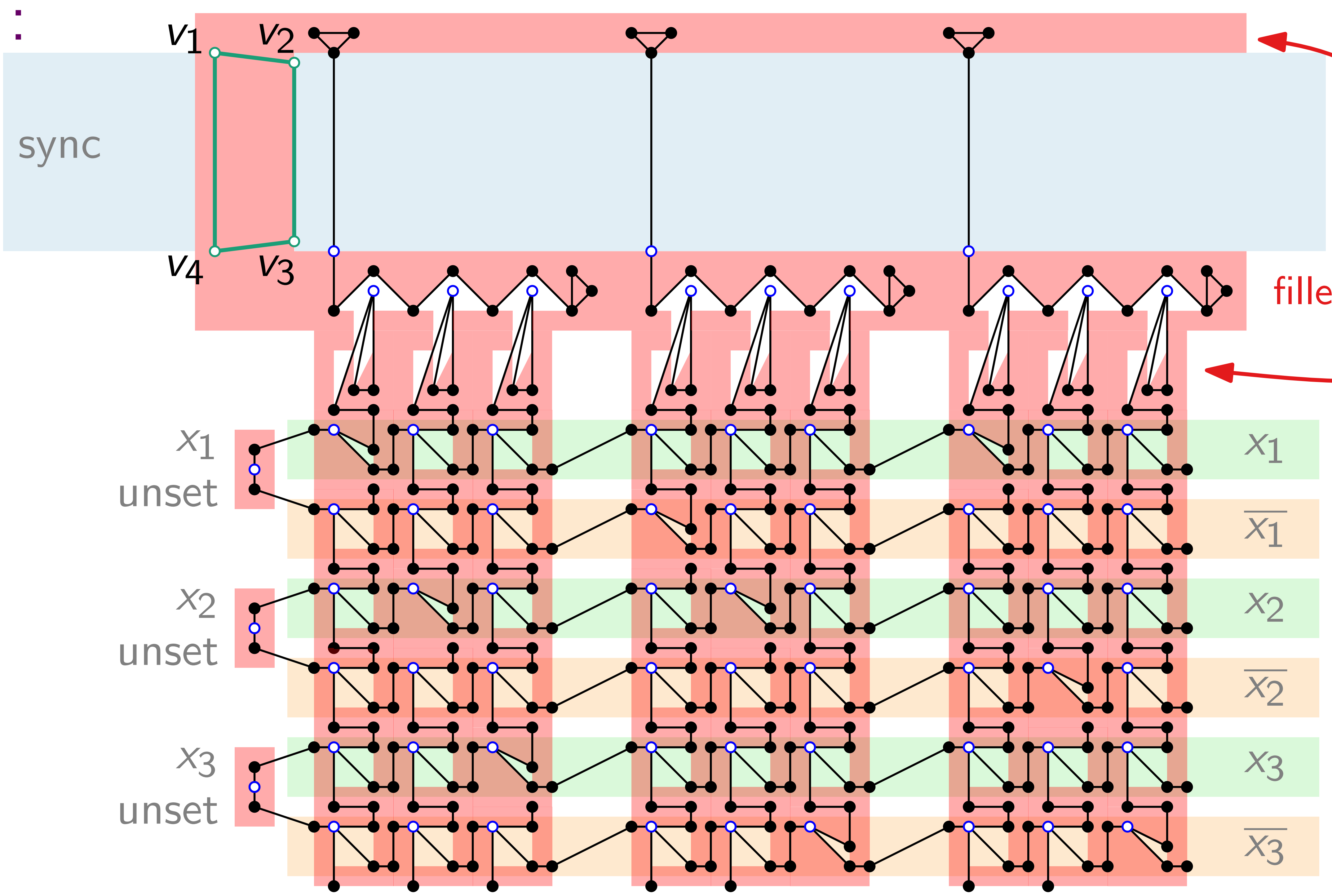


sync									
	$x_1 \vee x_2 \vee x_3$			$\overline{x_1} \vee x_2 \vee \overline{x_3}$			$x_1 \vee \overline{x_2} \vee \overline{x_3}$		
	L	L	L	L	L	L	L	L	L
x_1	S	C	C	C	C	C	S	C	C
$\overline{x_1}$	C	C	C	S	C	C	C	C	C
x_2	C	S	C	C	C	C	C	S	C
$\overline{x_2}$	C	C	C	C	S	C	C	C	C
x_3	C	C	S	C	C	C	C	C	C
$\overline{x_3}$	C	C	C	C	C	S	C	C	S

Γ :

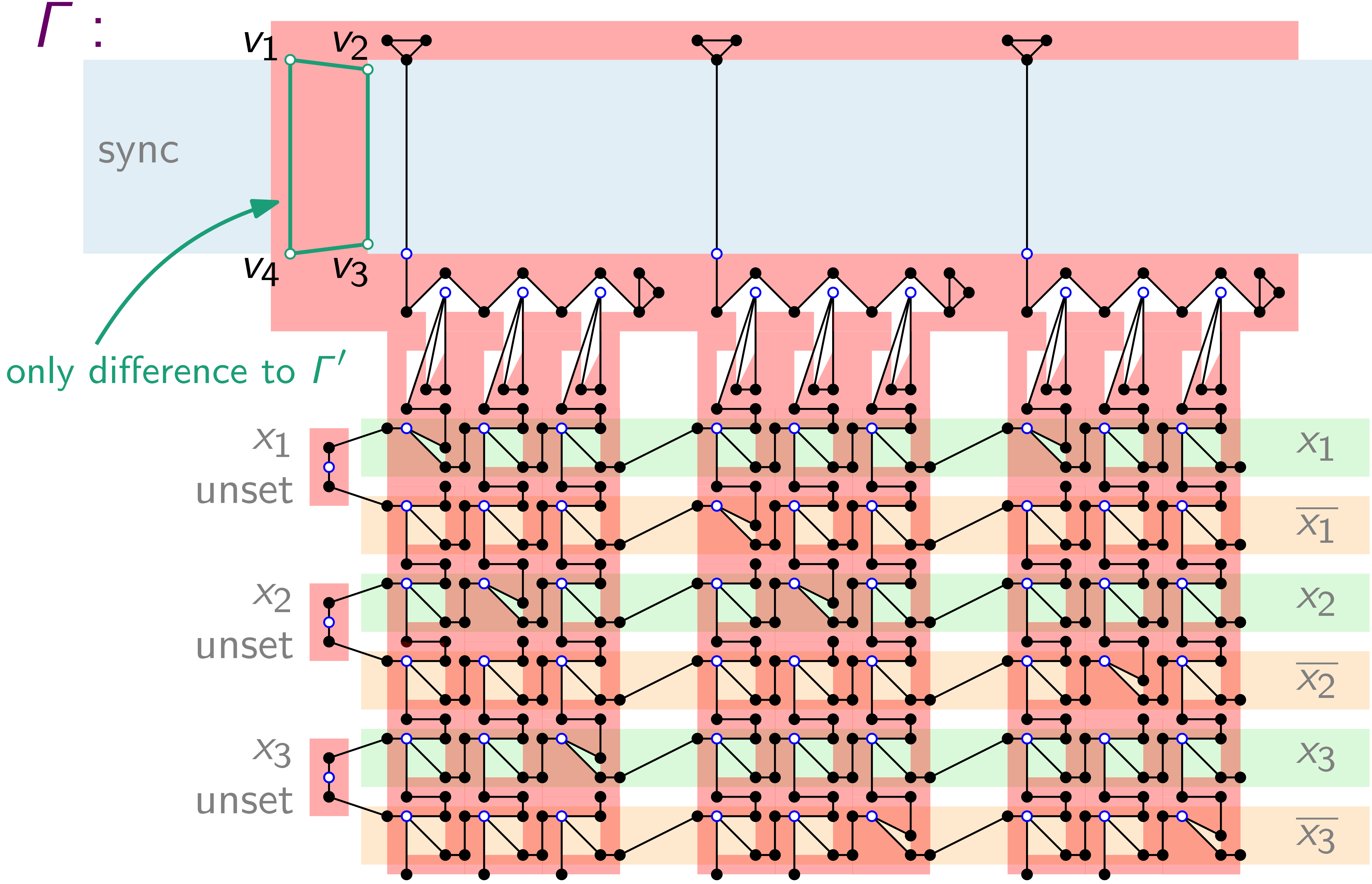

v_1
v_2
v_4
v_3
sync
x_1
unset
x_2
unset
x_3
unset
x_1
$\overline{x_1}$
x_2
$\overline{x_2}$
x_3
$\overline{x_3}$

Γ :

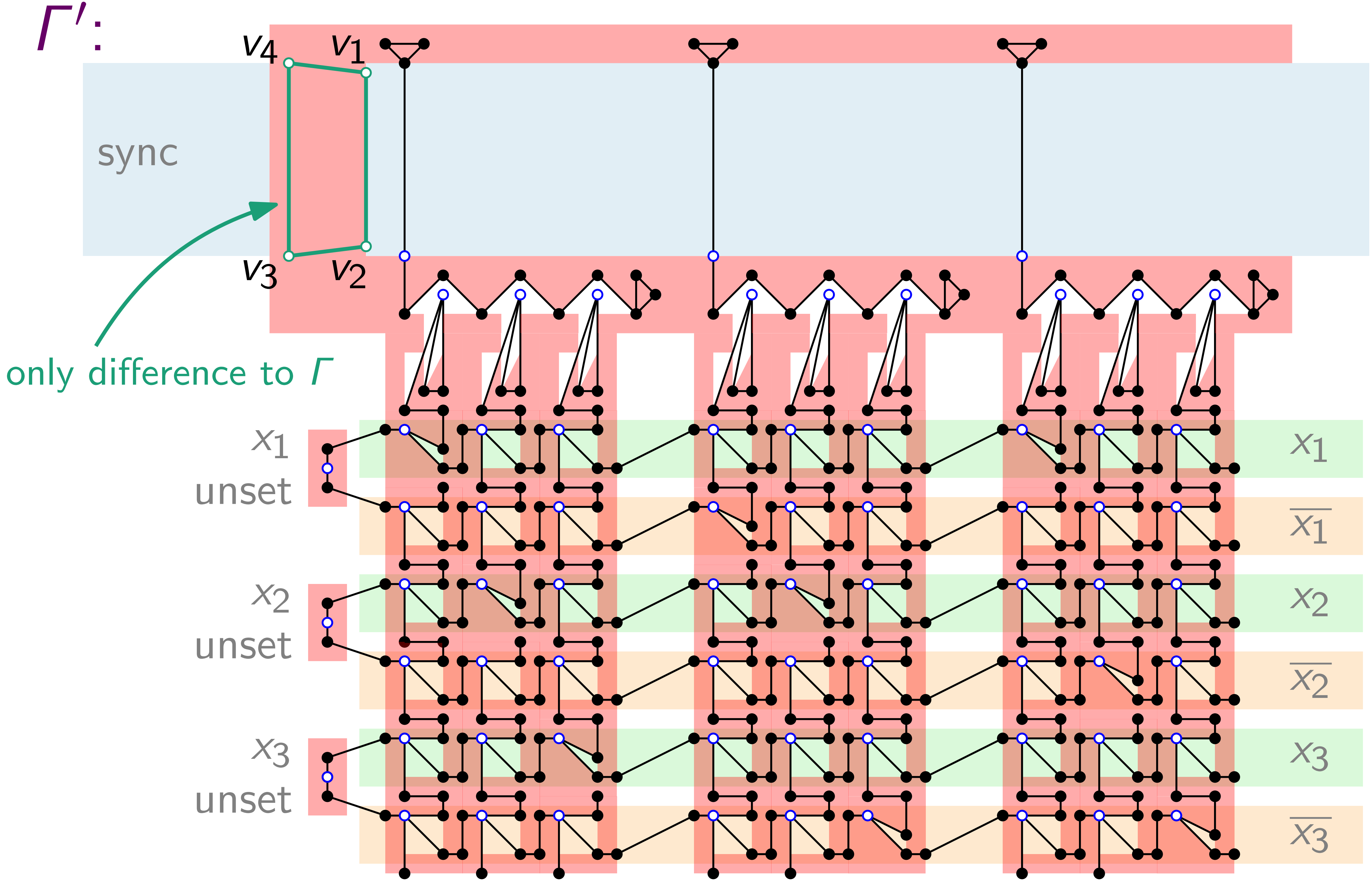


filled with obstacles

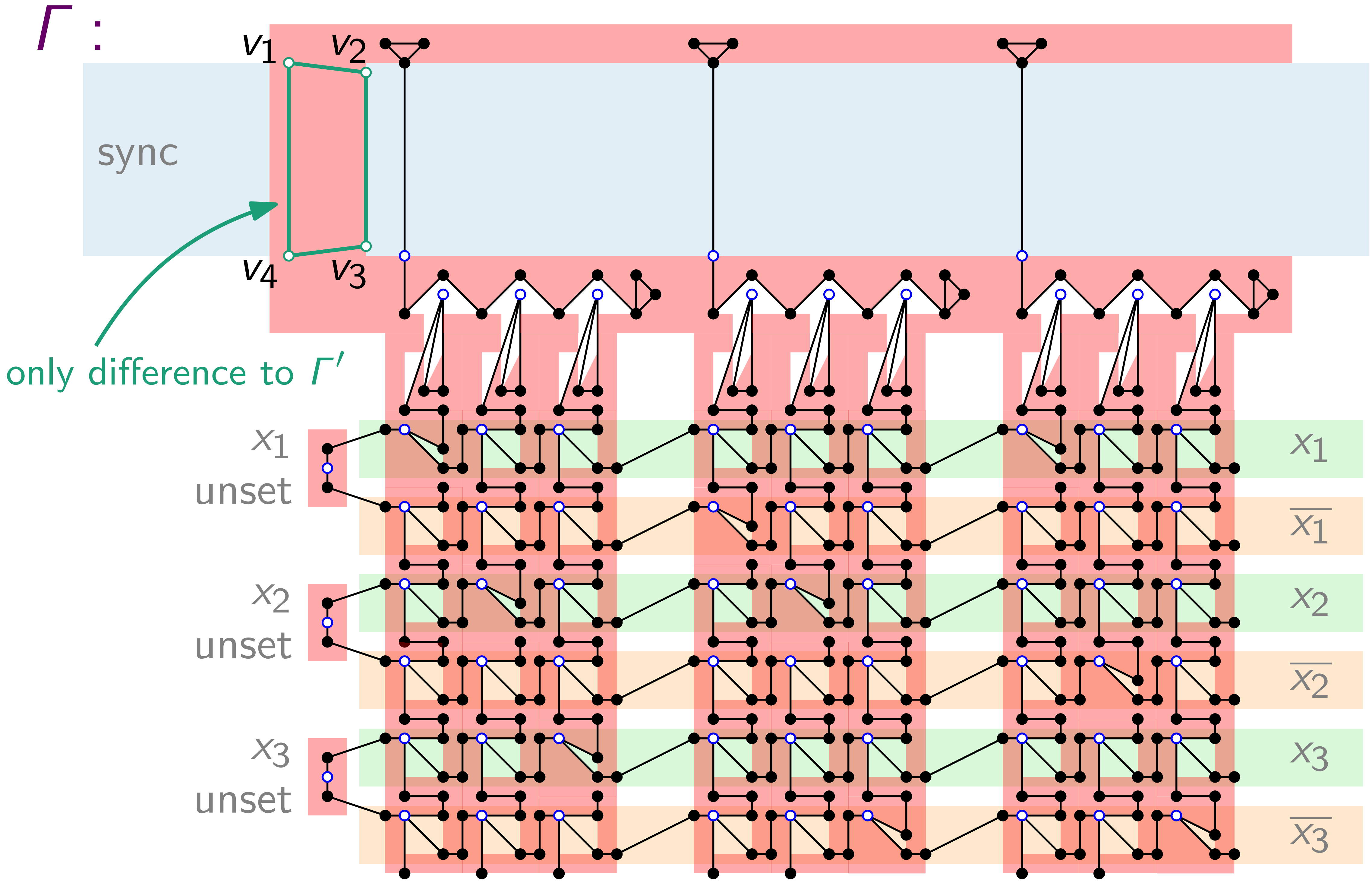
Γ :

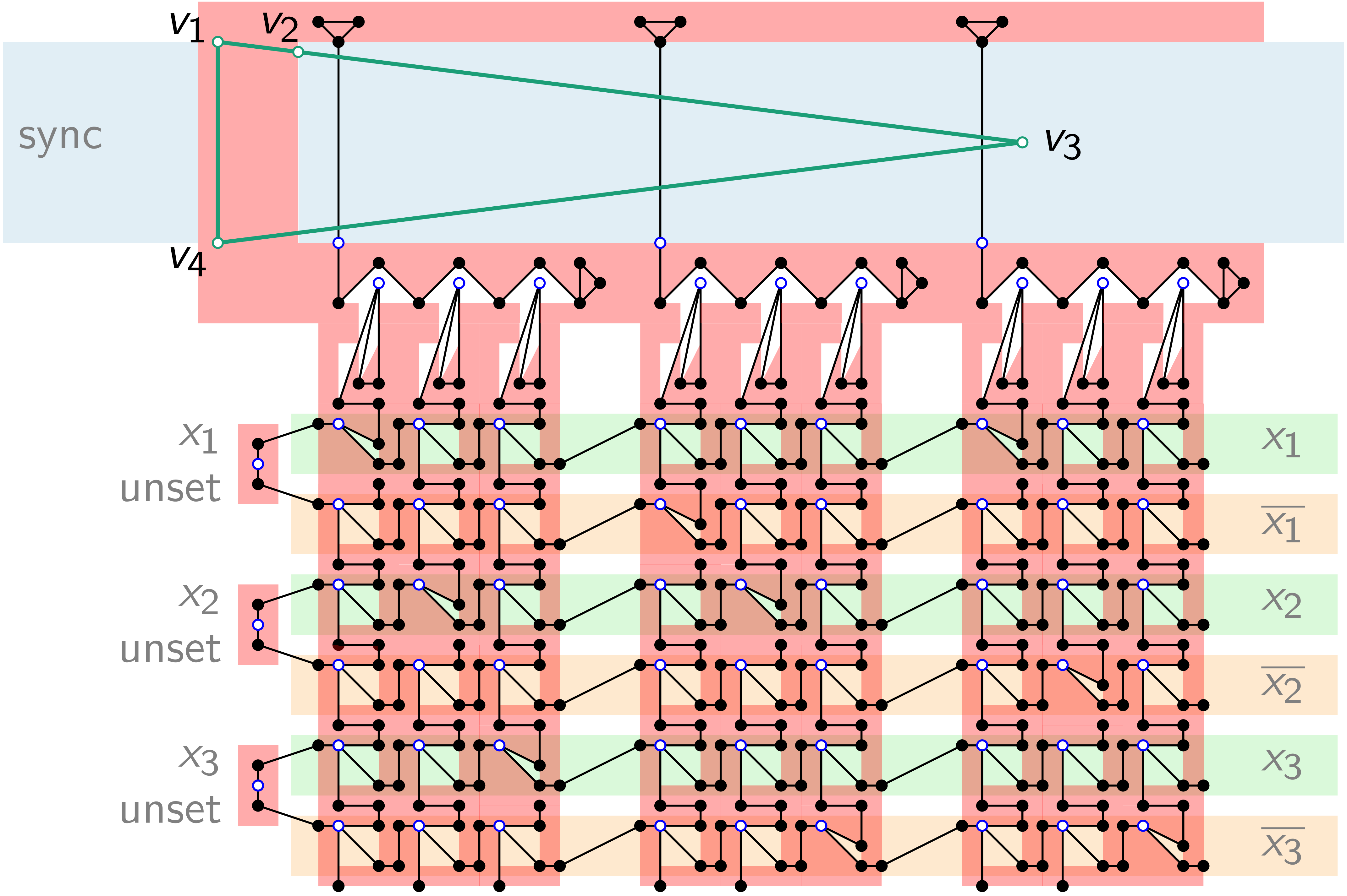

v_1
v_2
v_3
v_4
sync
only difference to Γ'
x_1 unset
x_2 unset
x_3 unset
x_1
$\overline{x_1}$
x_2
$\overline{x_2}$
x_3
$\overline{x_3}$

Γ':

