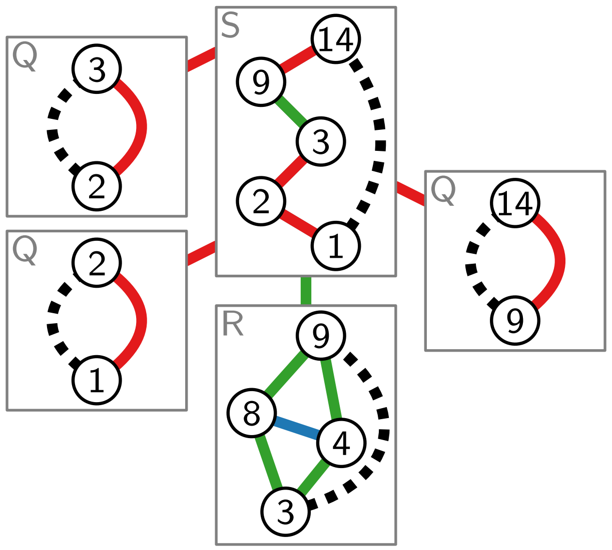
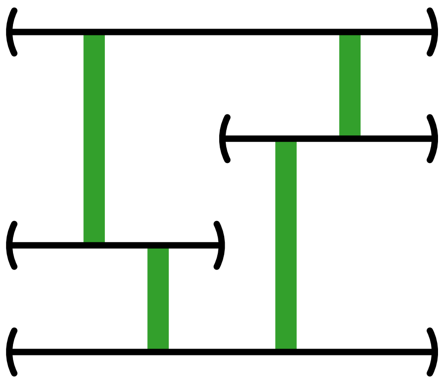
Visualization of Graphs

Lecture 10:
Partial Visibility Representation Extension



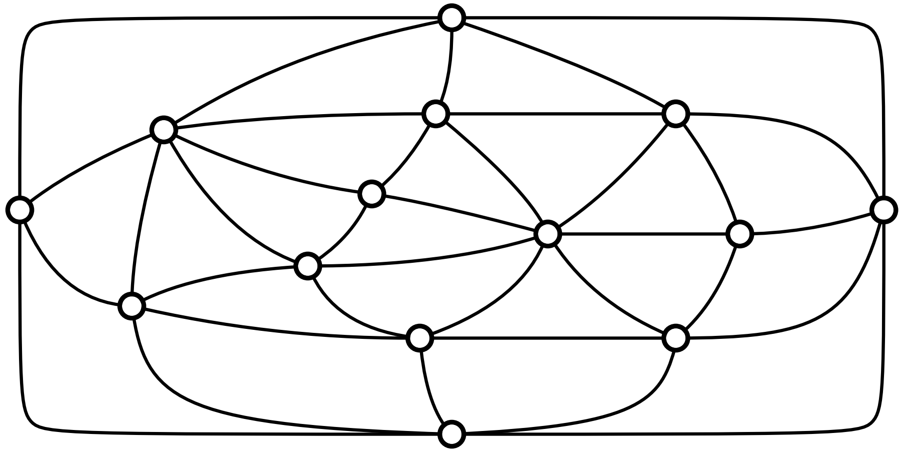
Alexander Wolff



Summer semester 2025

Partial Representation Extension Problem

Let G be a graph.



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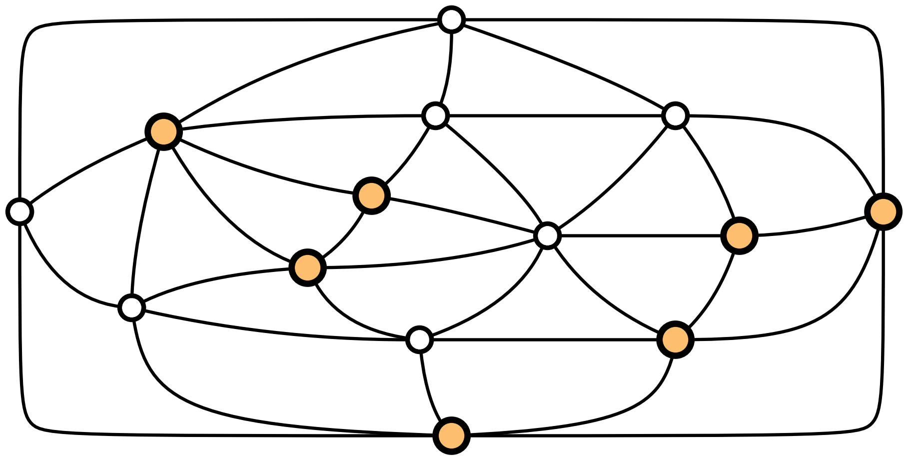
Let G be a graph.

Let $V' \subseteq V(G)$



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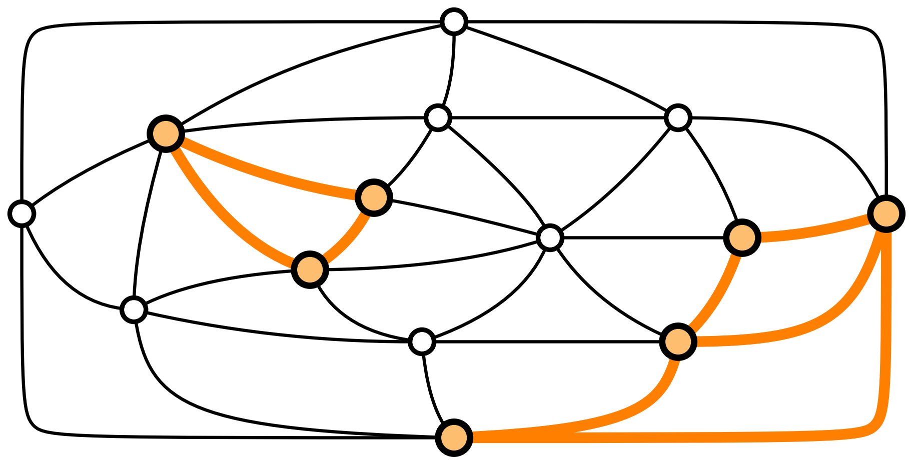

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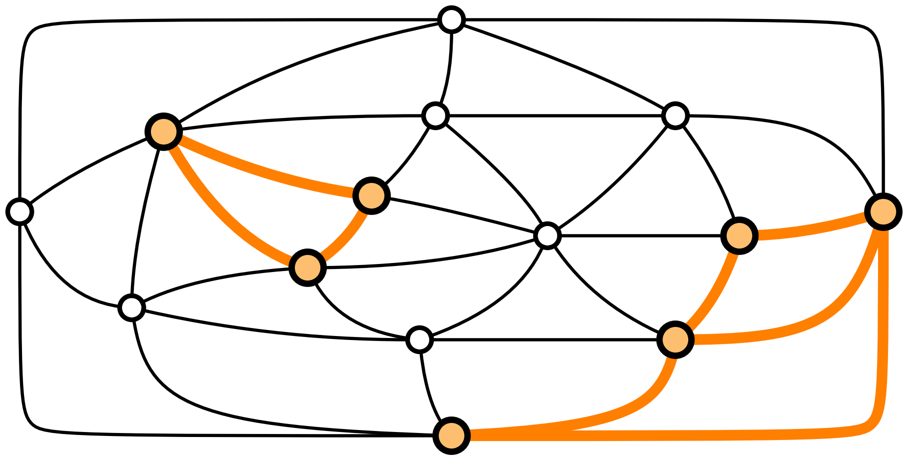

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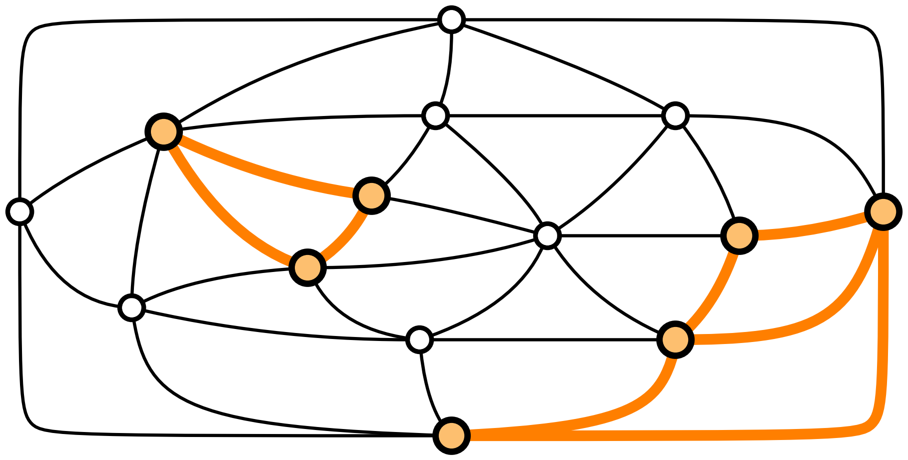

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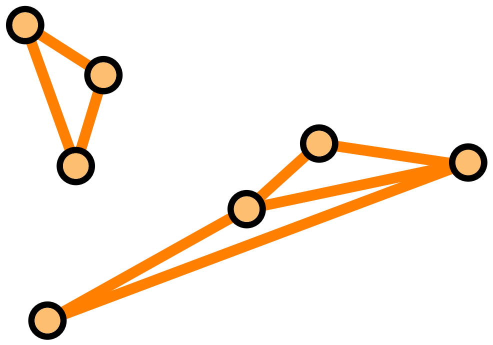

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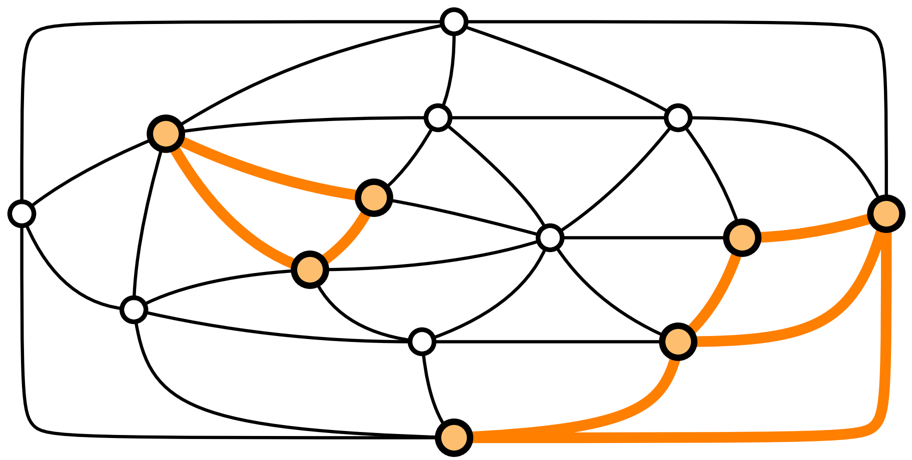

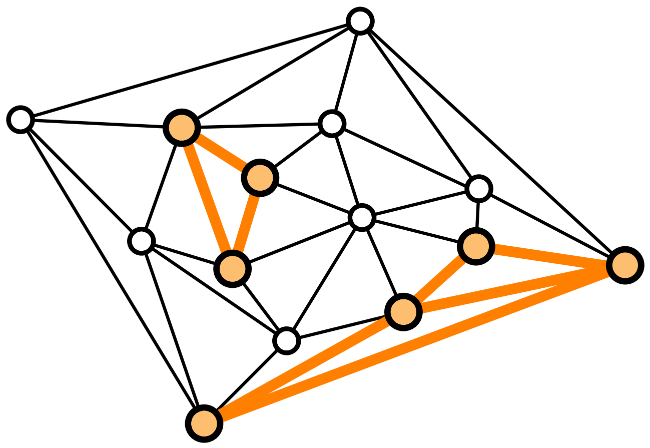

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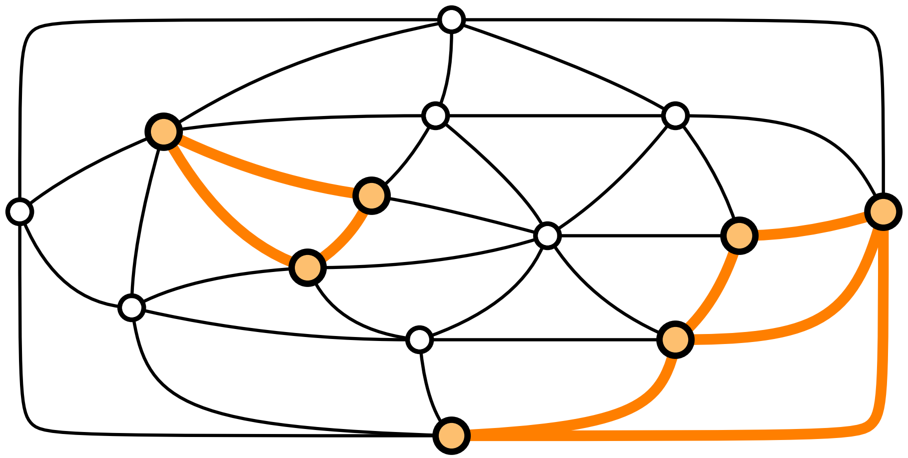

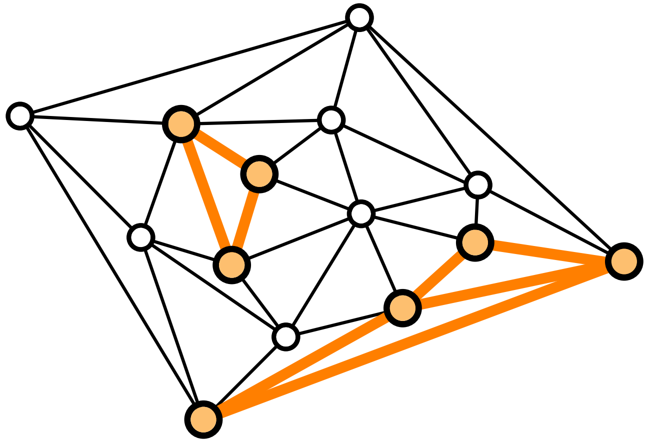

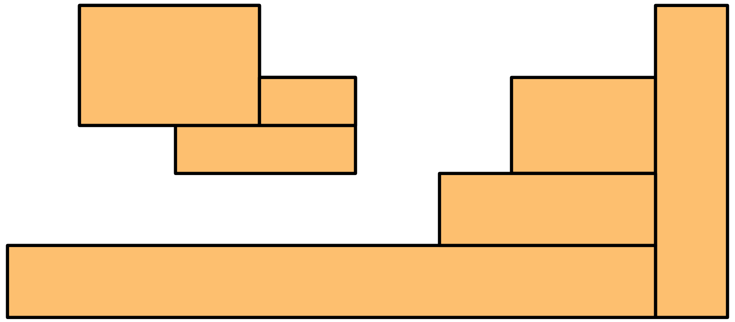

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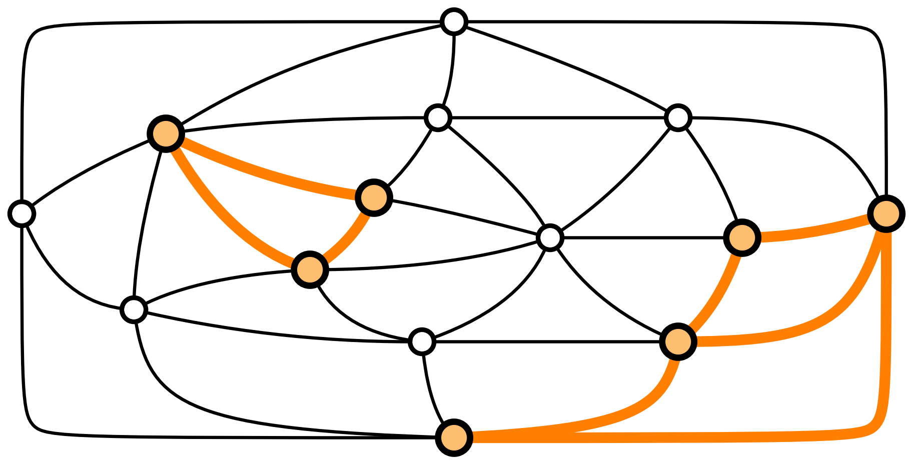

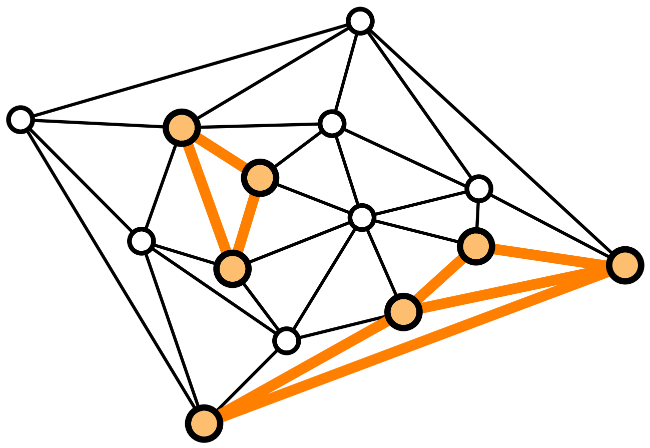

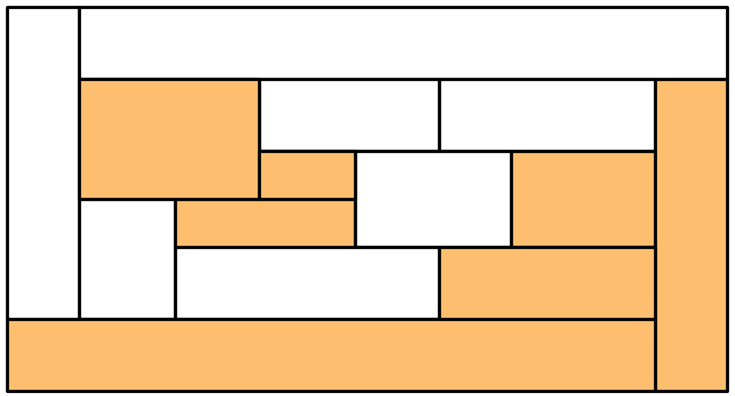

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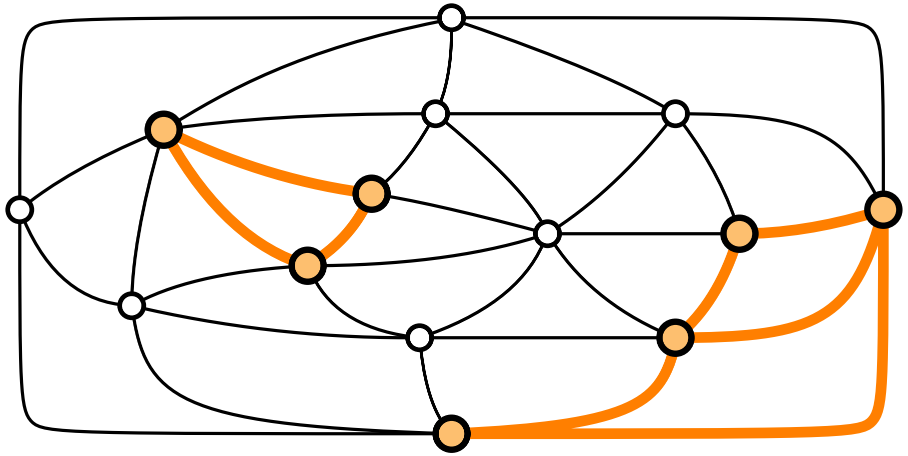

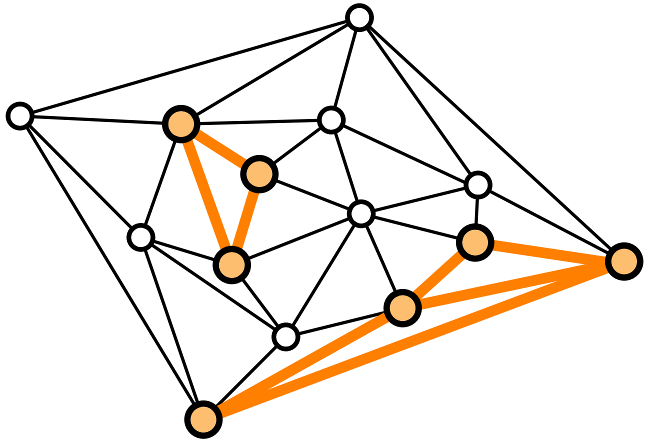

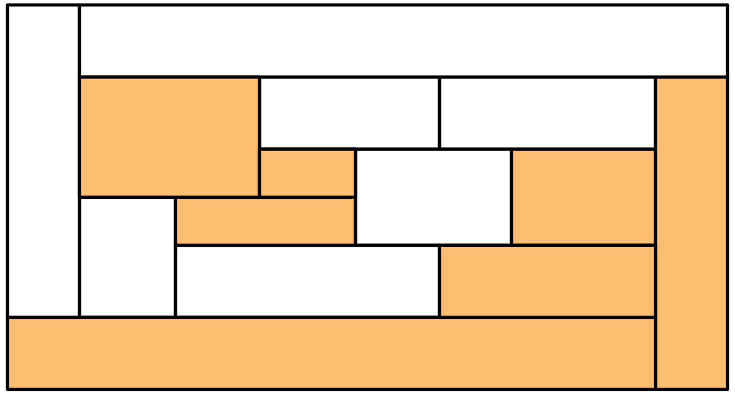

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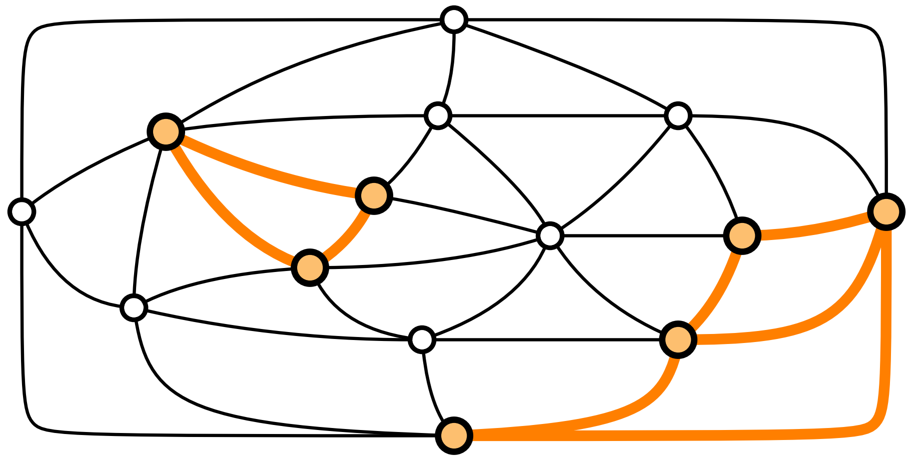
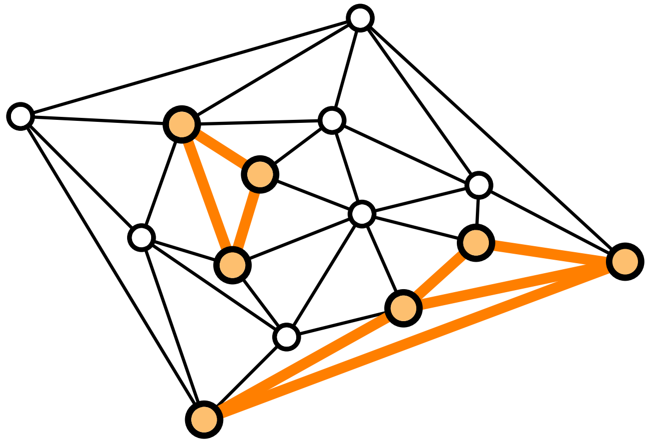
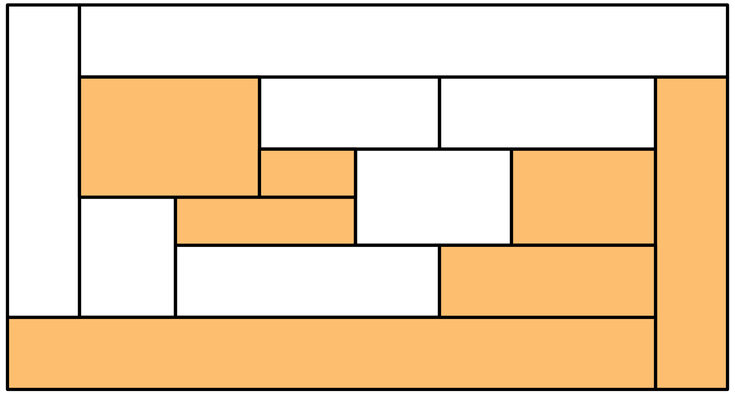
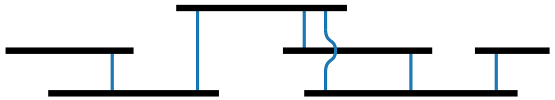






Polytime for:

- (unit) interval graphs



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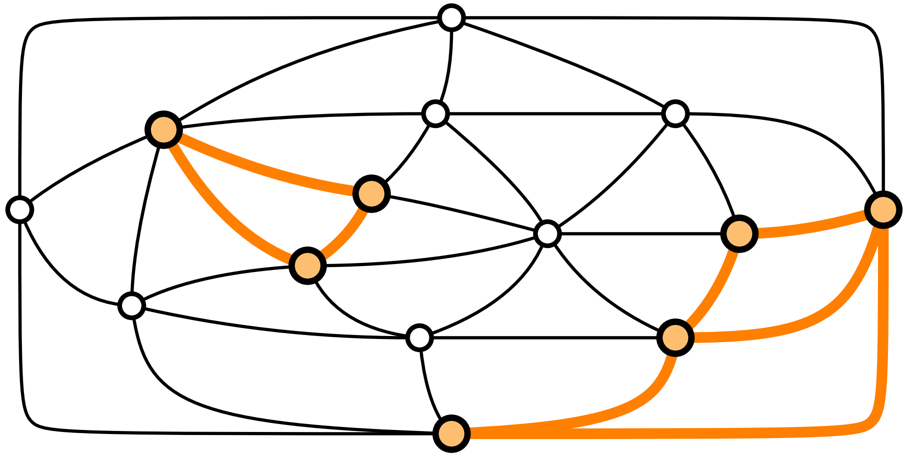

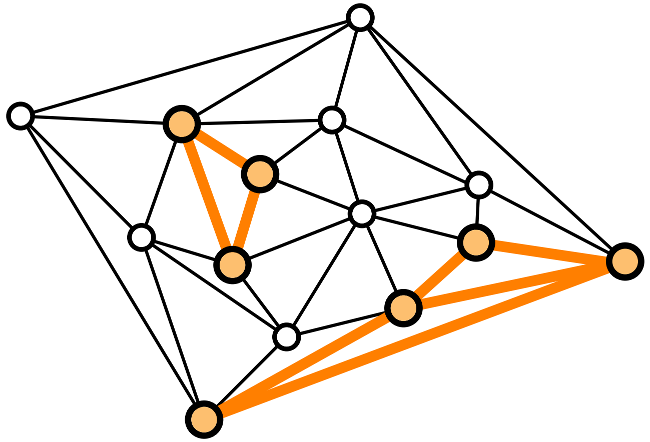

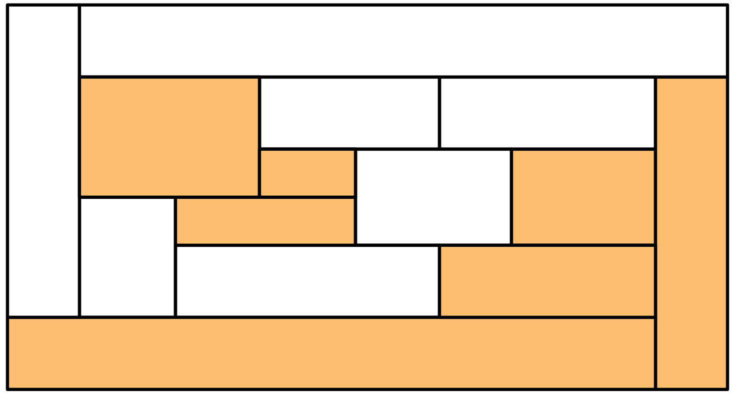

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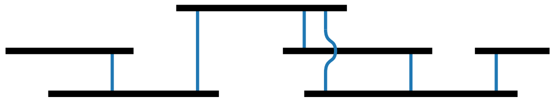

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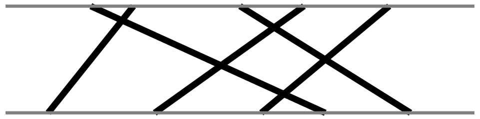

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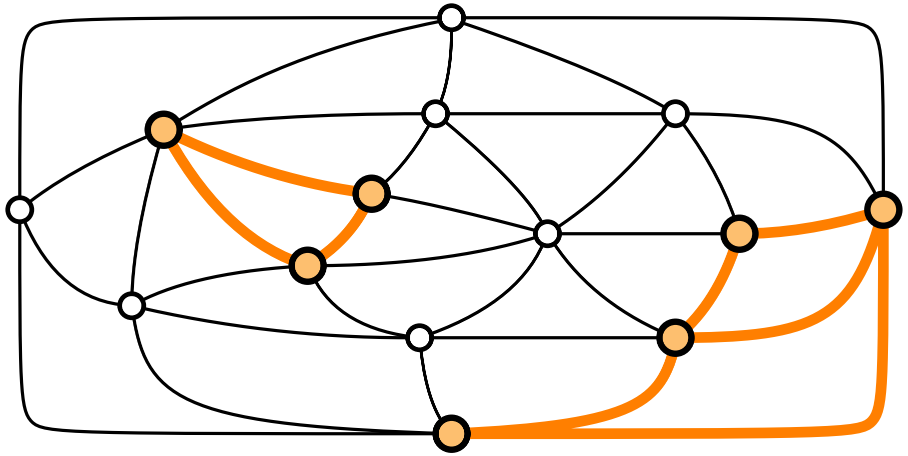

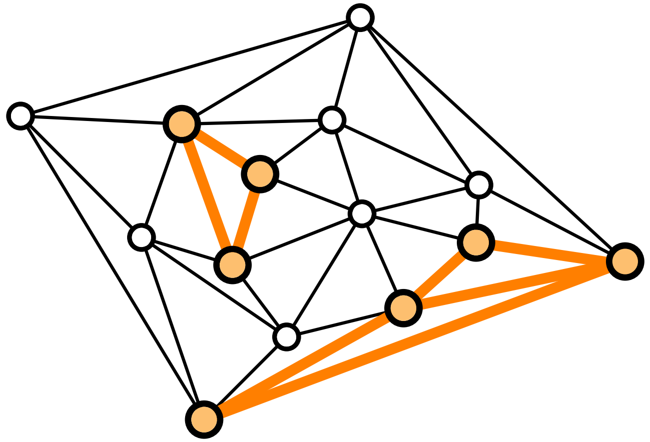

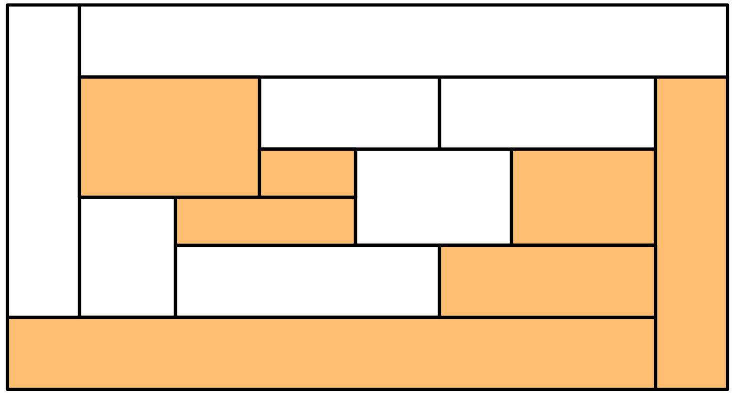

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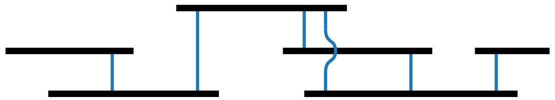

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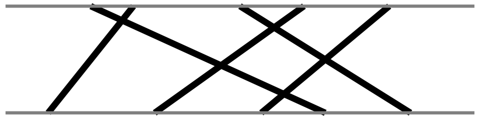

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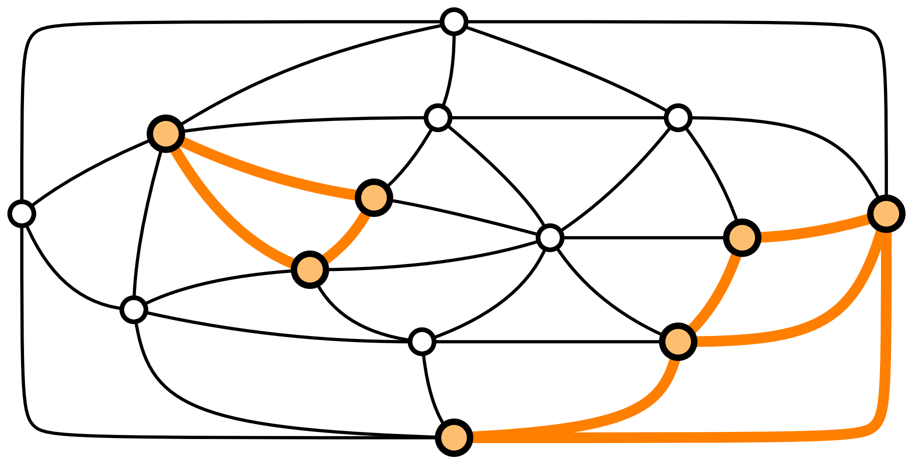