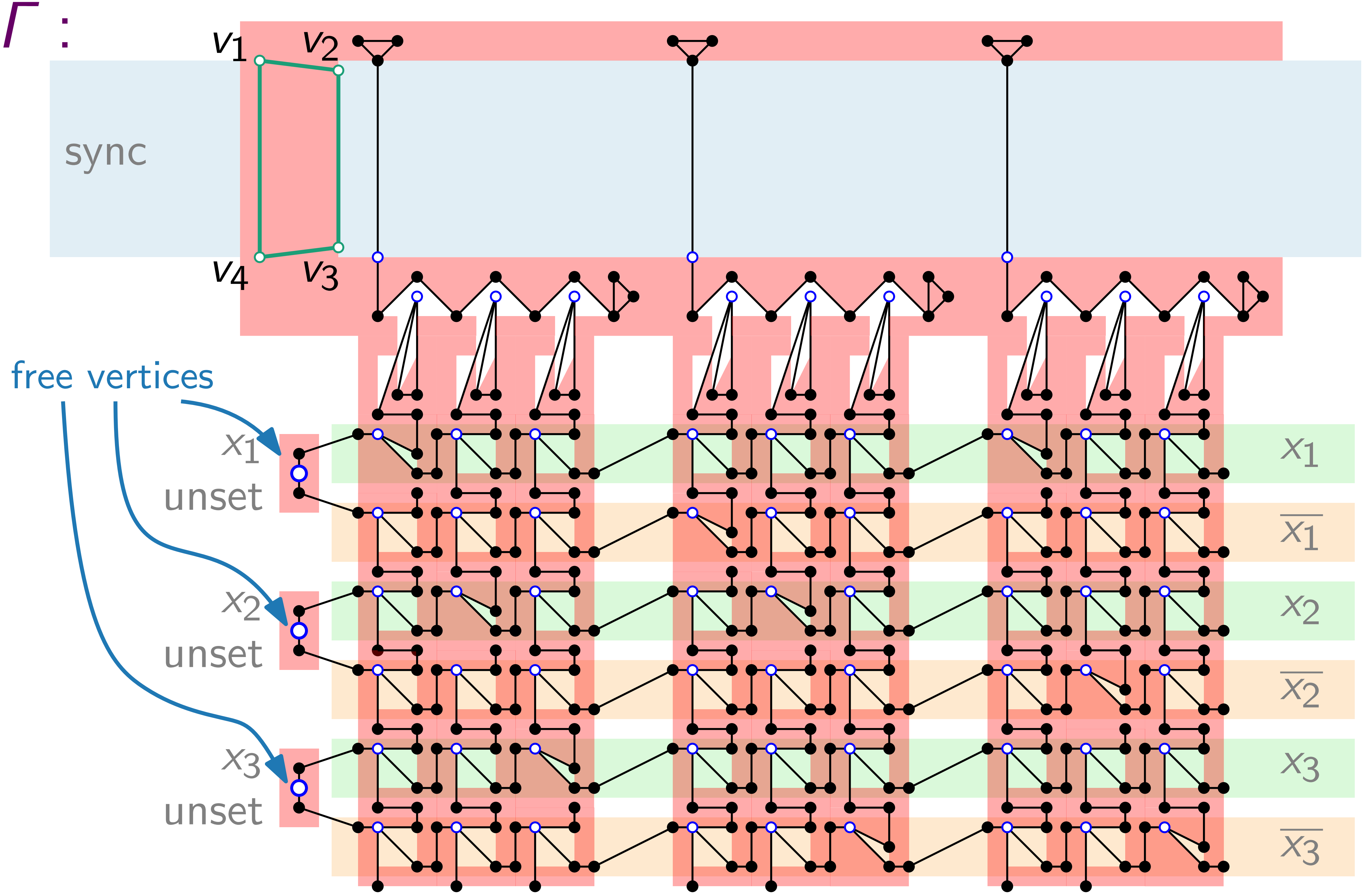

v_4
v_1
v_3
v_2
sync
only difference to Γ
x_1
unset
x_2
unset
x_3
unset
x_1
$\overline{x_1}$
x_2
$\overline{x_2}$
x_3
$\overline{x_3}$

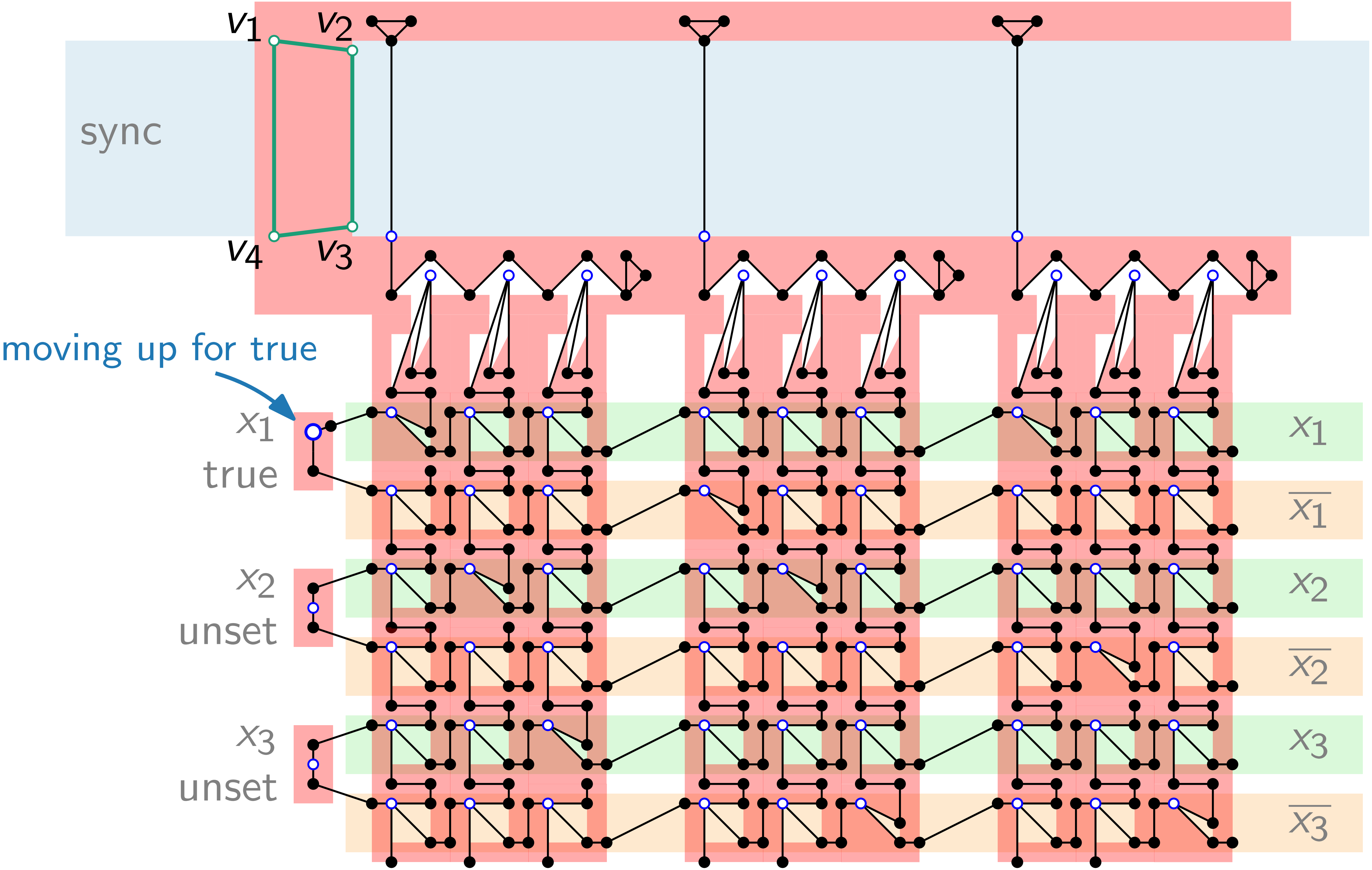
Γ :

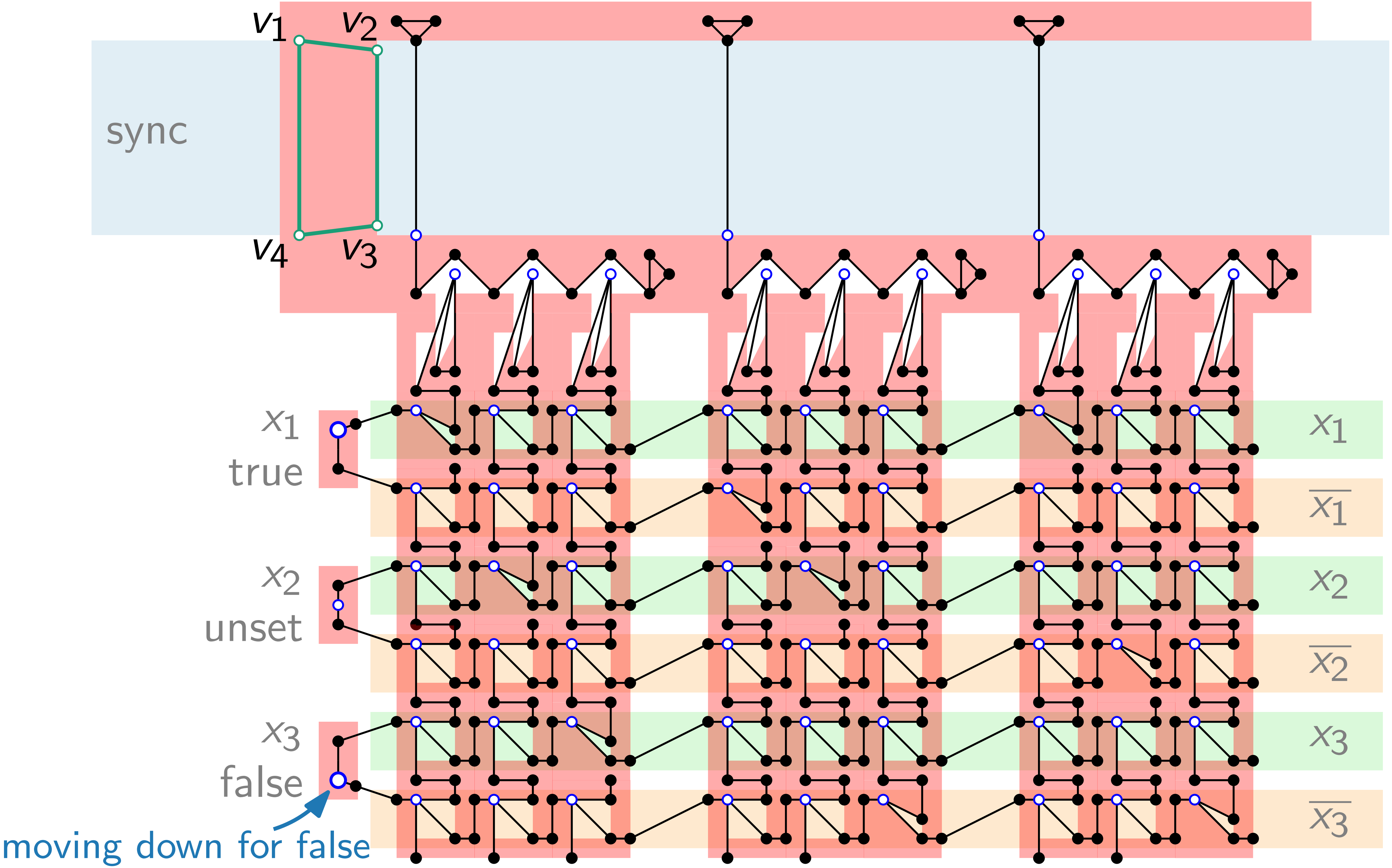

v_1
v_2
v_3
v_4
sync
only difference to Γ'
x_1
unset
x_2
unset
x_3
unset
x_1
$\overline{x_1}$
x_2
$\overline{x_2}$
x_3
$\overline{x_3}$

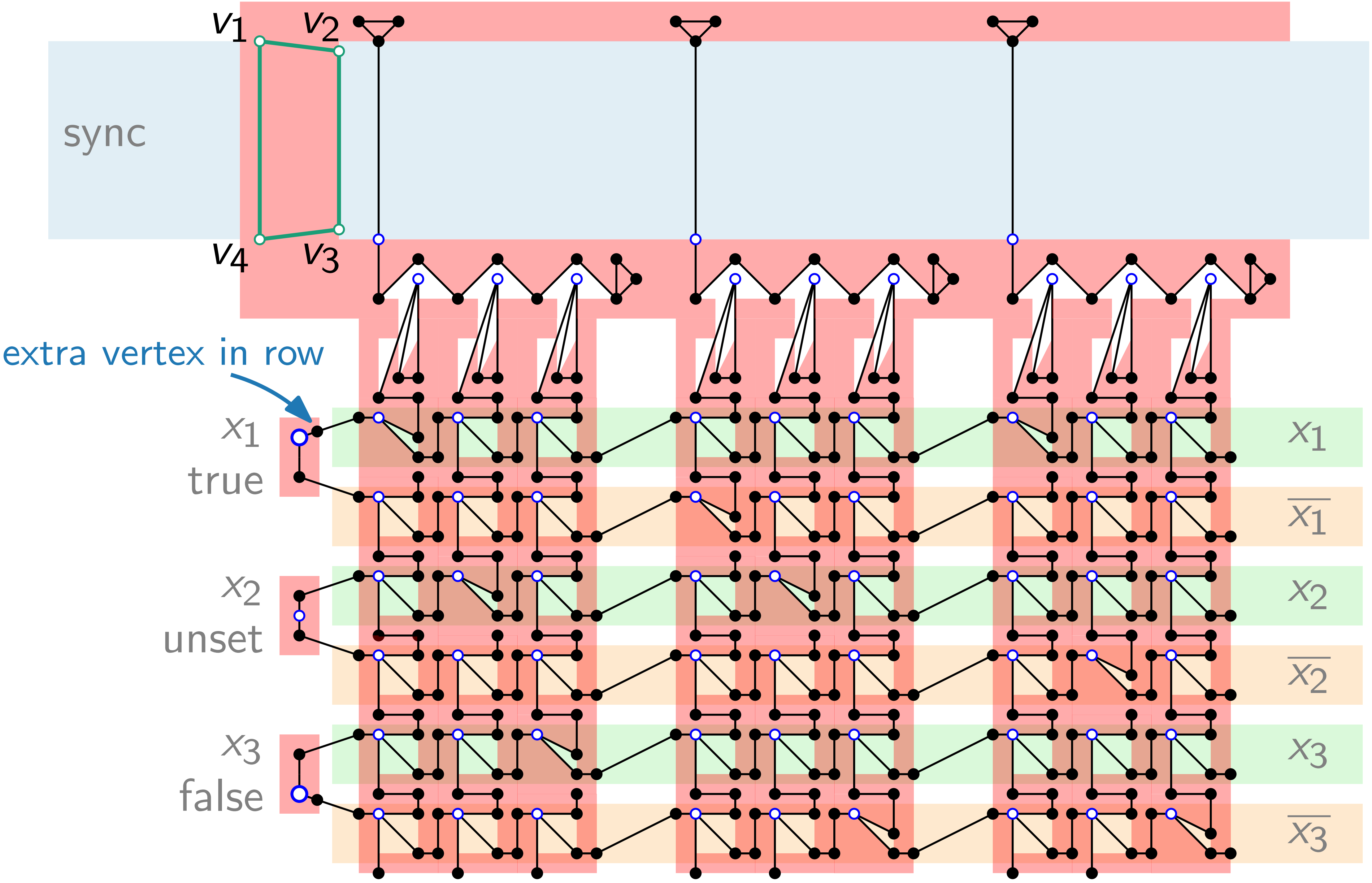

v_1
v_2
v_3
v_4
sync
x_1
unset
x_2
unset
x_3
unset
x_1
$\overline{x_1}$
x_2
$\overline{x_2}$
x_3
$\overline{x_3}$

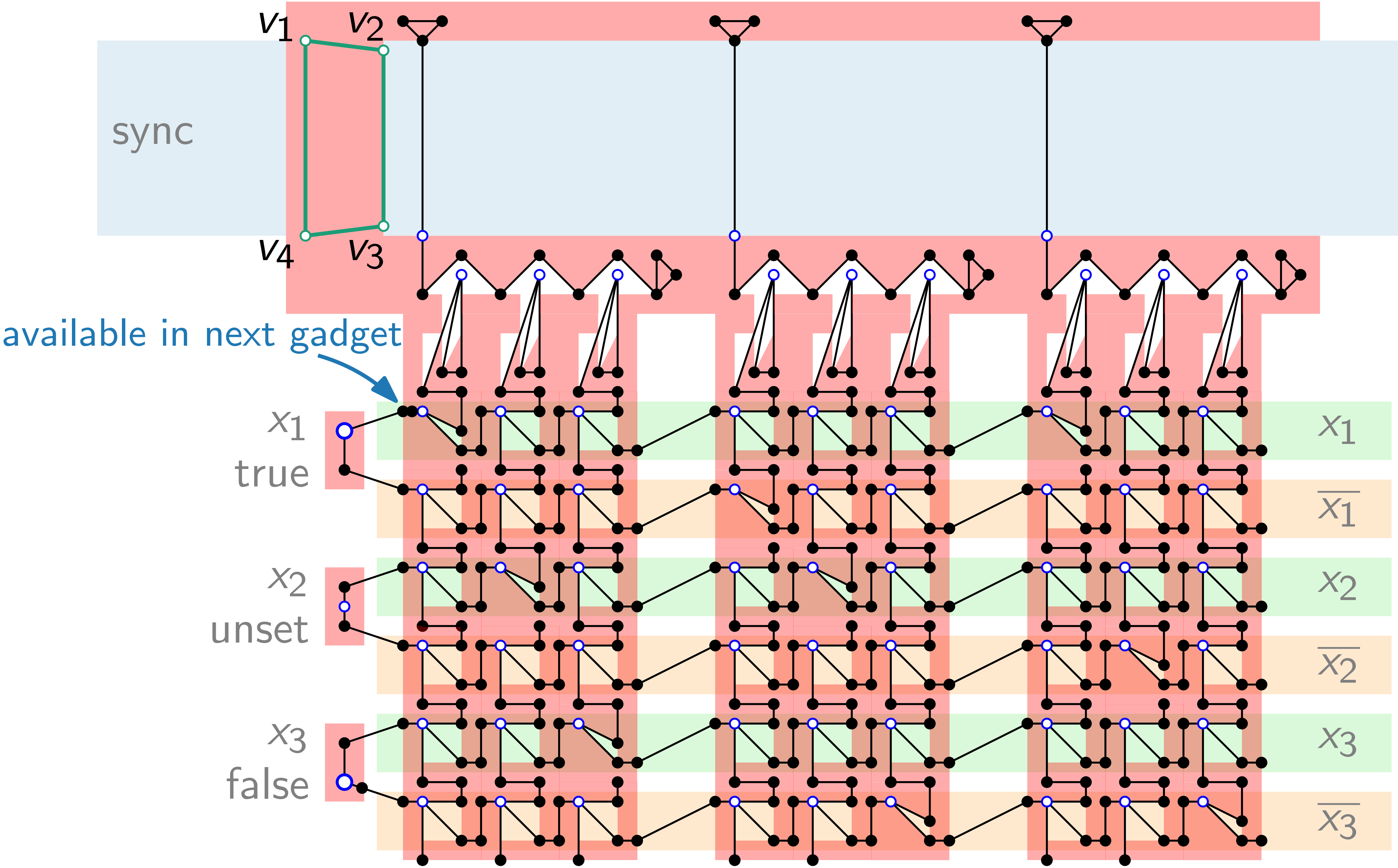
Γ :

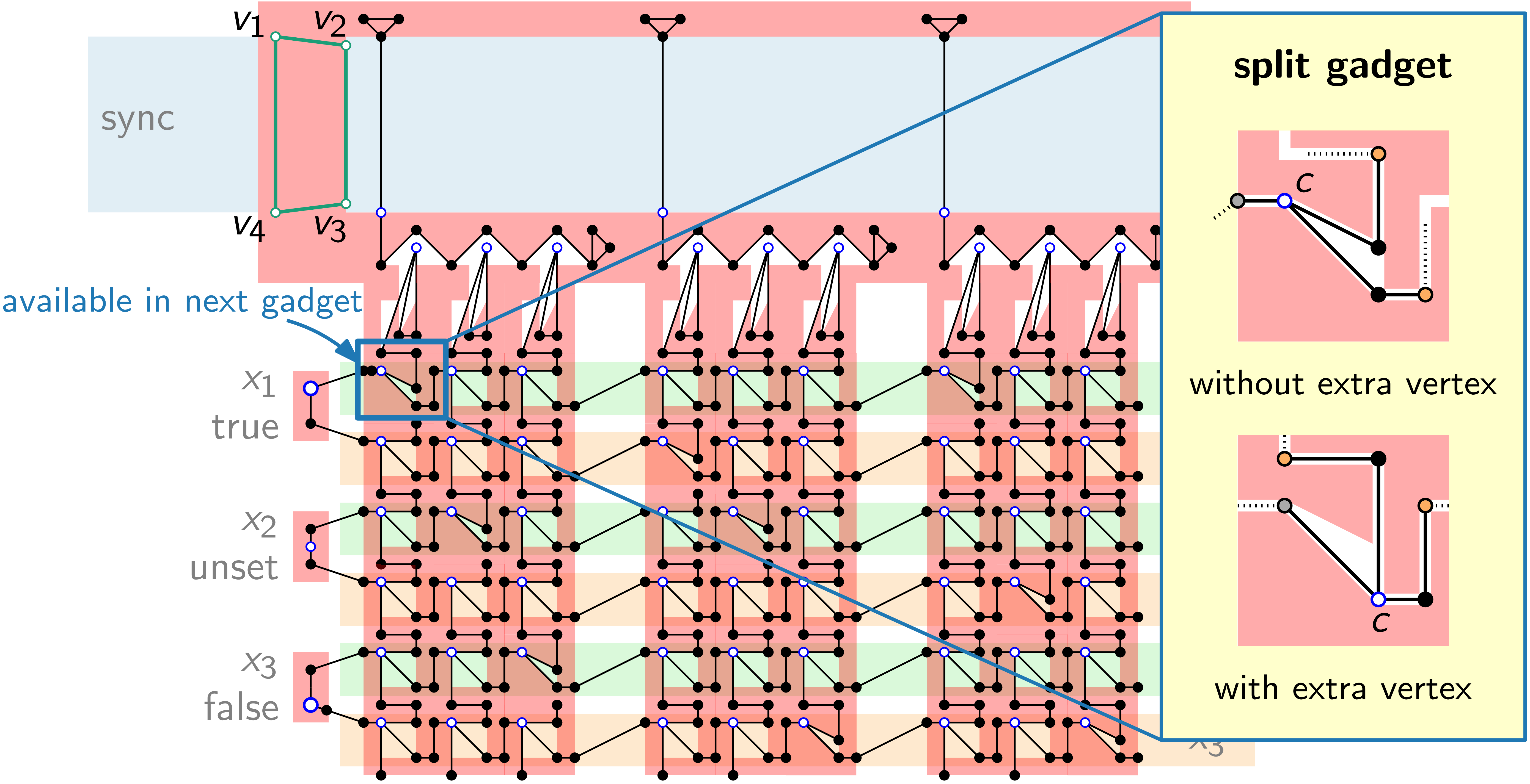

v_1
v_2
v_3
v_4
sync
free vertices
x_1
unset
x_2
unset
x_3
unset
x_1
$\overline{x_1}$
x_2
$\overline{x_2}$
x_3
$\overline{x_3}$


v_1
v_2
sync
v_4
v_3
moving up for true
x_1
true
x_2
unset
x_3
unset
x_1
$\overline{x_1}$
x_2
$\overline{x_2}$
x_3
$\overline{x_3}$

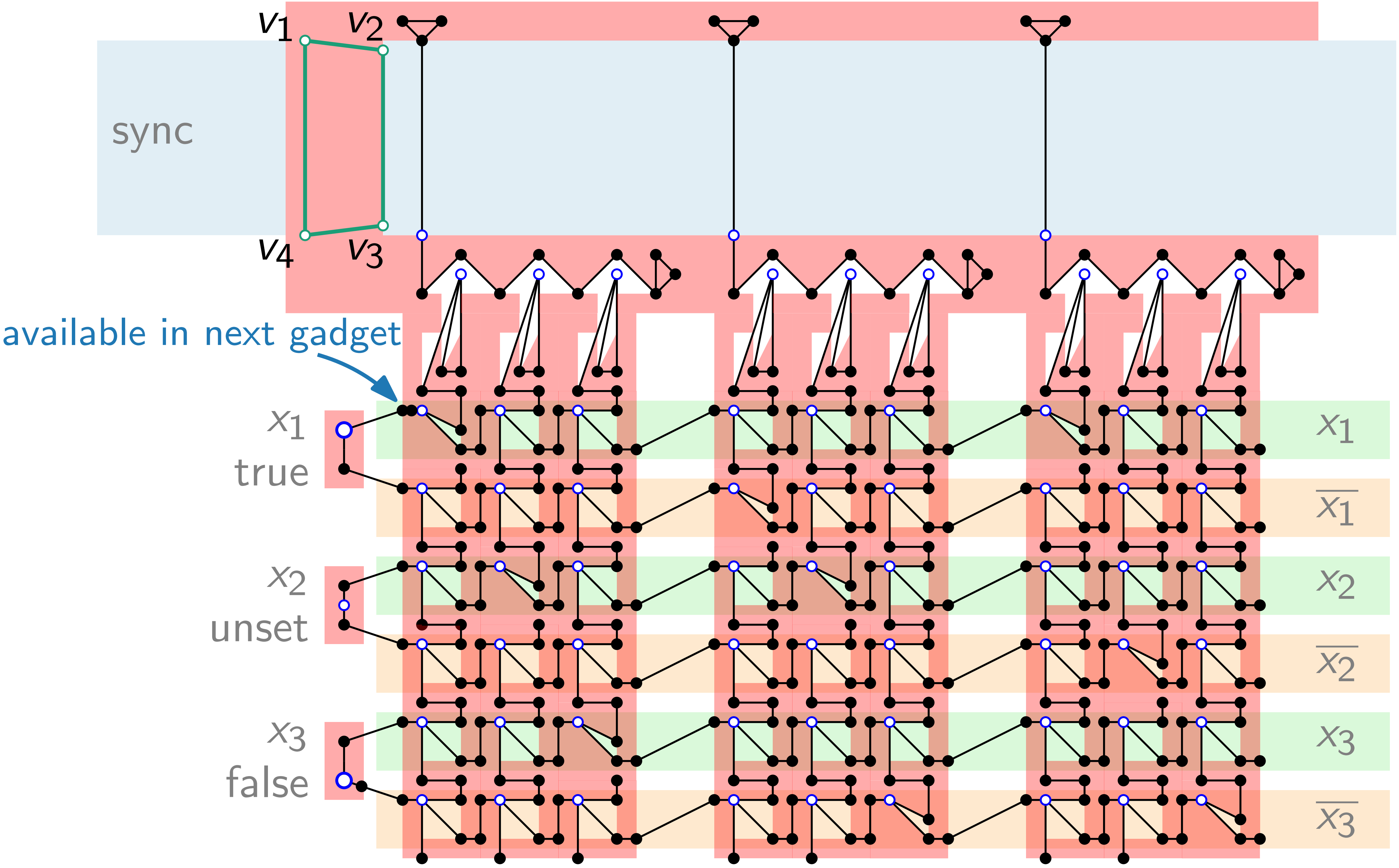

v_1
v_2
v_3
v_4
sync
x_1
true
x_2
unset
x_3
false
moving down for false
x_1
$\overline{x_1}$
x_2
$\overline{x_2}$
x_3
$\overline{x_3}$

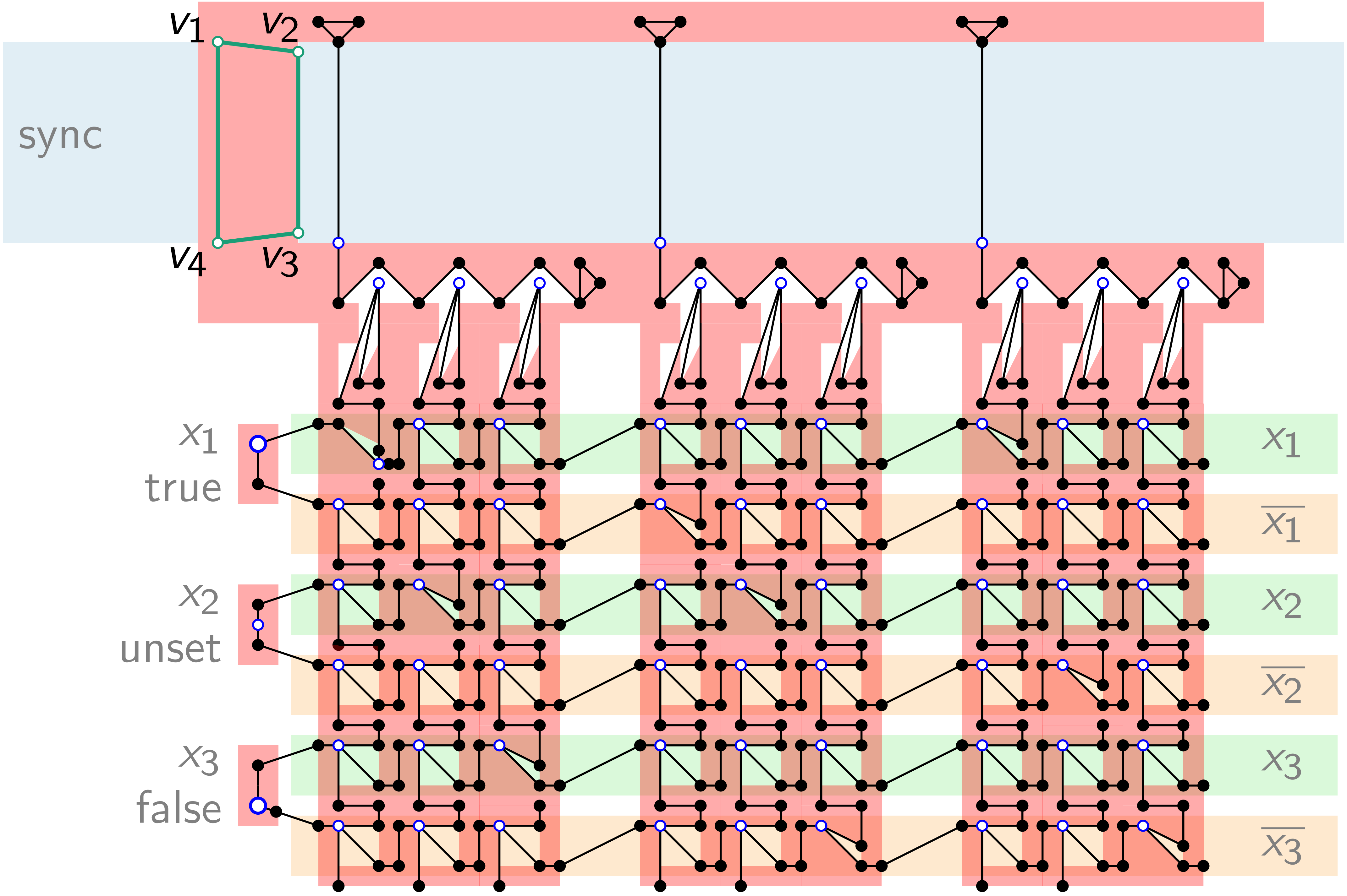

v_1
v_2
v_4
v_3
sync
extra vertex in row
x_1
true
x_2
unset
x_3
false
x_1
$\overline{x_1}$
x_2
$\overline{x_2}$
x_3
$\overline{x_3}$

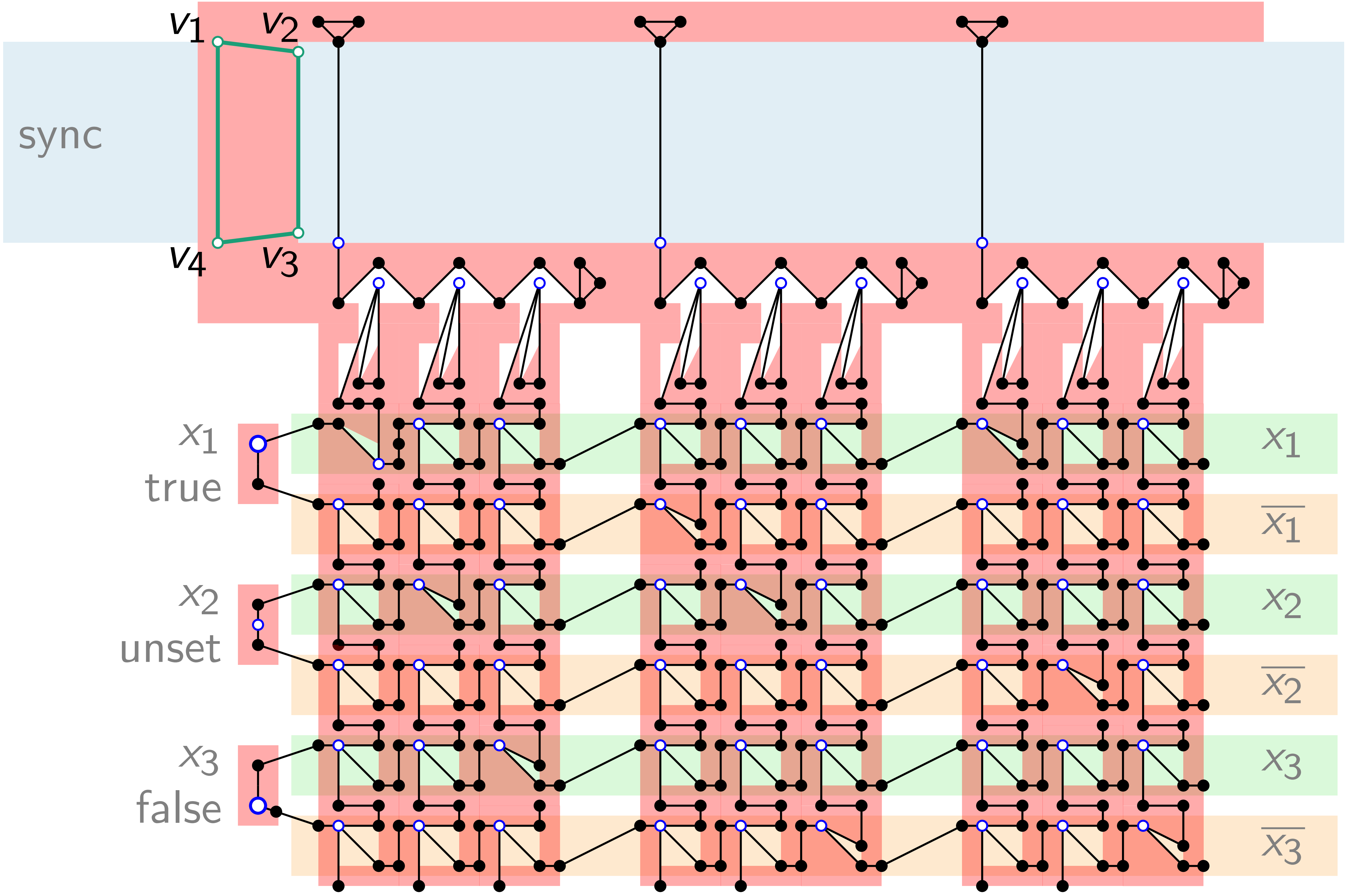

v_1
v_2
v_3
v_4
sync
available in next gadget
x_1
true
x_2
unset
x_3
false
x_1
$\overline{x_1}$
x_2
$\overline{x_2}$
x_3
$\overline{x_3}$

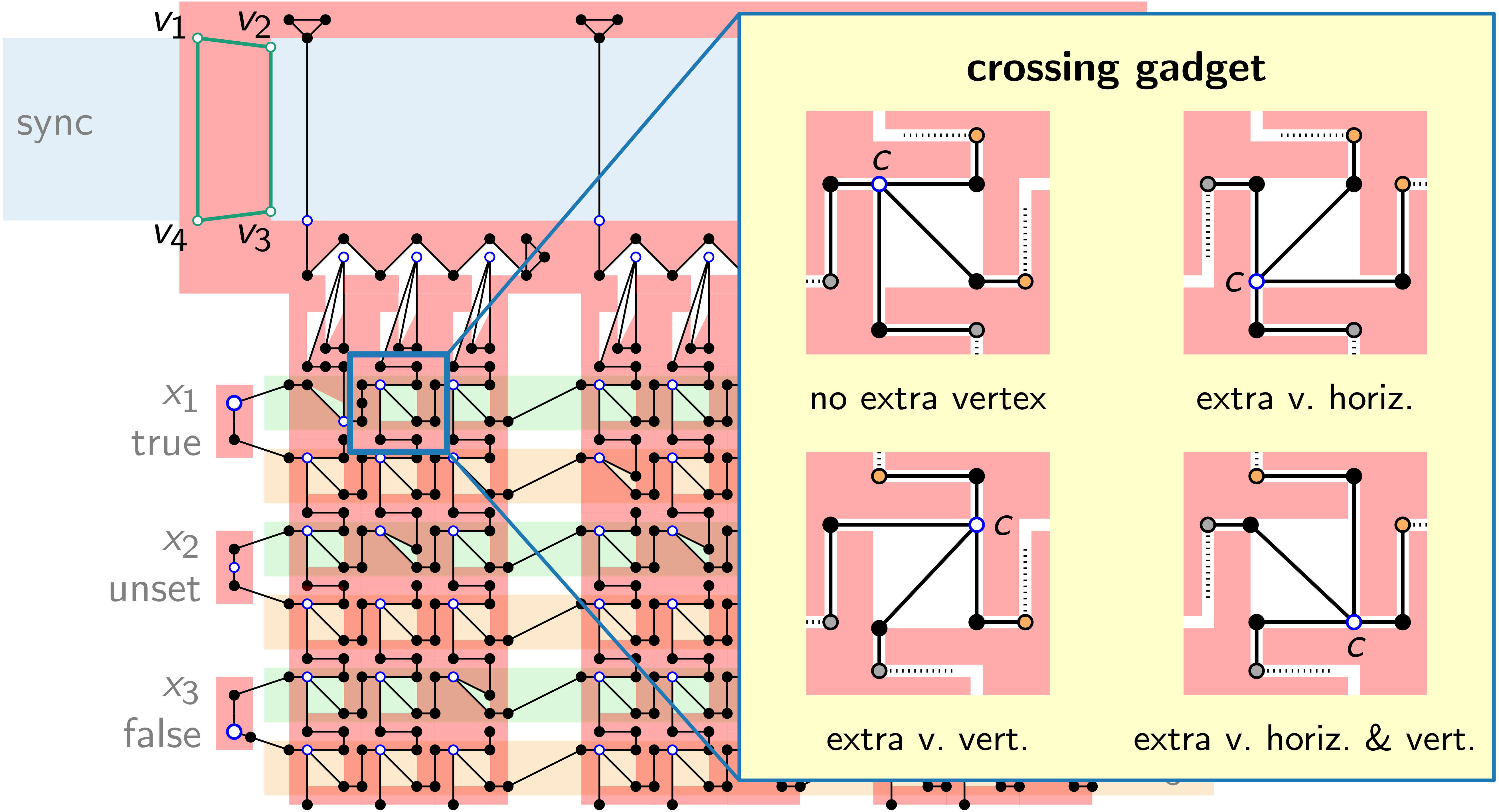


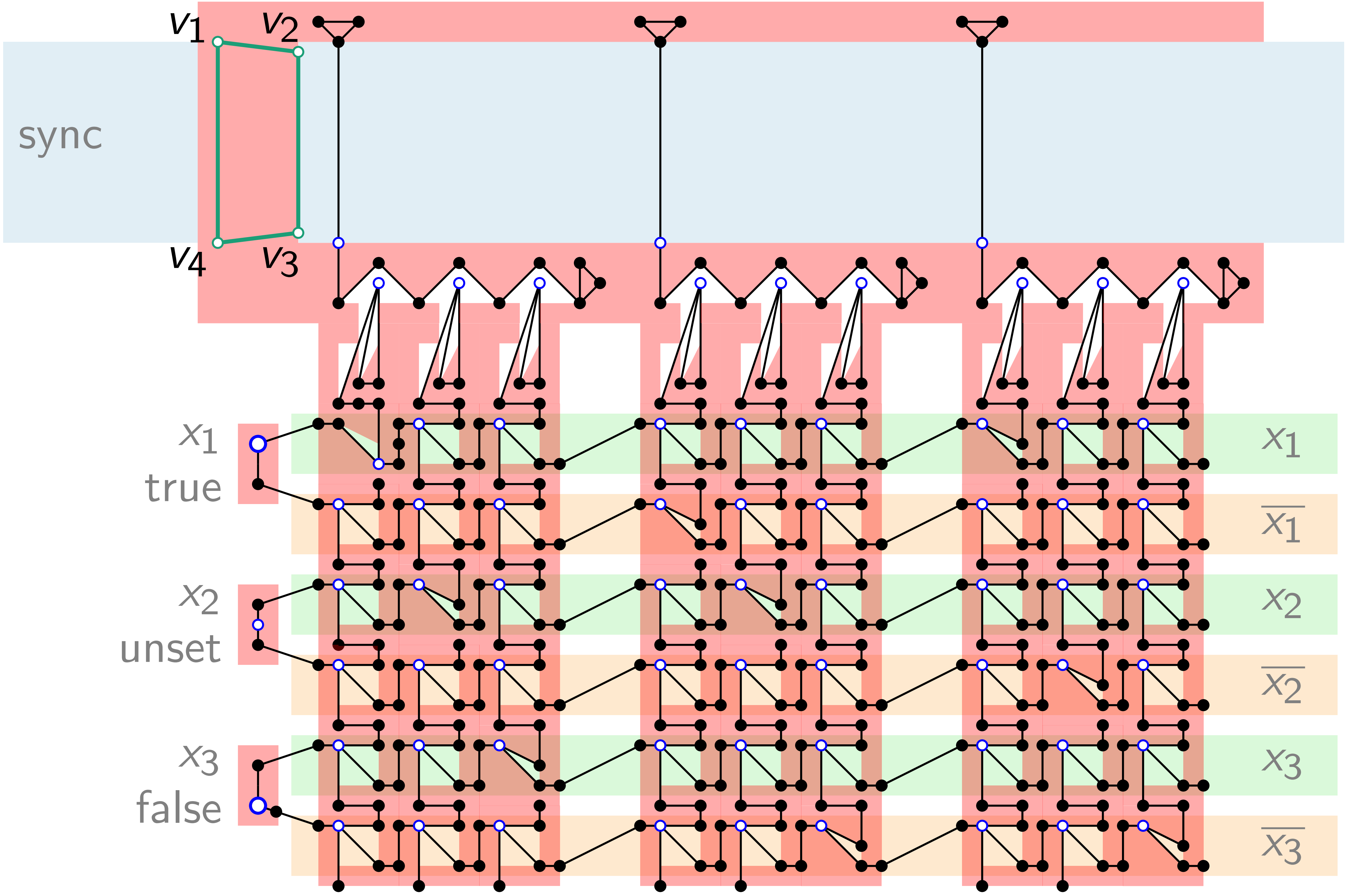
v_1
v_2
v_3
v_4
sync
available in next gadget
x_1
true
x_2
unset
x_3
false
x_3
split gadget
c
without extra vertex
c
with extra vertex