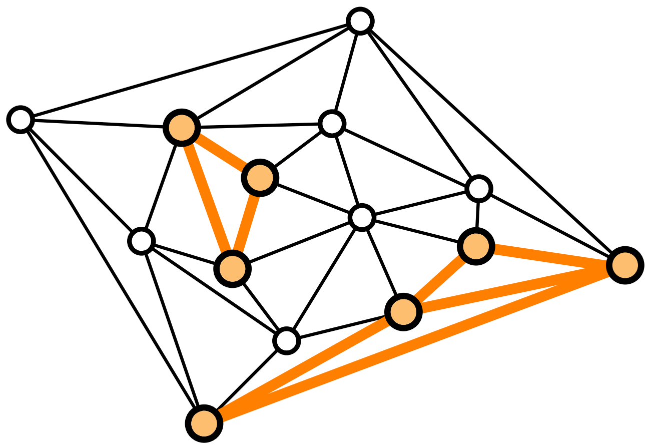

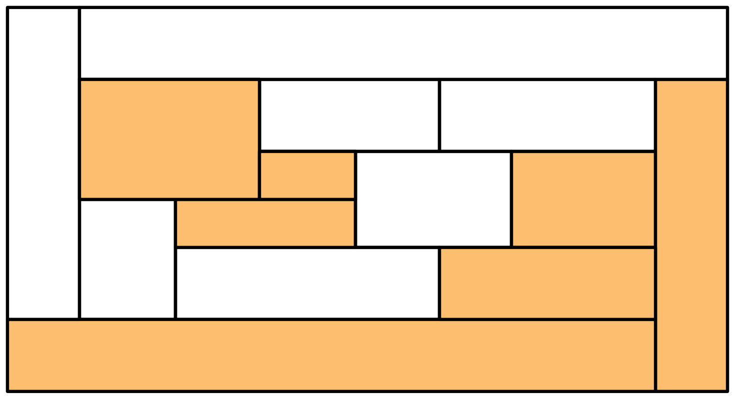

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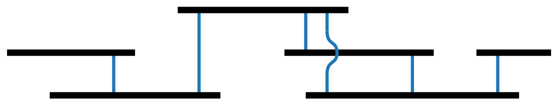

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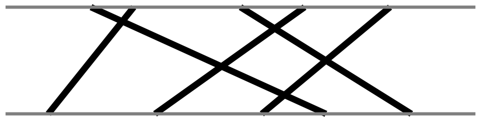

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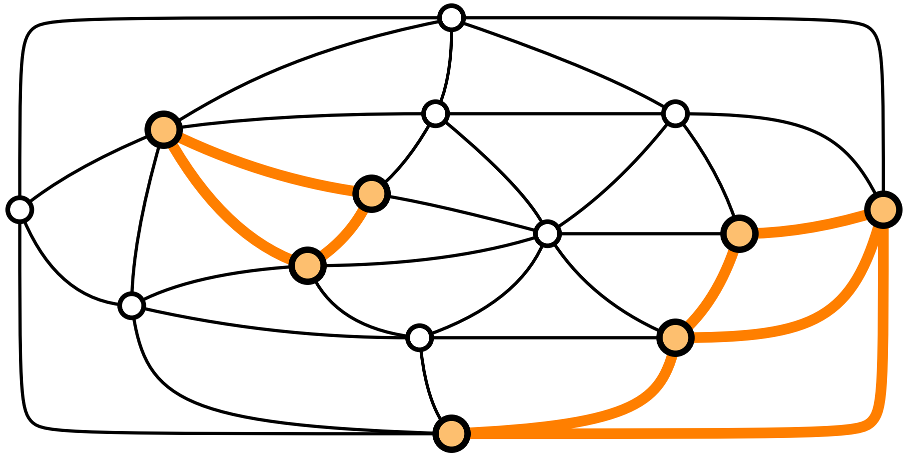

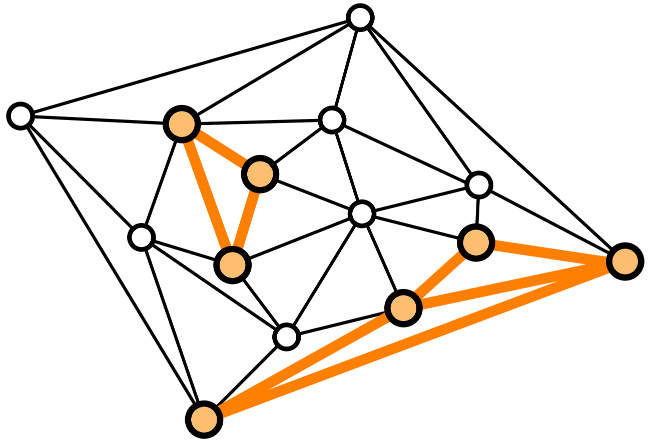

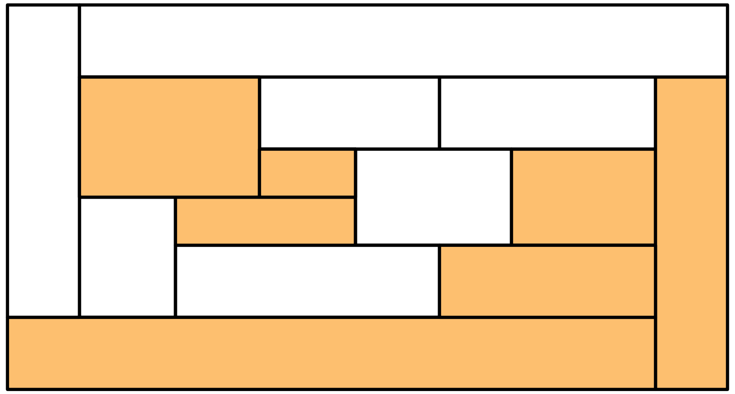

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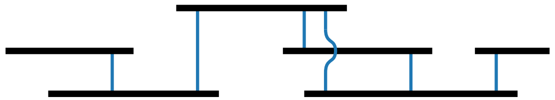

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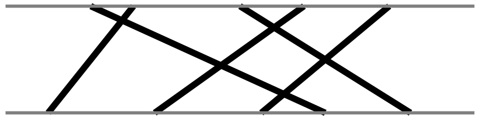

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NP-hard for:

- planar straight-line drawings

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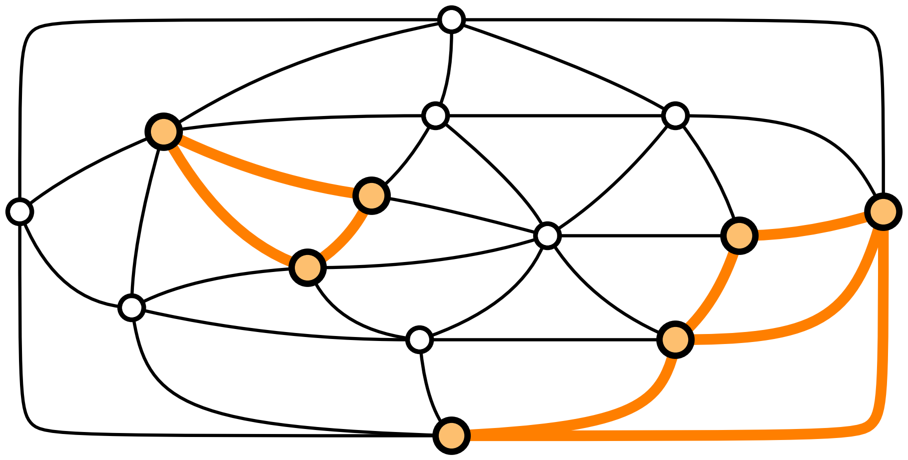

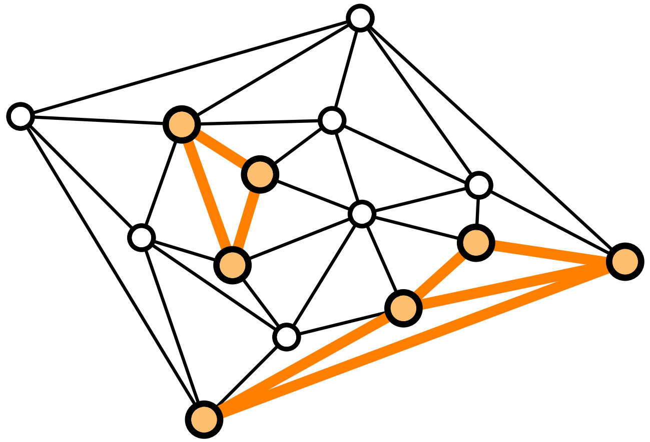

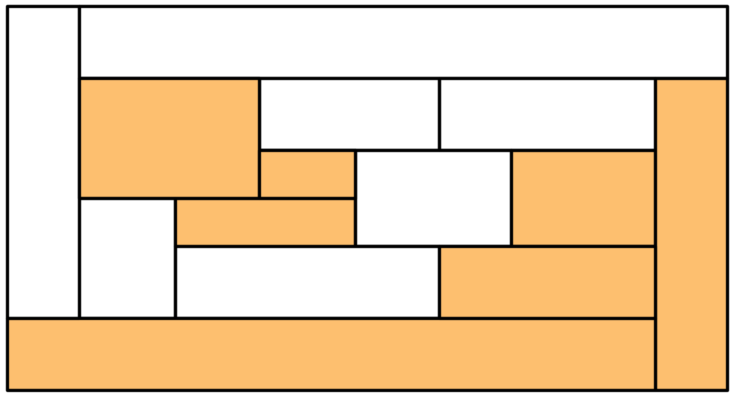

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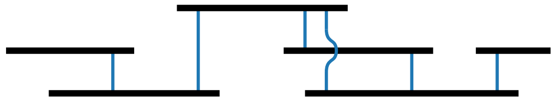

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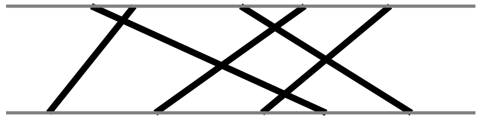

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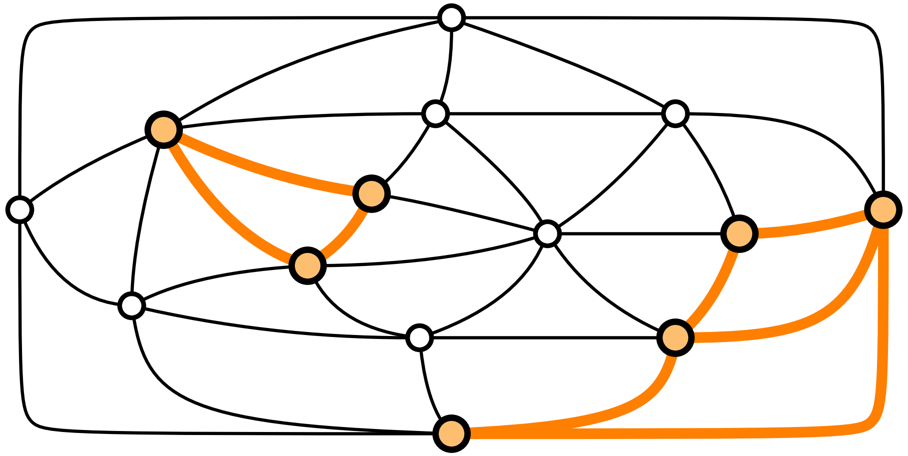

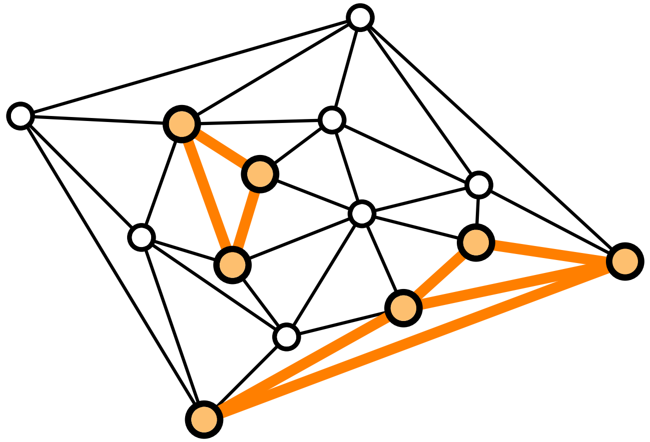

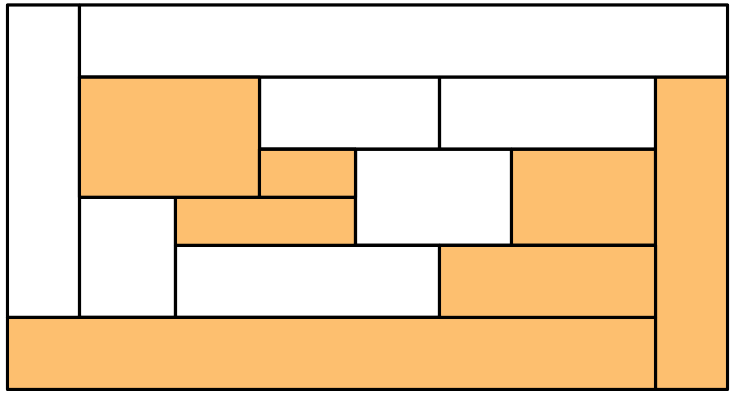

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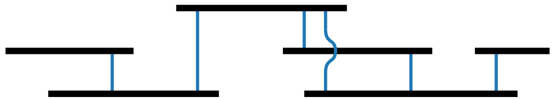

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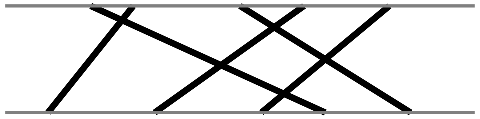

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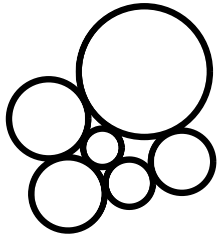

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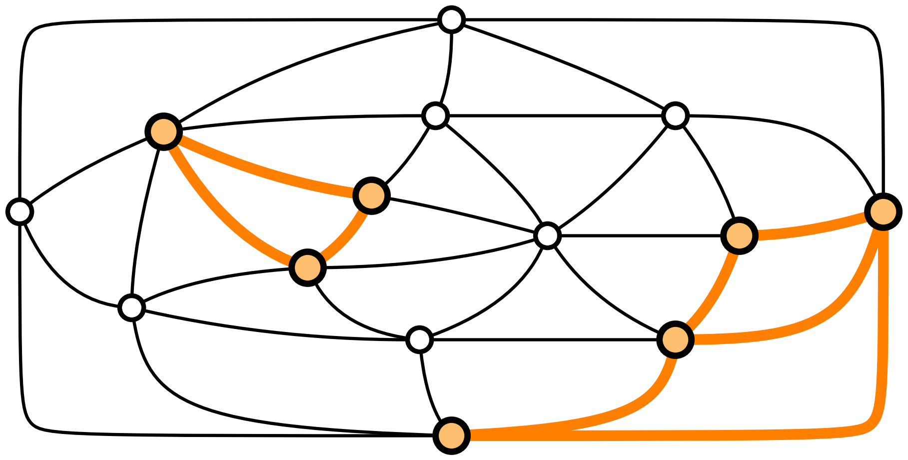

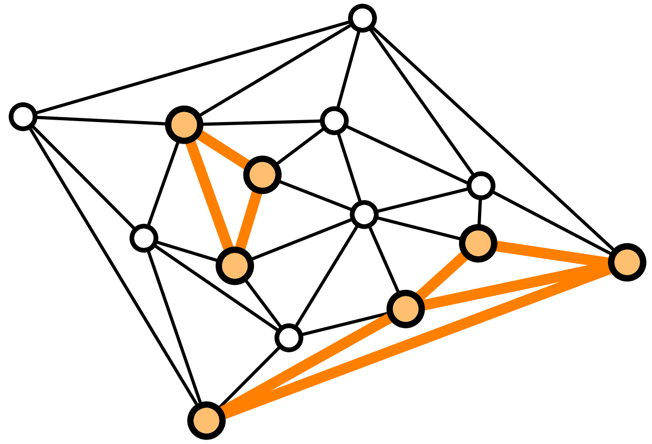

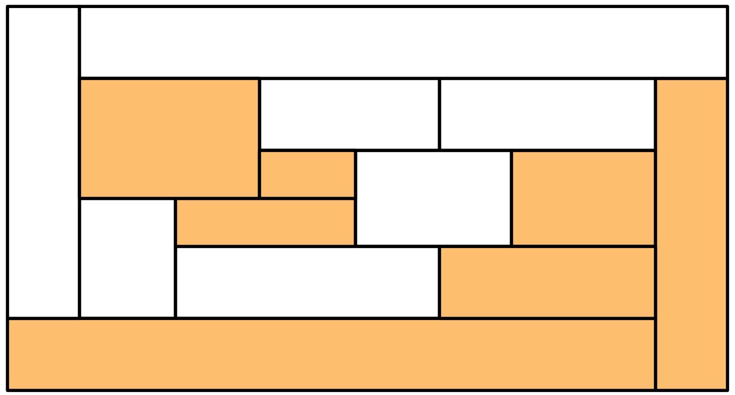

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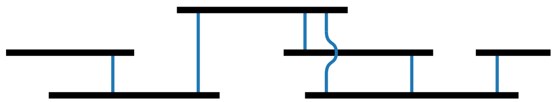

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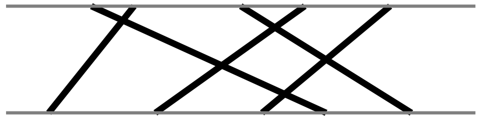

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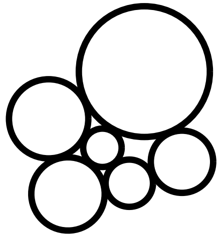

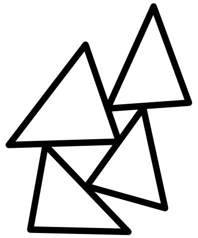

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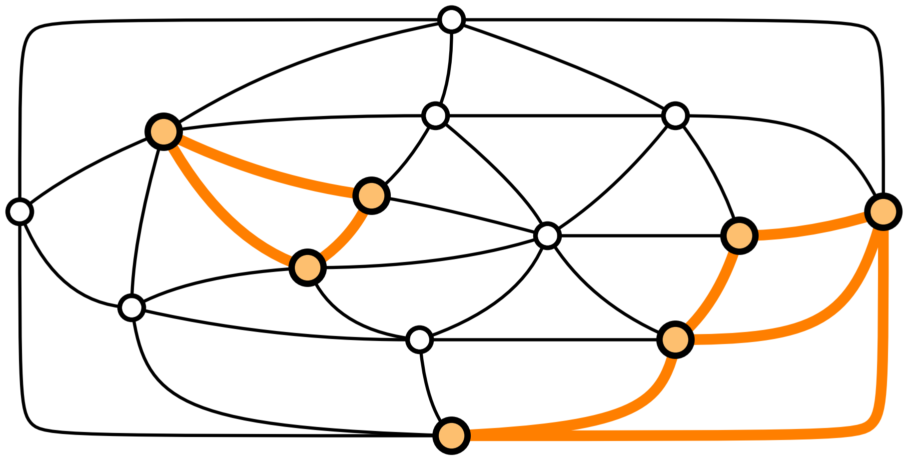
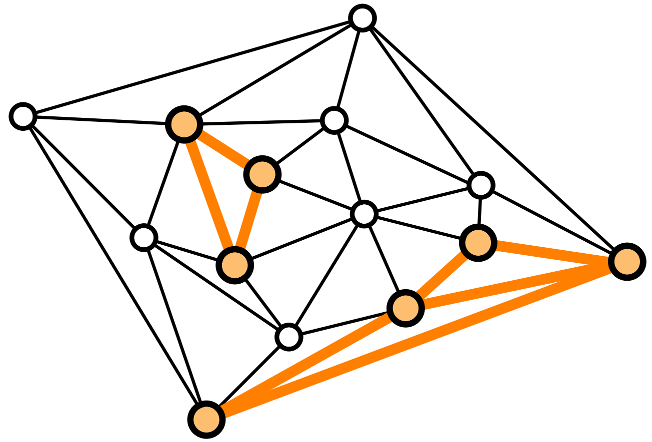
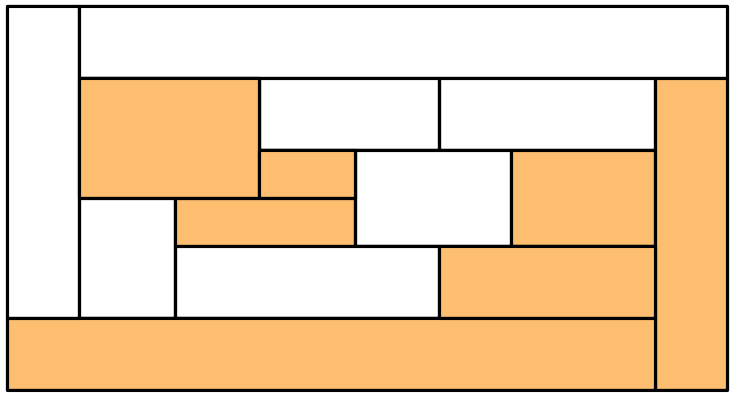
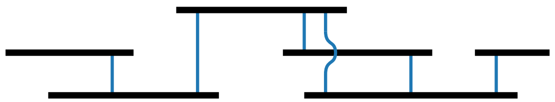




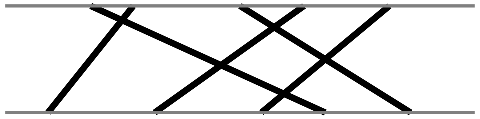


Polytime for:

- (unit) interval graphs



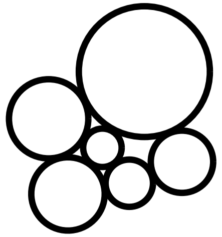
- permutation graphs

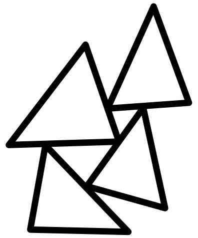


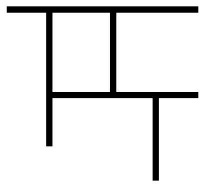
- circle graphs

NP-hard for:

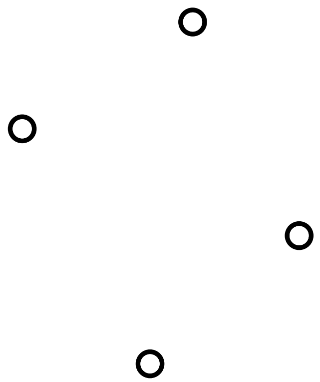
- planar straight-line drawings
- contacts of
  - disks
  - triangles
  - orthogonal segments







Bar Visibility Representation



Bar Visibility Representation

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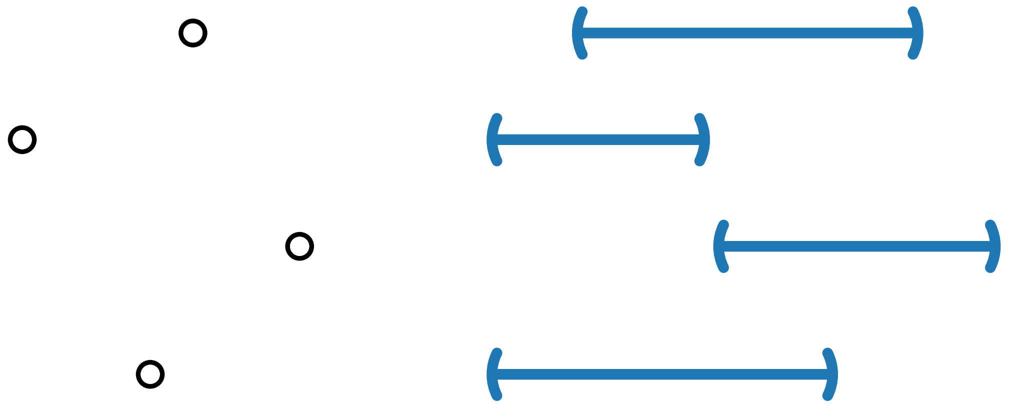

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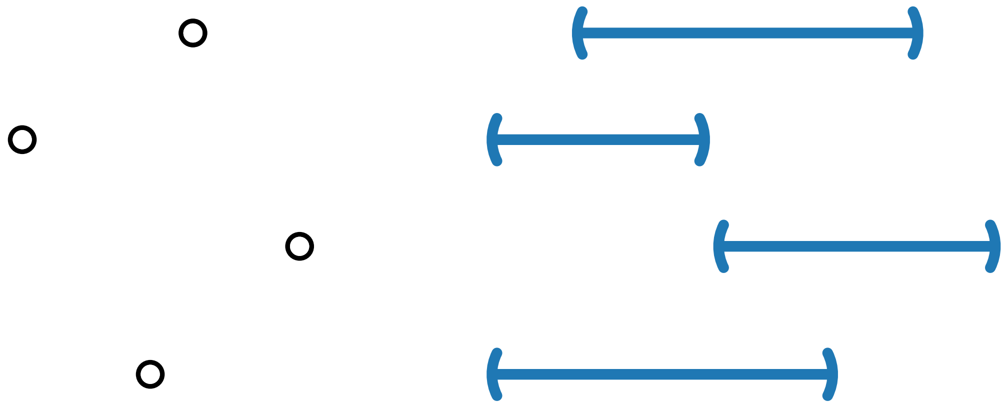

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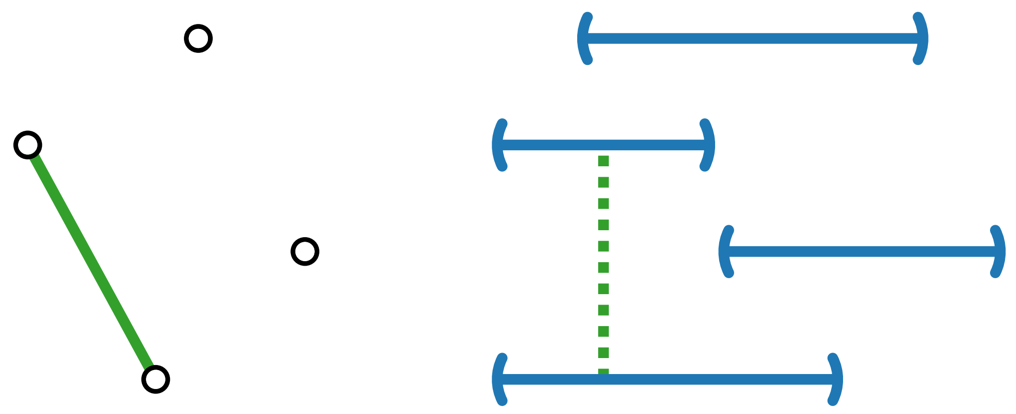

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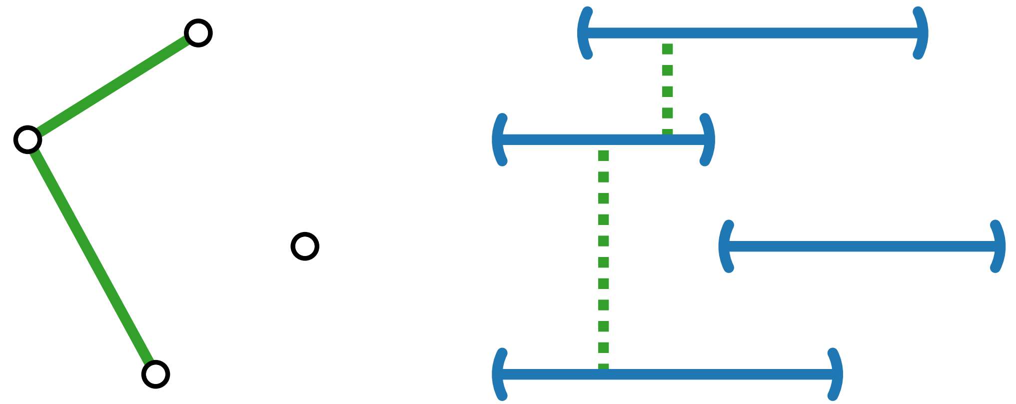

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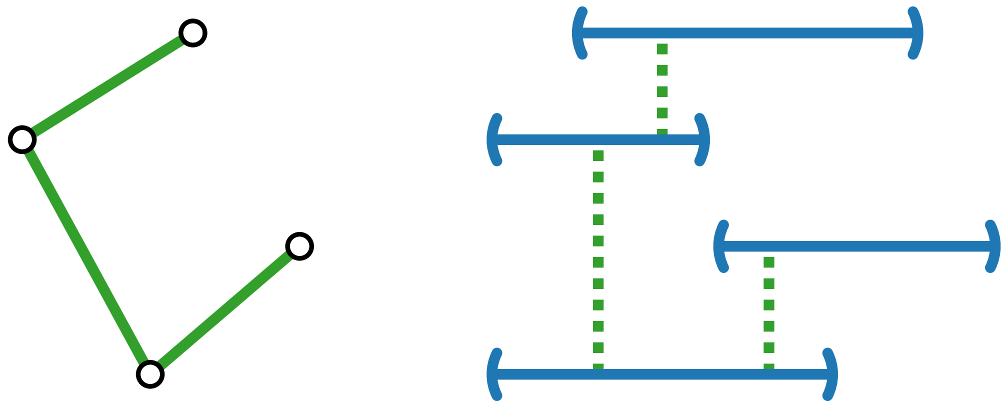

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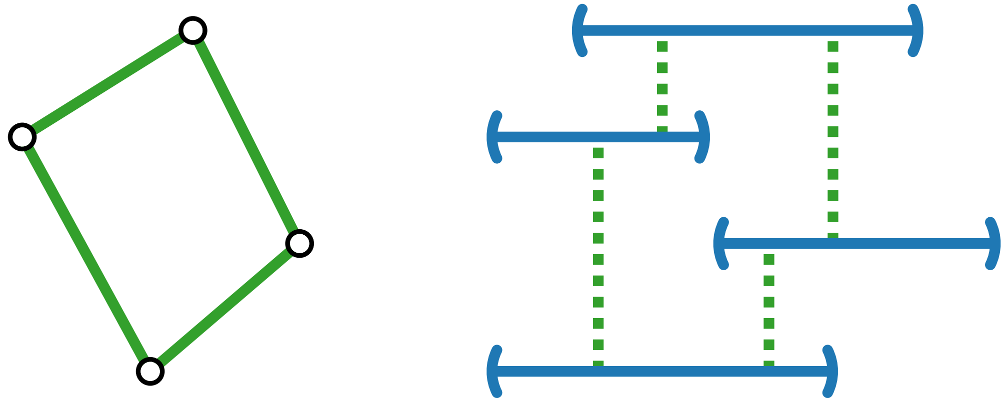

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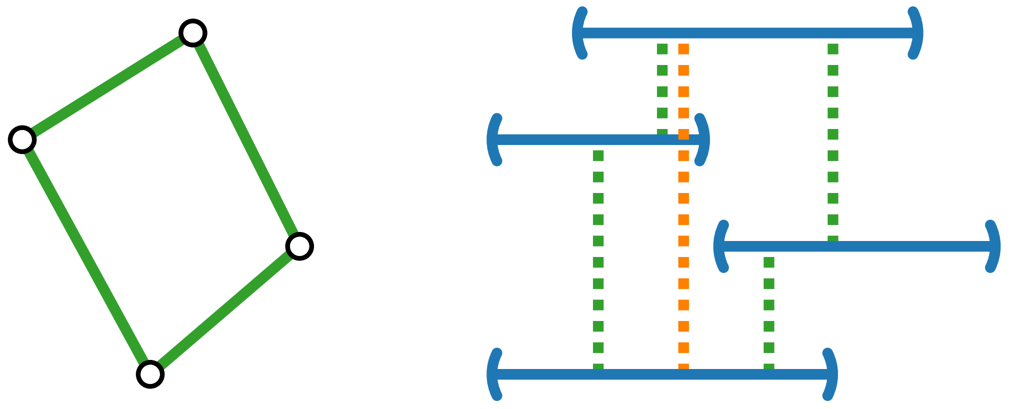

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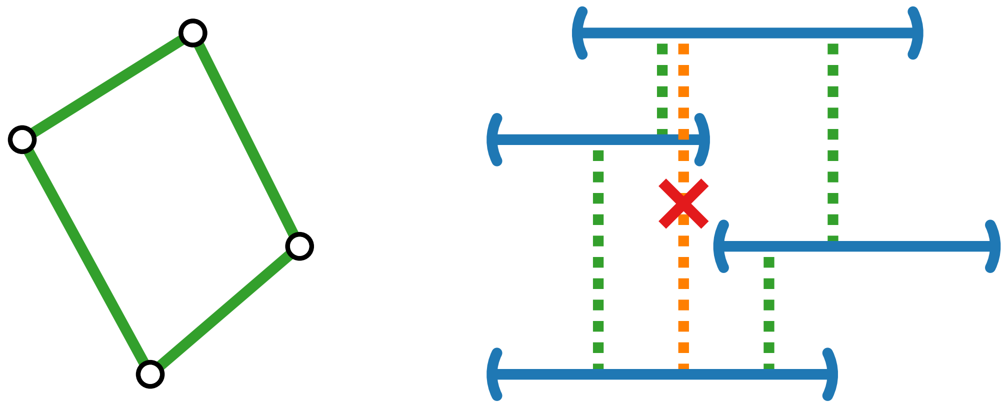

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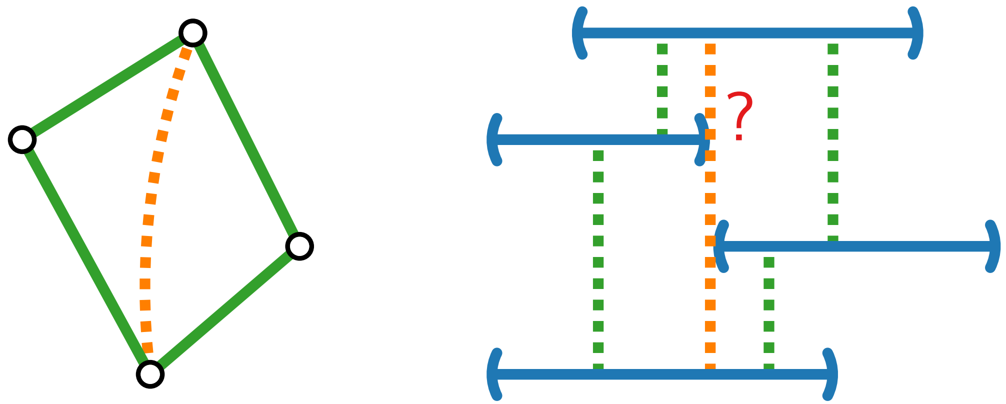

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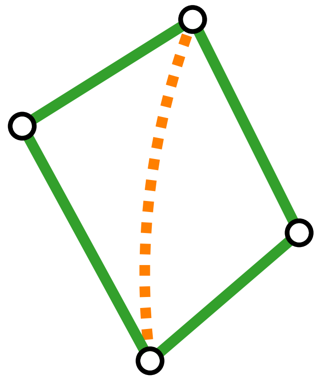

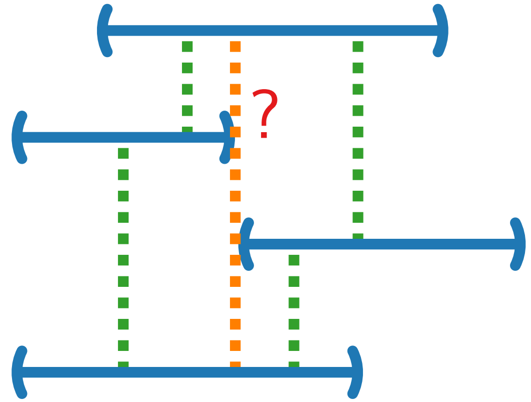

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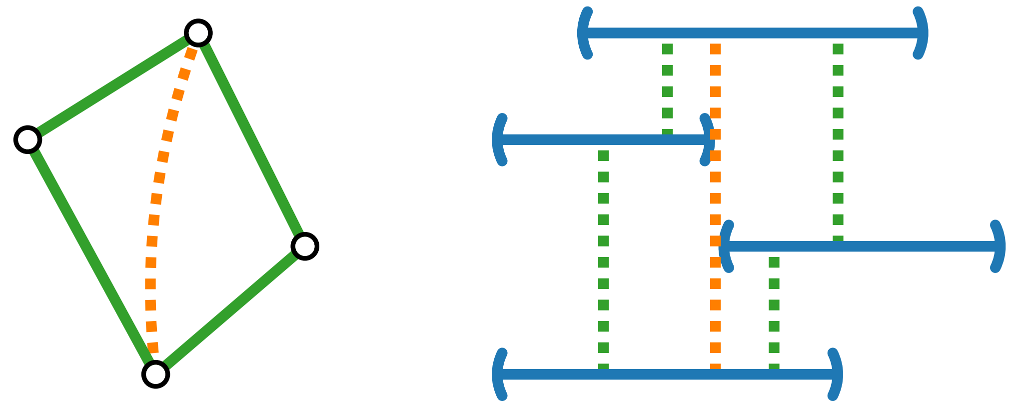

Models.