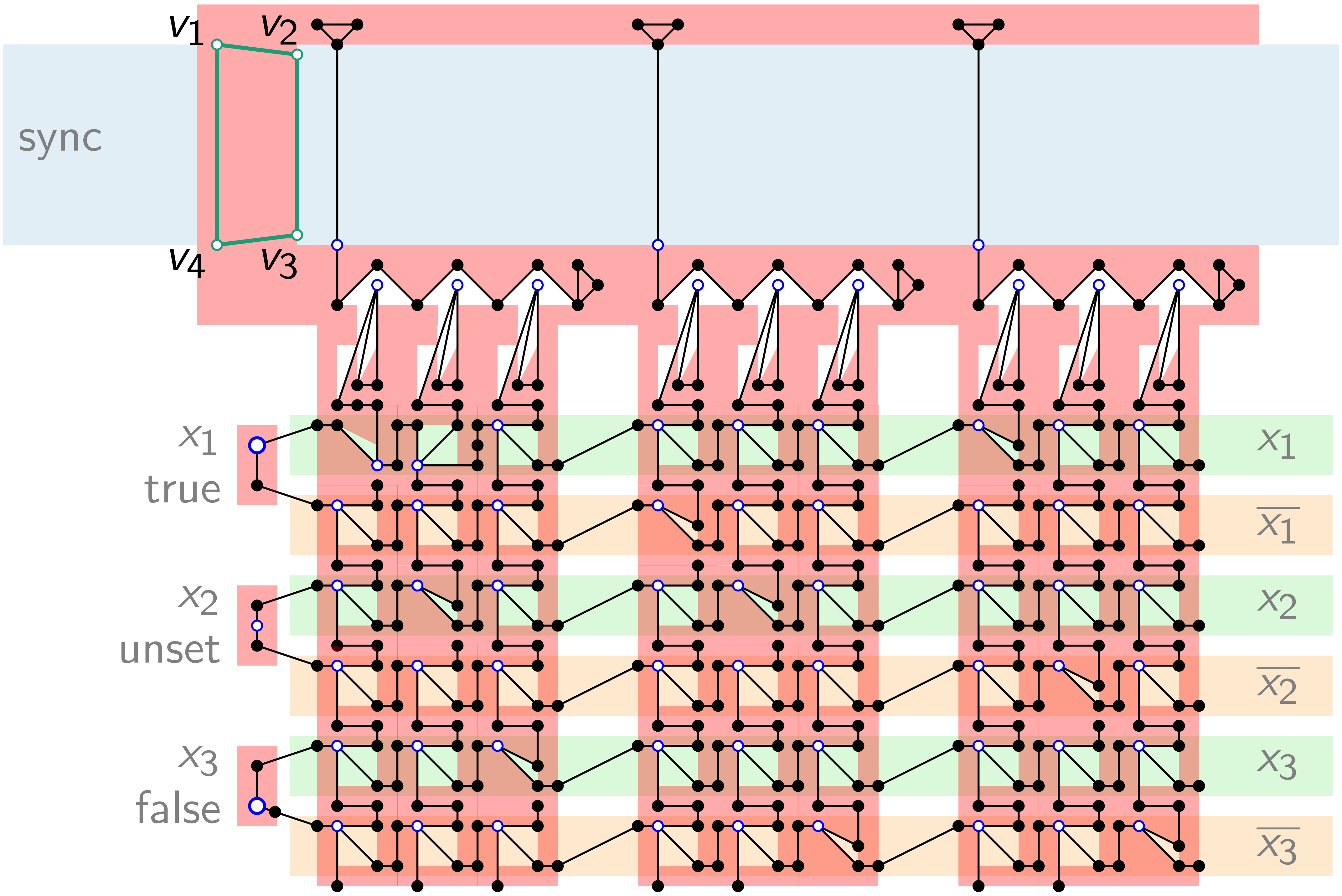

v_1
v_2
v_3
v_4
sync
available in next gadget
x_1
true
x_2
unset
x_3
false
x_1
$\overline{x_1}$
x_2
$\overline{x_2}$
x_3
$\overline{x_3}$

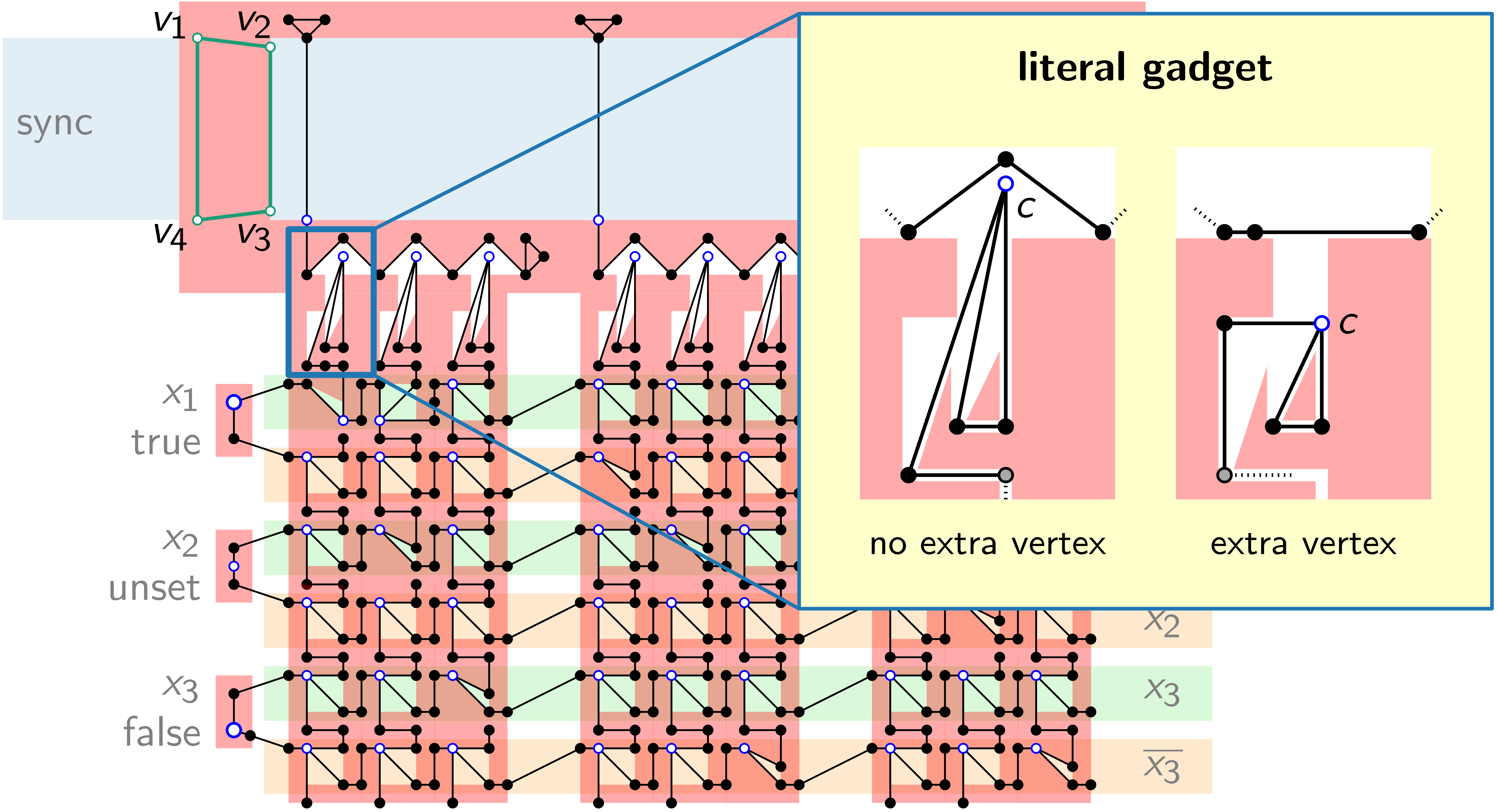

v_1
v_2
v_4
v_3
sync
x_1
true
x_2
unset
x_3
false
x_1
$\overline{x_1}$
x_2
$\overline{x_2}$
x_3
$\overline{x_3}$

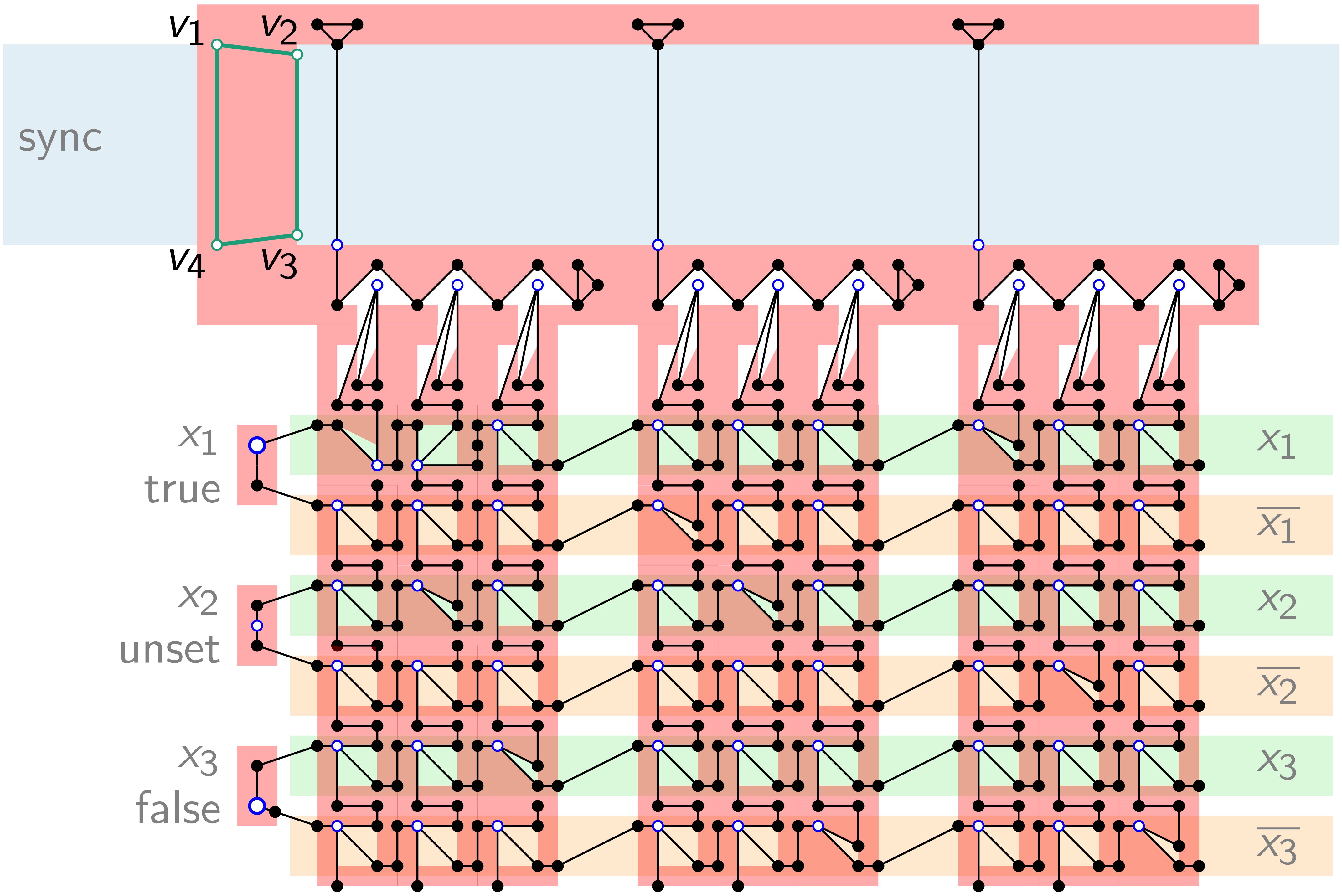

v_1
v_2
v_3
v_4
sync
x_1
true
x_2
unset
x_3
false
x_1
$\overline{x_1}$
x_2
$\overline{x_2}$
x_3
$\overline{x_3}$

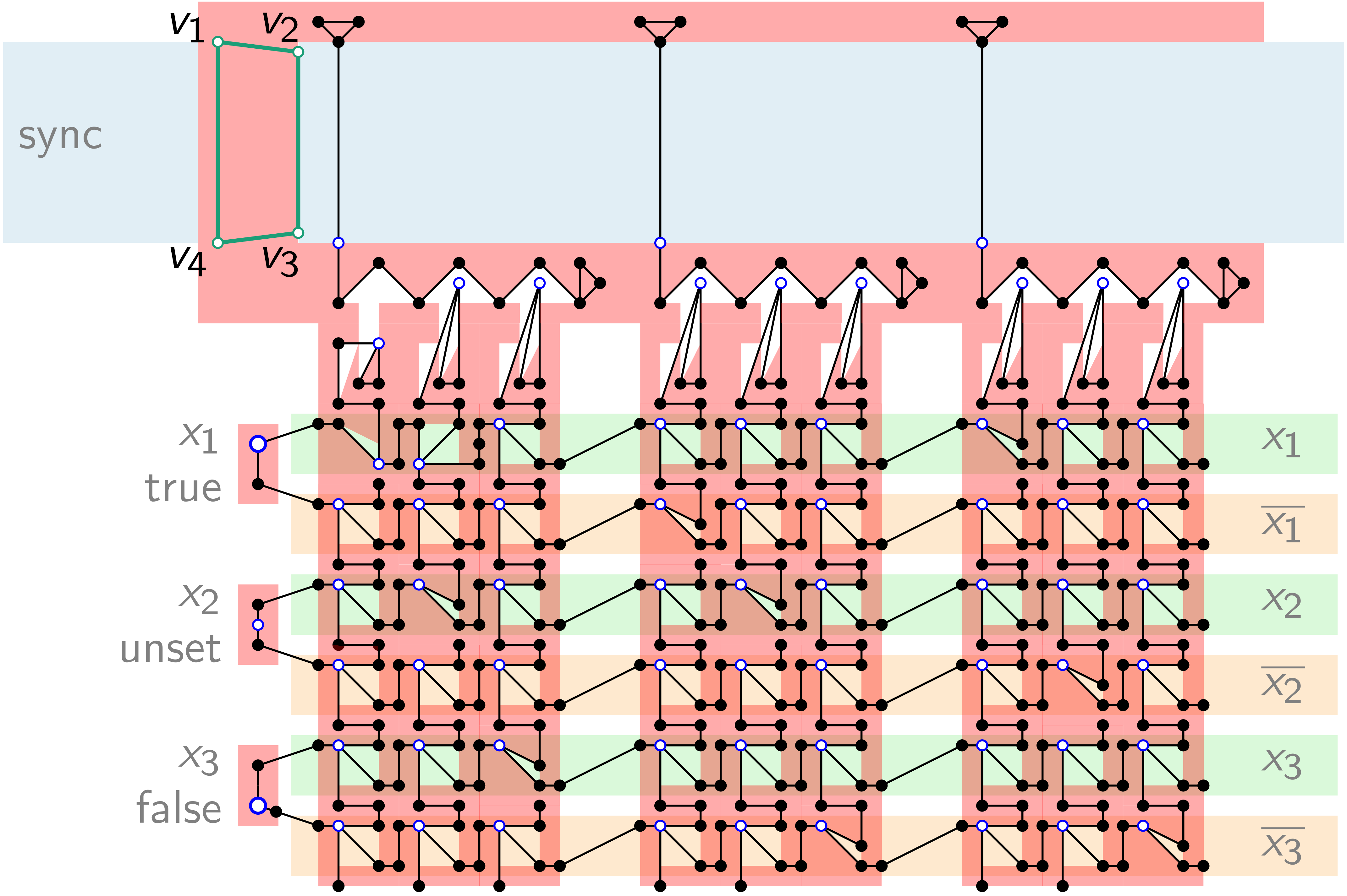

v_1
v_2
v_3
v_4
sync
x_1
true
x_2
unset
x_3
false
crossing gadget
c
no extra vertex
extra v. horiz.
extra v. vert.
extra v. horiz. & vert.

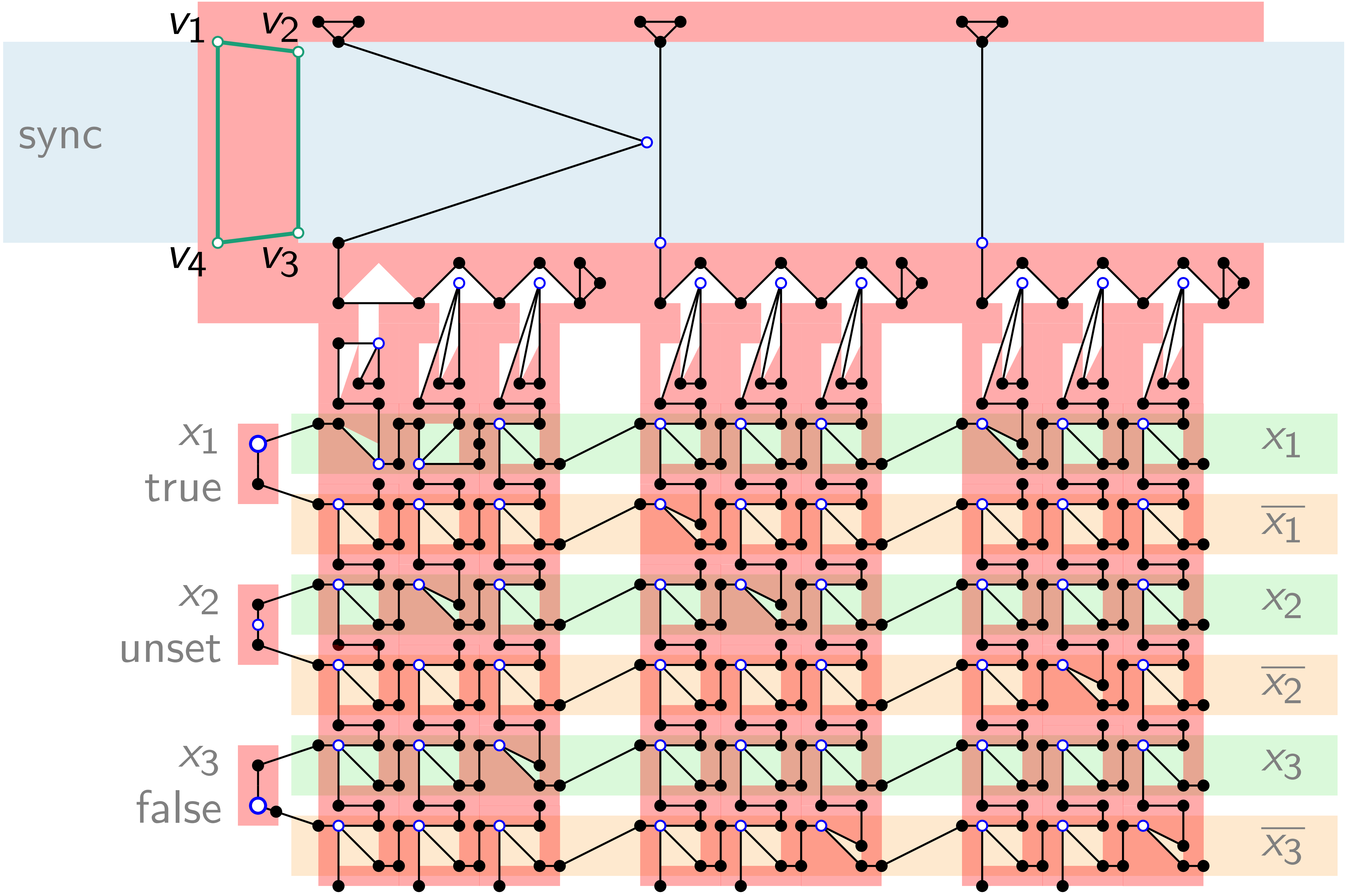

sync
v_1
v_2
v_3
v_4
x_1
true
x_2
unset
x_3
false
x_1
$\overline{x_1}$
x_2
$\overline{x_2}$
x_3
$\overline{x_3}$

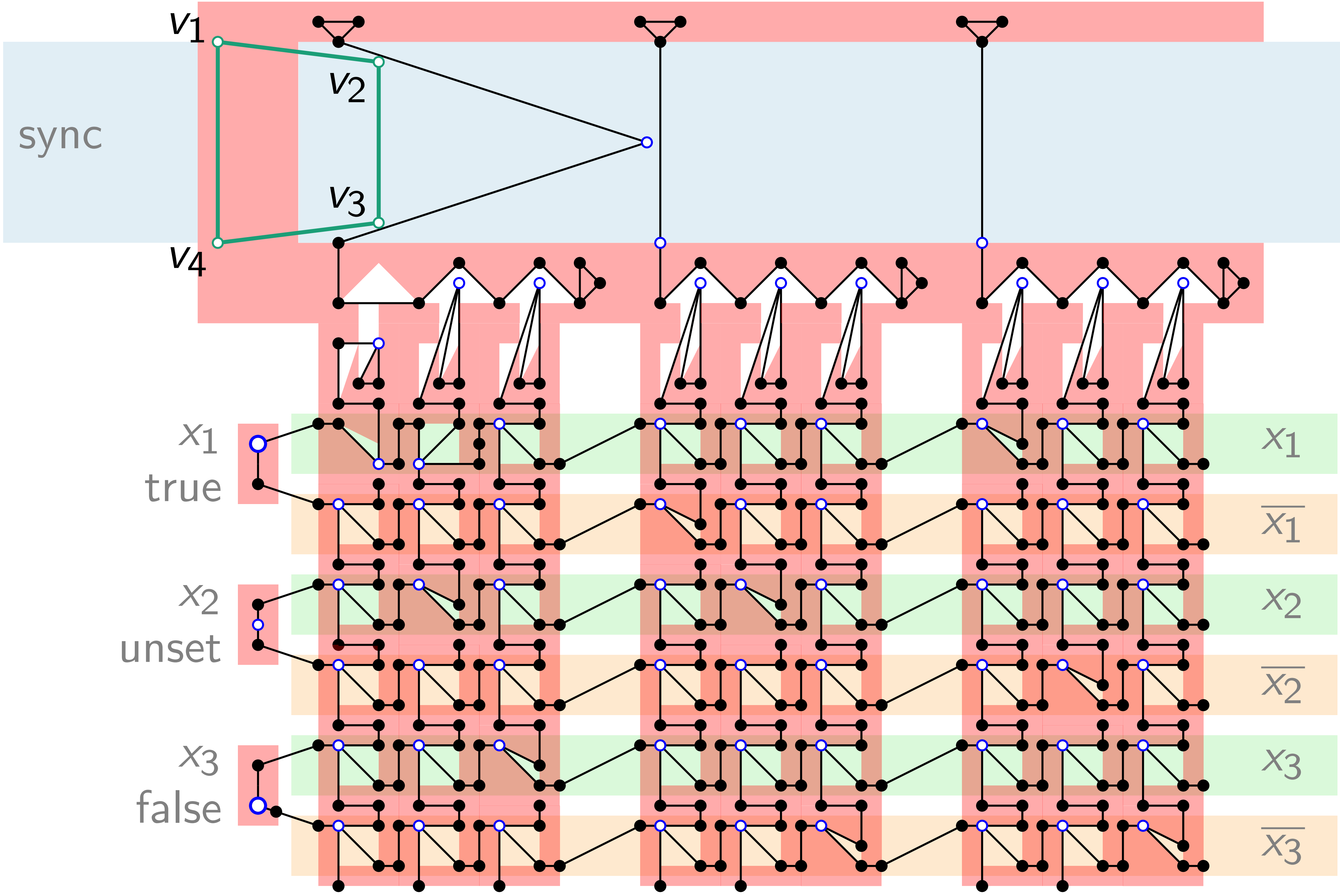

v_1
v_2
v_3
v_4
sync
x_1
true
x_2
unset
x_3
false
x_1
$\overline{x_1}$
x_2
$\overline{x_2}$
x_3
$\overline{x_3}$

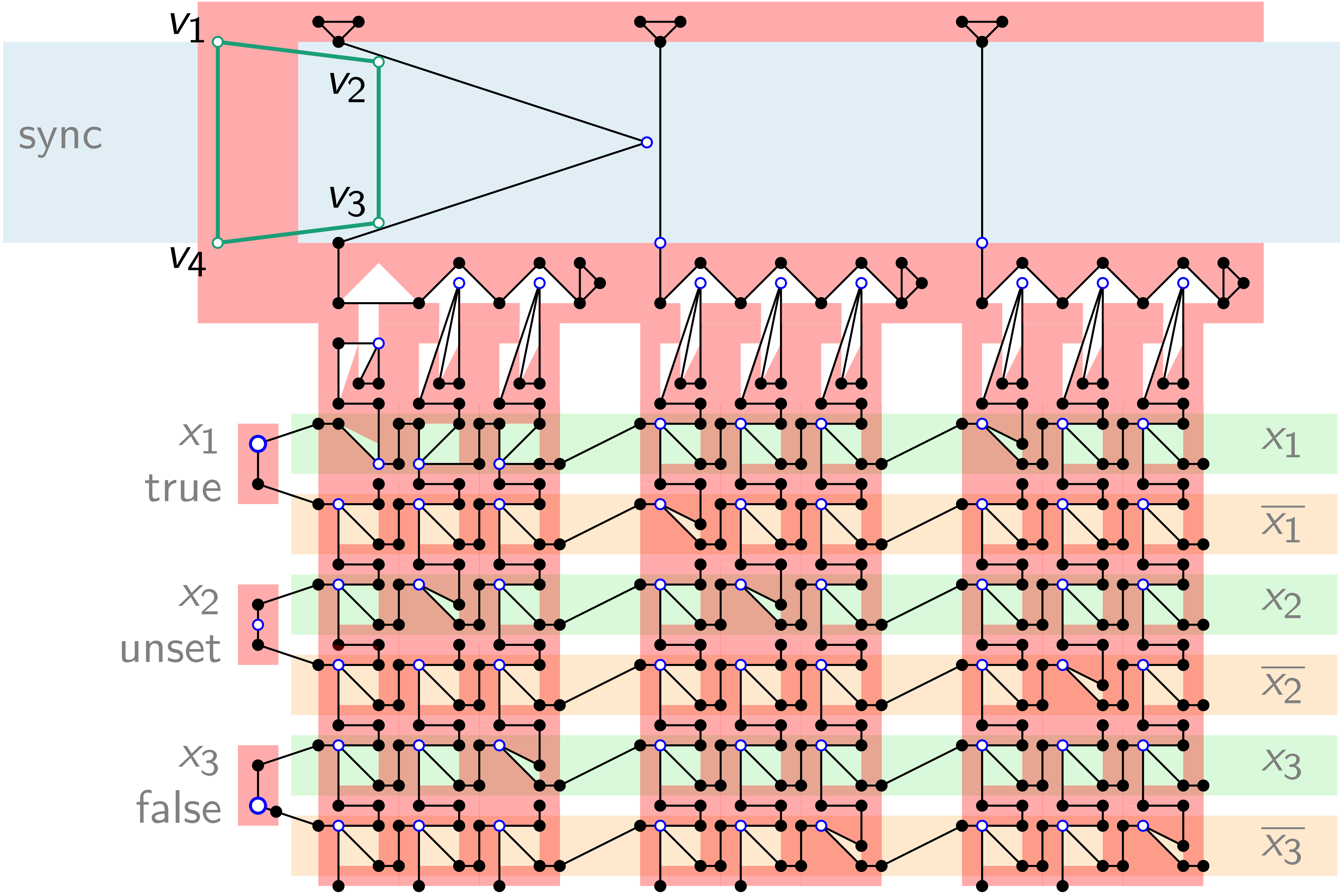

sync
v_1
v_2
v_3
v_4
x_1
true
x_2
unset
x_3
false
x_2
x_3
$\overline{x_3}$
literal gadget
c
c
no extra vertex
extra vertex

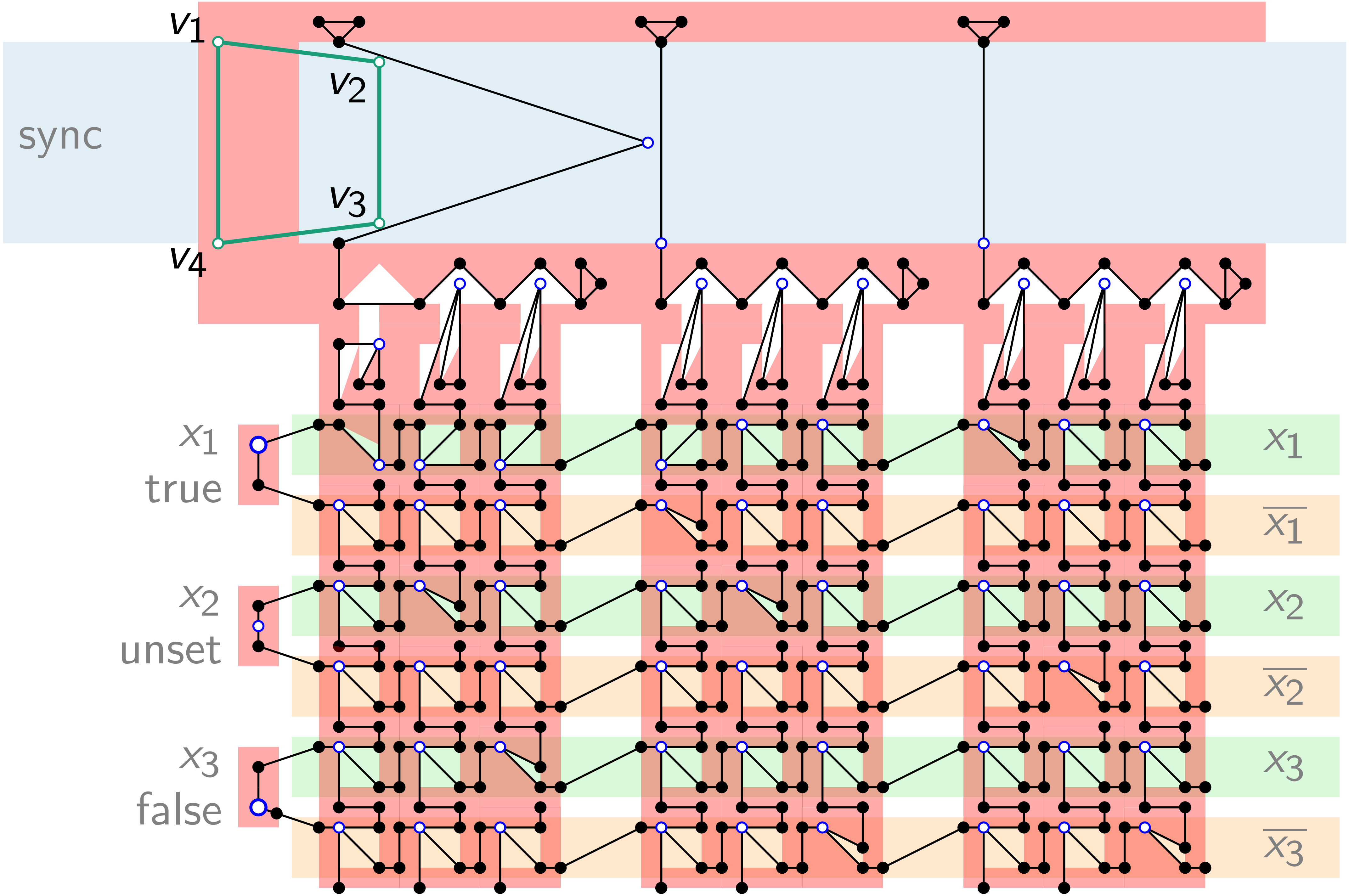

sync
v_1
v_2
v_3
v_4
x_1
true
x_2
unset
x_3
false
x_1
$\overline{x_1}$
x_2
$\overline{x_2}$
x_3
$\overline{x_3}$


v_1
v_2
sync
v_4
v_3
x_1
true
x_2
unset
x_3
false
x_1
$\overline{x_1}$
x_2
$\overline{x_2}$
x_3
$\overline{x_3}$


v_1
v_2
v_3
v_4
sync
x_1
true
x_2
unset
x_3
false
x_1
$\overline{x_1}$
x_2
$\overline{x_2}$
x_3
$\overline{x_3}$


v_1
v_2
v_3
v_4
sync
x_1
true
x_2
unset
x_3
false
x_1
$\overline{x_1}$
x_2
$\overline{x_2}$
x_3
$\overline{x_3}$