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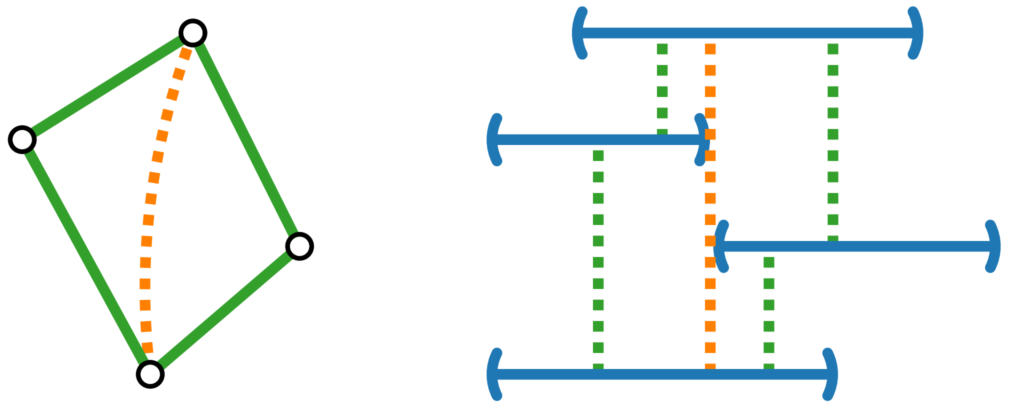

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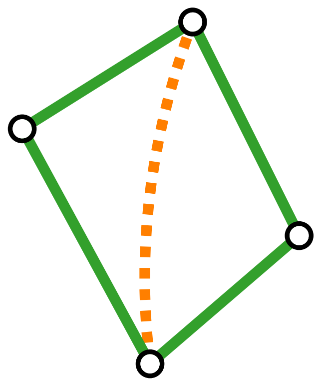

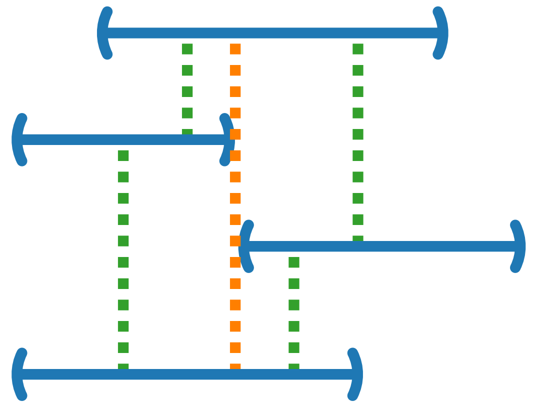

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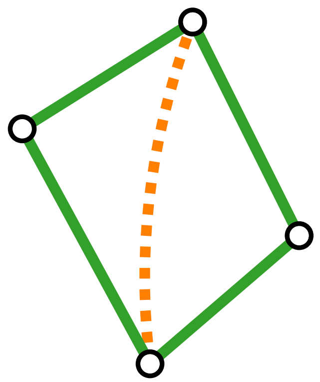

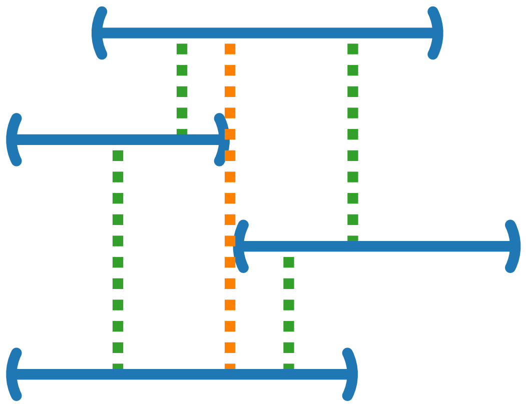

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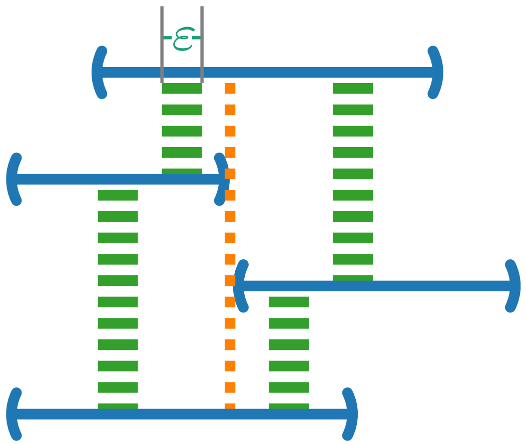

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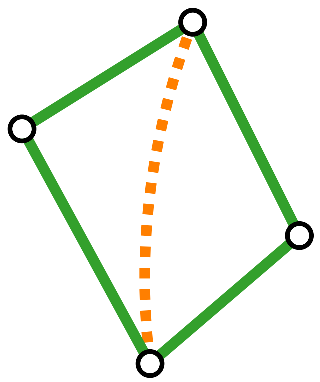

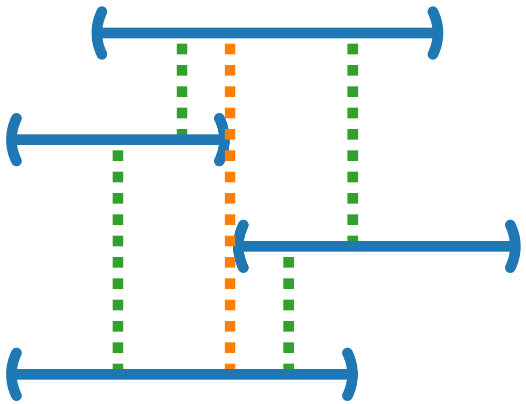

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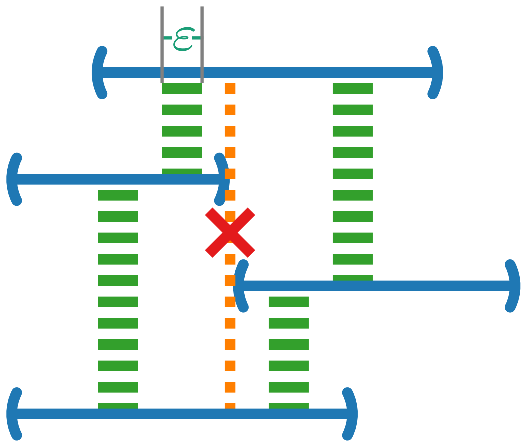

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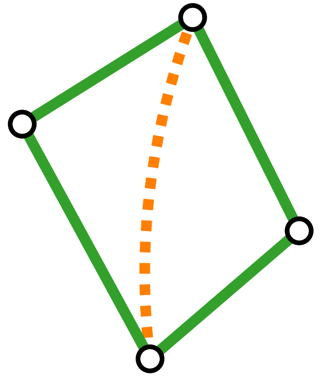

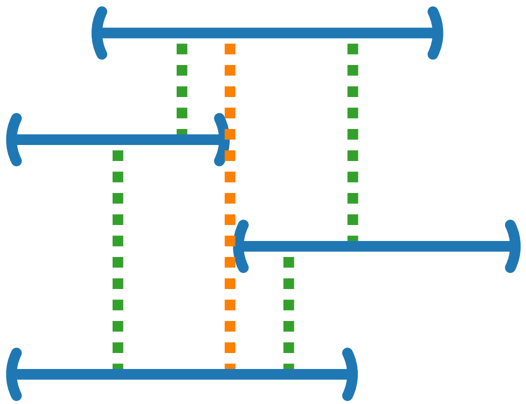

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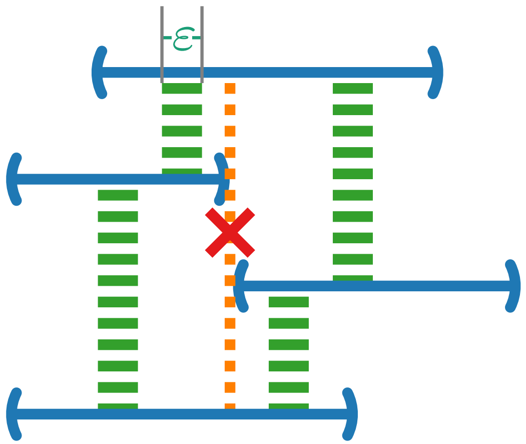
  Edge $uv \Rightarrow$ unobstructed vertical lines of sight exists, i.e., any subset of *visible* pairs



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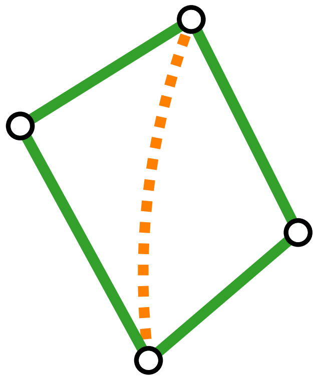

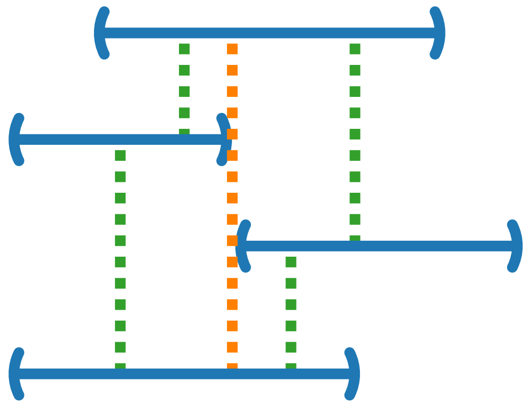

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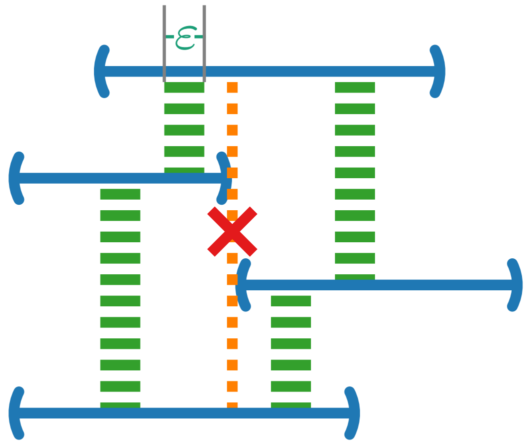
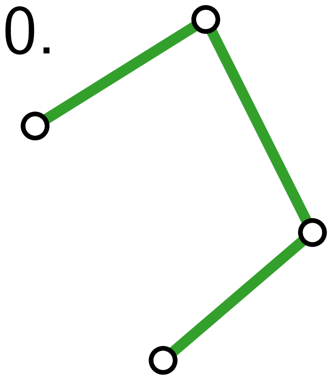
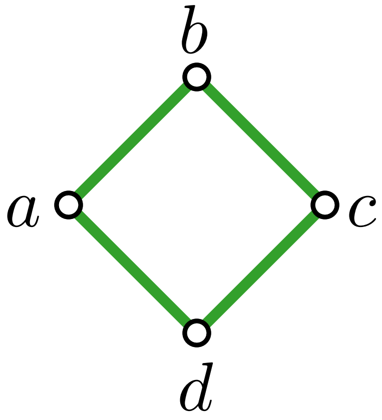
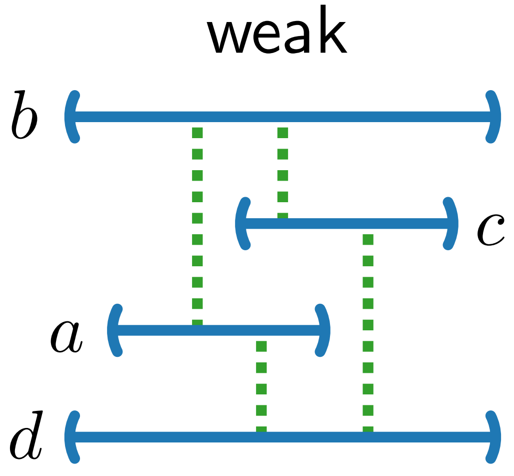




Problems





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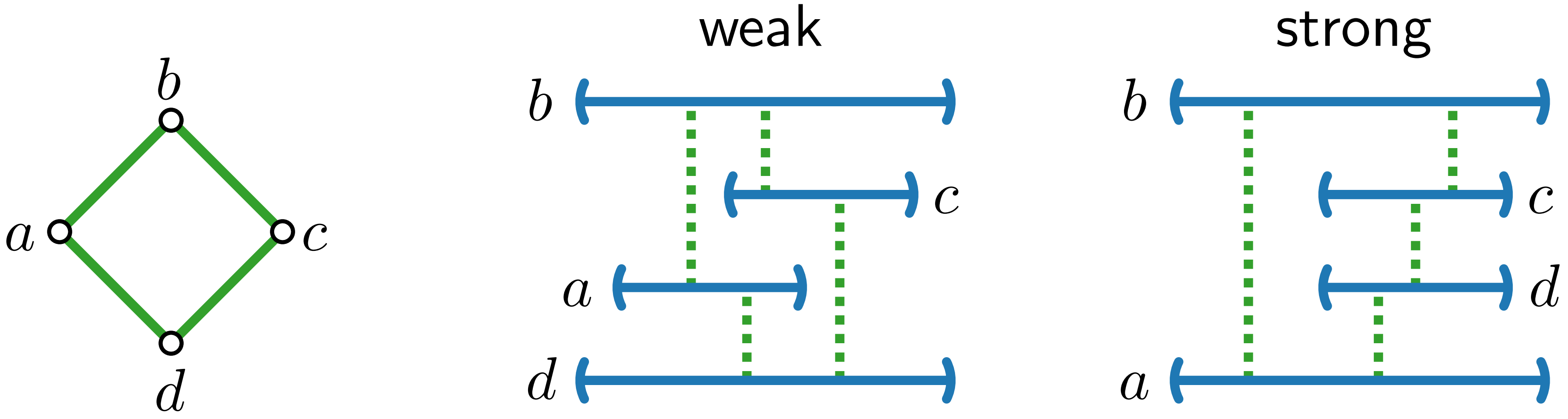

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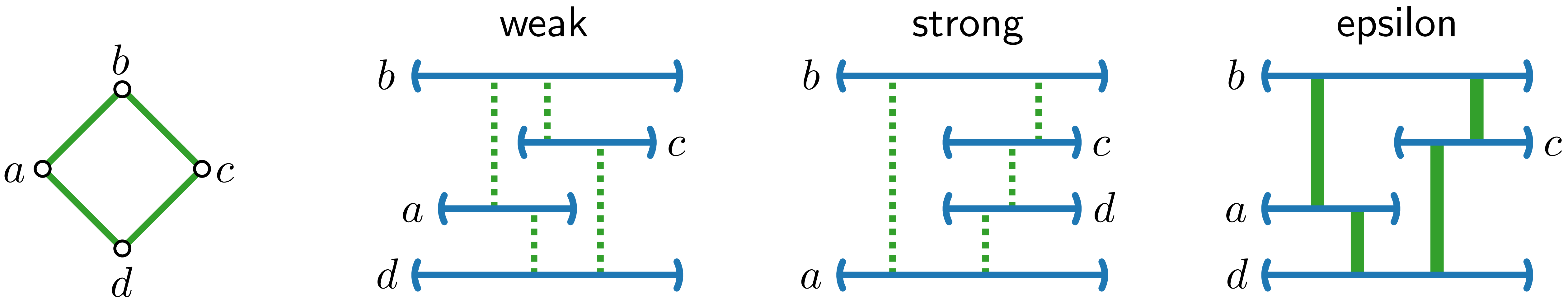

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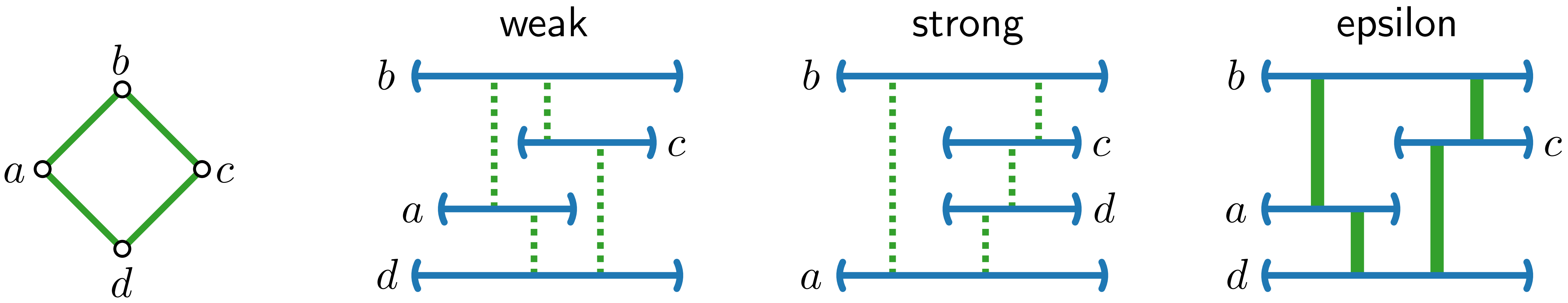
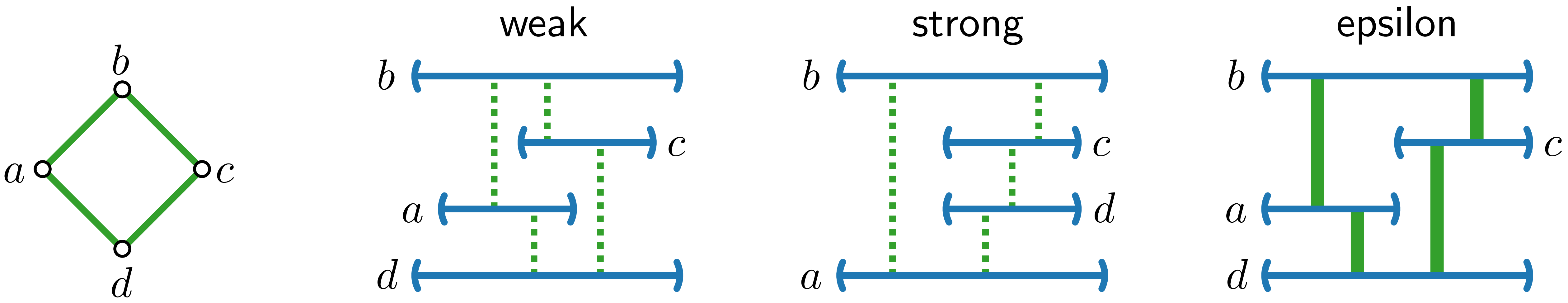


Recognition Problem.
Given a graph G, **decide** whether there exists a weak/strong/ε-bar visibility representation ψ of G.

Problems



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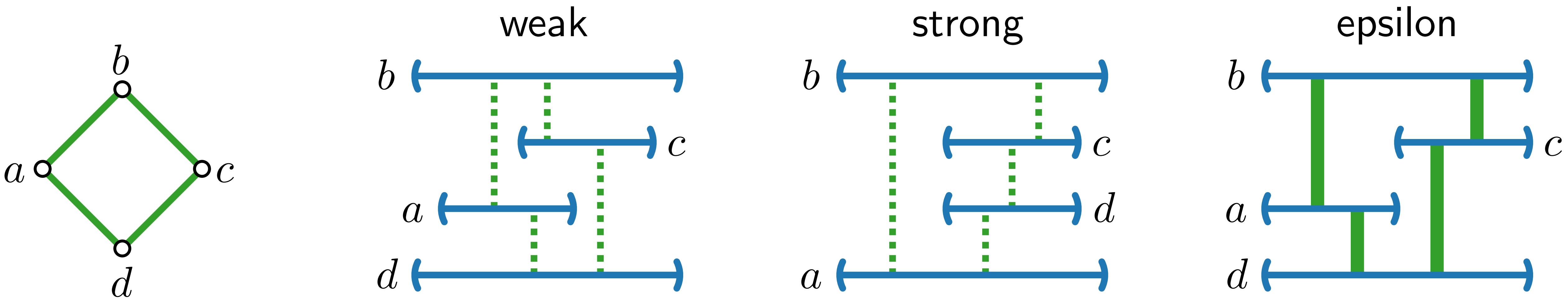

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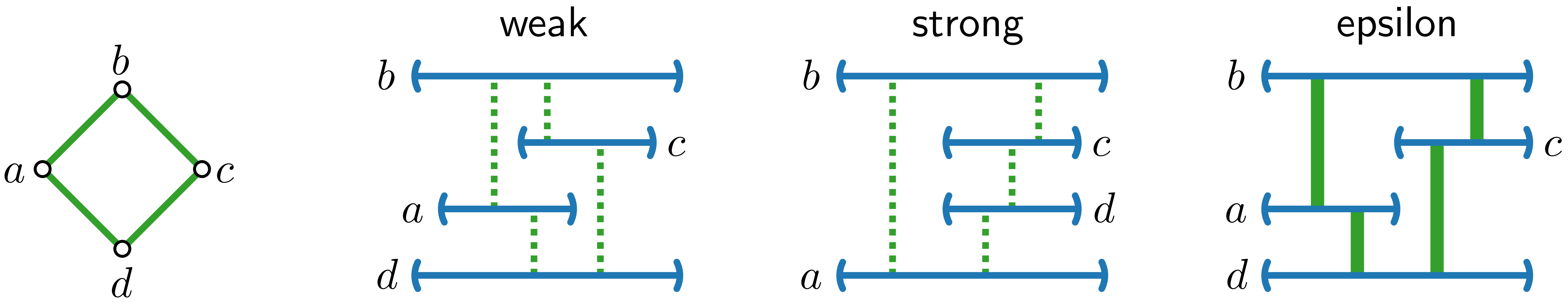
Partial Representation Extension Problem.
Given a graph G and a **set of bars ψ' of $V' \subseteq V(G)$**, **decide** whether there exists a weak/strong/ε-bar visibility representation ψ of G **where $\psi|_{V'} = \psi'$** (and **construct** ψ if a representation exists).

Background



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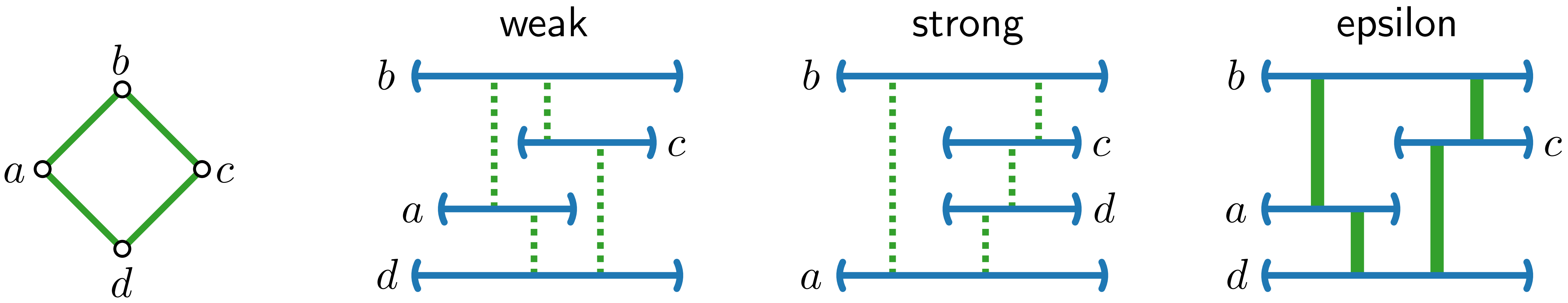

Weak Bar Visibility.

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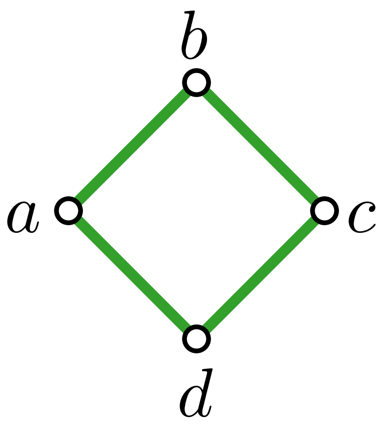

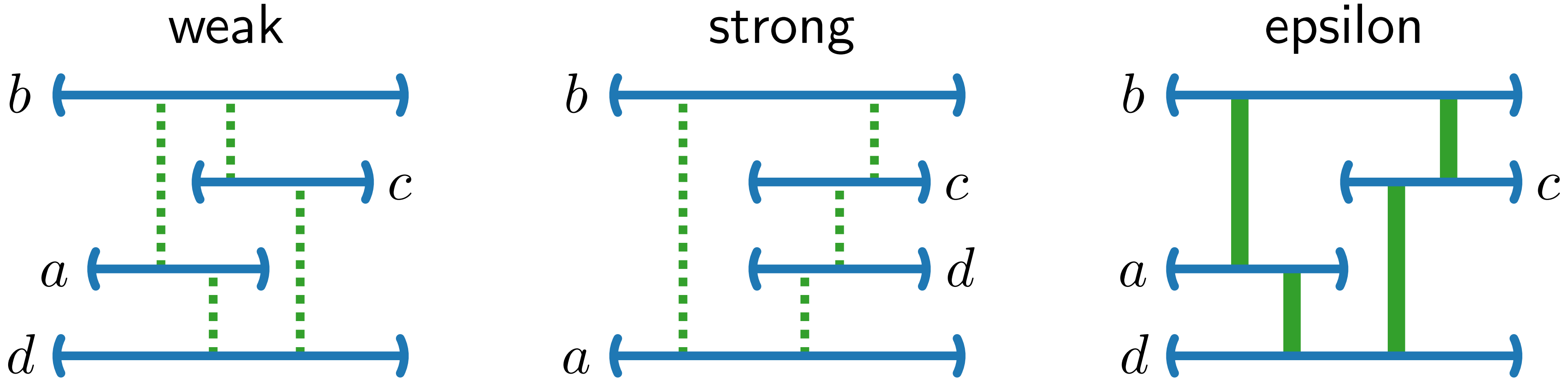

Weak Bar Visibility.

- Exactly all planar graphs [Tamassia & Tollis '86; Wismath '85]

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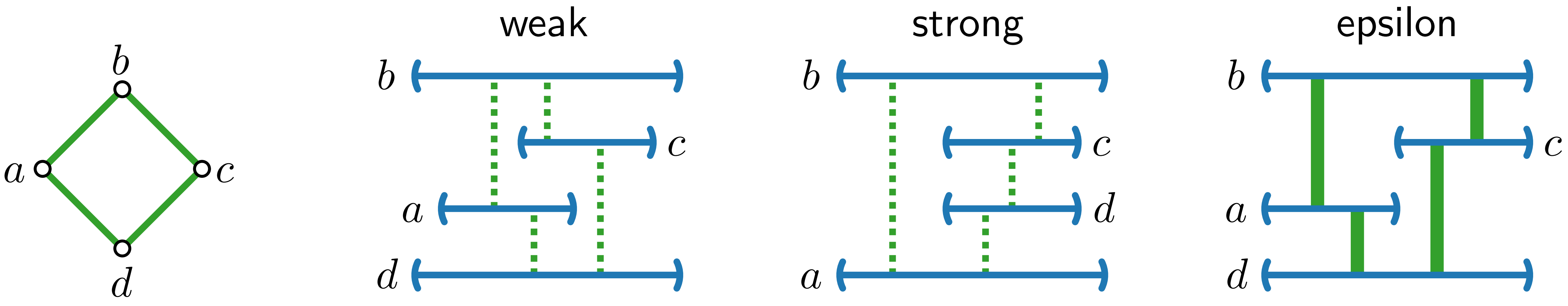

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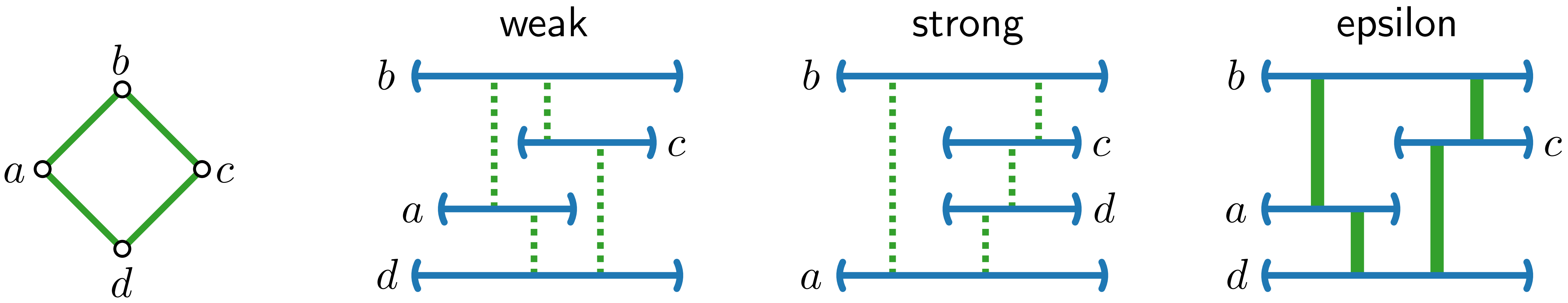

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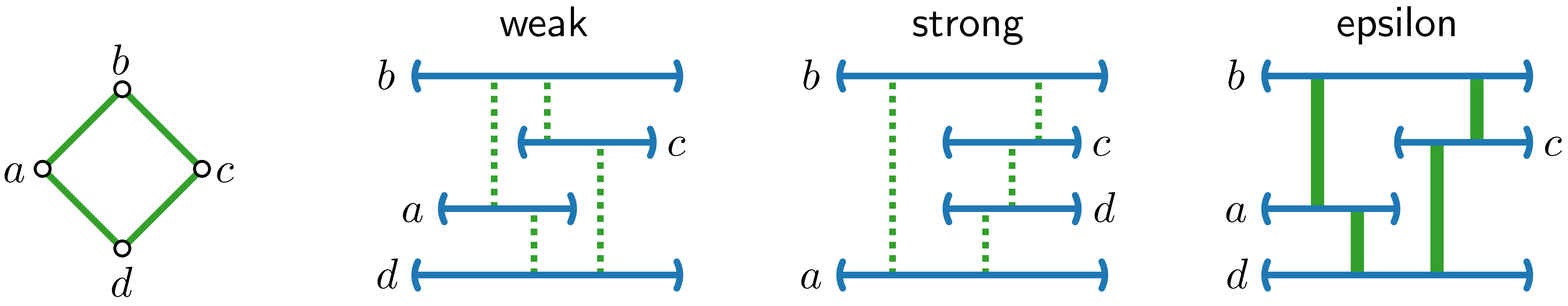

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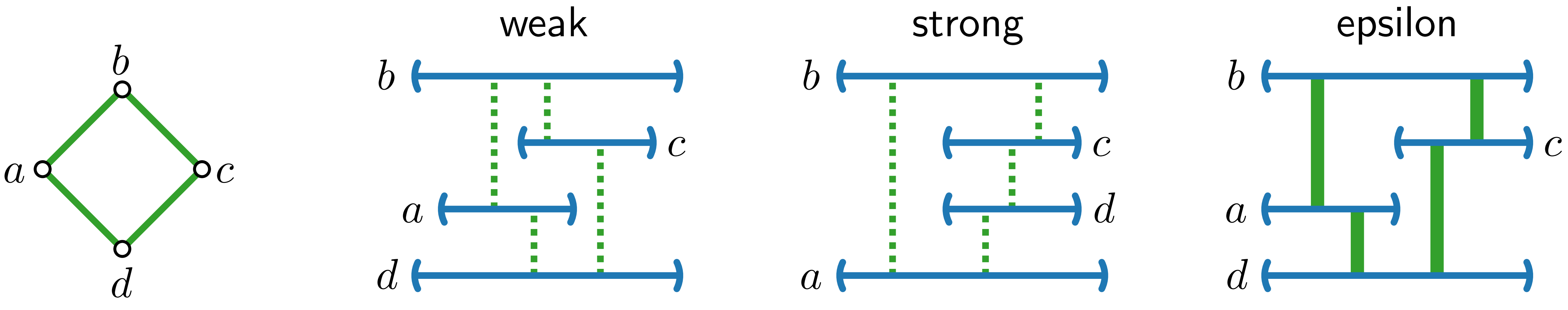

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Strong Bar Visibility.