v_1
v_2
v_3
v_4
sync
x_1
true
x_2
unset
x_3
false
x_1
$\overline{x_1}$
x_2
$\overline{x_2}$
x_3
$\overline{x_3}$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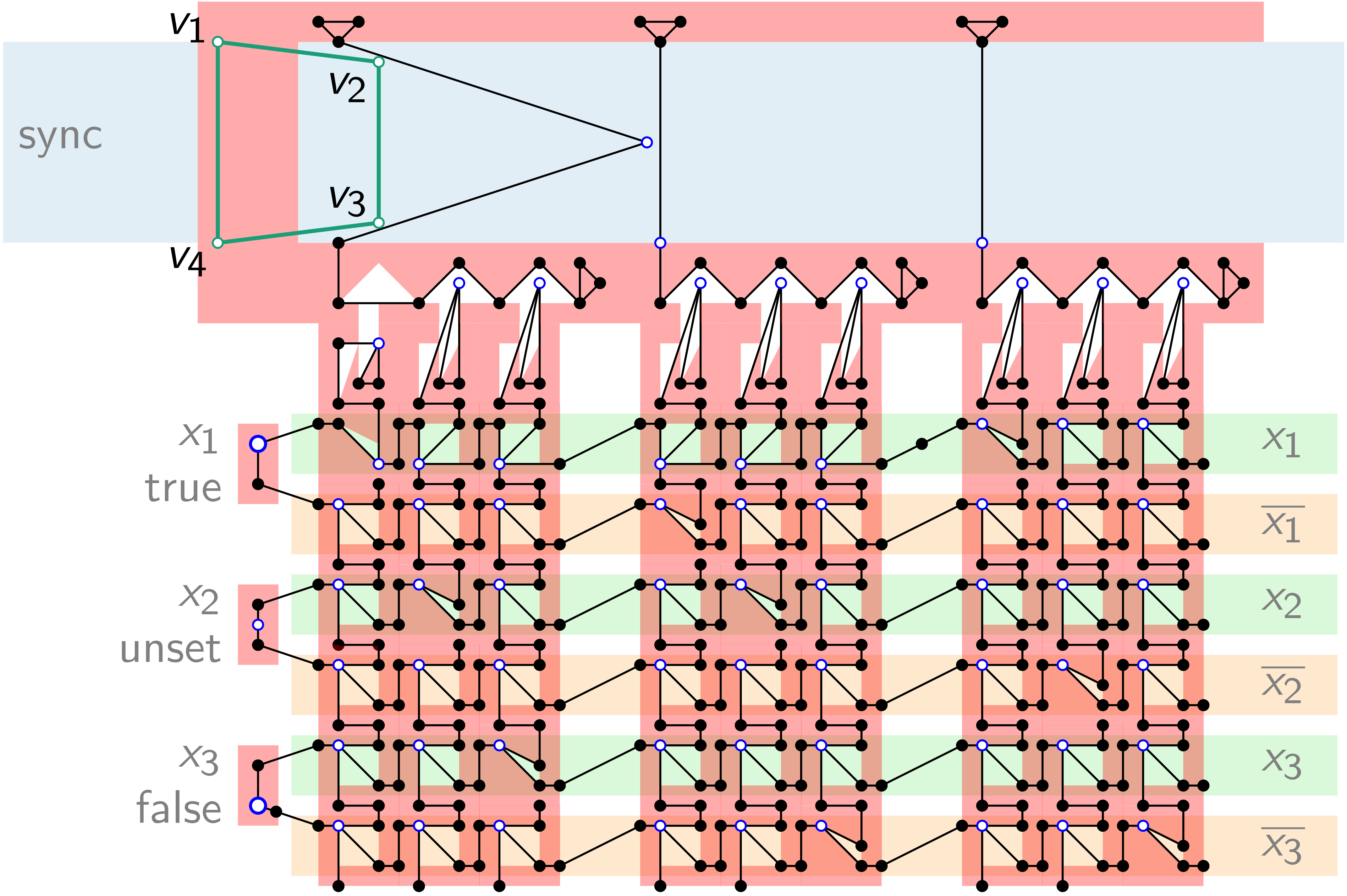
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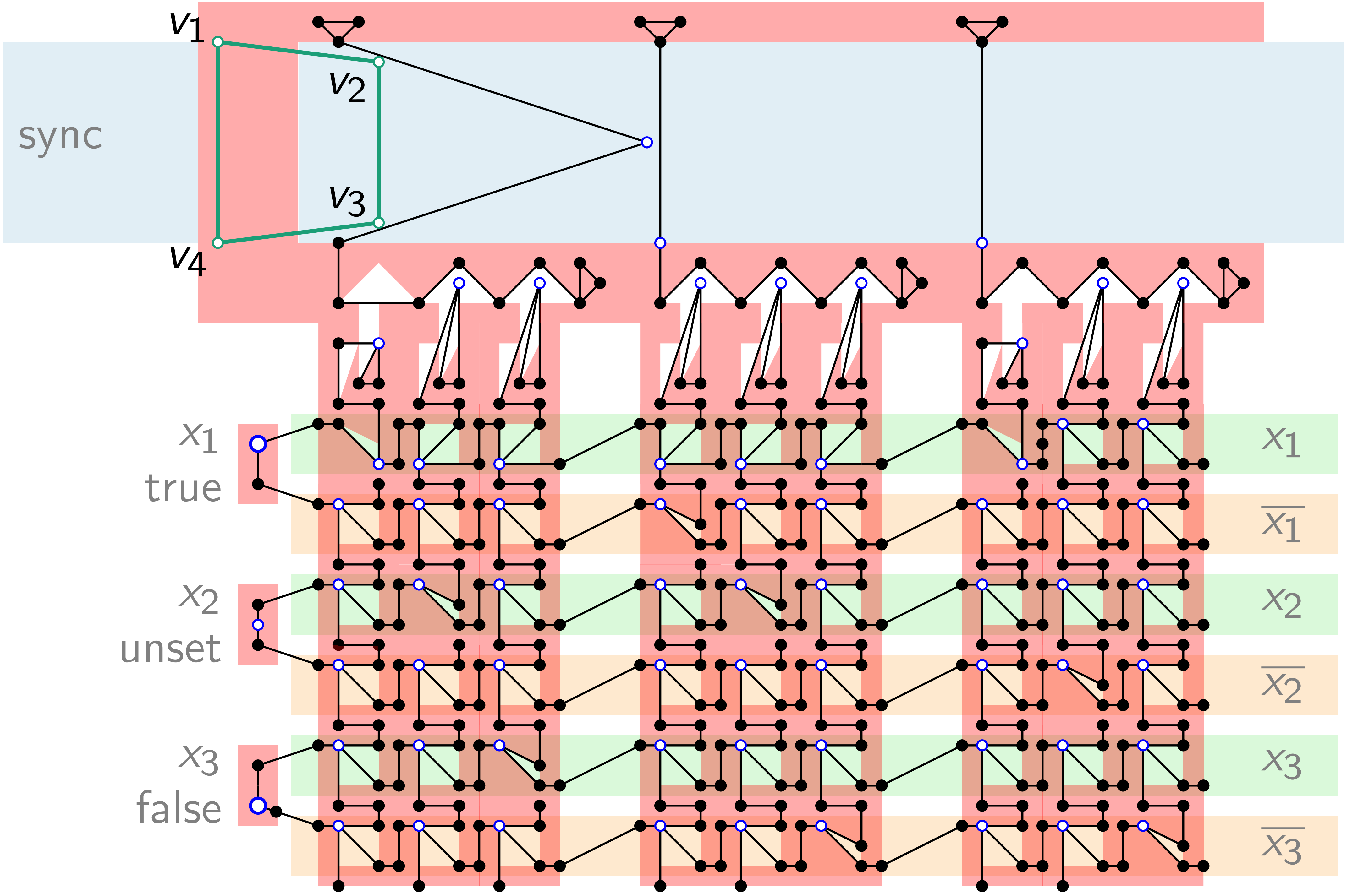
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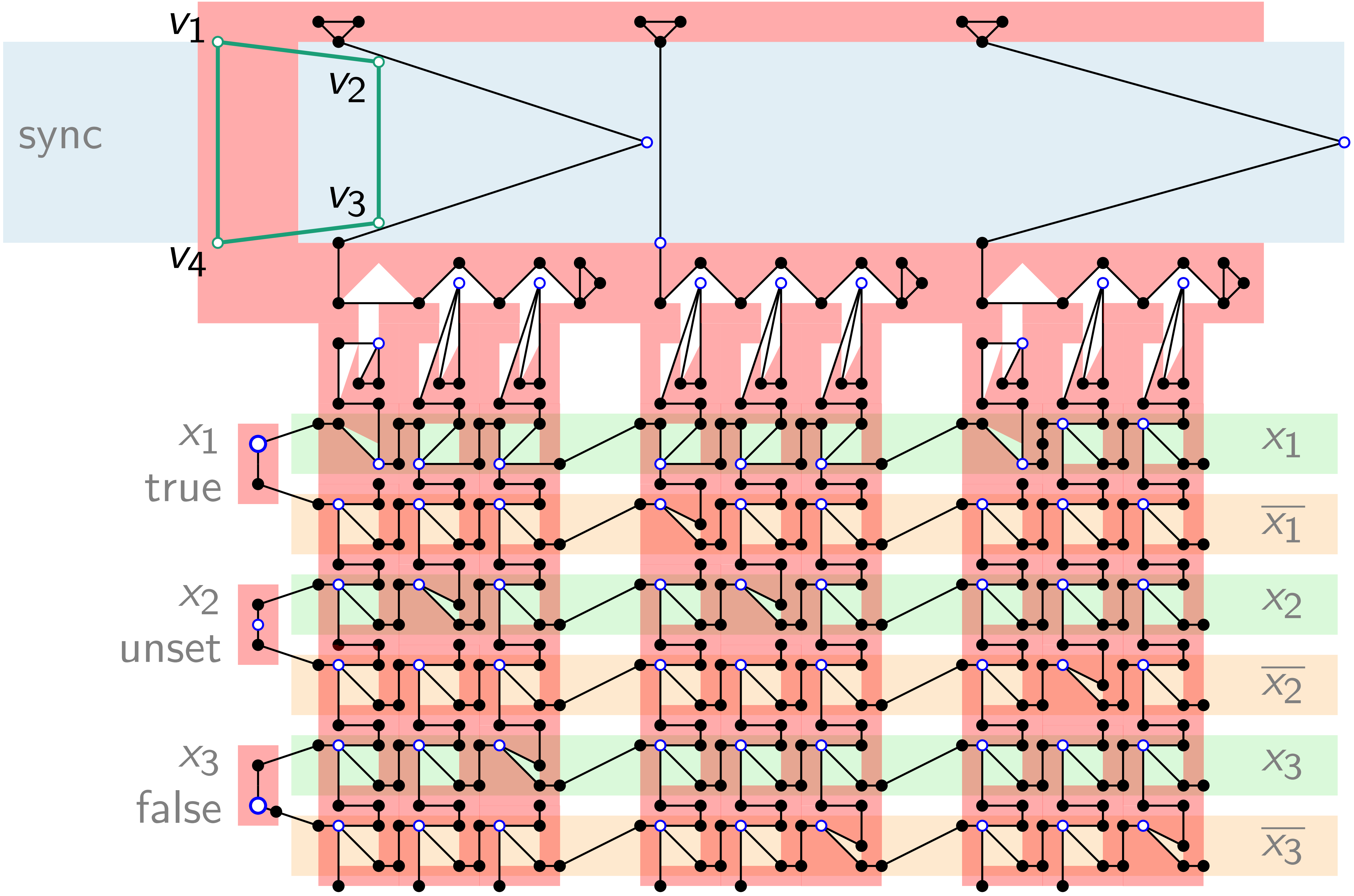
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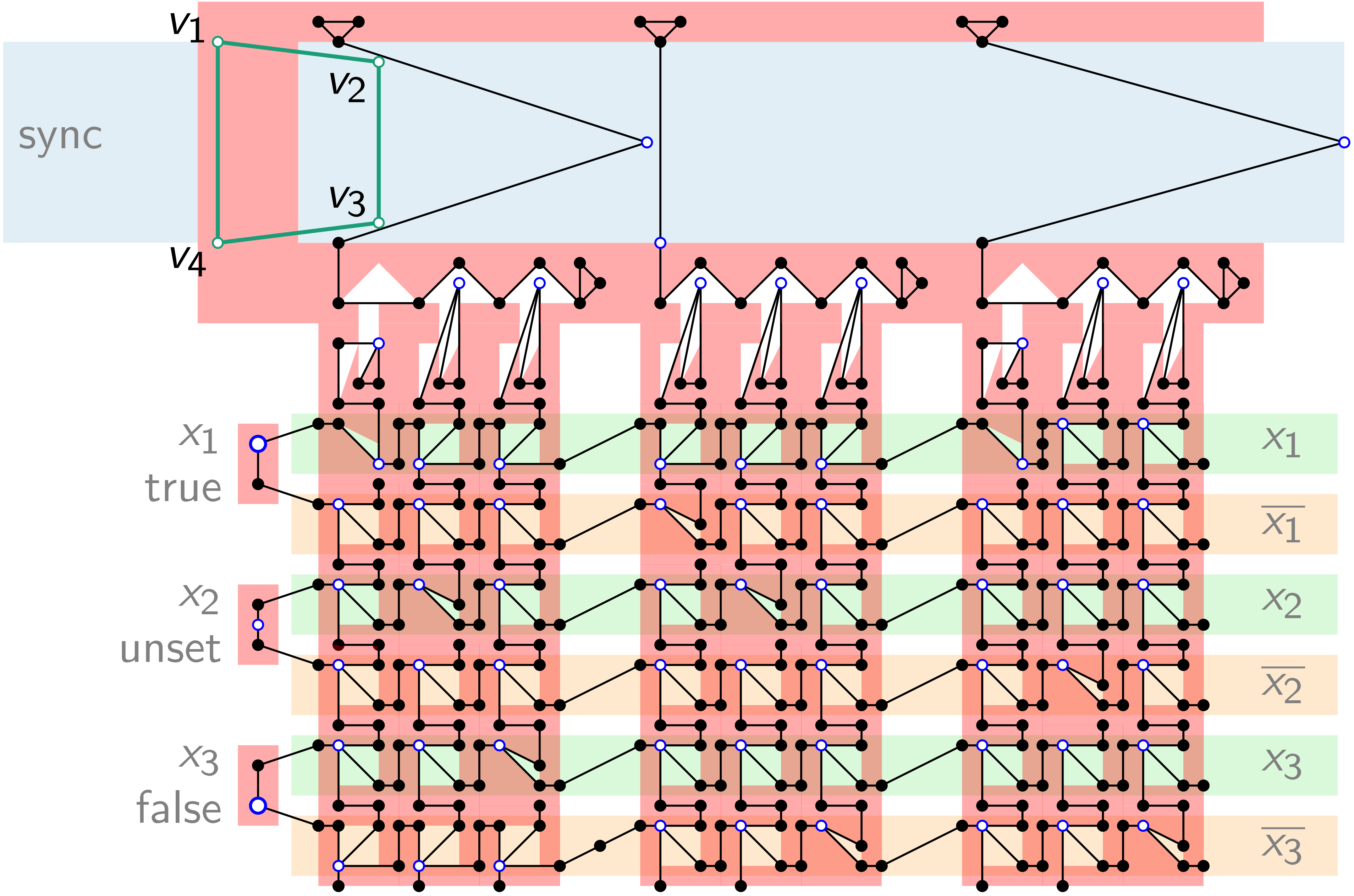
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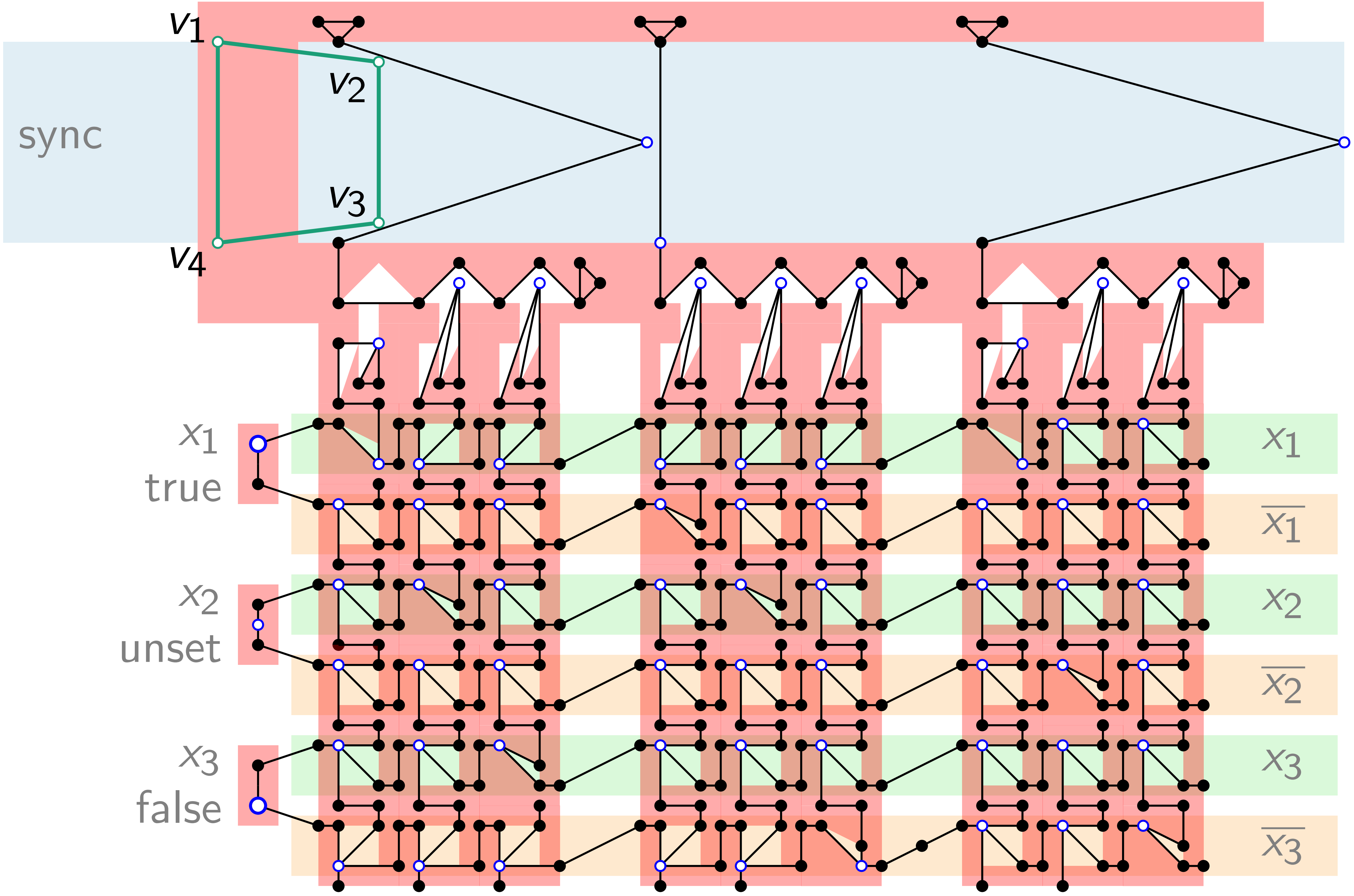
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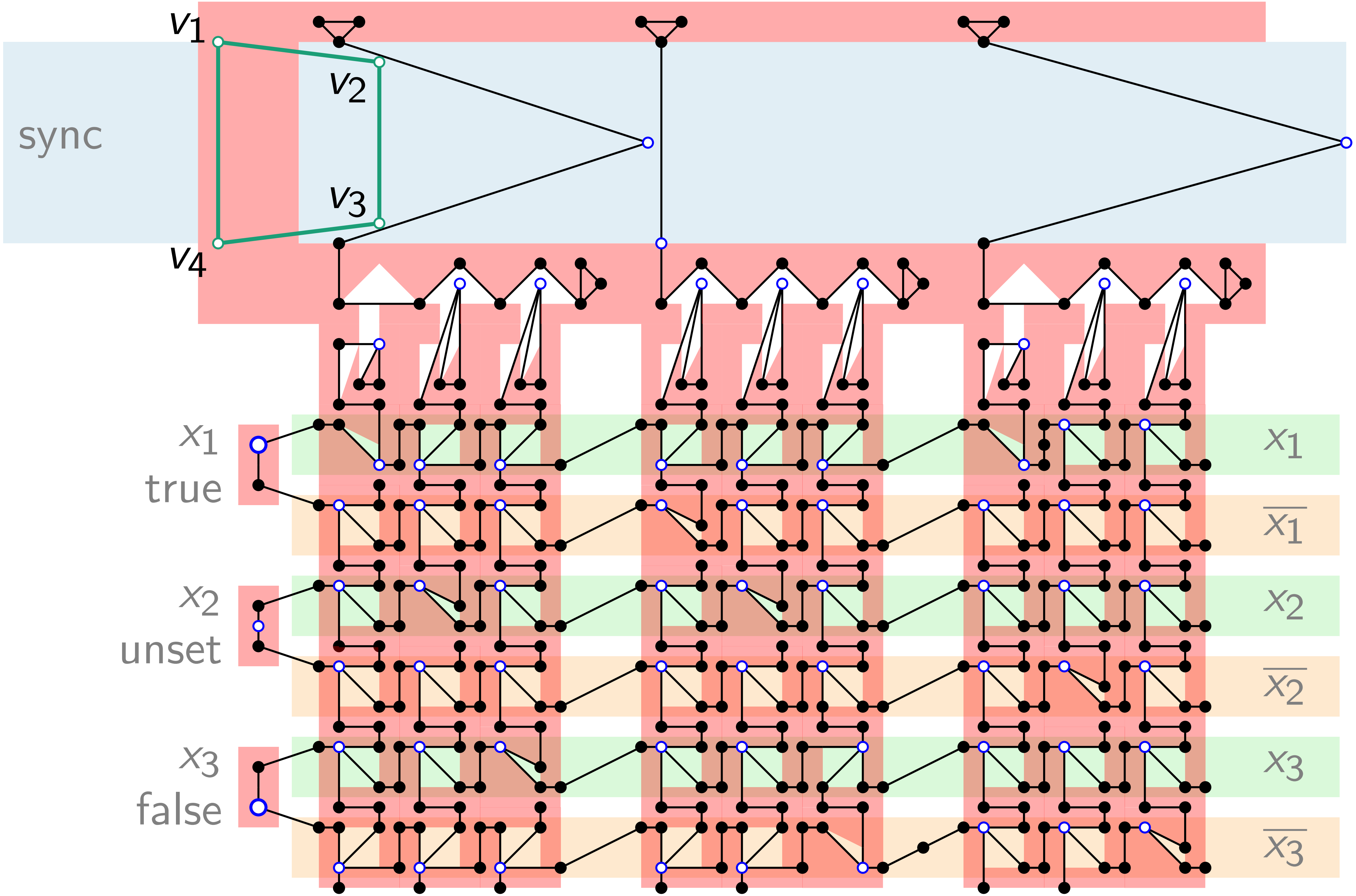
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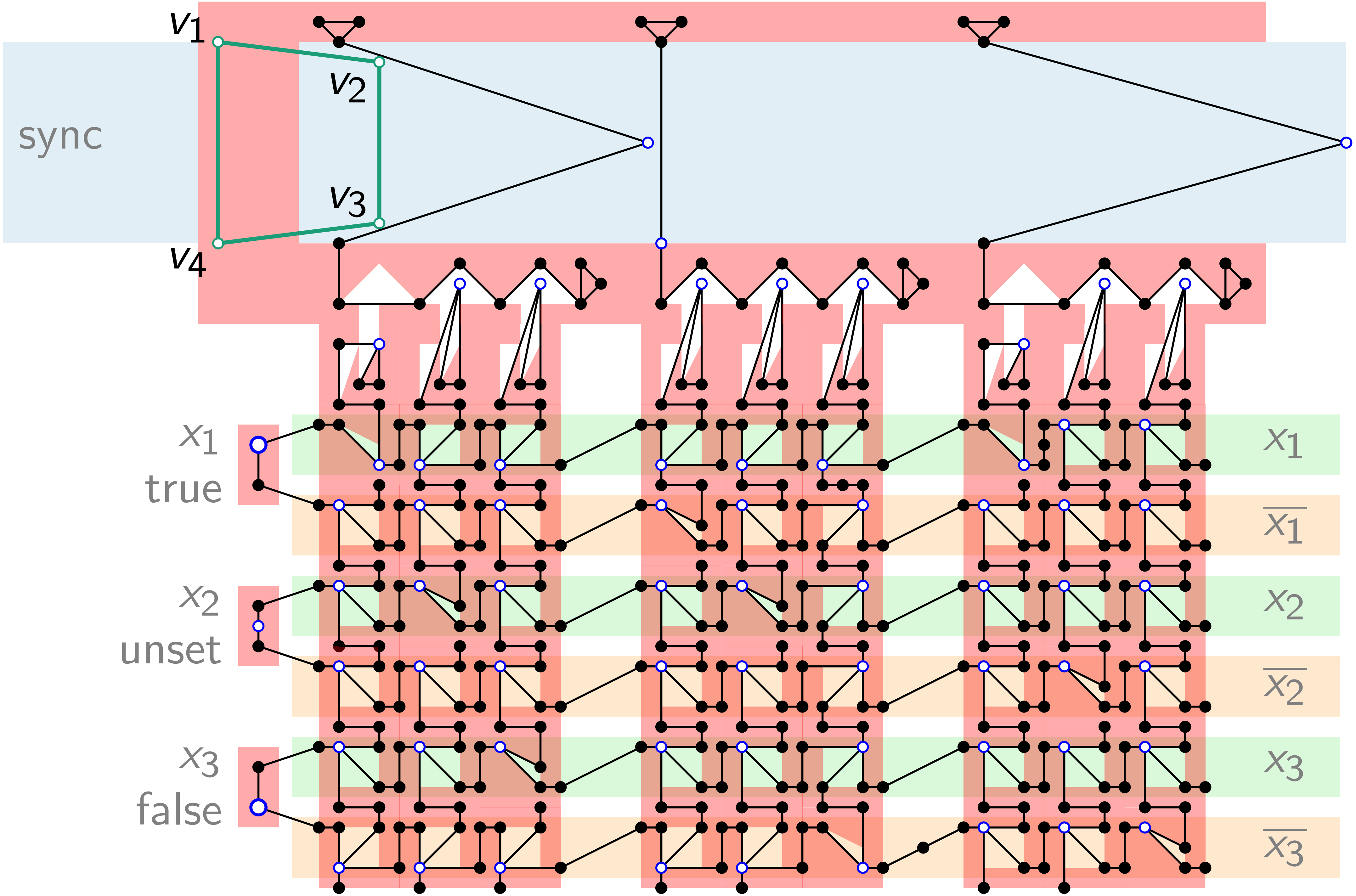
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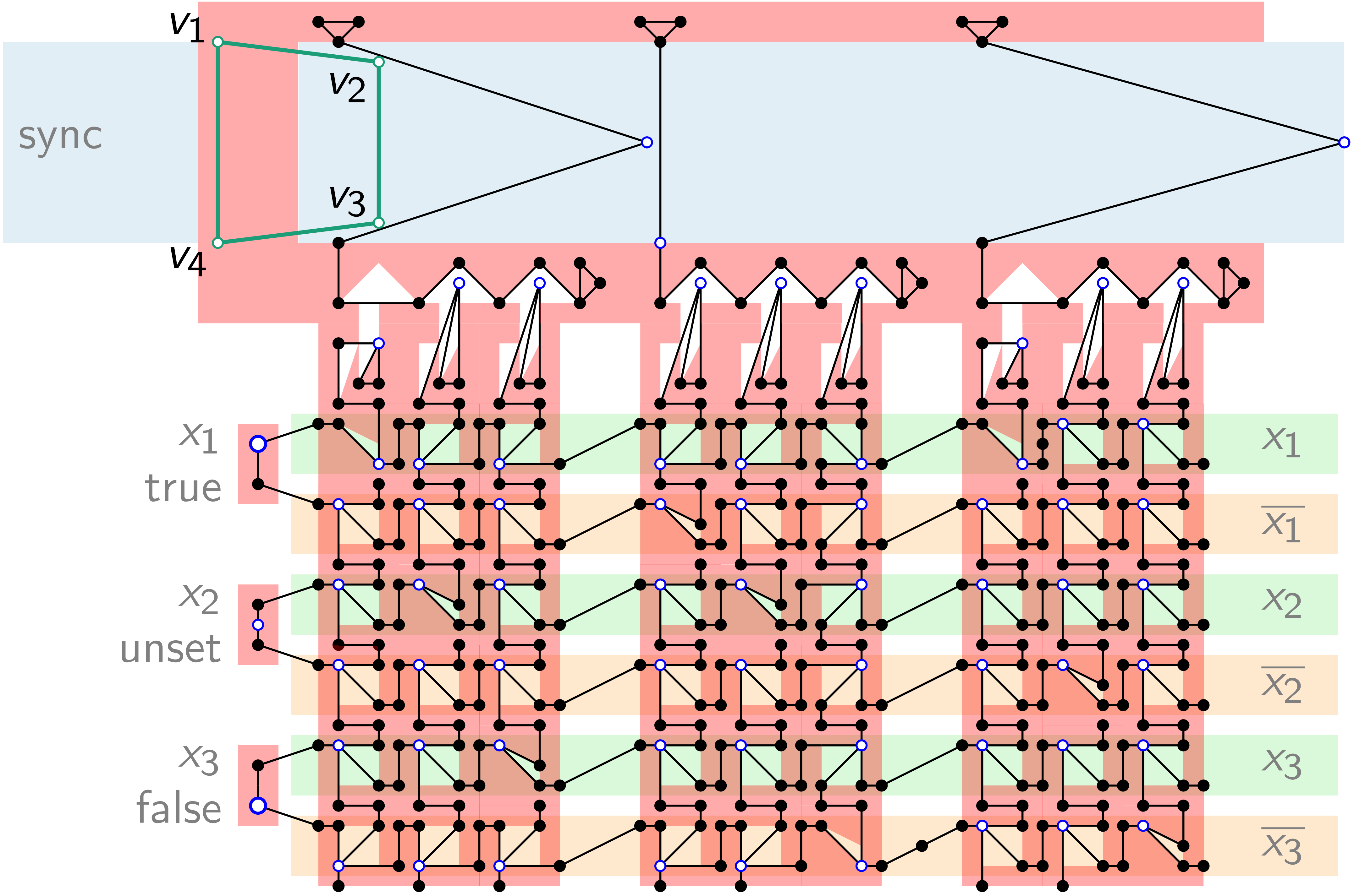
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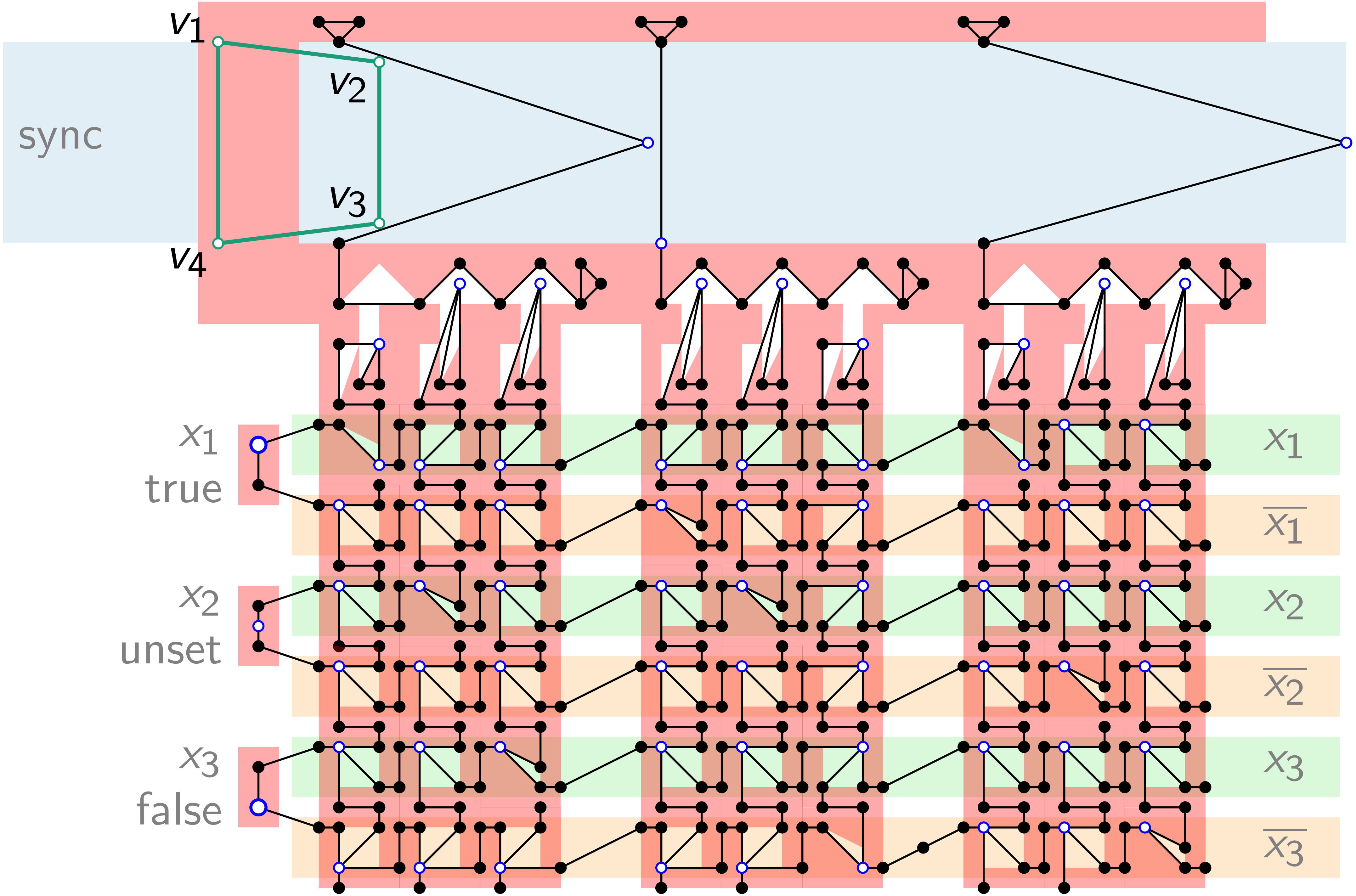