- NP-complete to recognize [Andreae '92]

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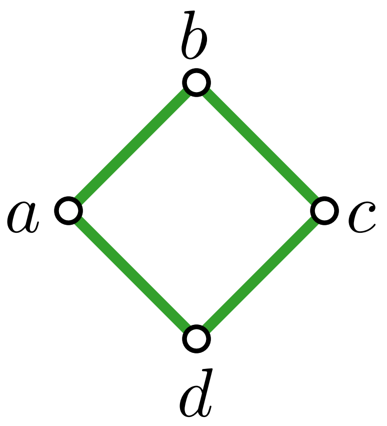
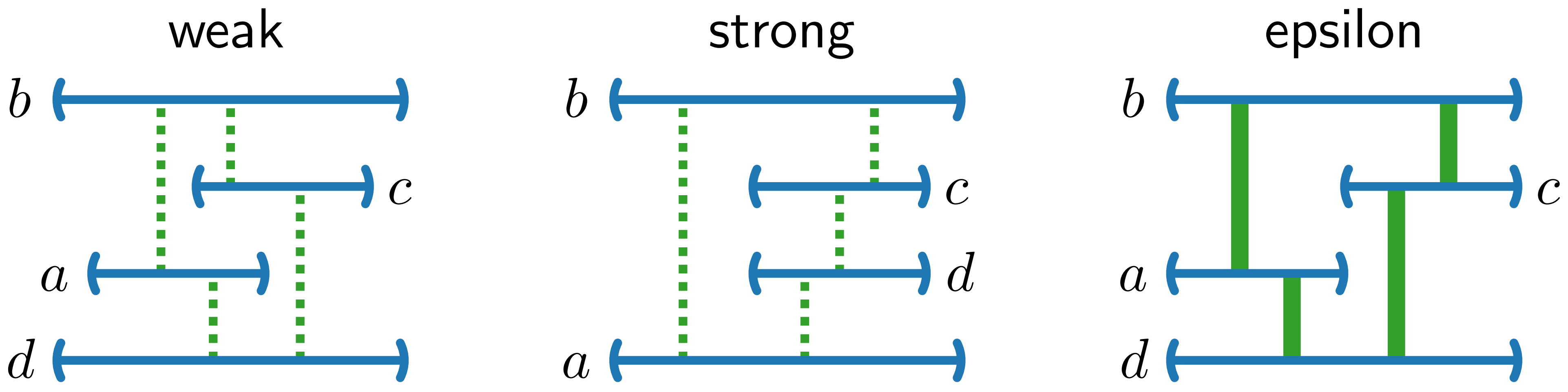
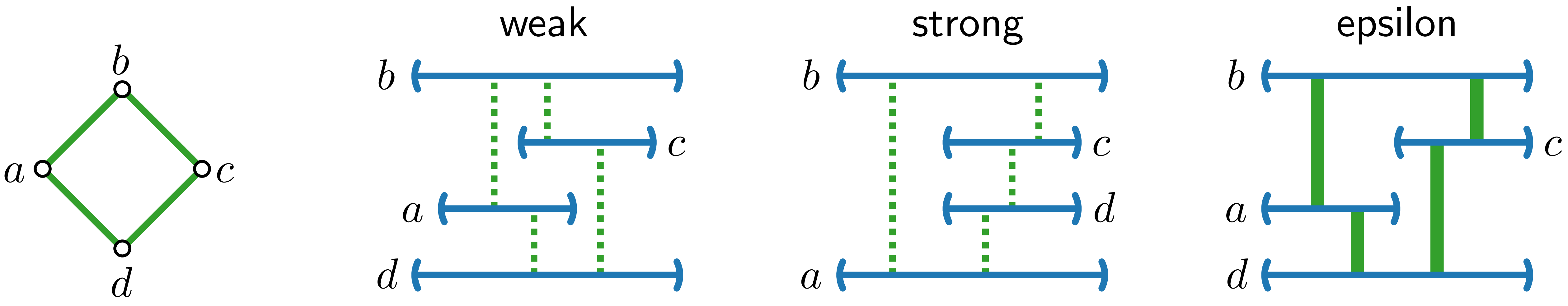




ε-Bar Visibility.

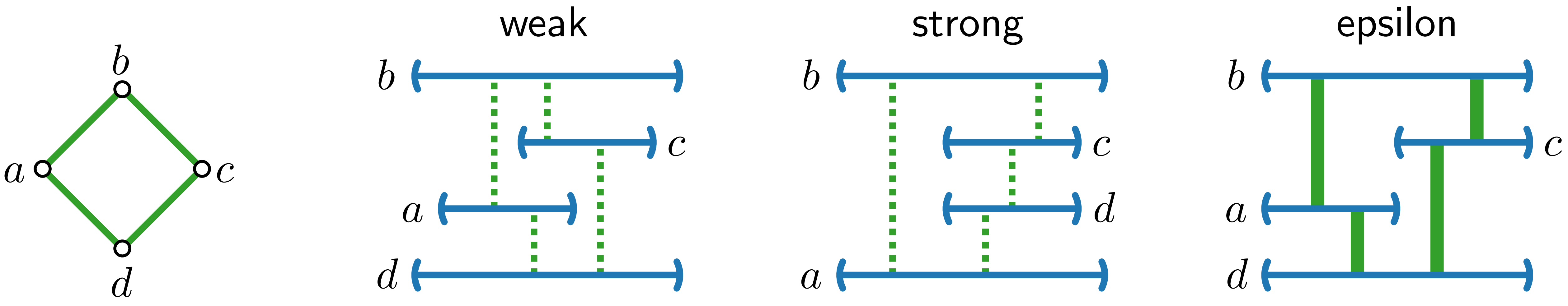
Background



ε-Bar Visibility.

- Exactly all planar graphs that can be embedded with all **cut vertices** on the outerface [T&T '86, Wismath '85]

Background



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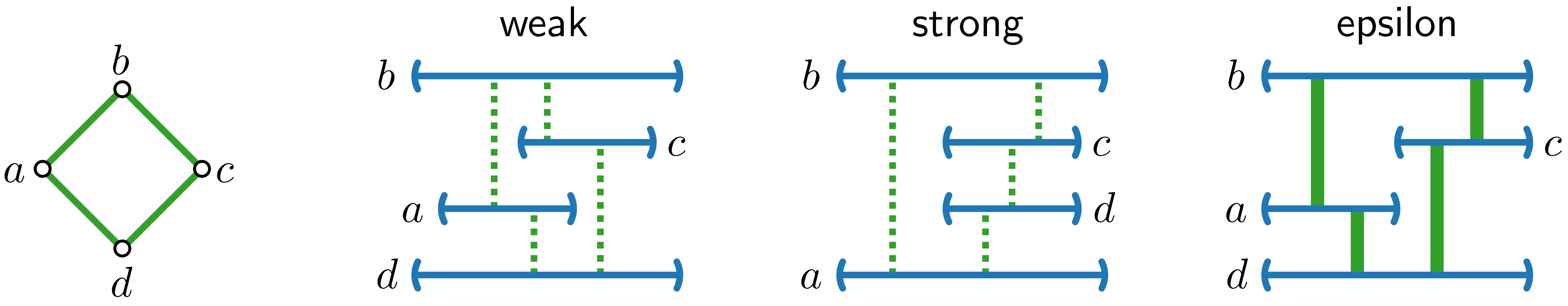

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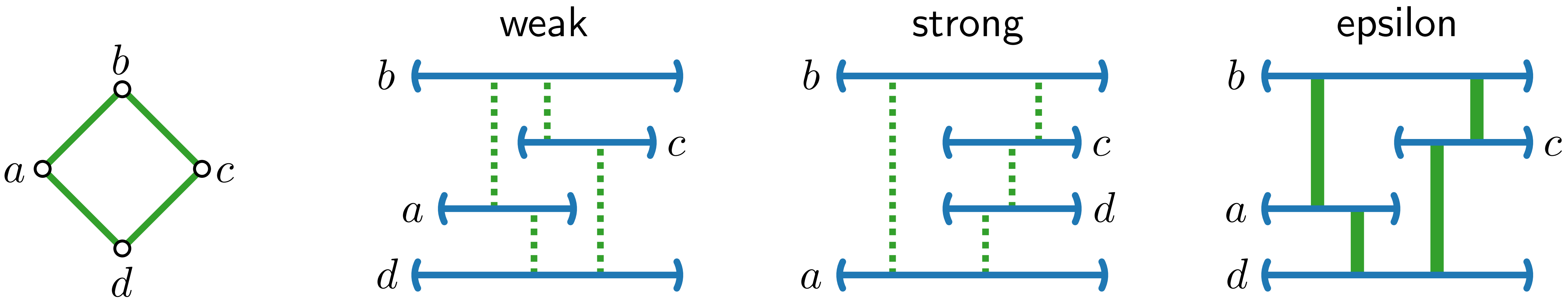
- Linear-time recognition and construction [T&T '86]
- Representation extension?

Background



ε-Bar Visibility.

- Exactly all planar graphs that can be embedded with all **cut vertices** on the outerface [T&T '86, Wismath '85]
- Linear-time recognition and construction [T&T '86]
- Representation extension? This Lecture!

Bar Visibility Representation of Digraphs

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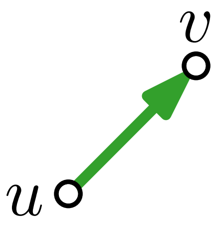

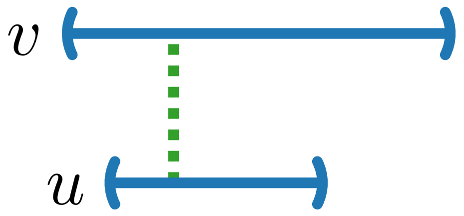

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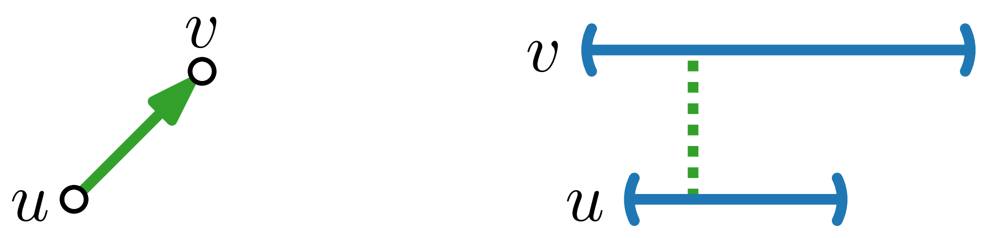

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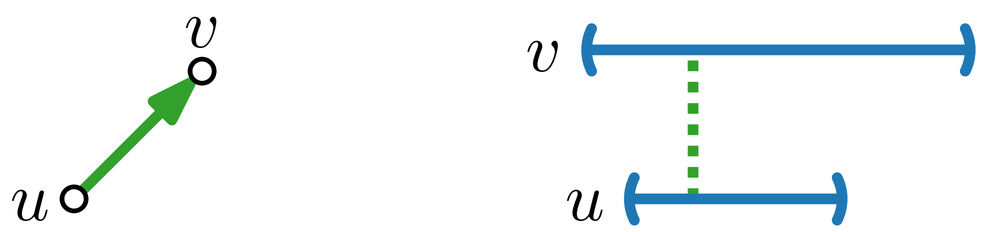

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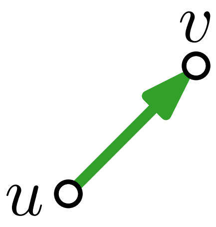

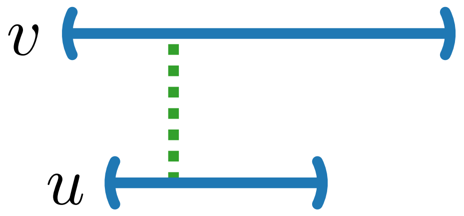

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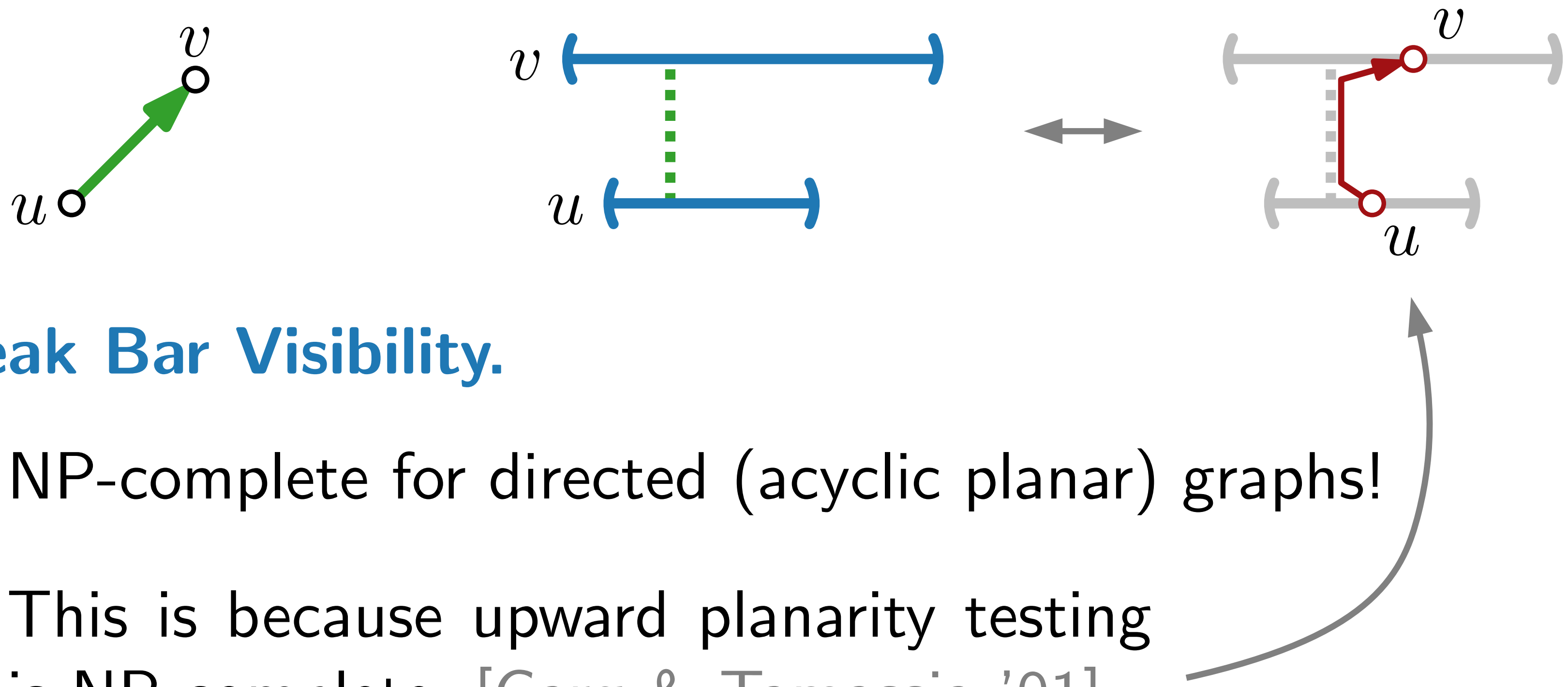

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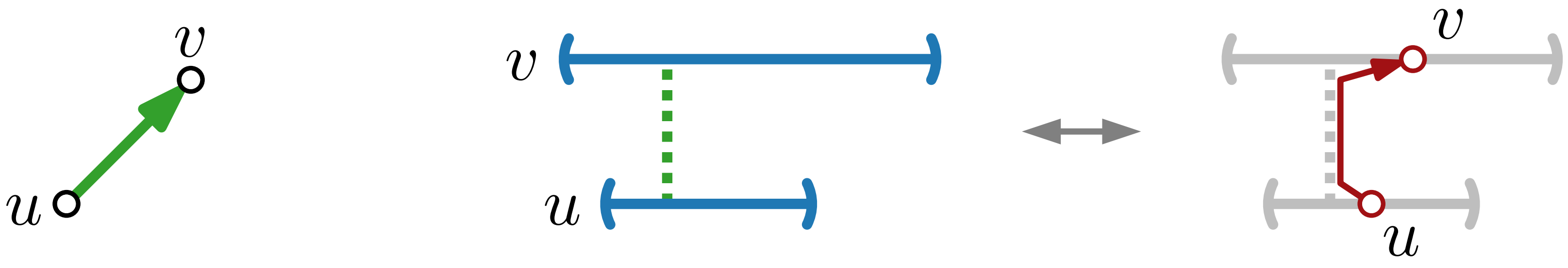

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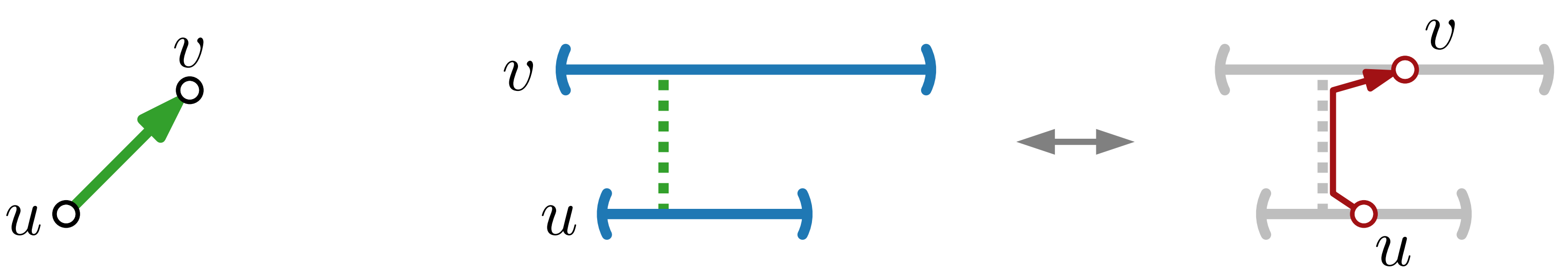

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Next, we consider ε-bar visibility representations of specific directed graphs ($\rightarrow$ st-graphs)

ε-Bar Visibility and st-Graphs

Recall that an **st-graph** is a planar acylic digraph G with exactly one source s and one sink t where s and t occur on the outer face of an embedding of G.

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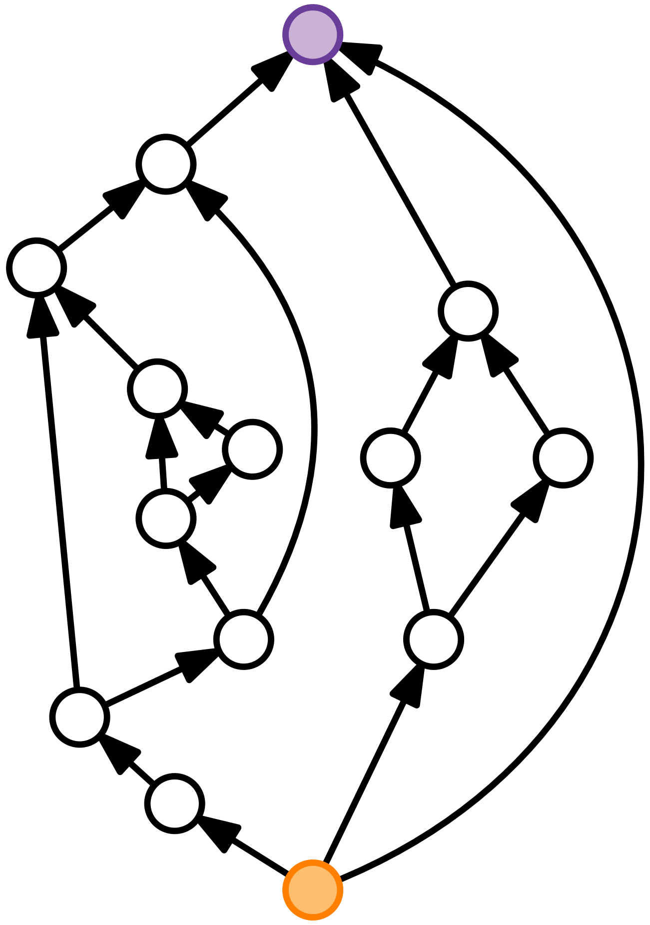

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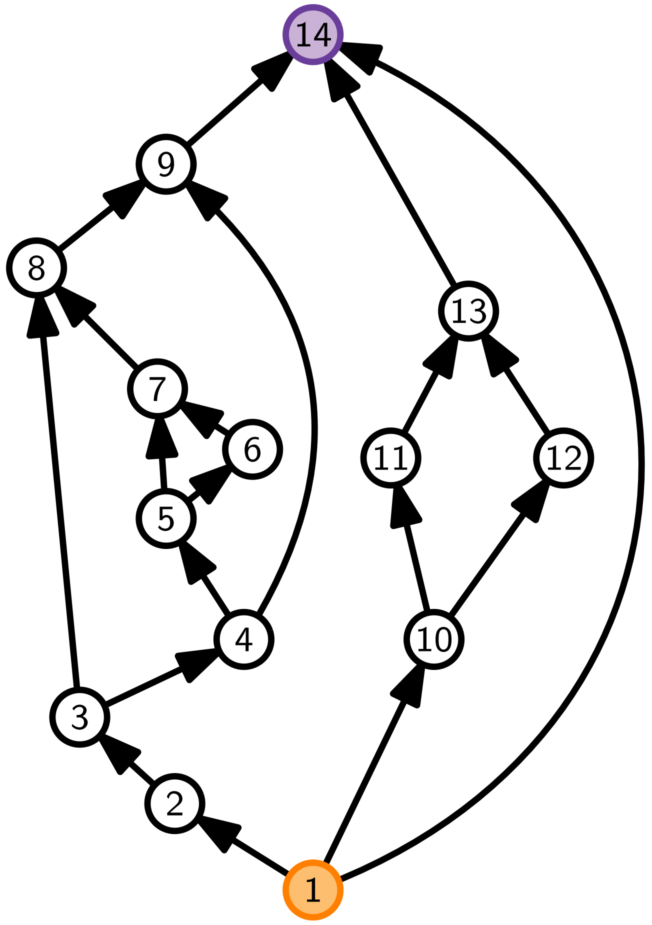

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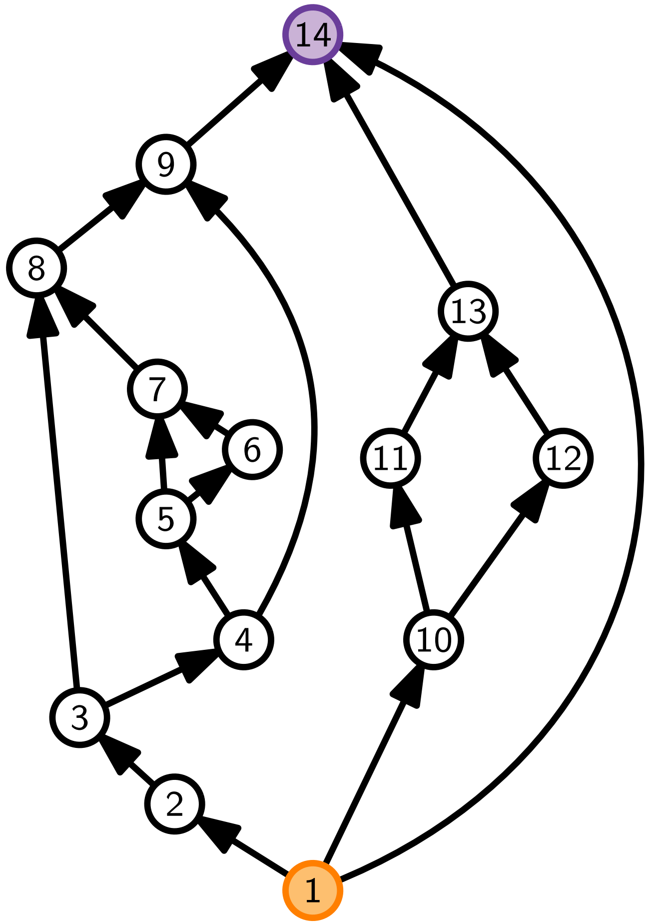

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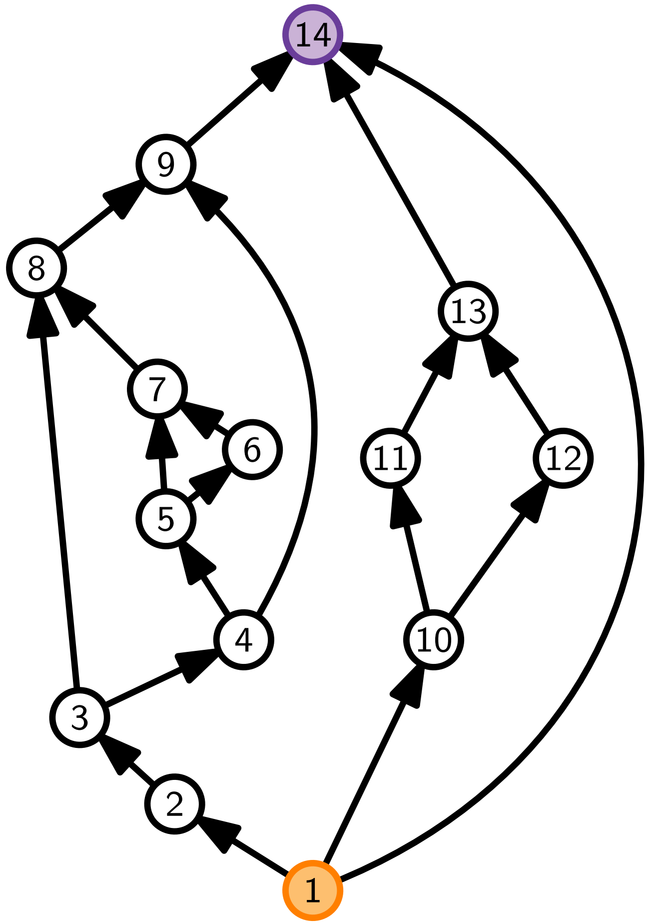

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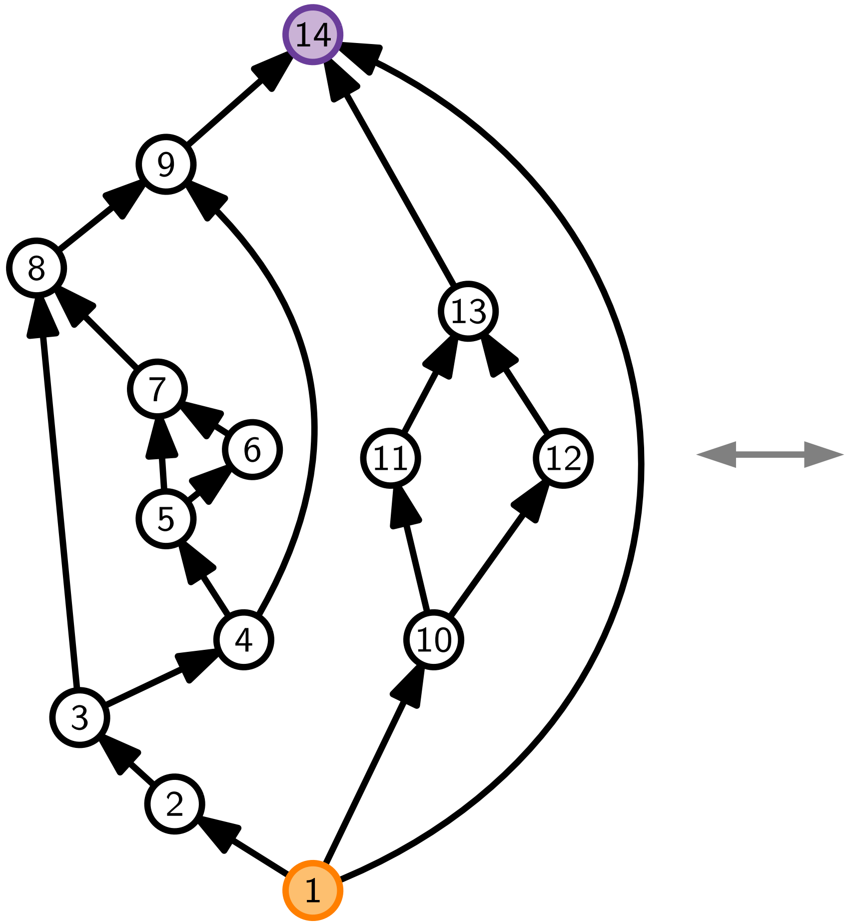

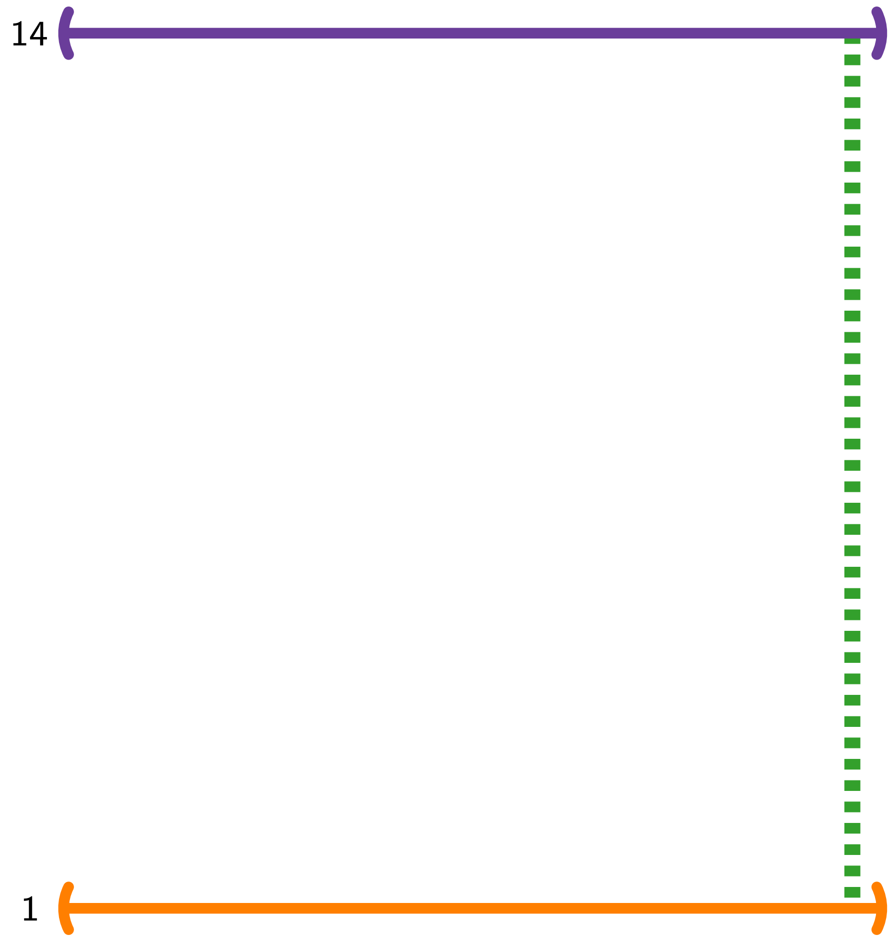

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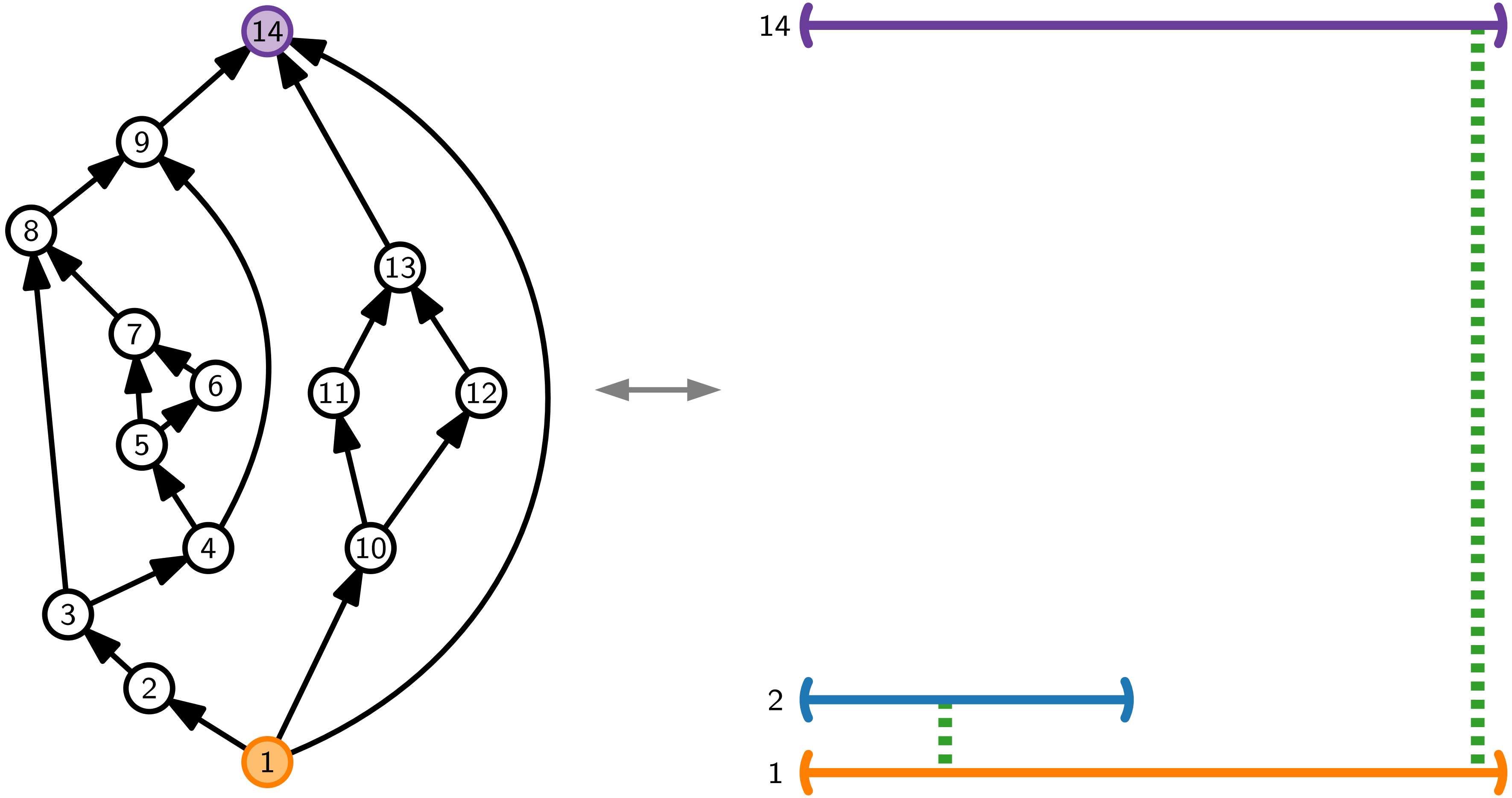

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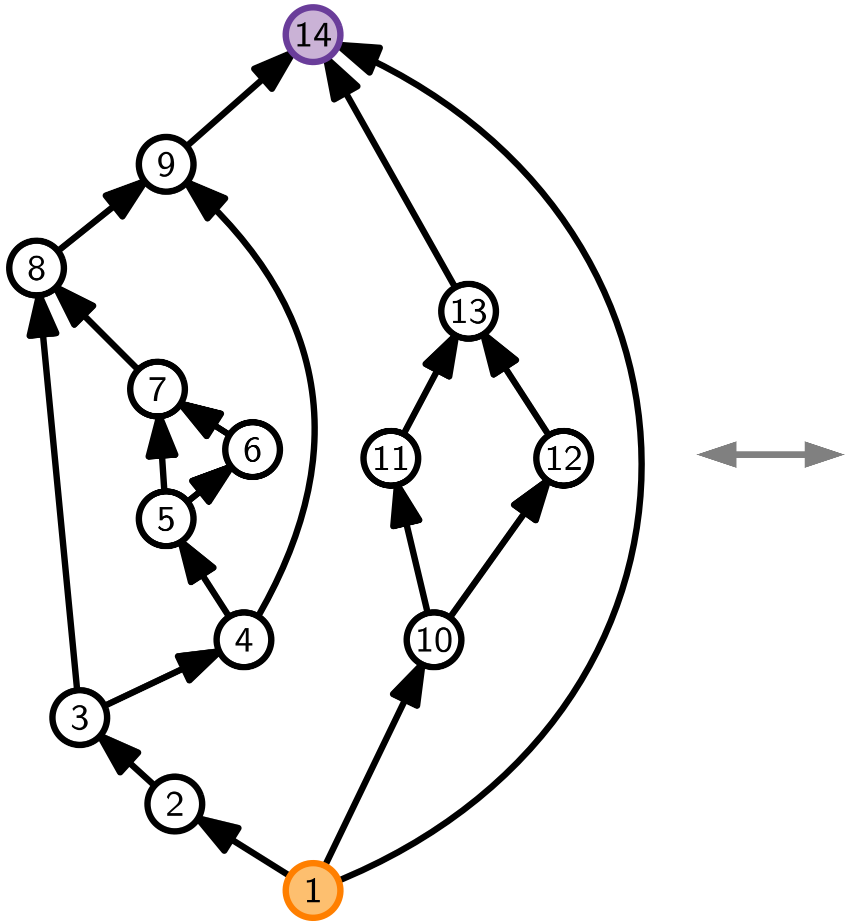

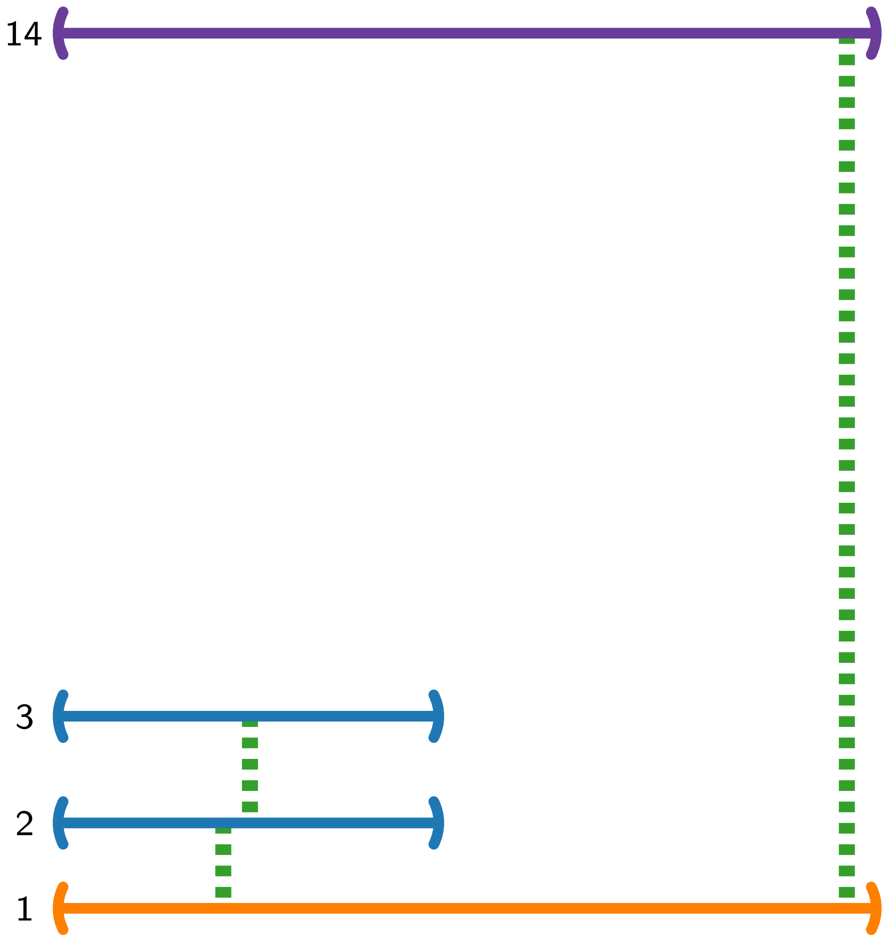

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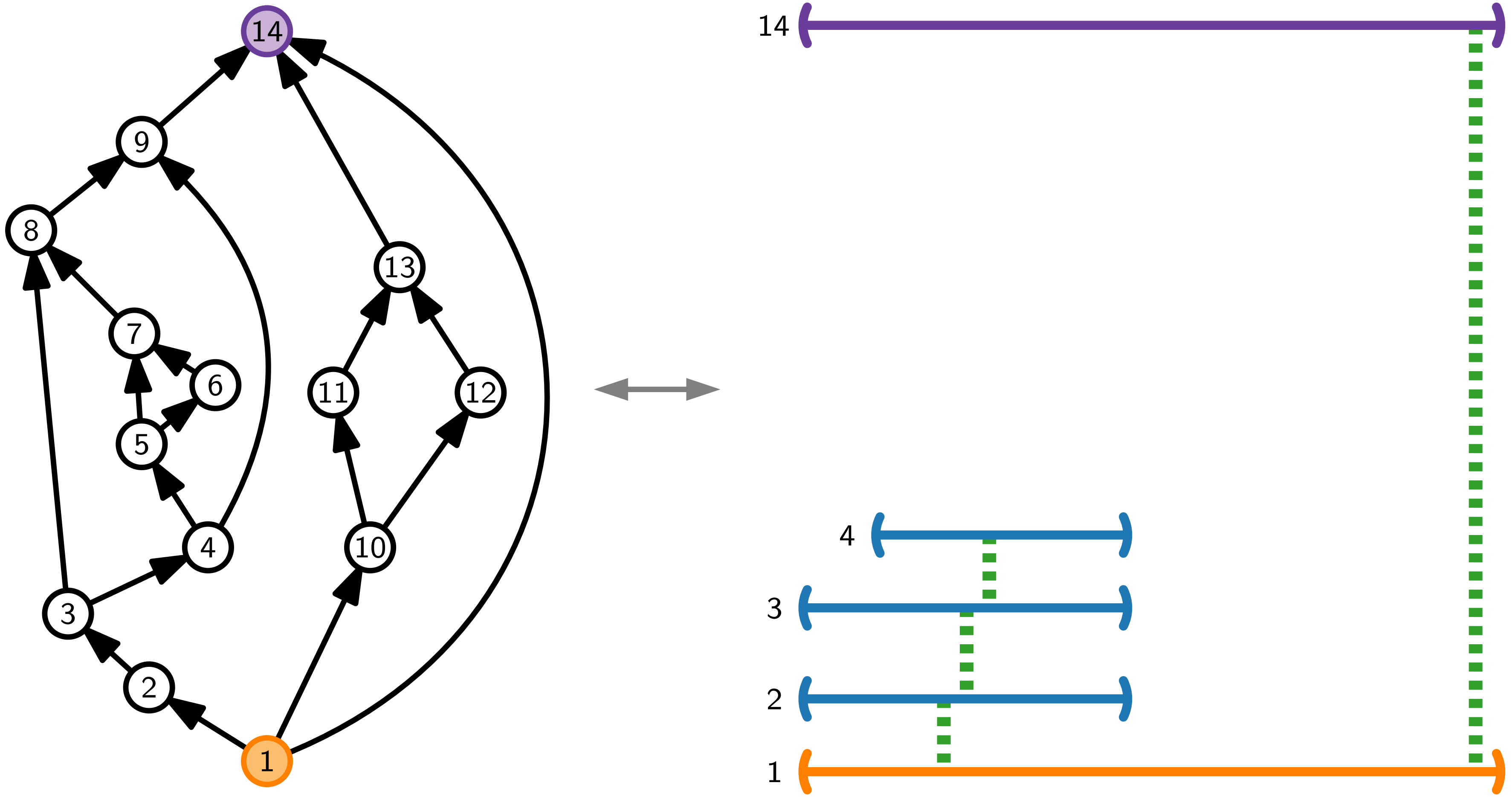

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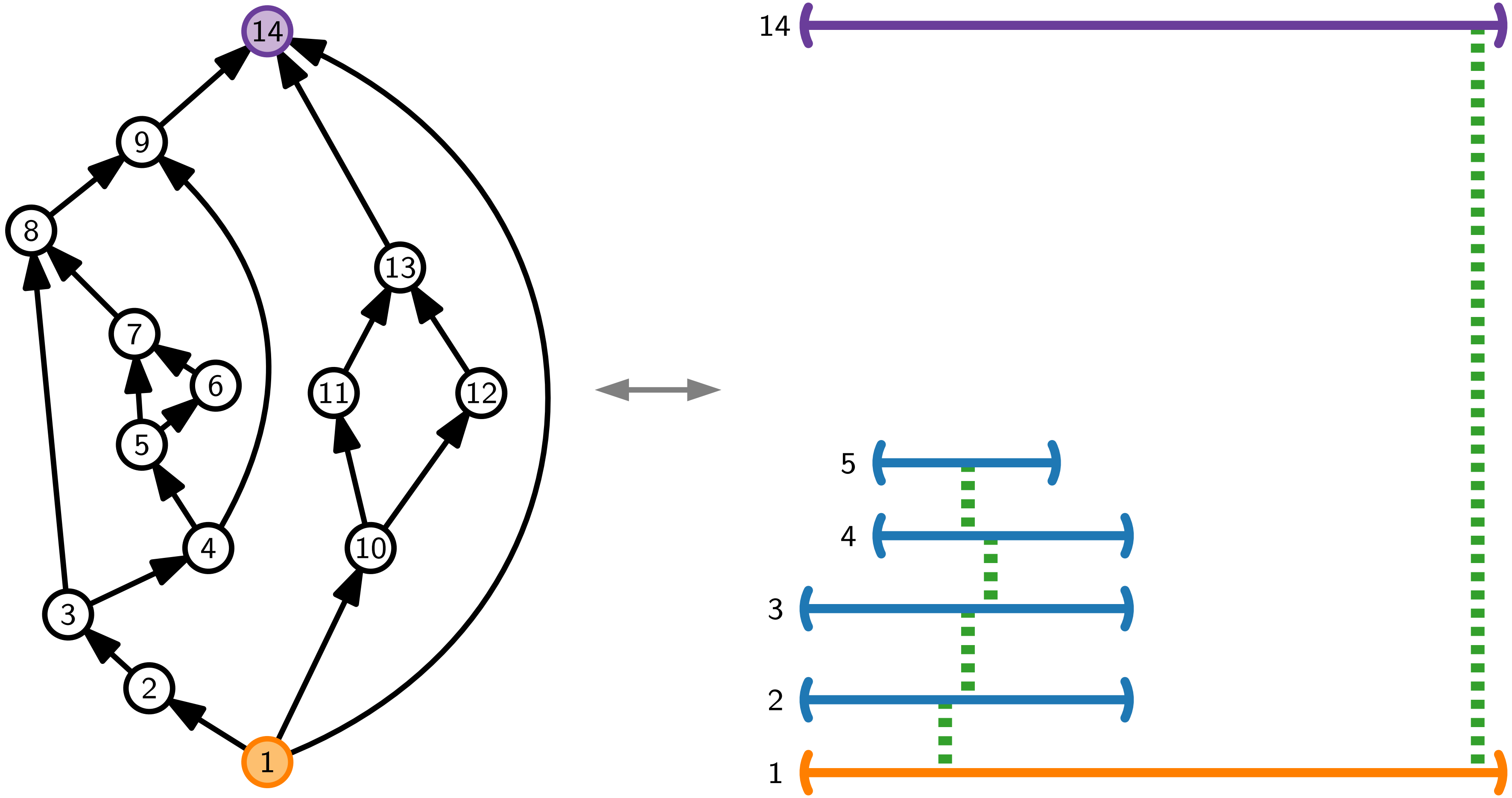

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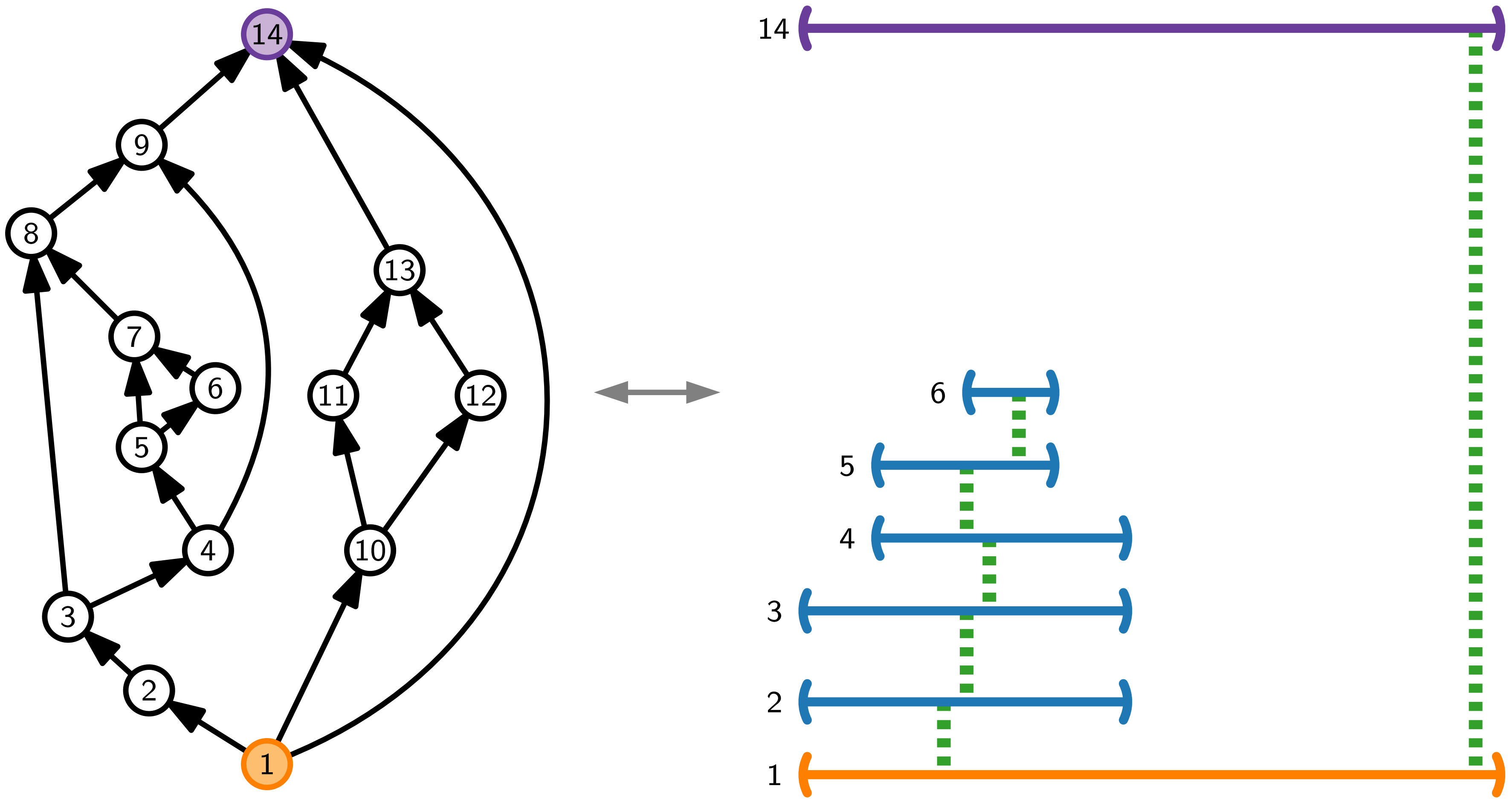

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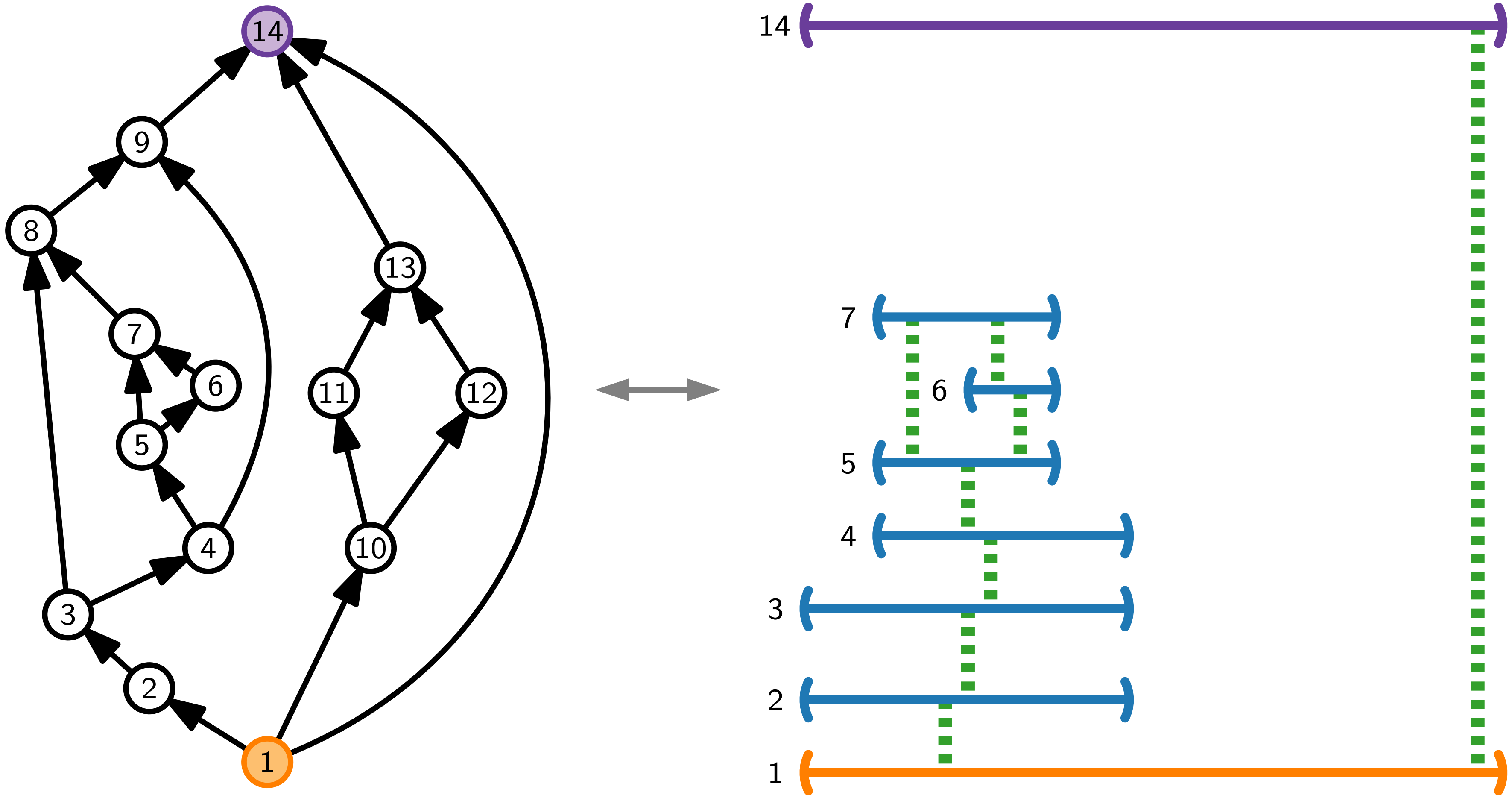

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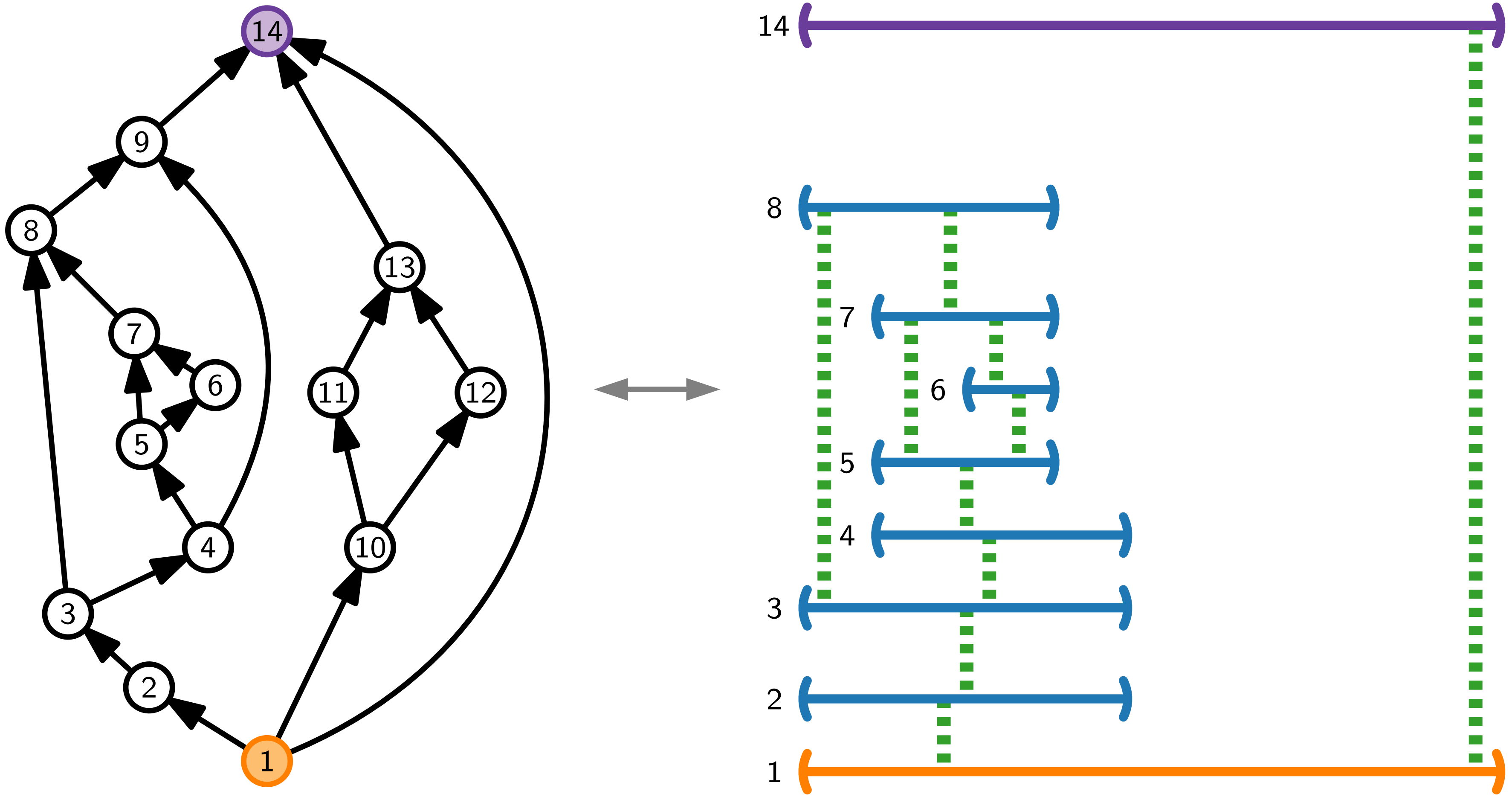

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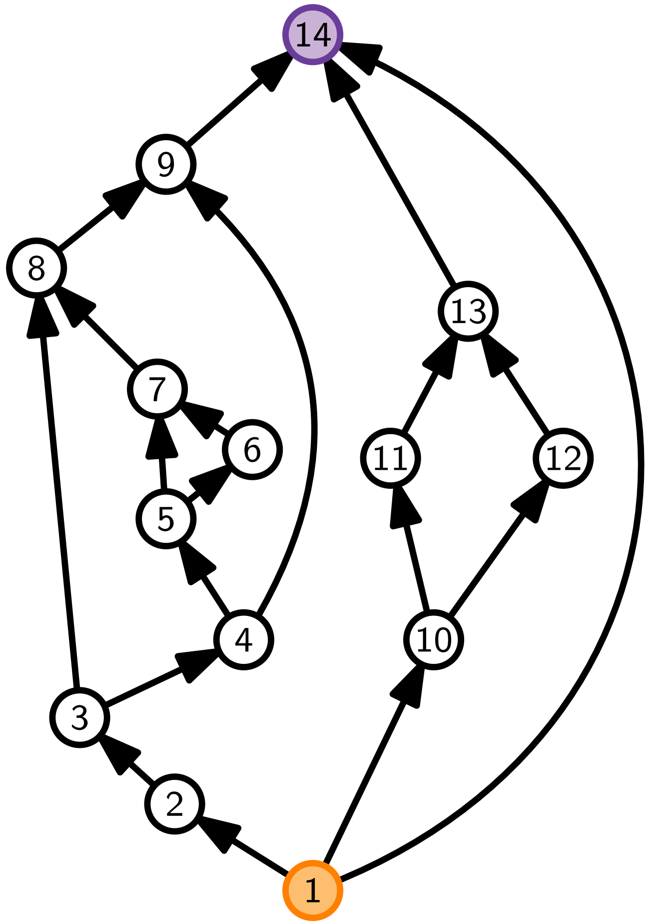

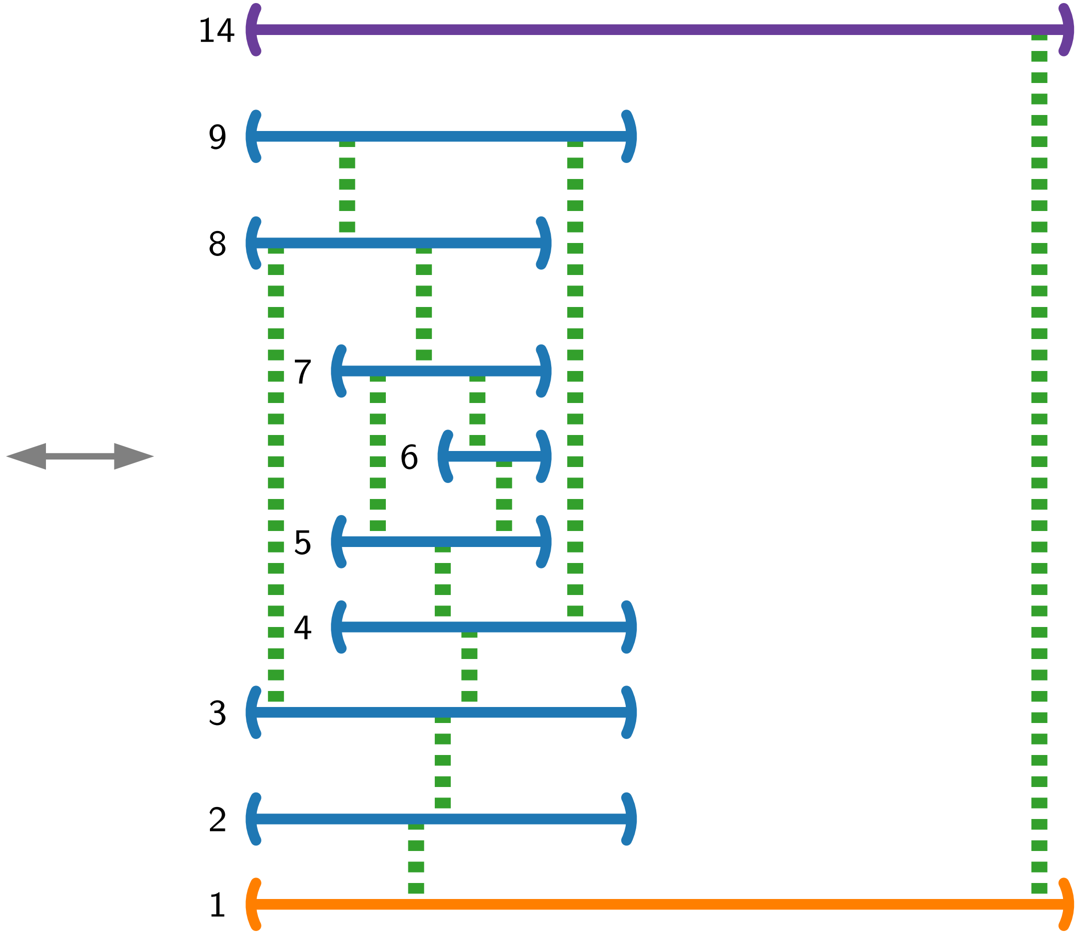

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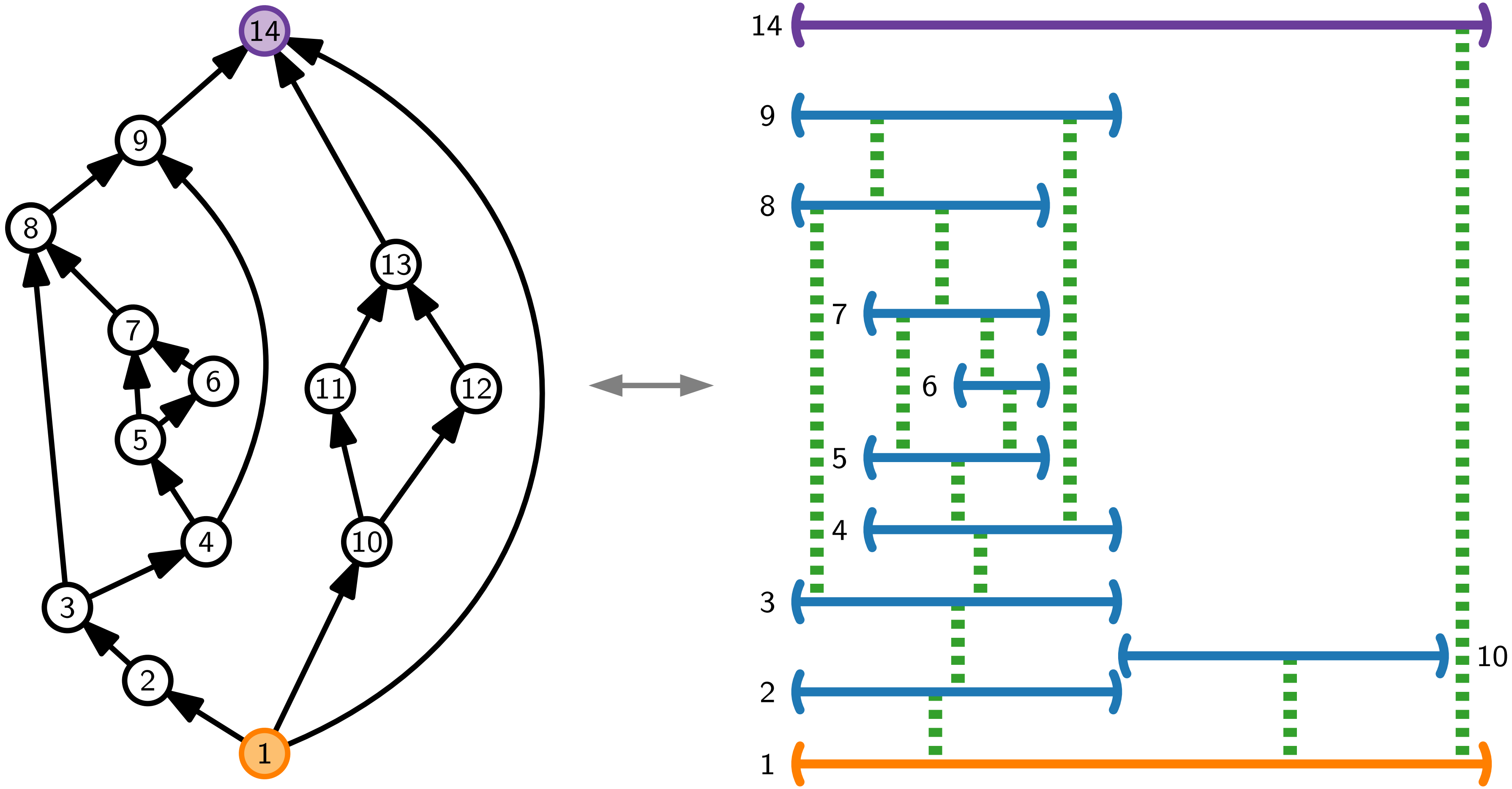

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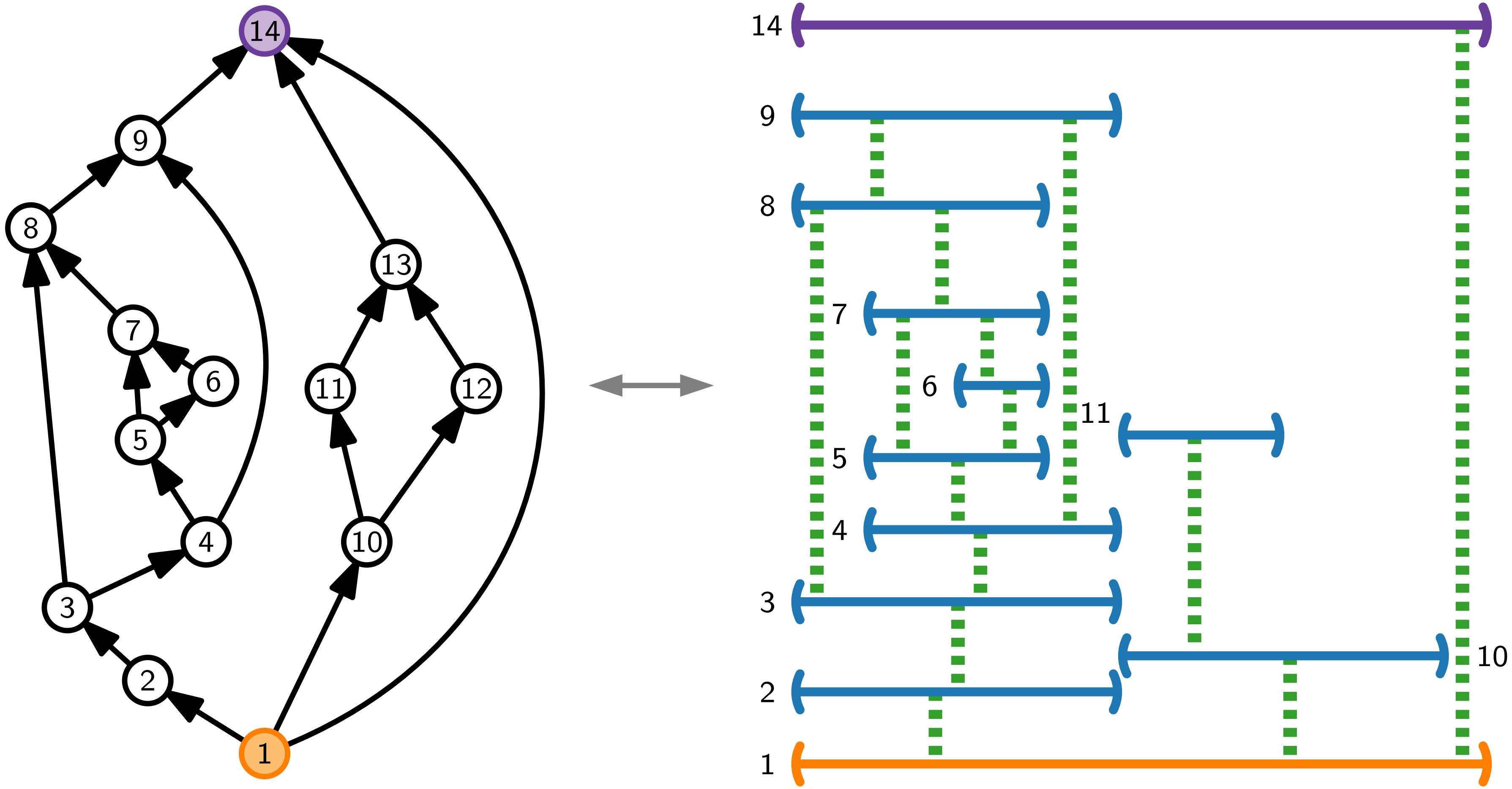