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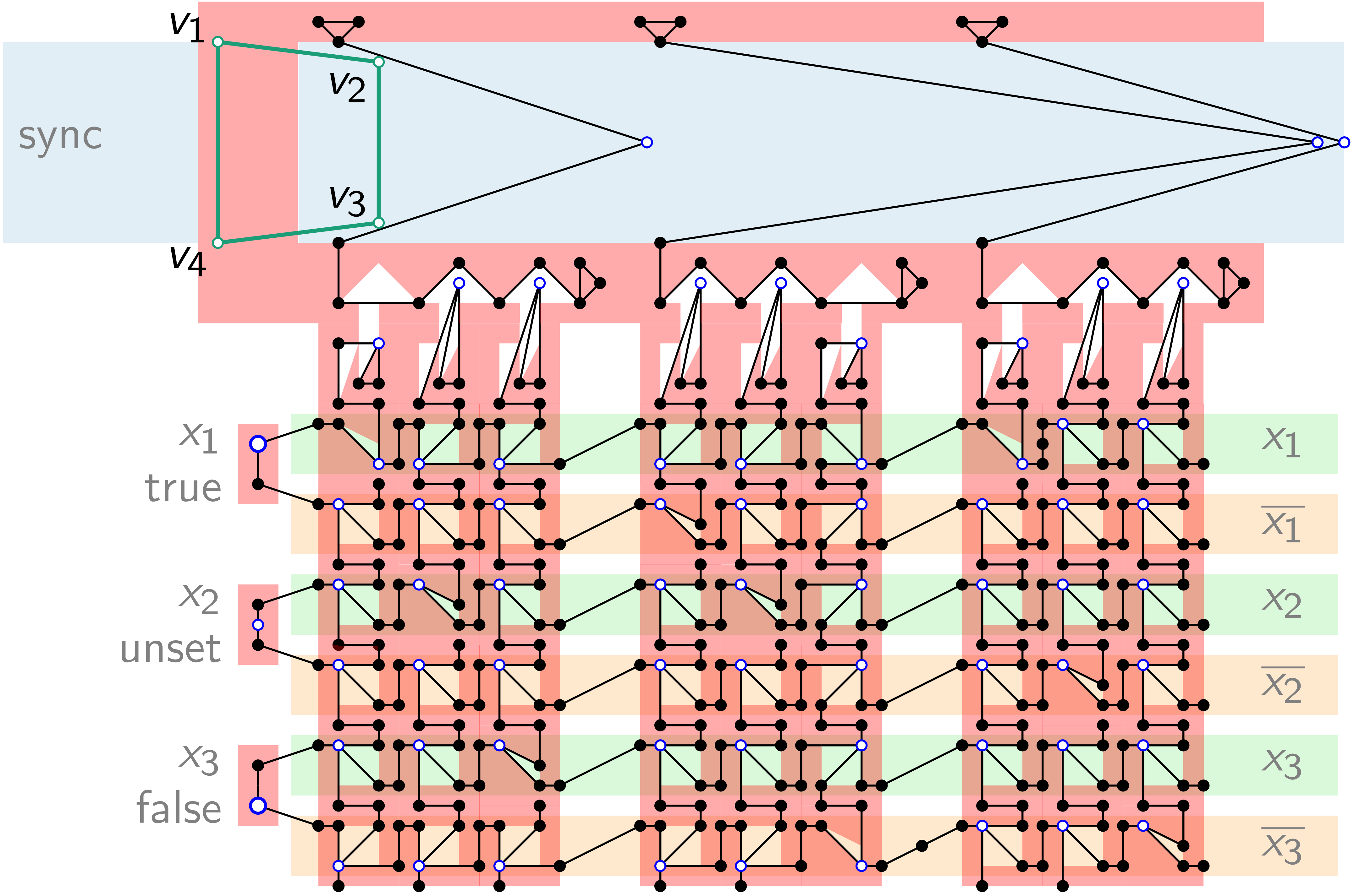
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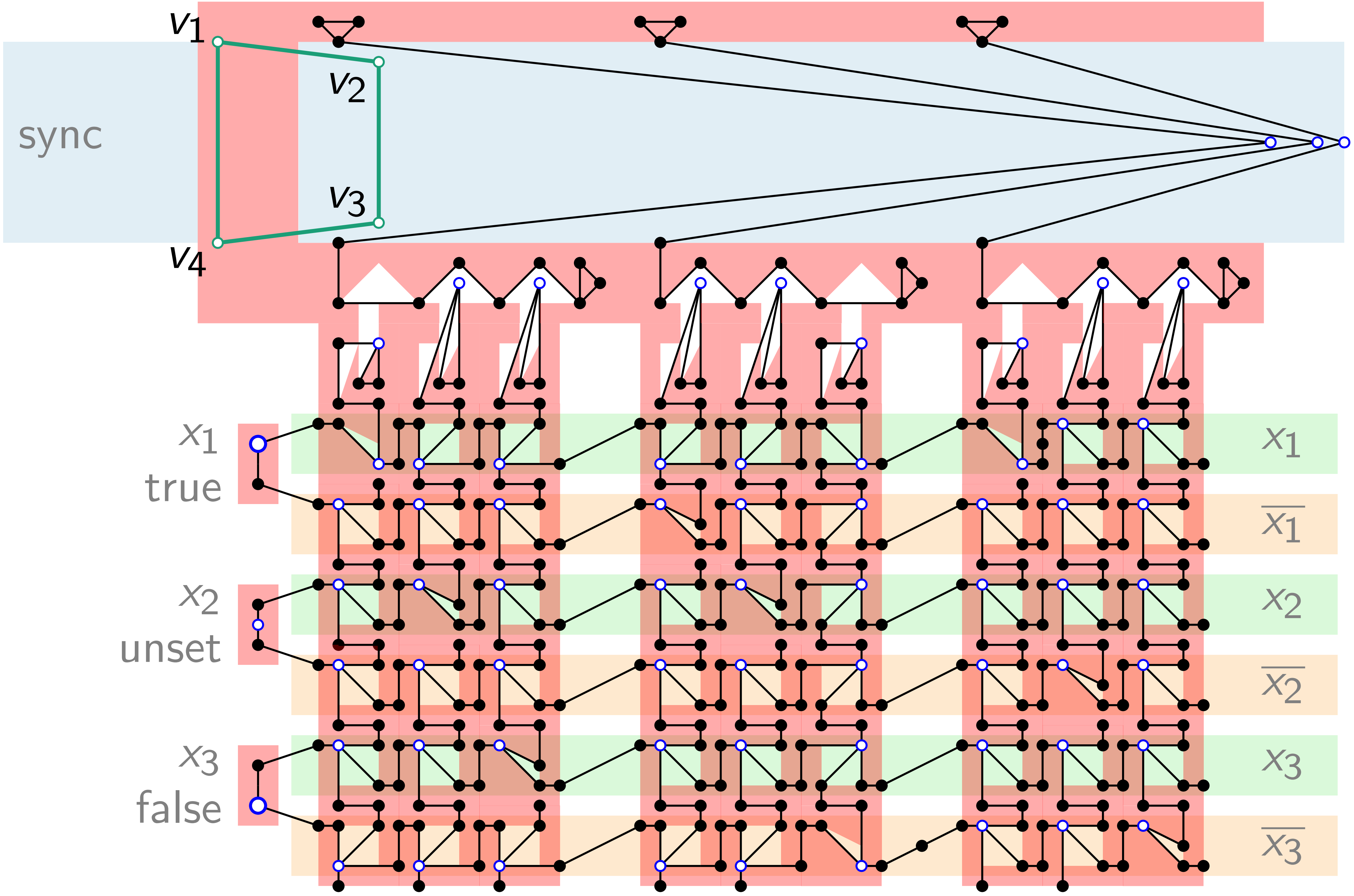
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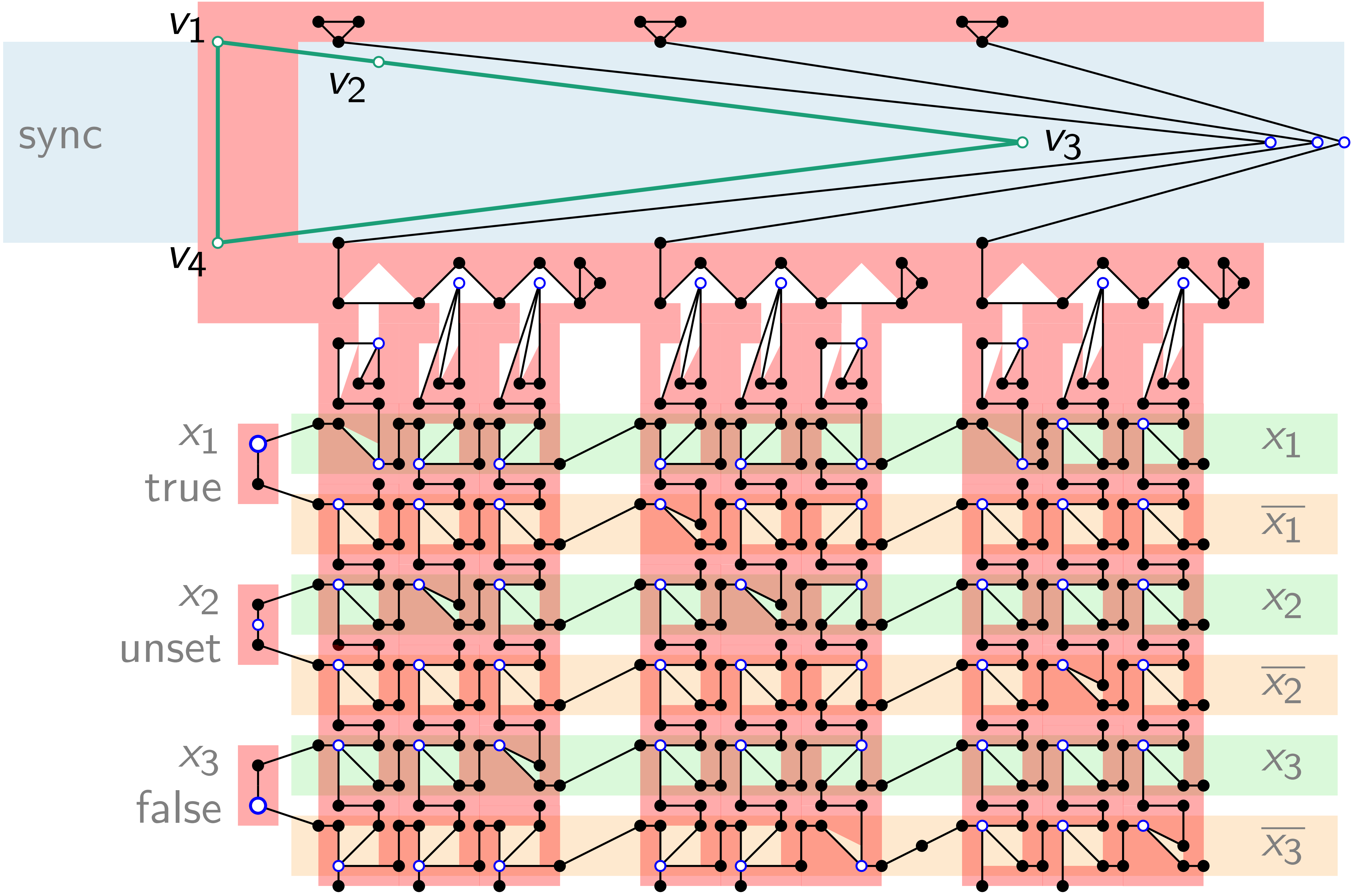
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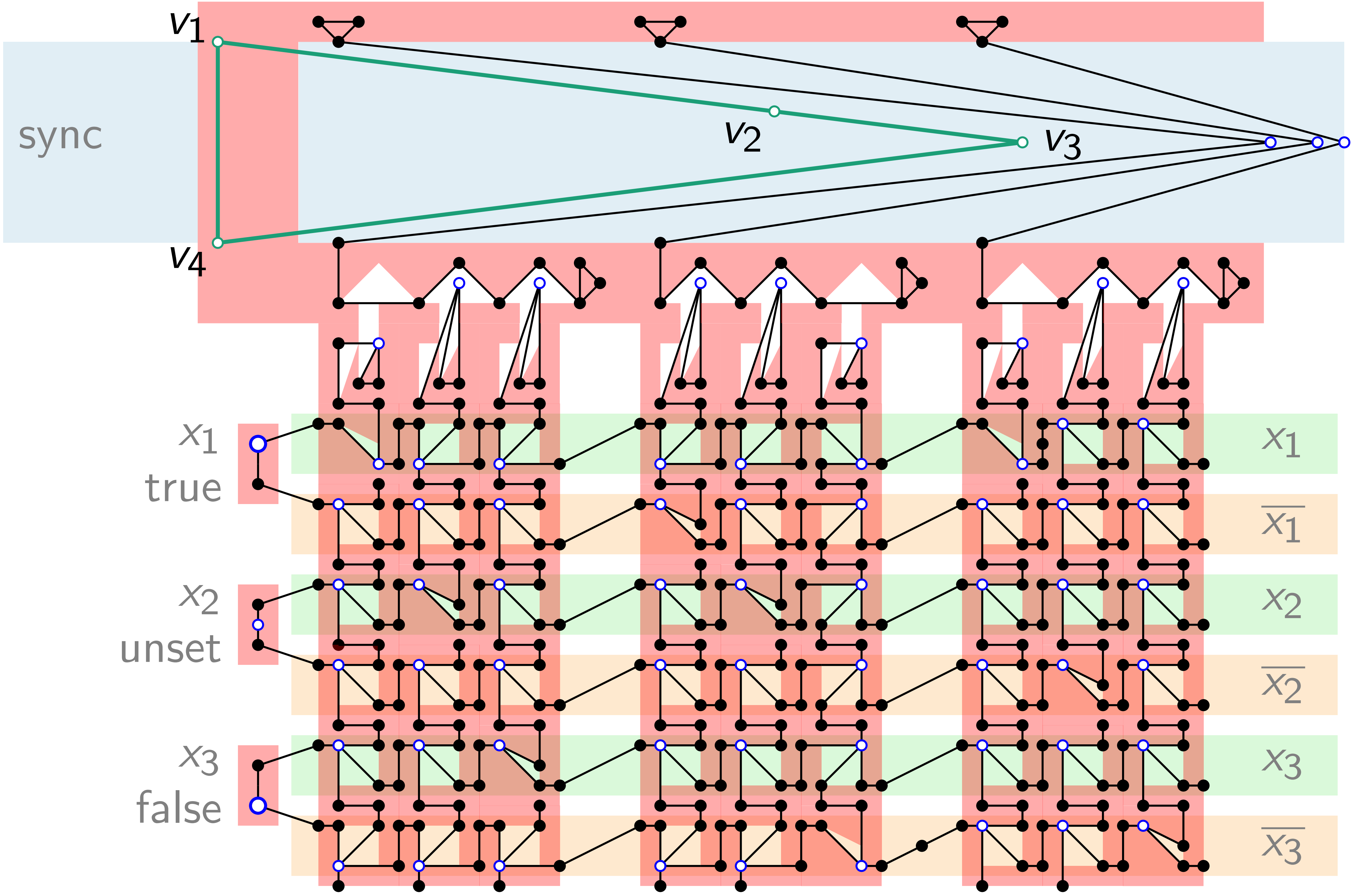
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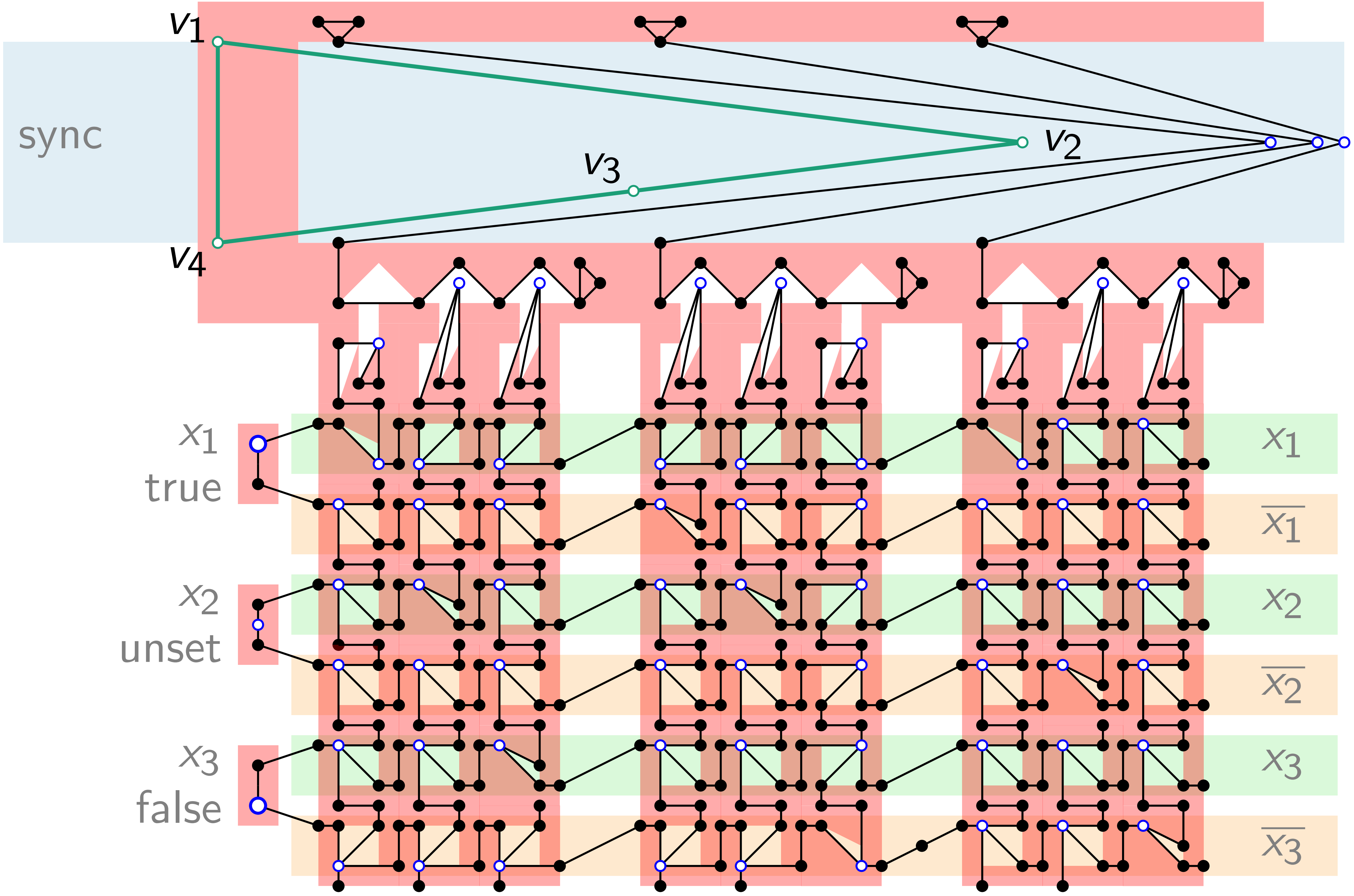
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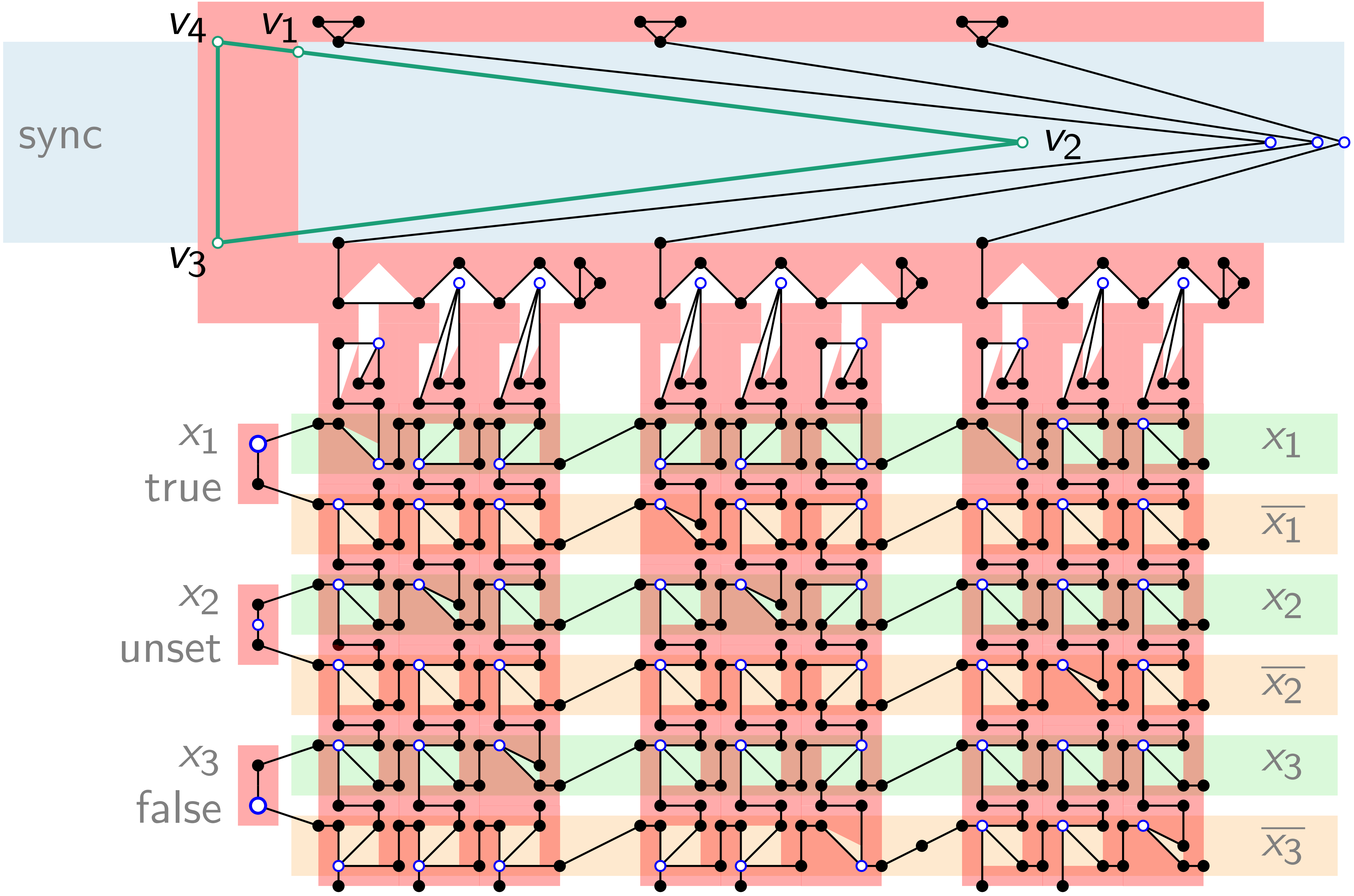
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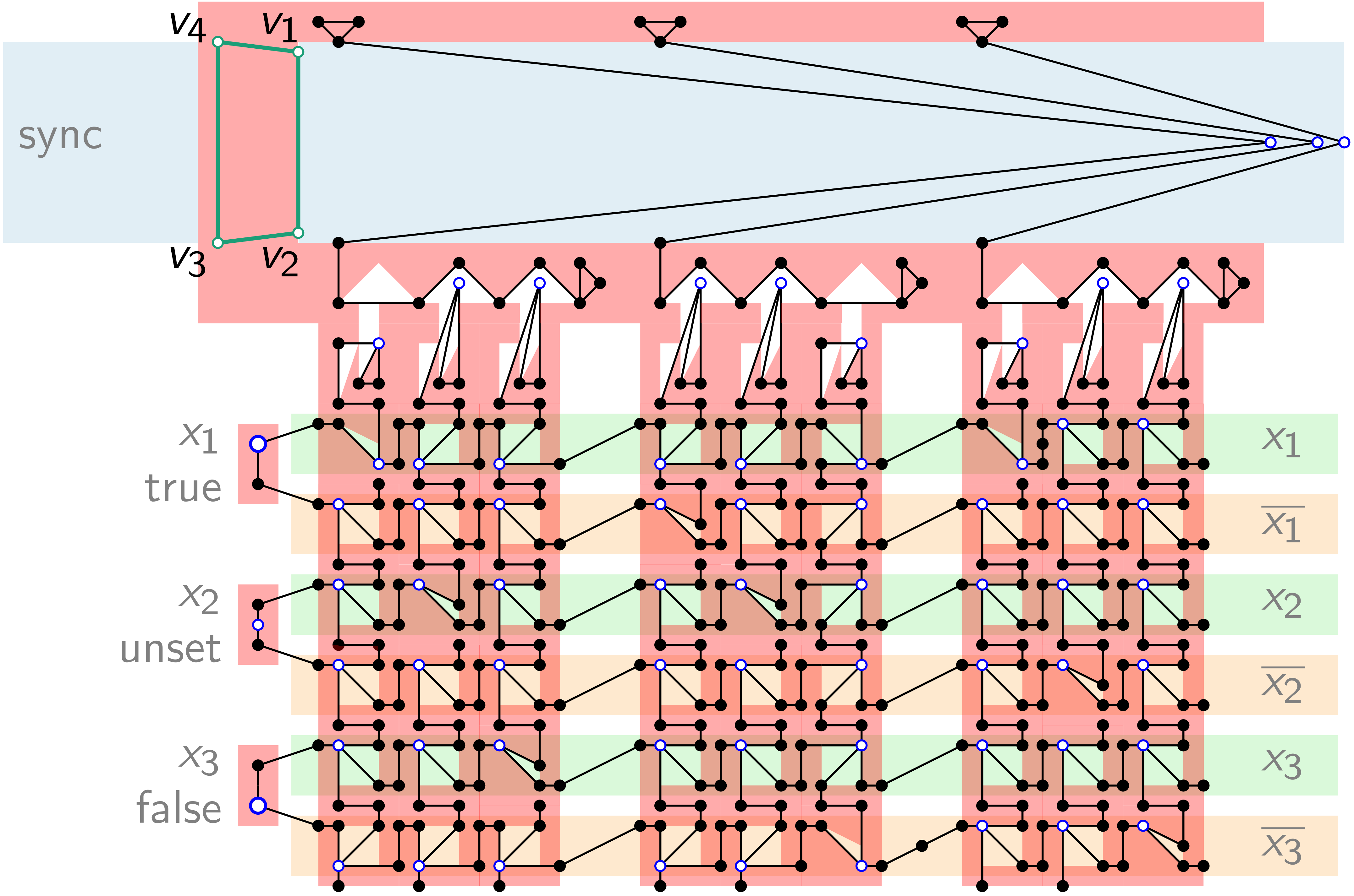
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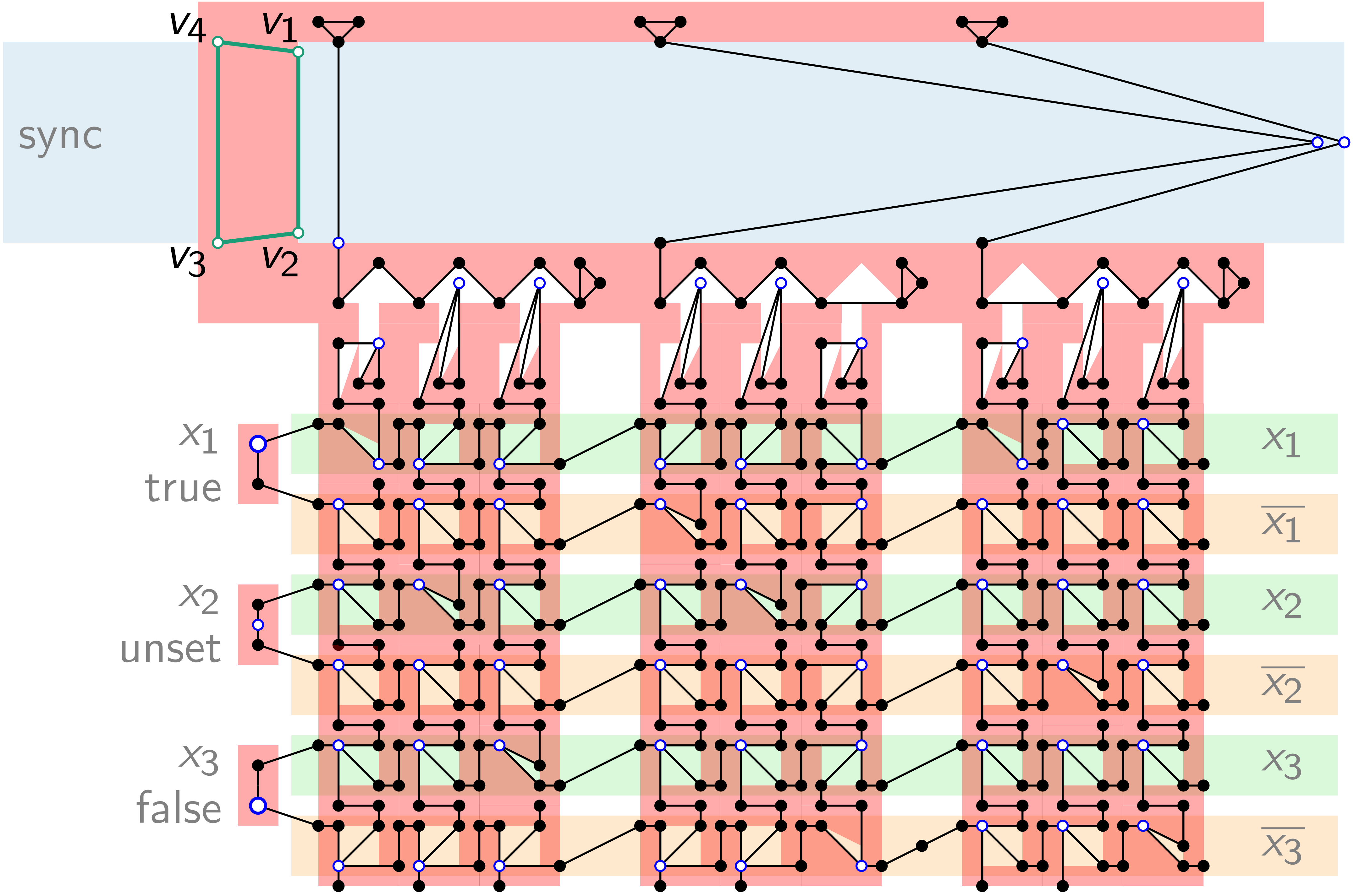
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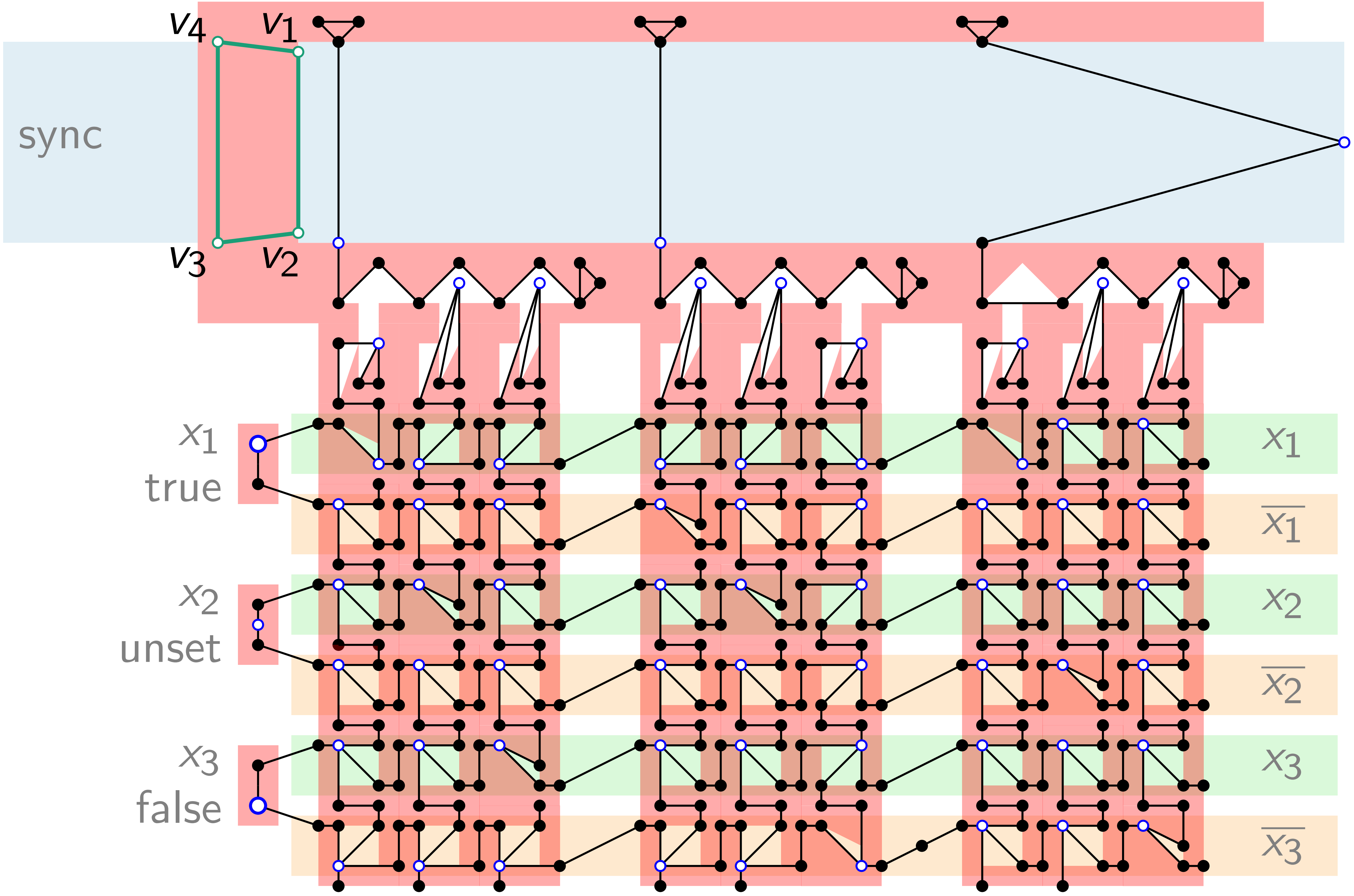
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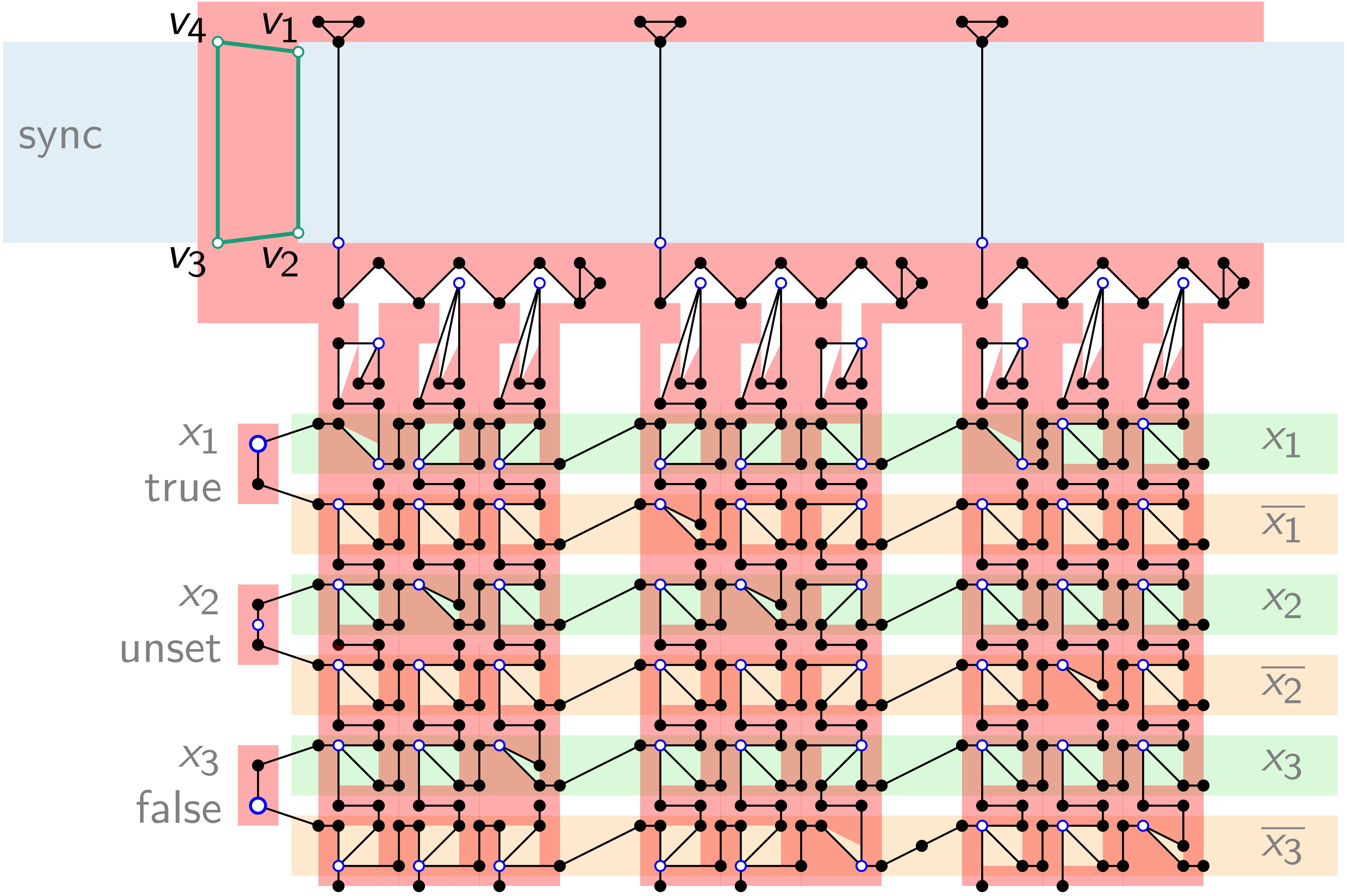