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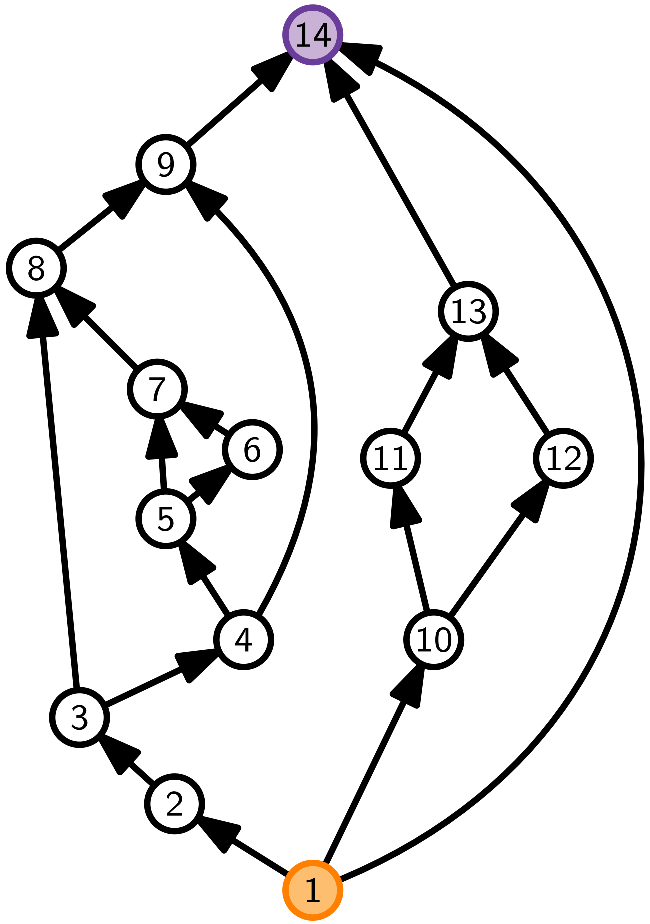

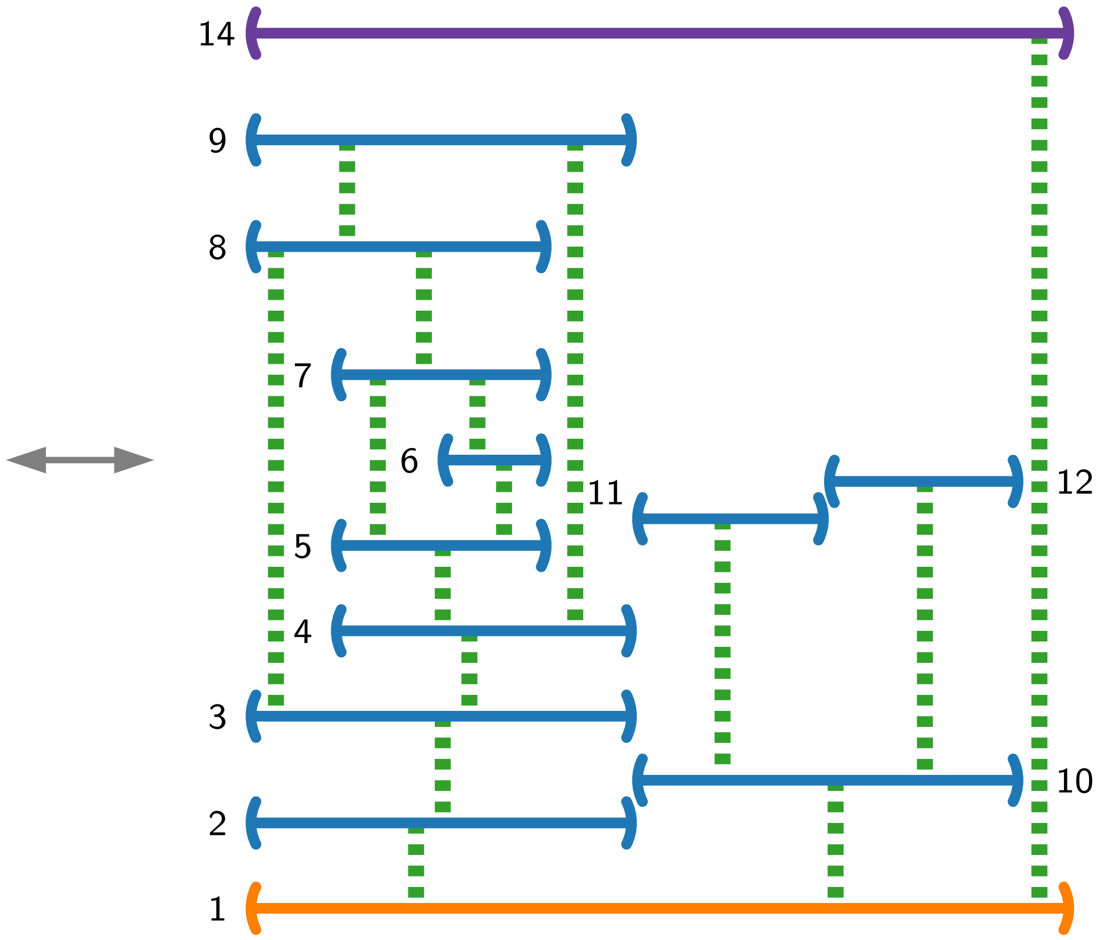

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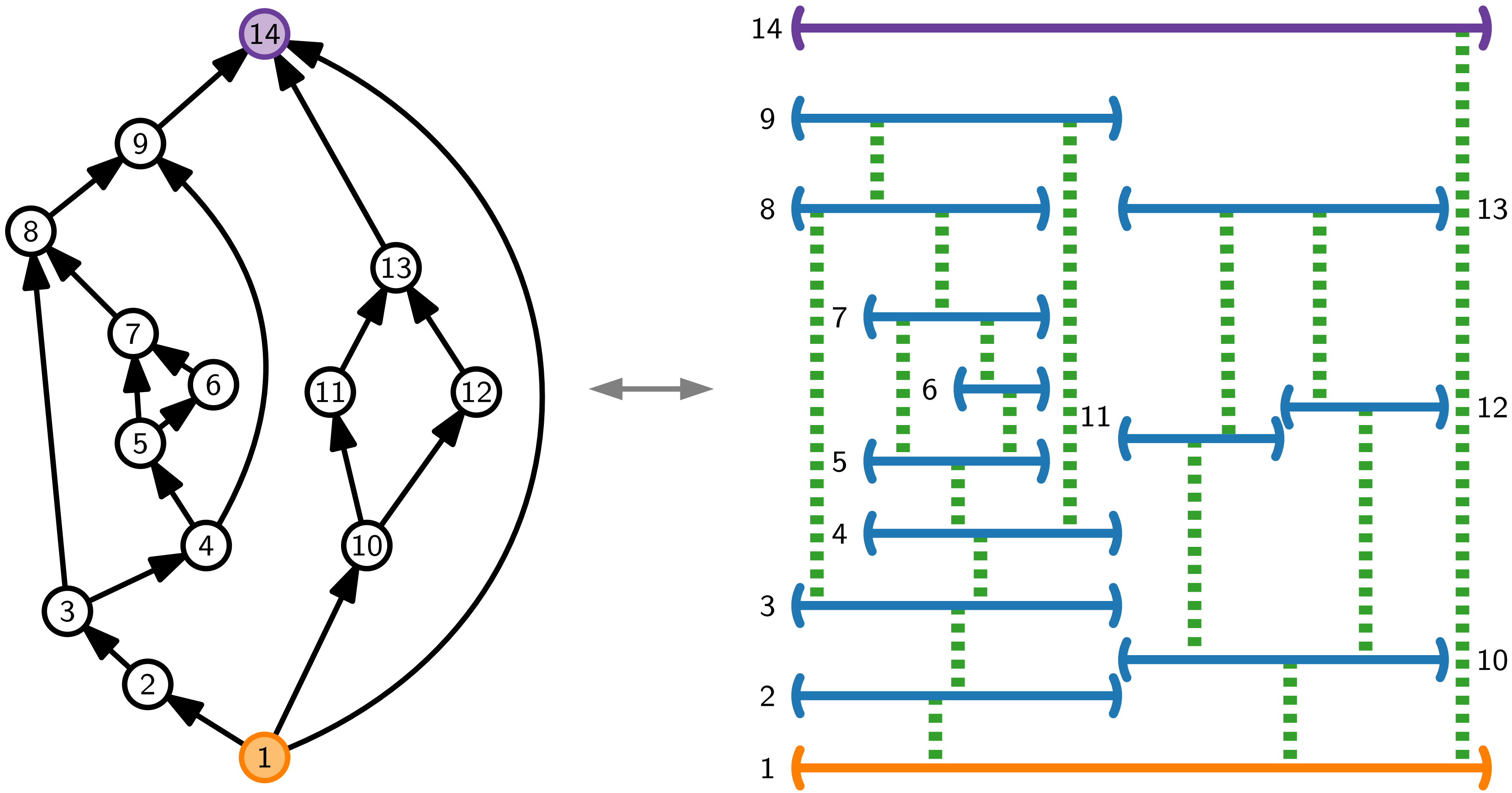

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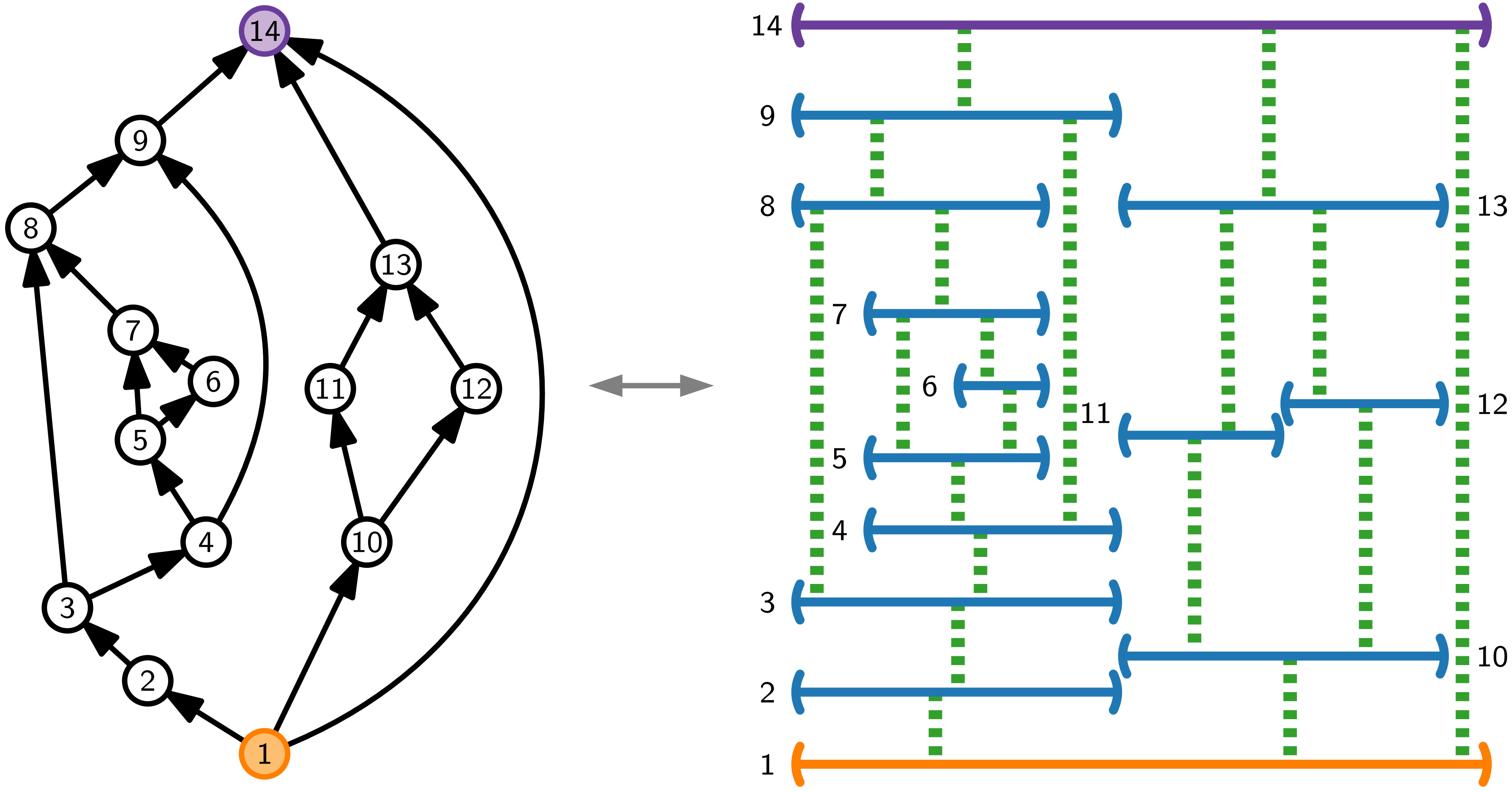

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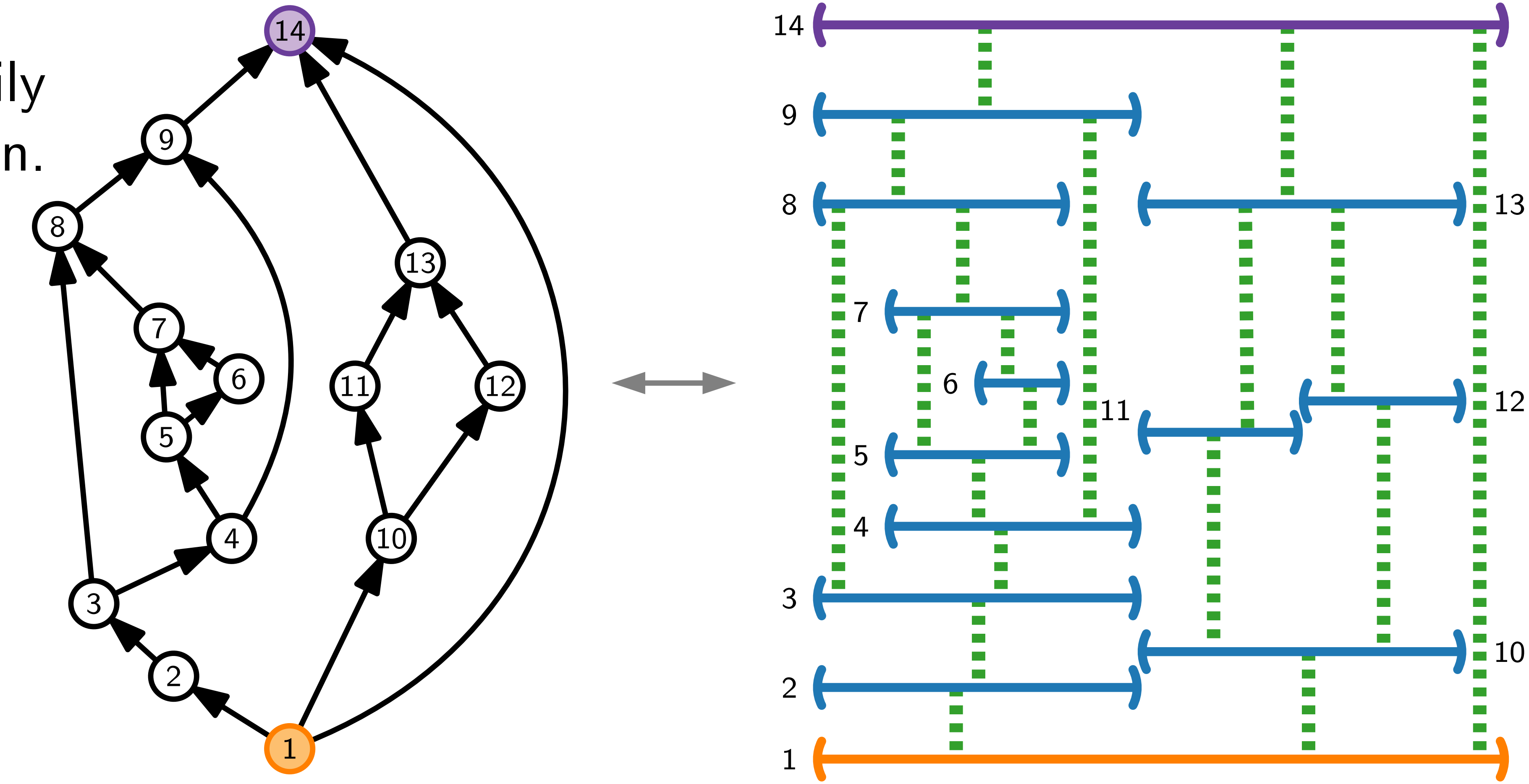

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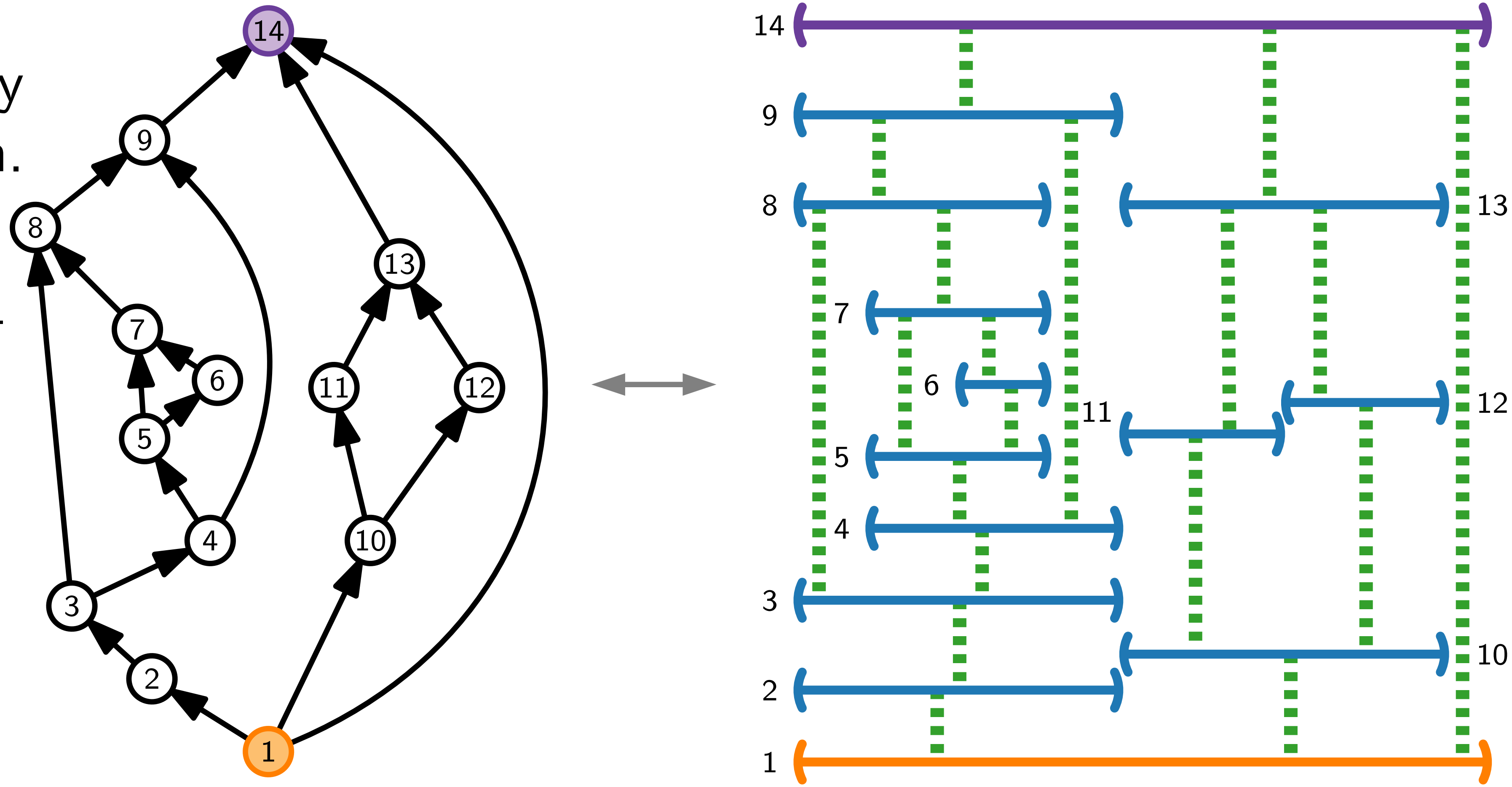

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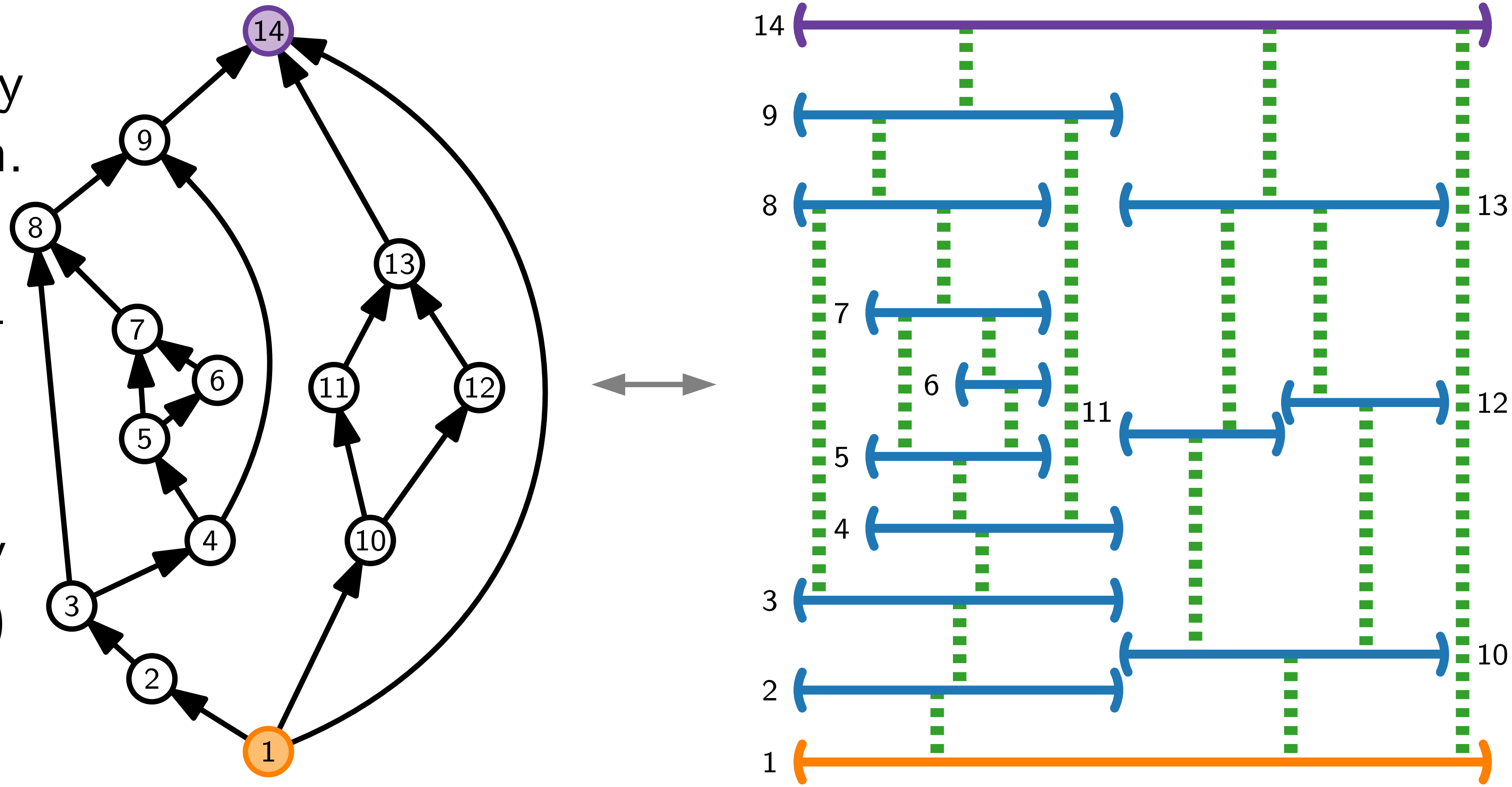

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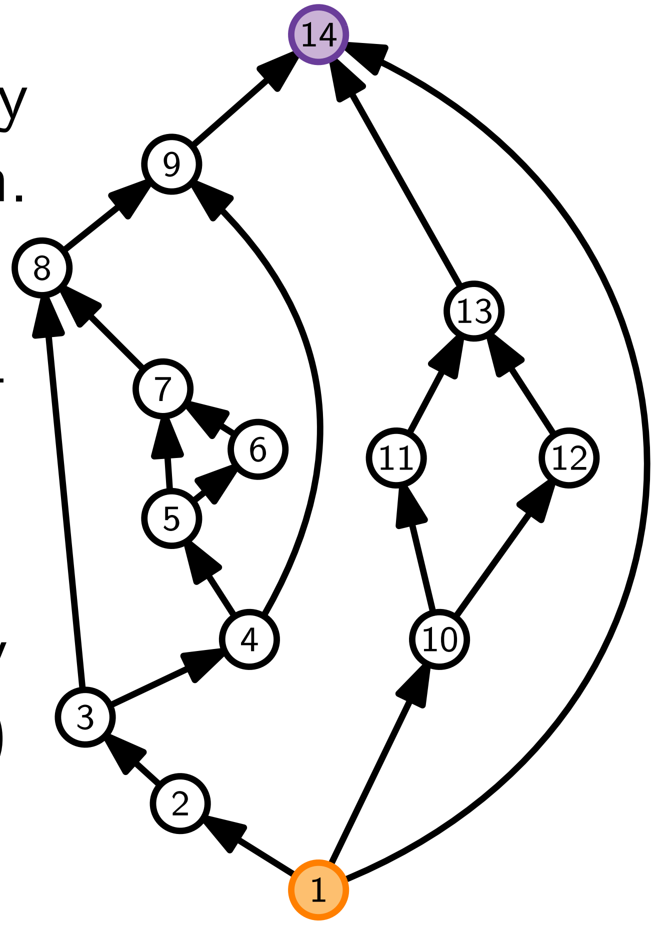

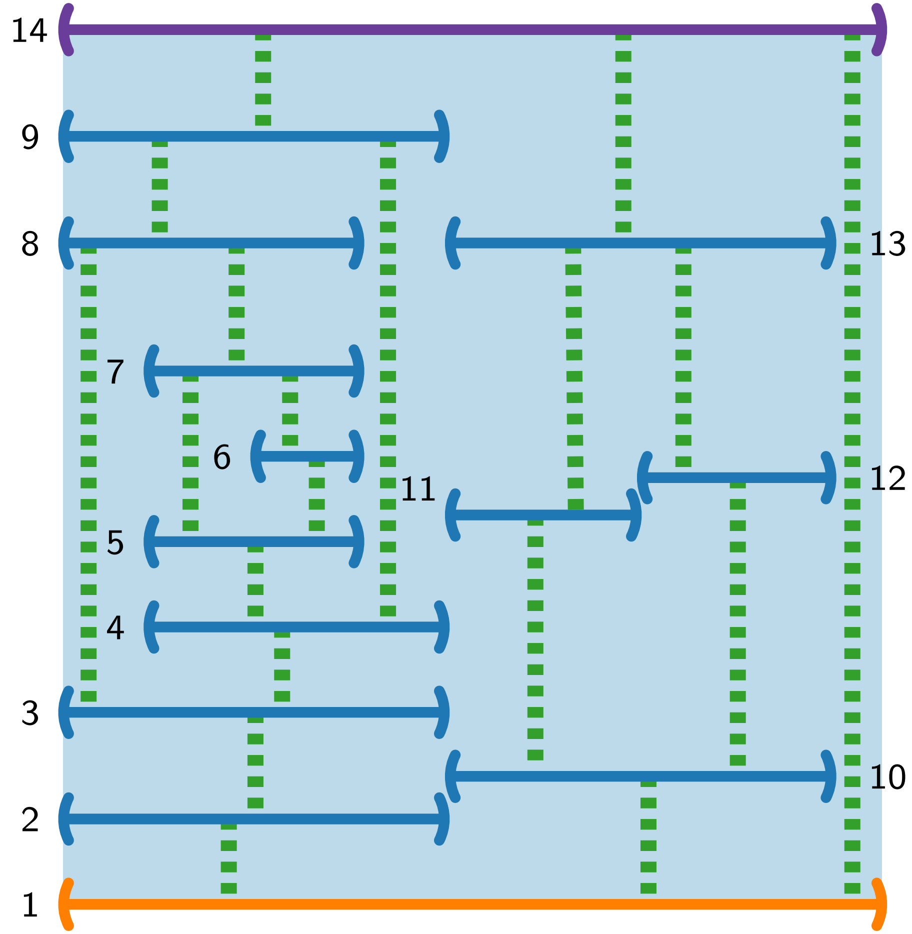

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[Chaplick, Guśpiel, Gutowski, Krawczyk, Liotta '18]

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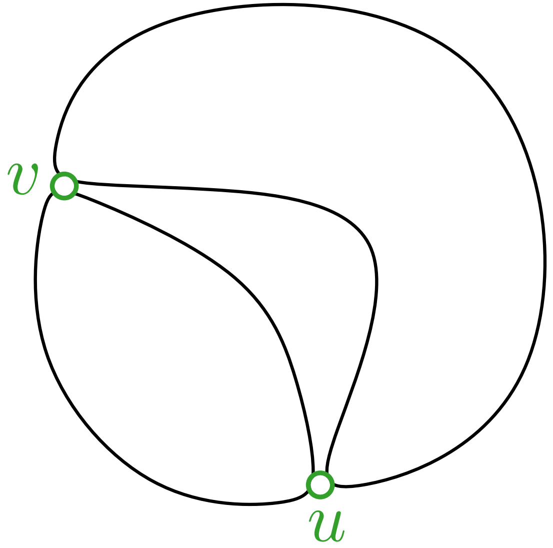

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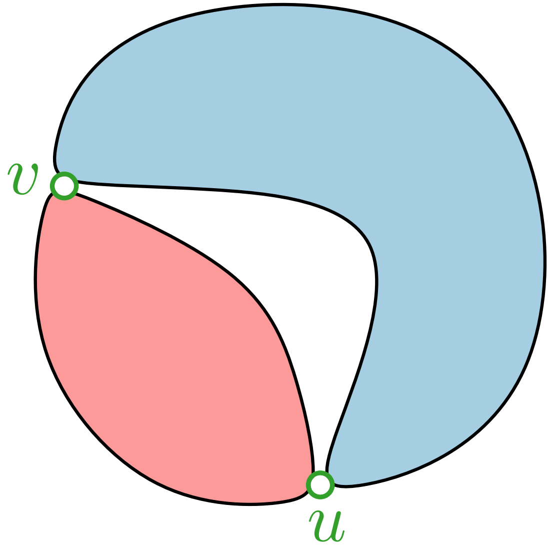

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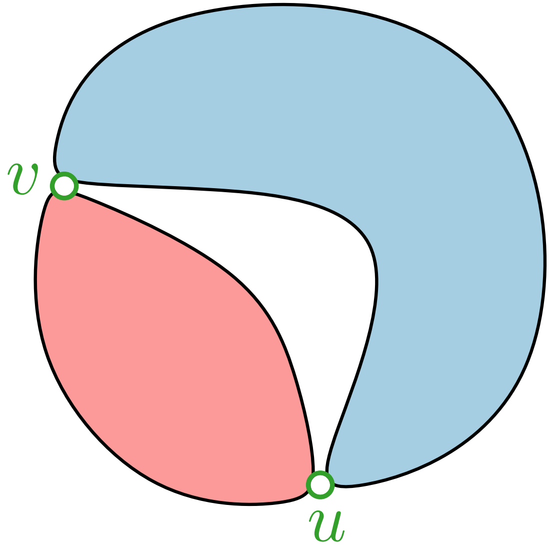

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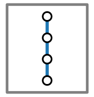

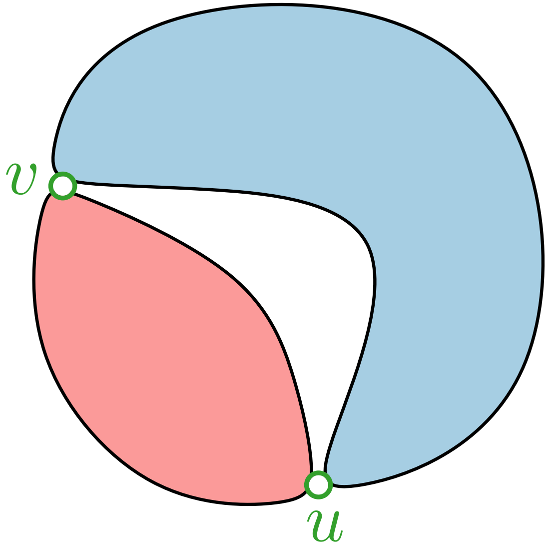

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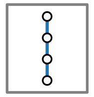

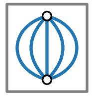

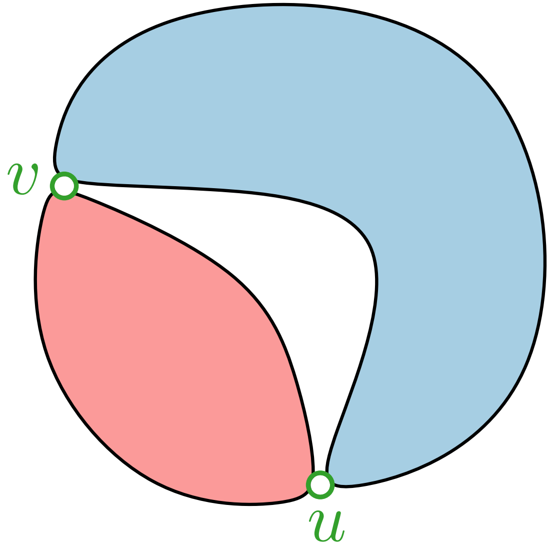

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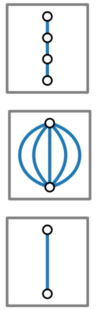

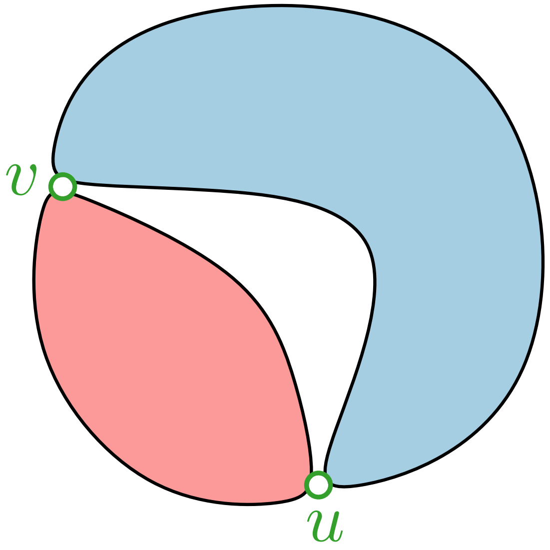

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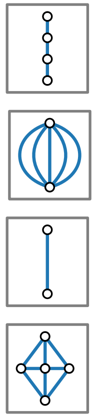

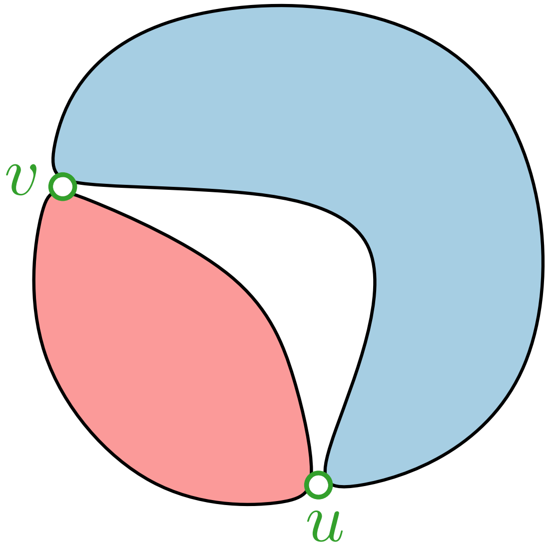

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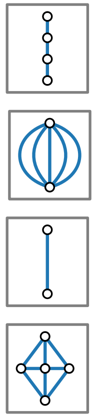

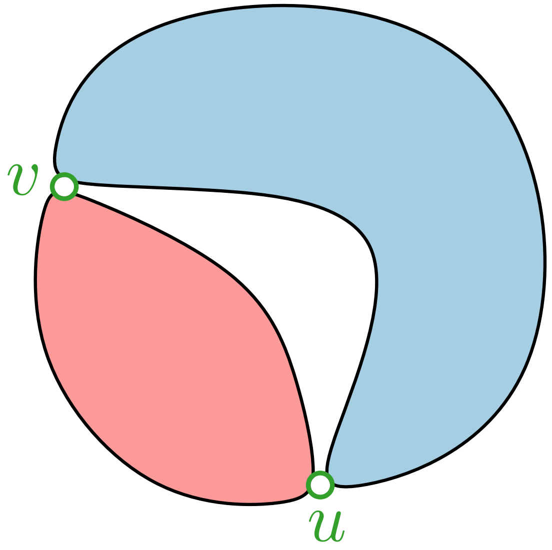

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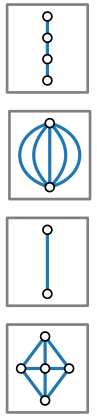

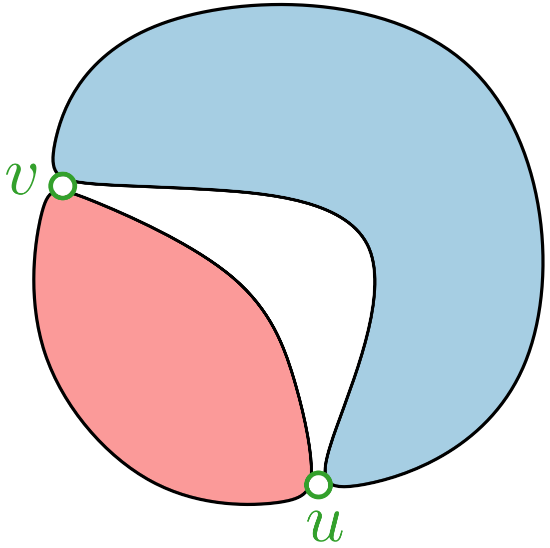

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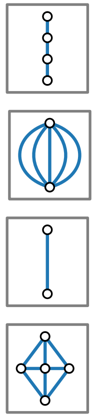

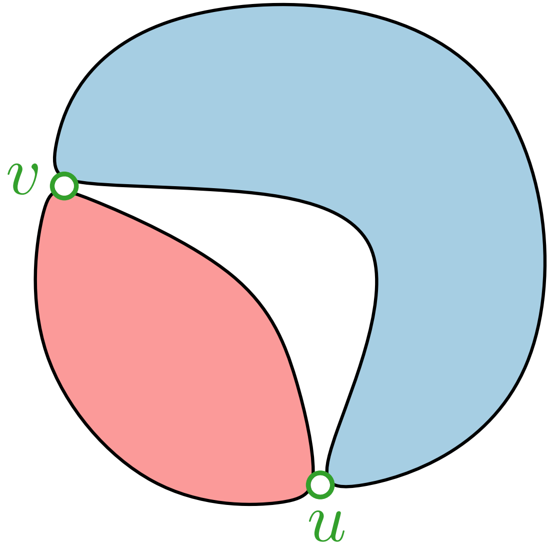

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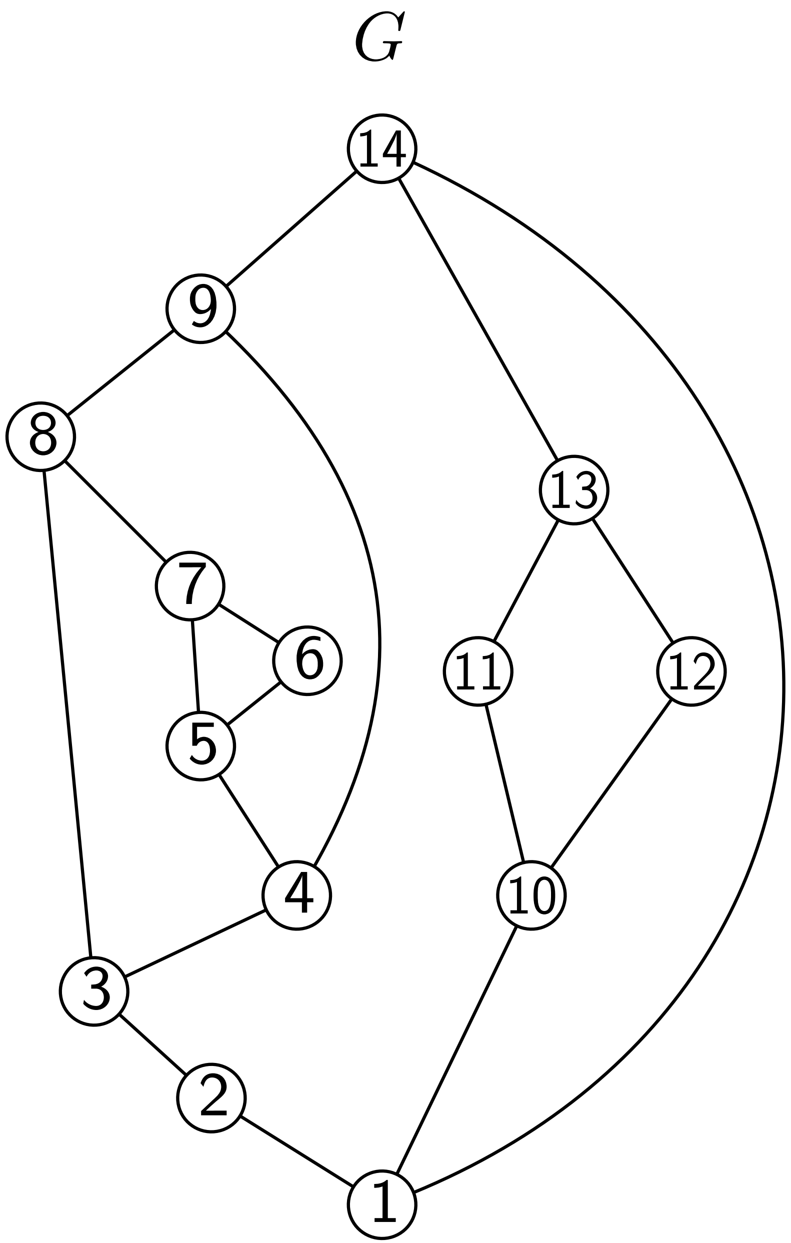
- T represents all planar embeddings of G.
- T can be computed in time linear in the size of G. [Gutwenger, Mutzel '01]

SPQR-Tree – Example



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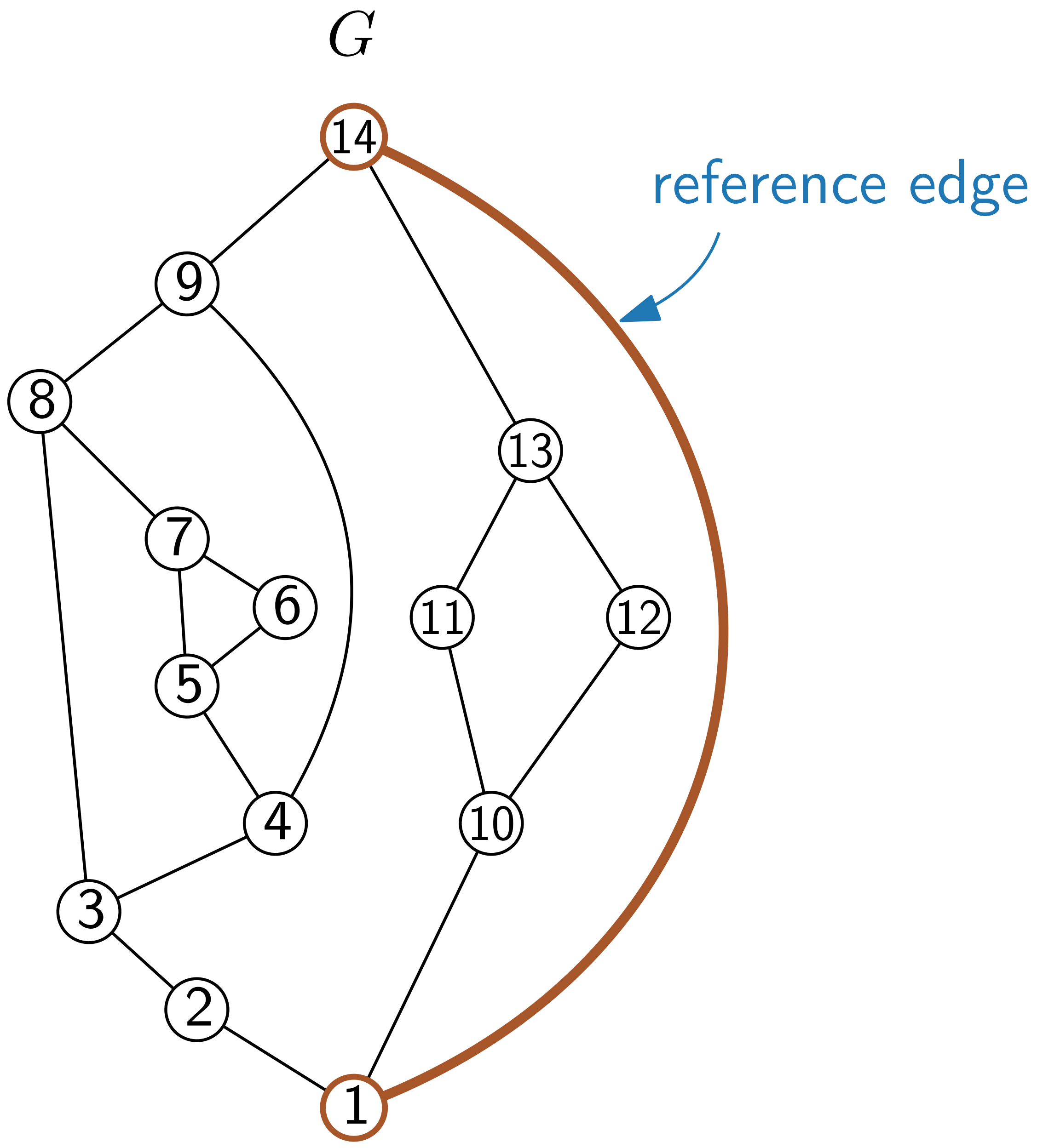

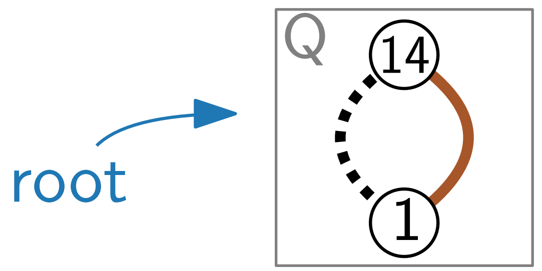

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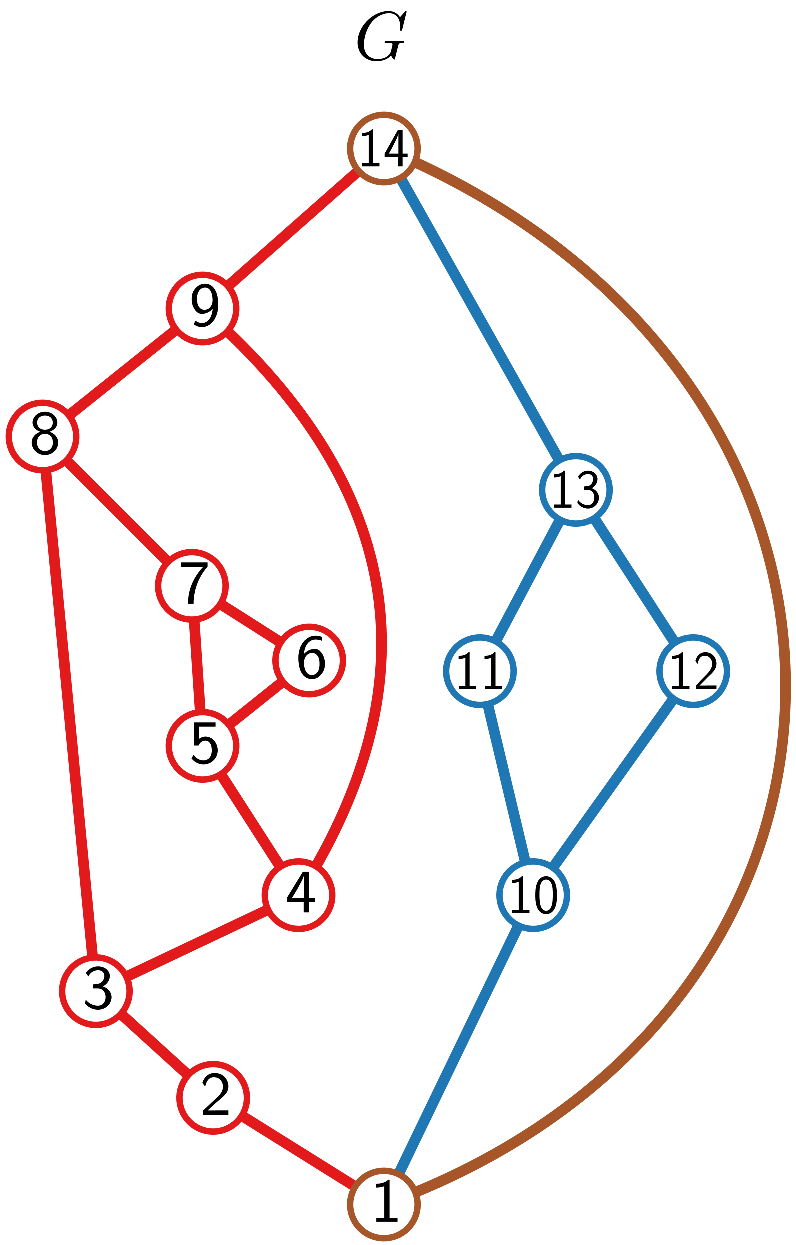

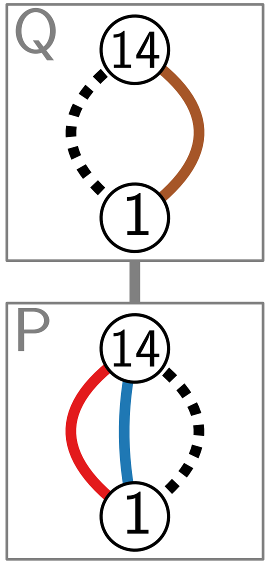

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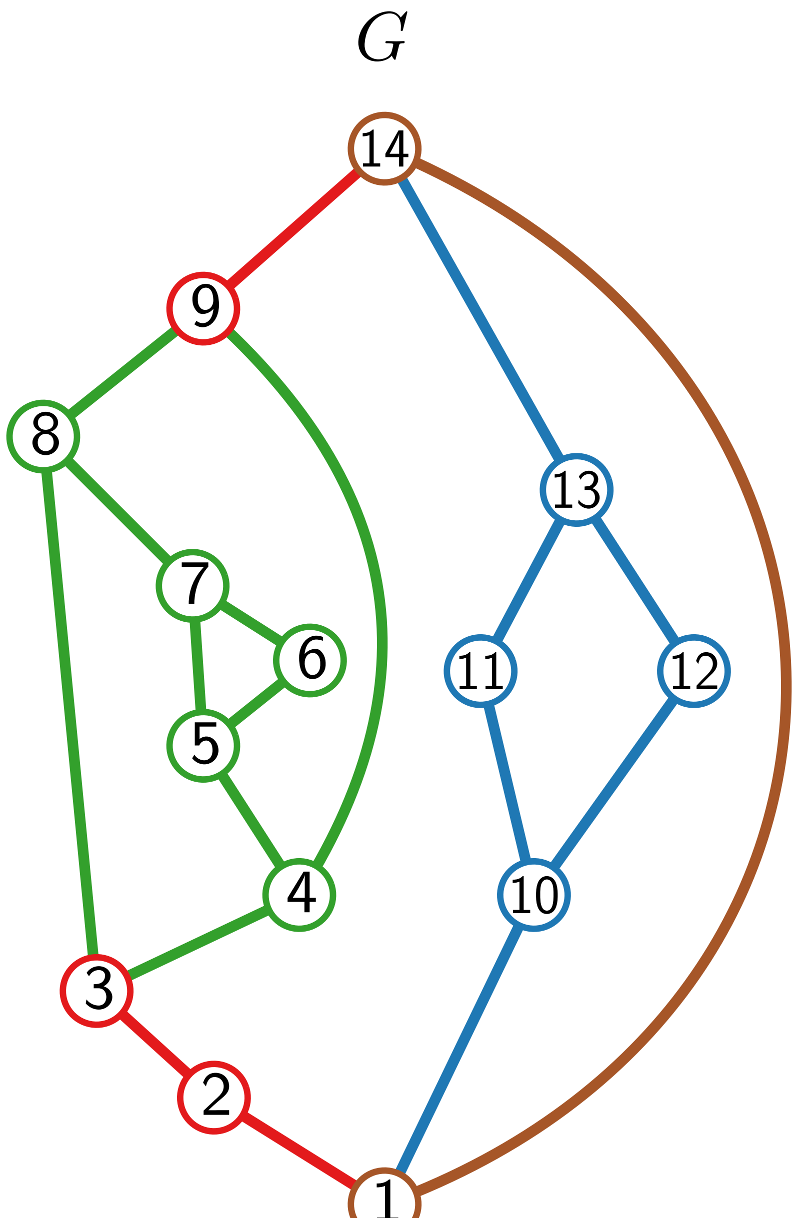

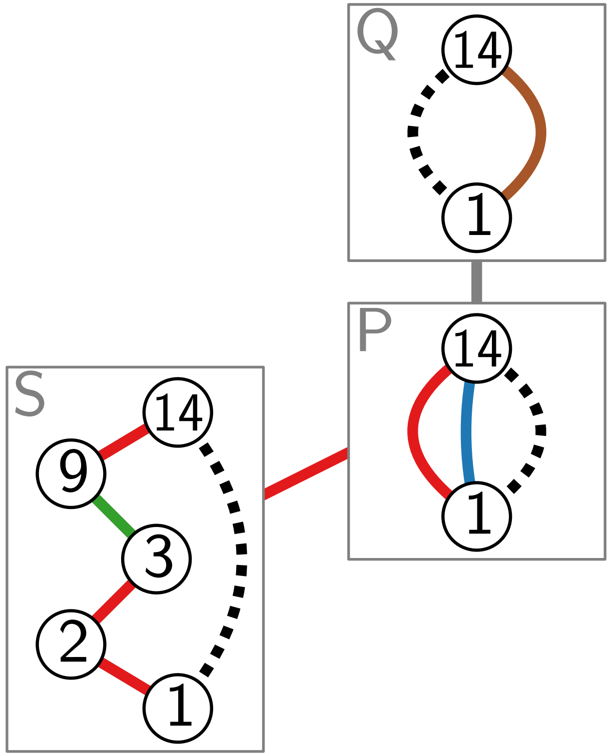

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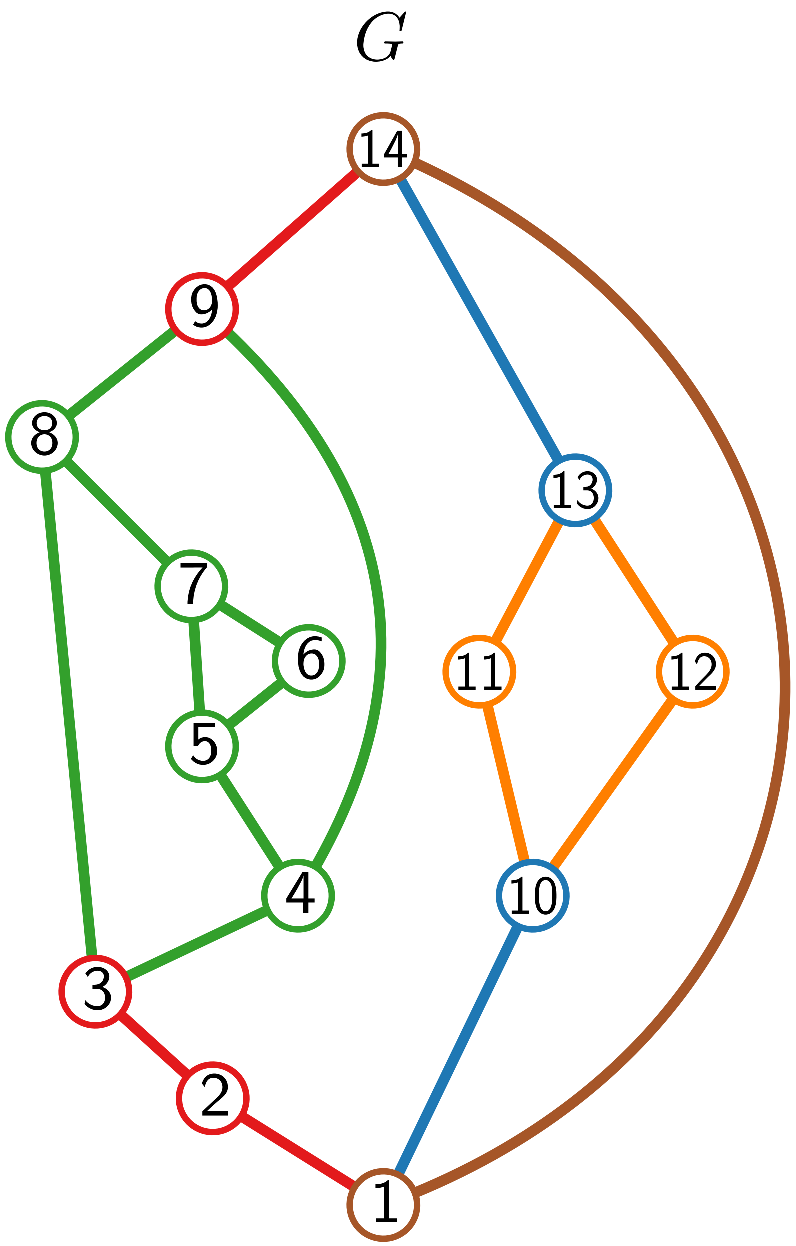

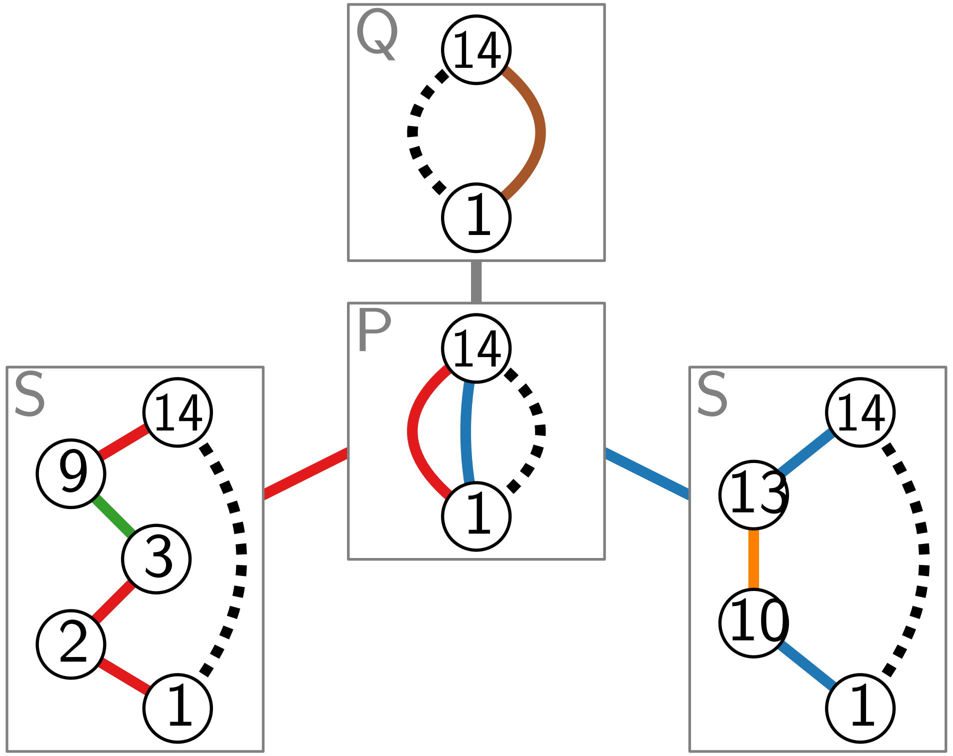

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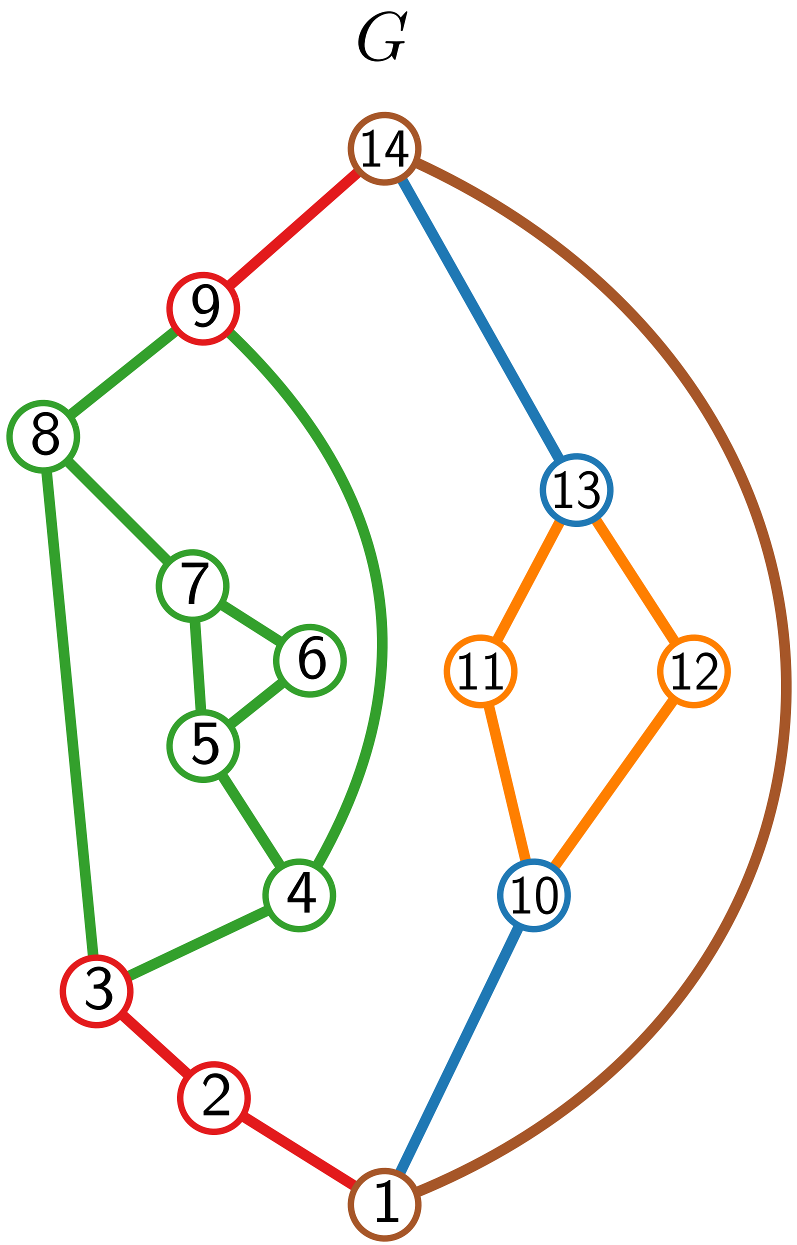

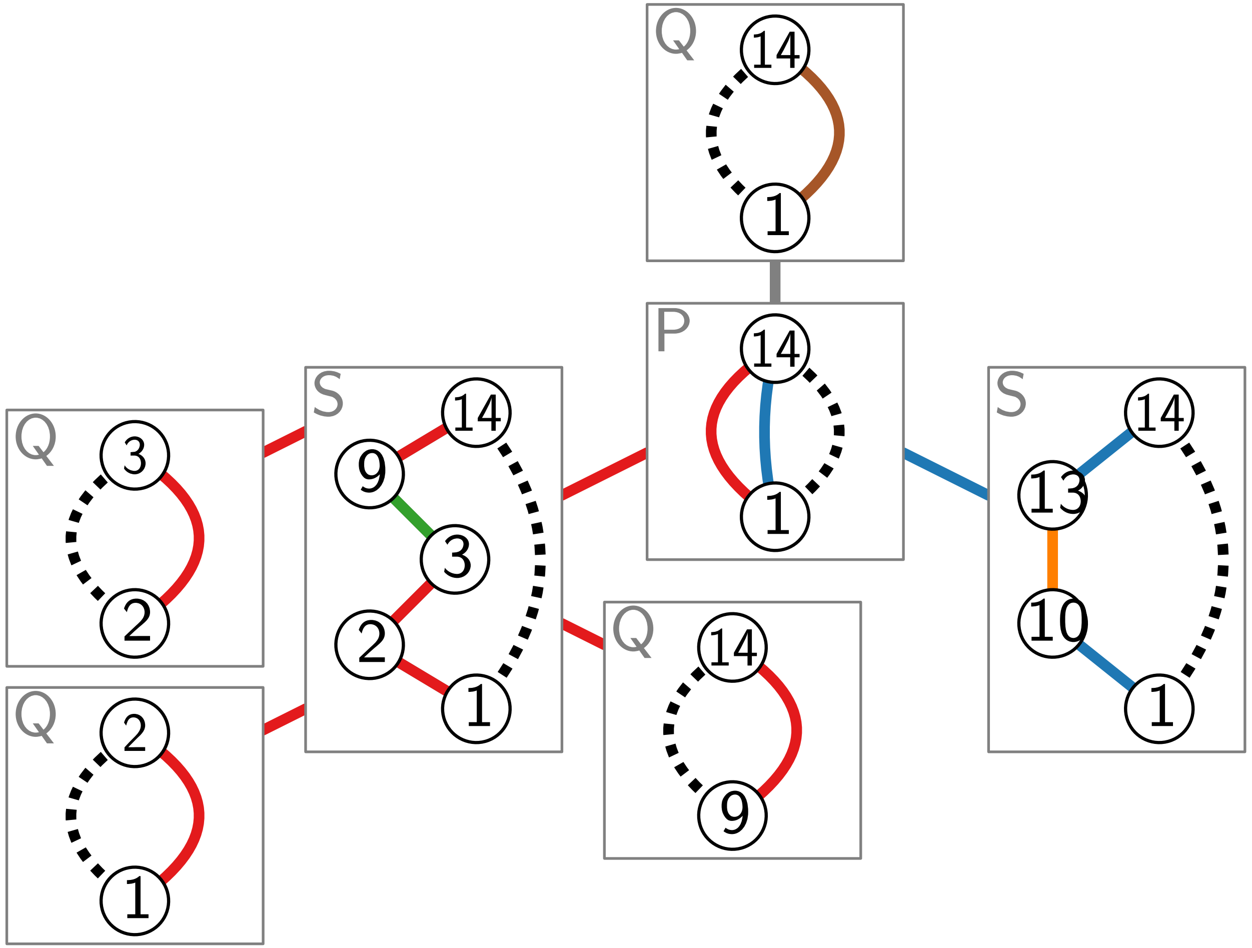

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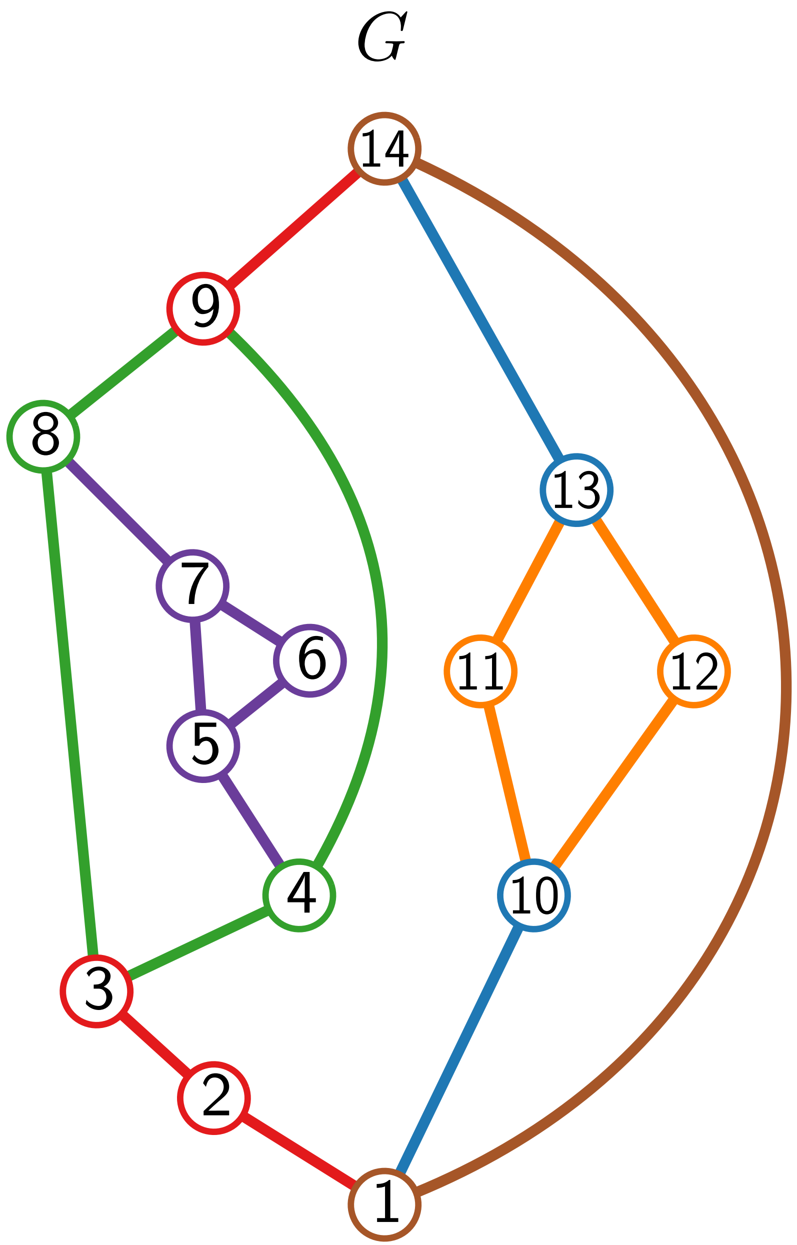