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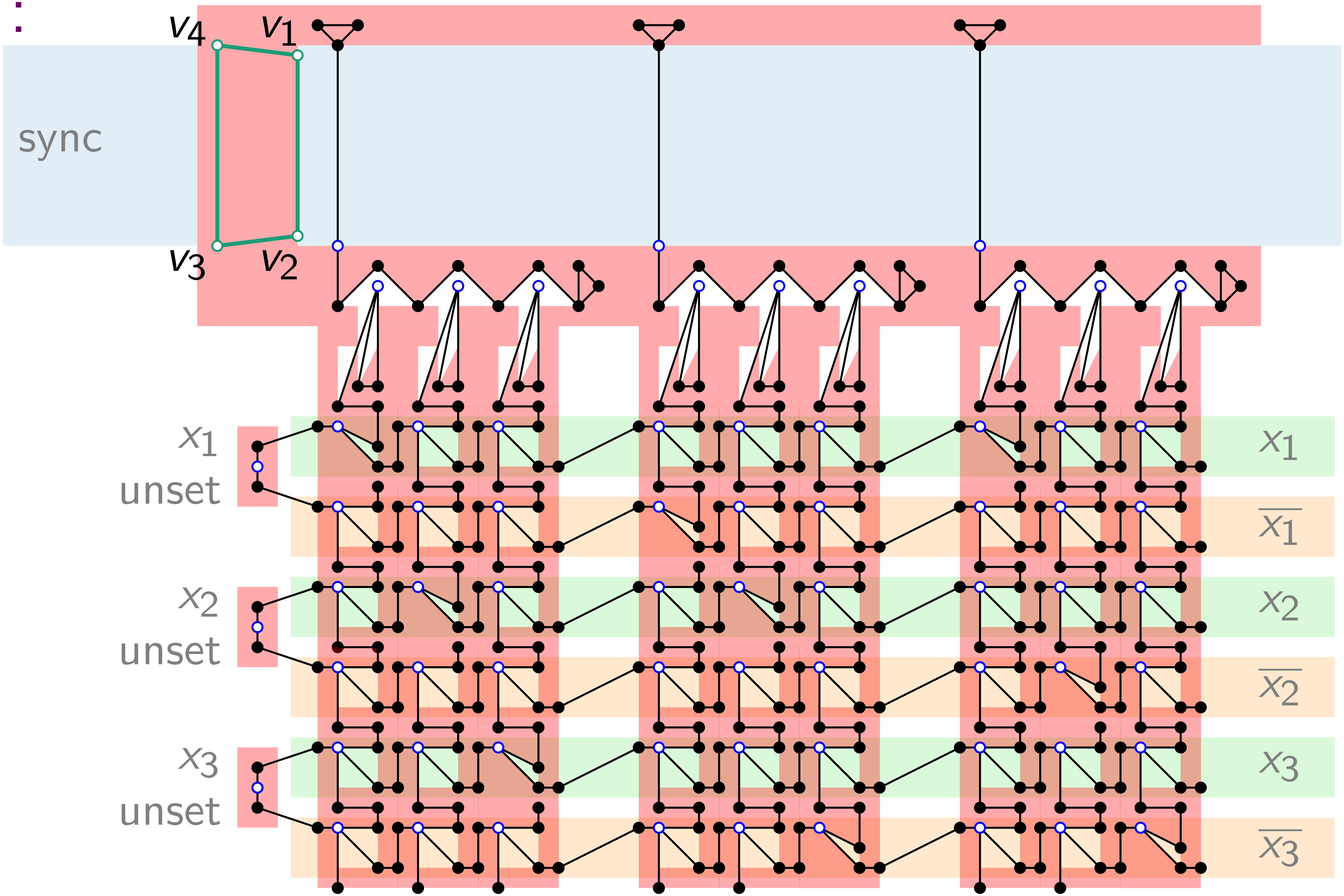
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- Given two drawings of the same graph, how many obstacles are necessary and sufficient to block them? Can this be computed efficiently?