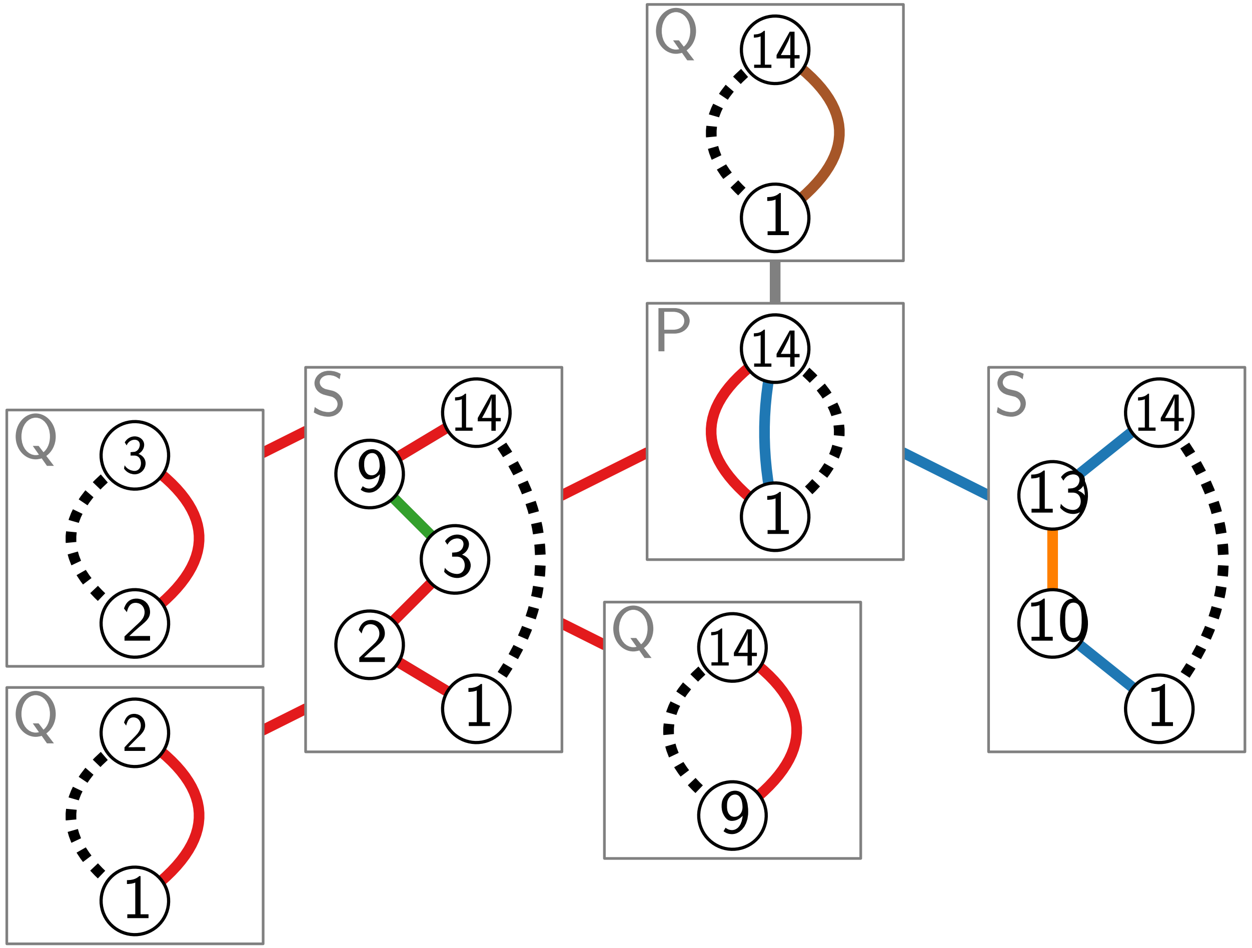

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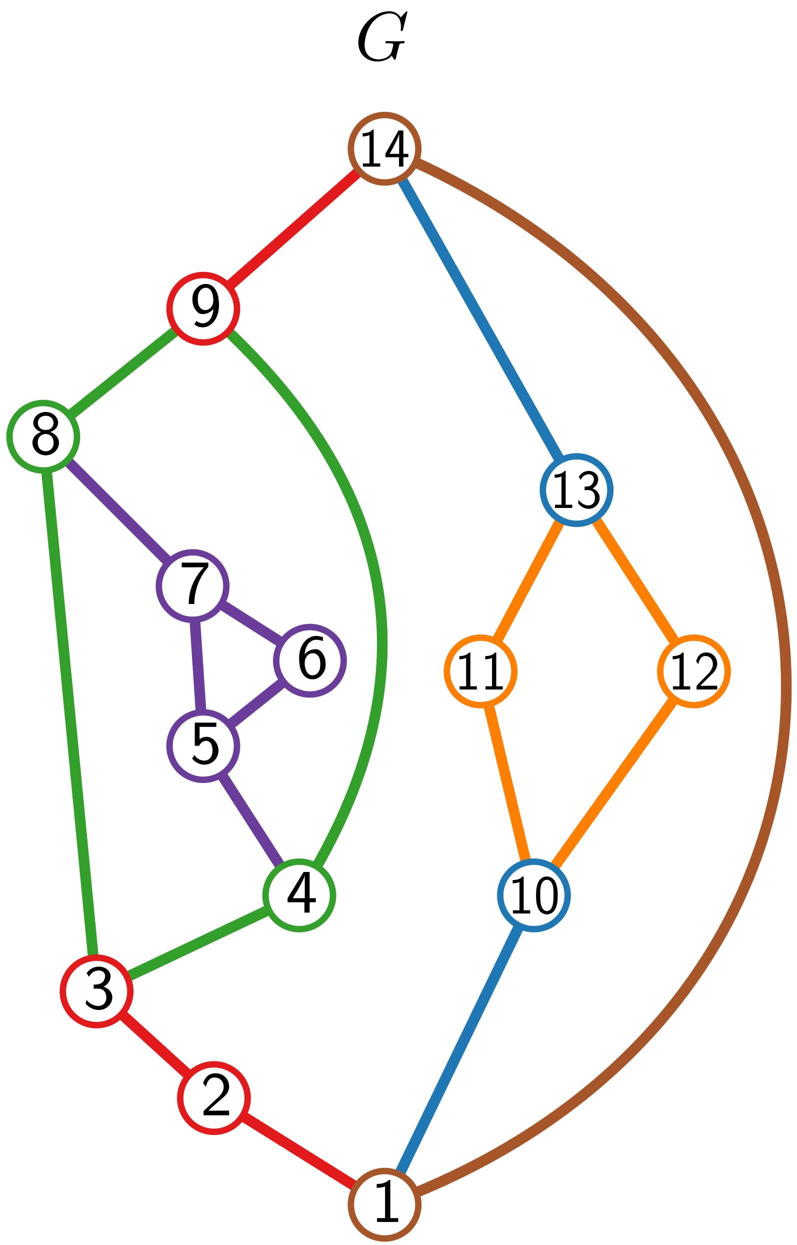

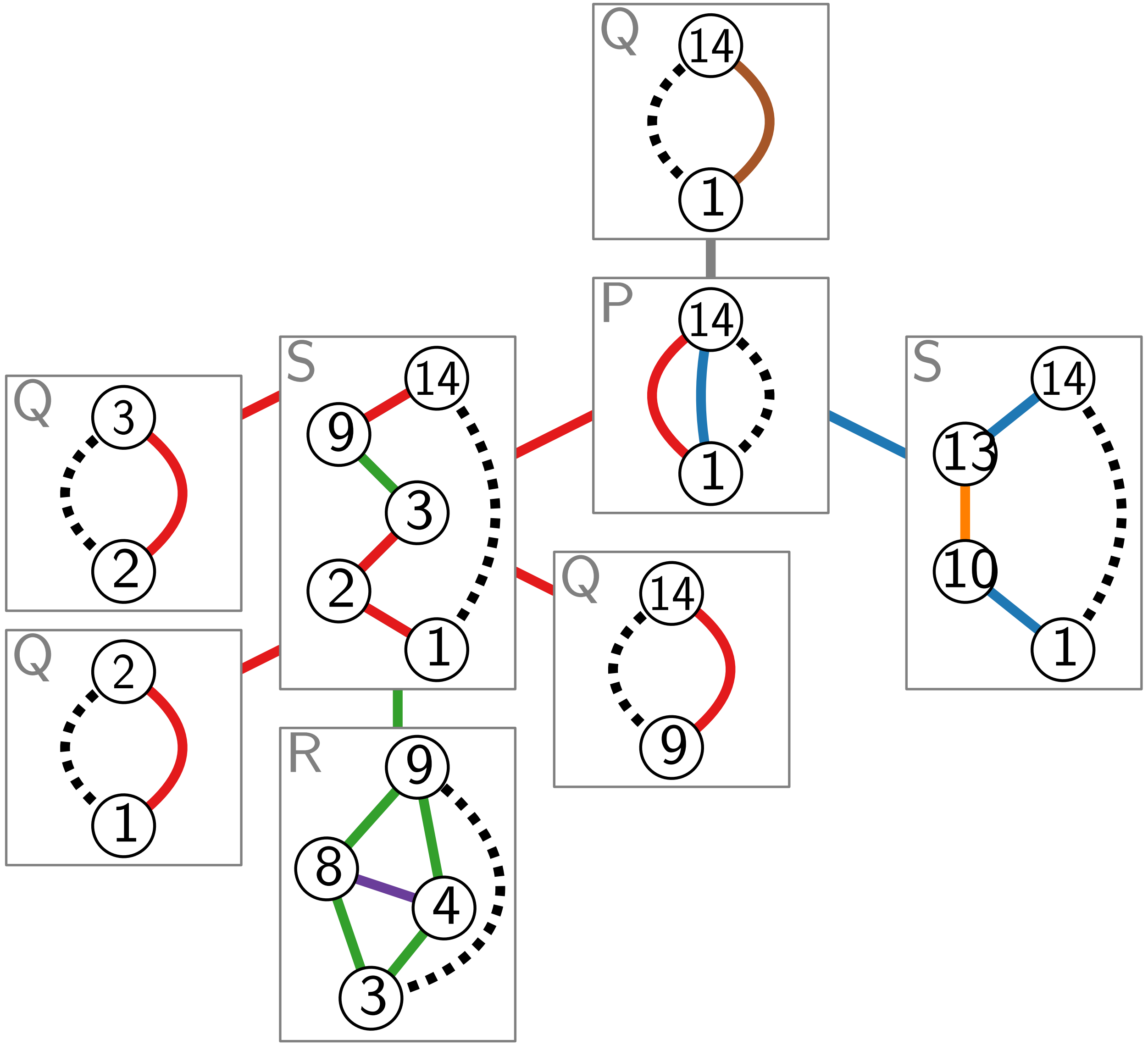

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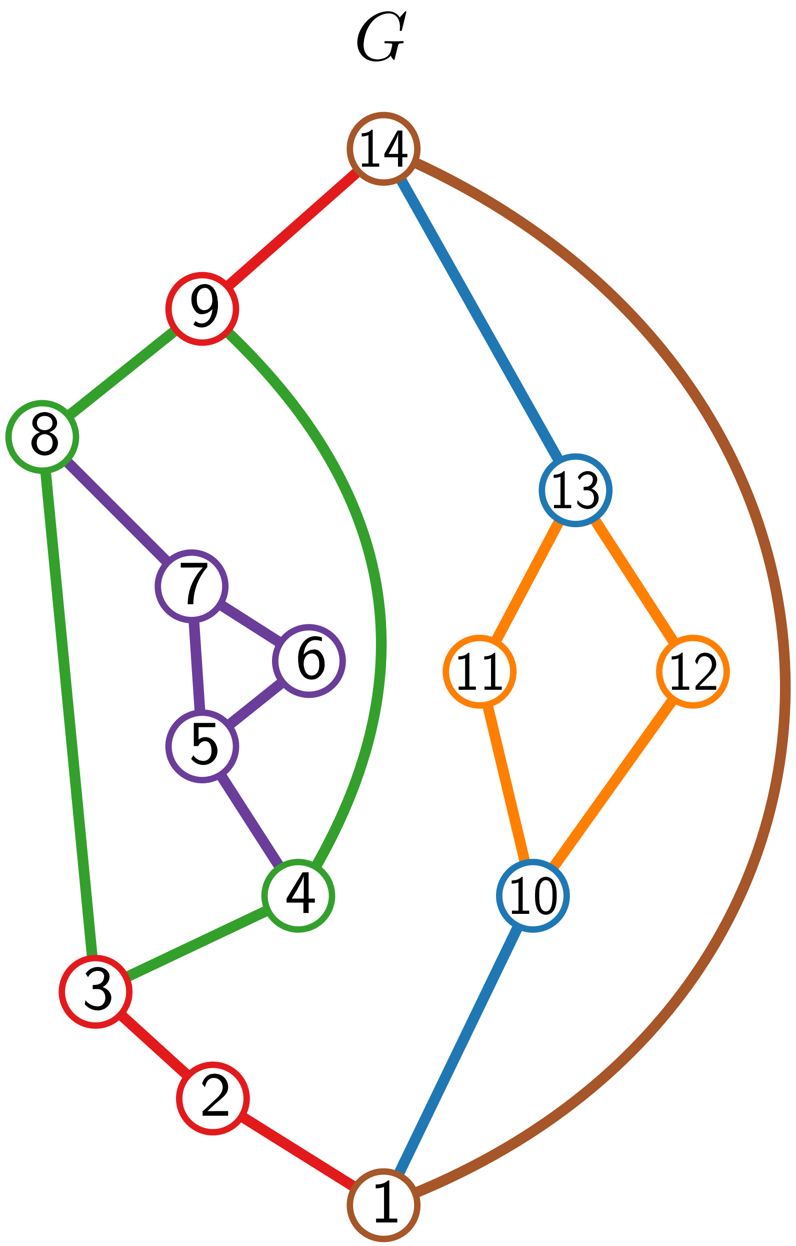

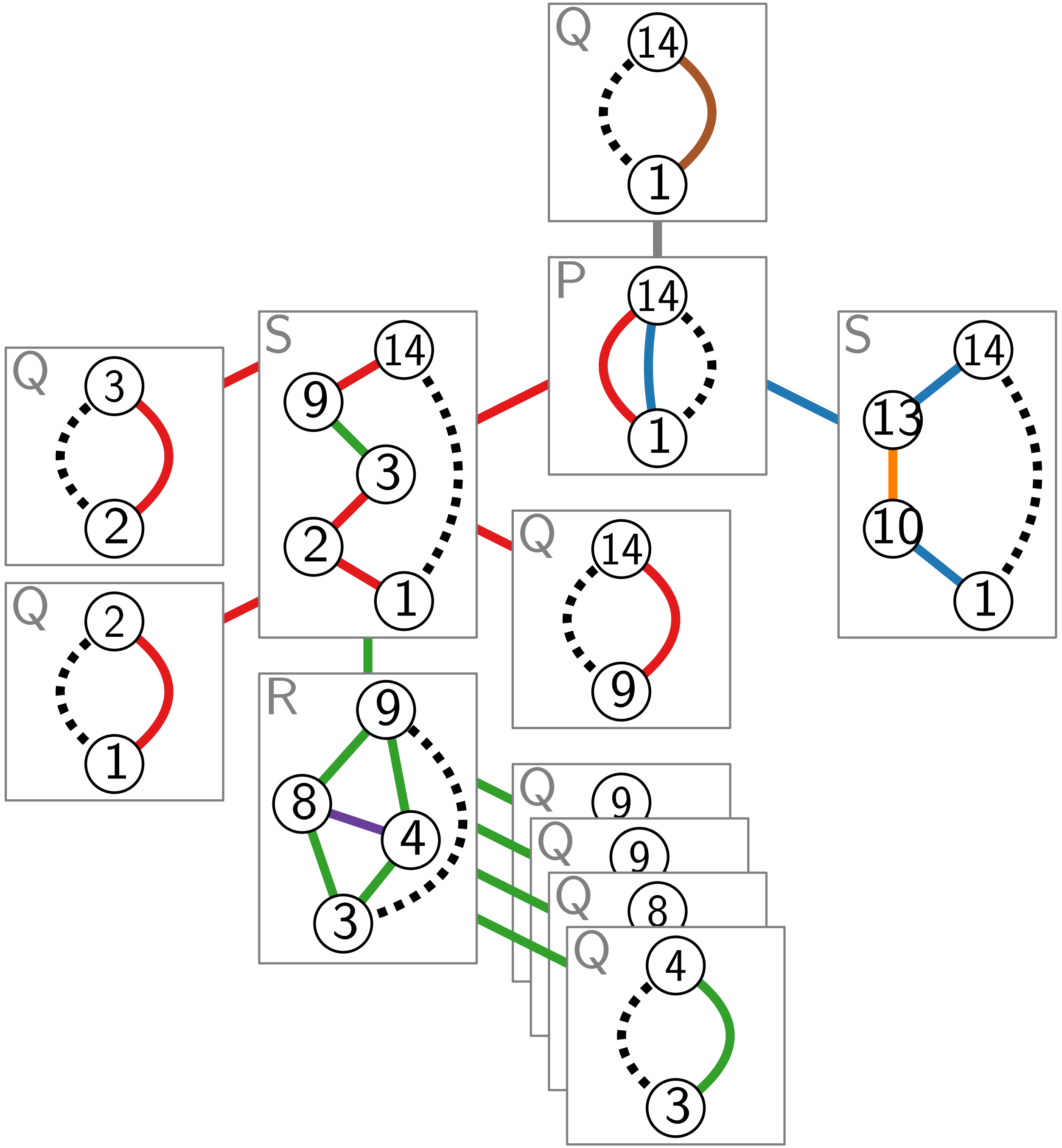

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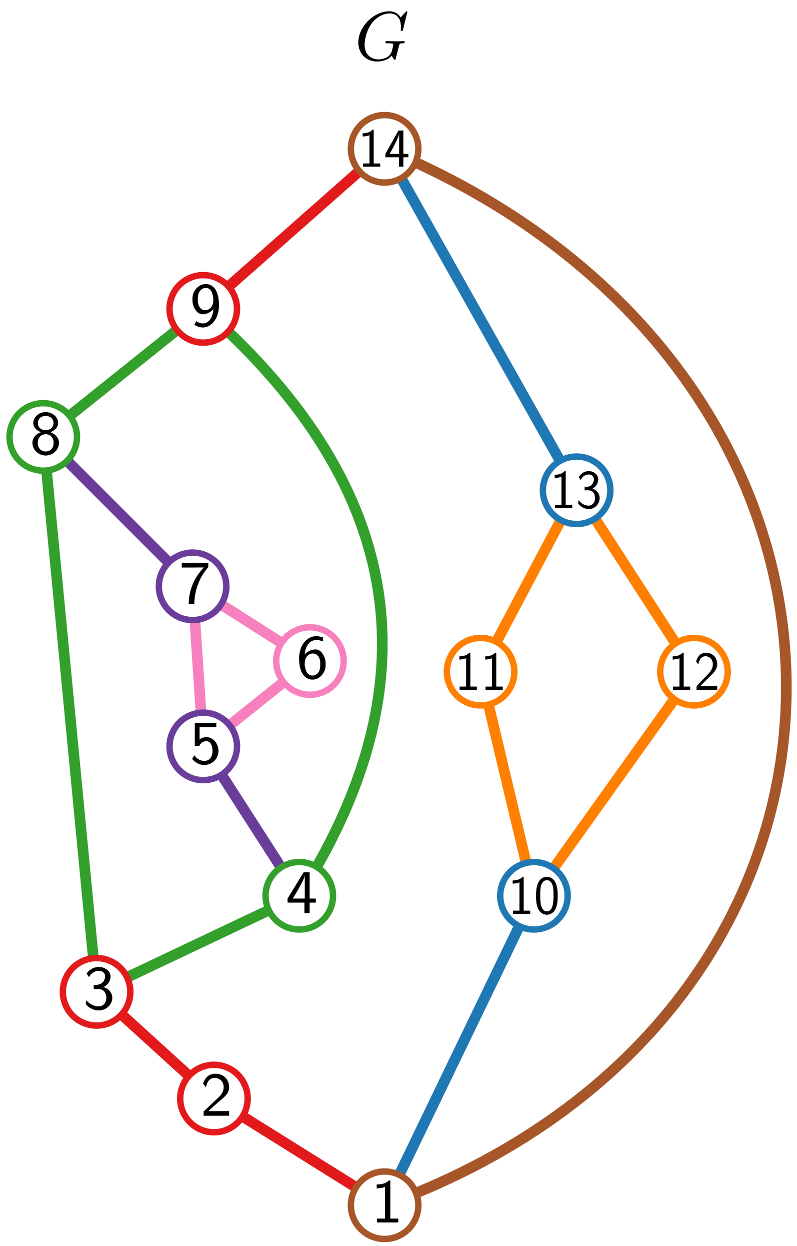

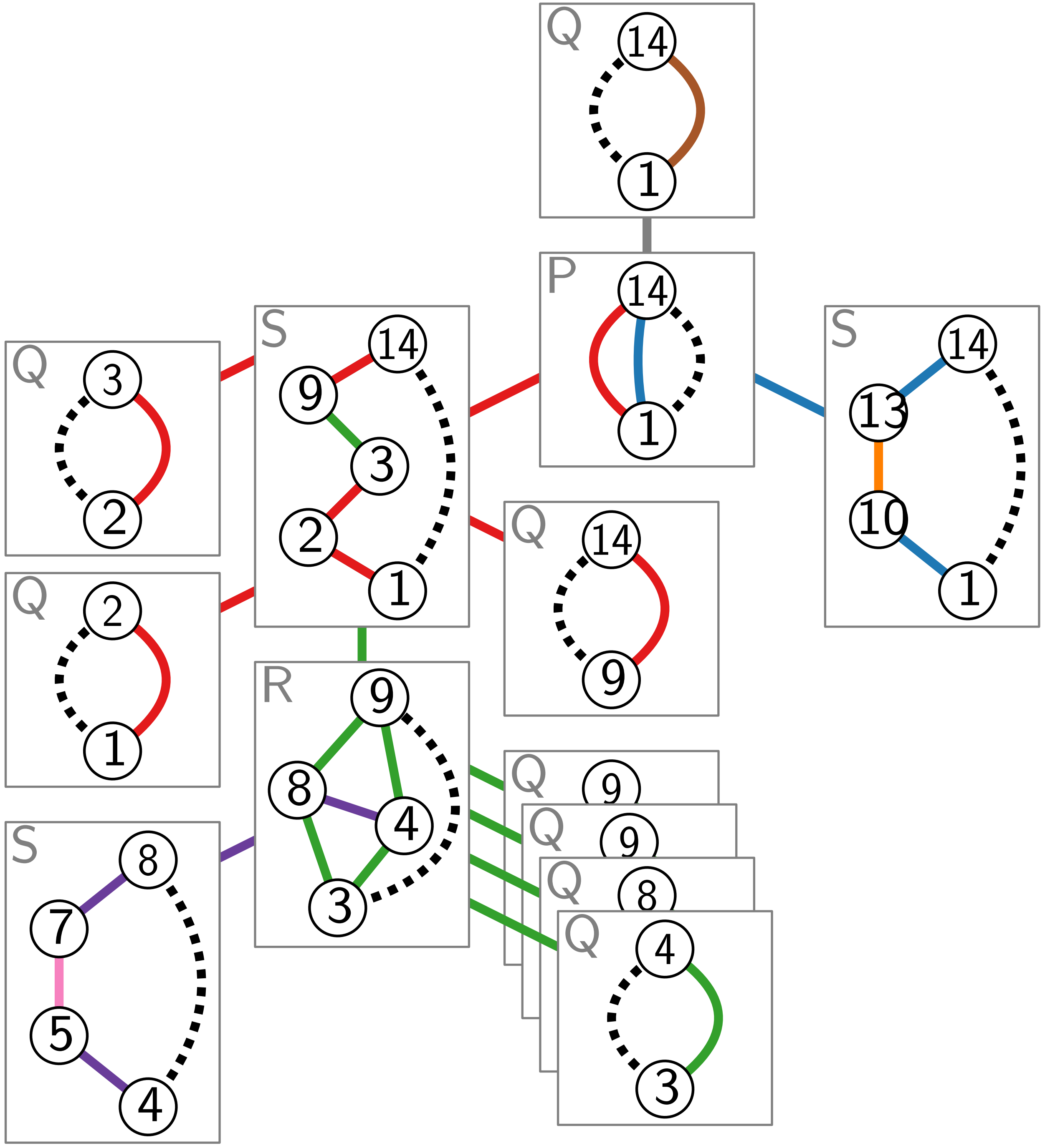

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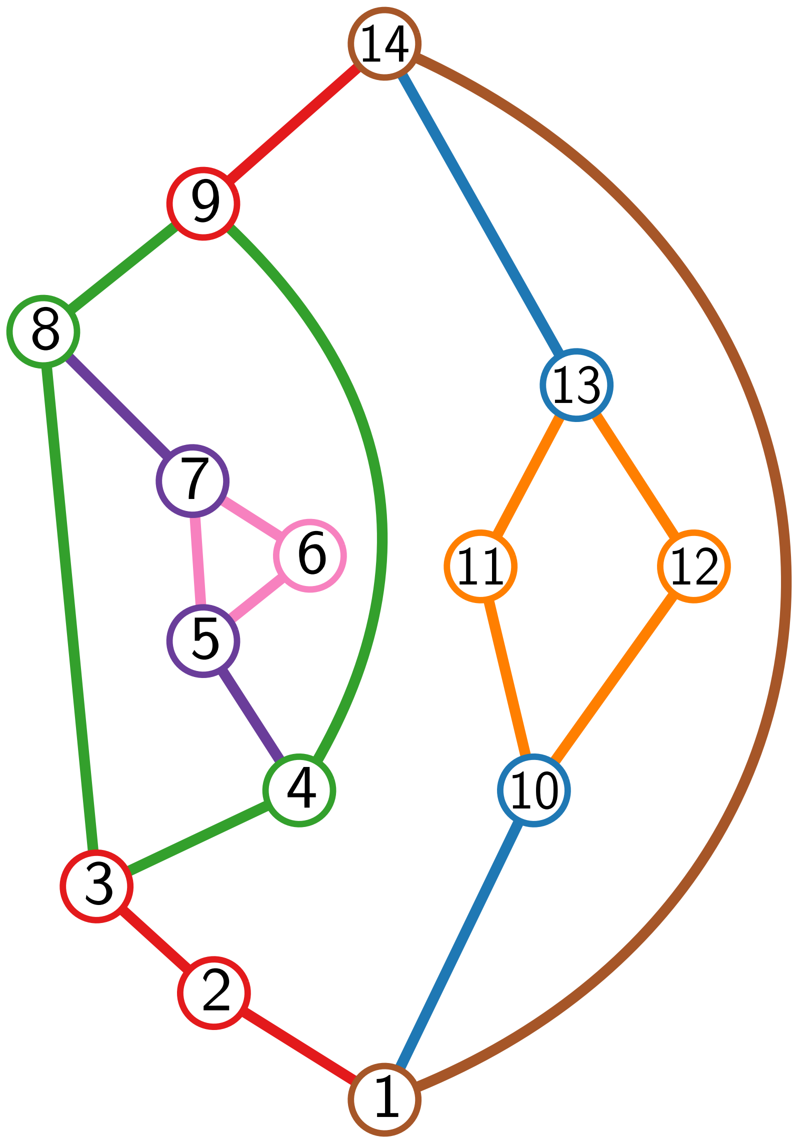
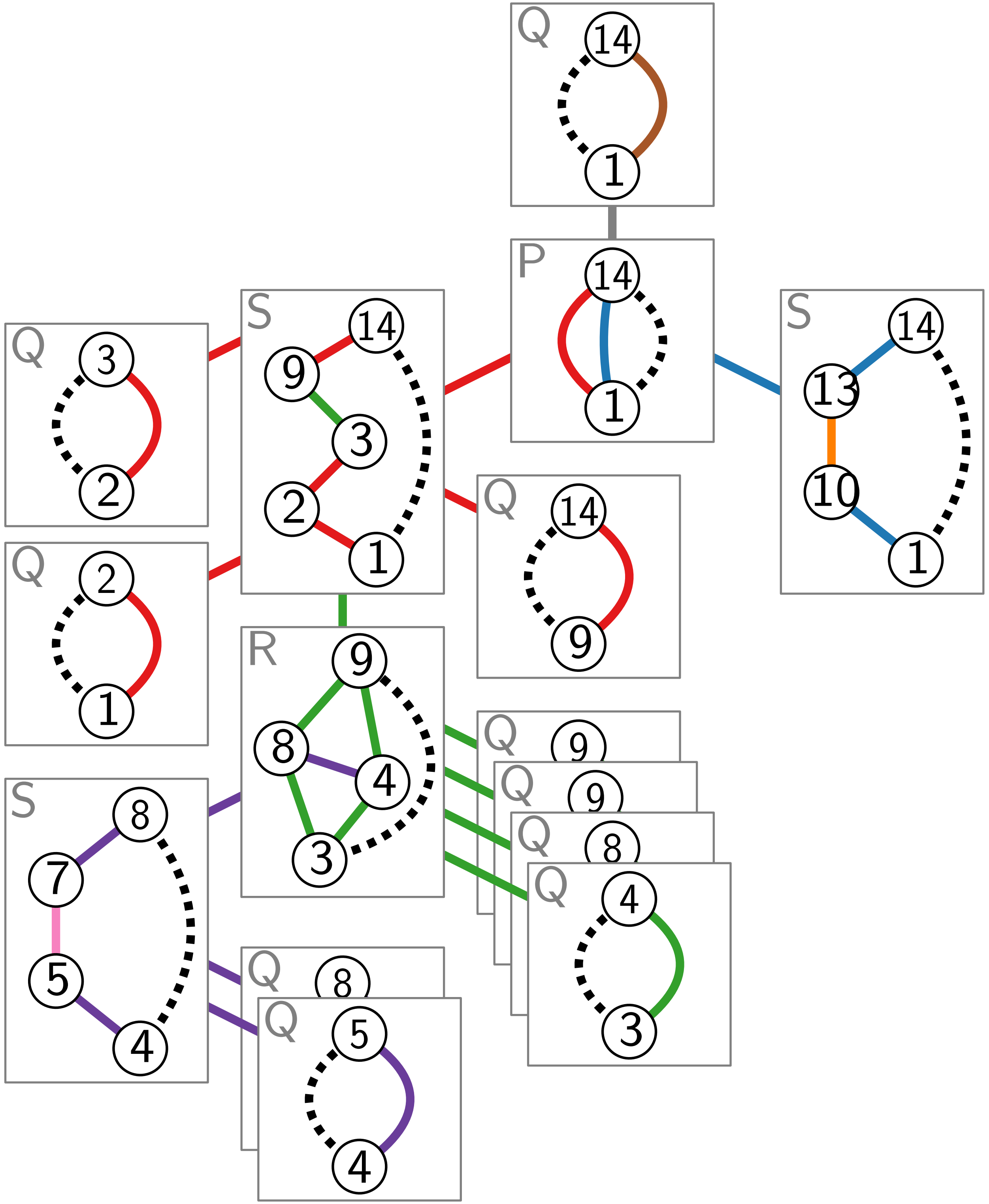
G





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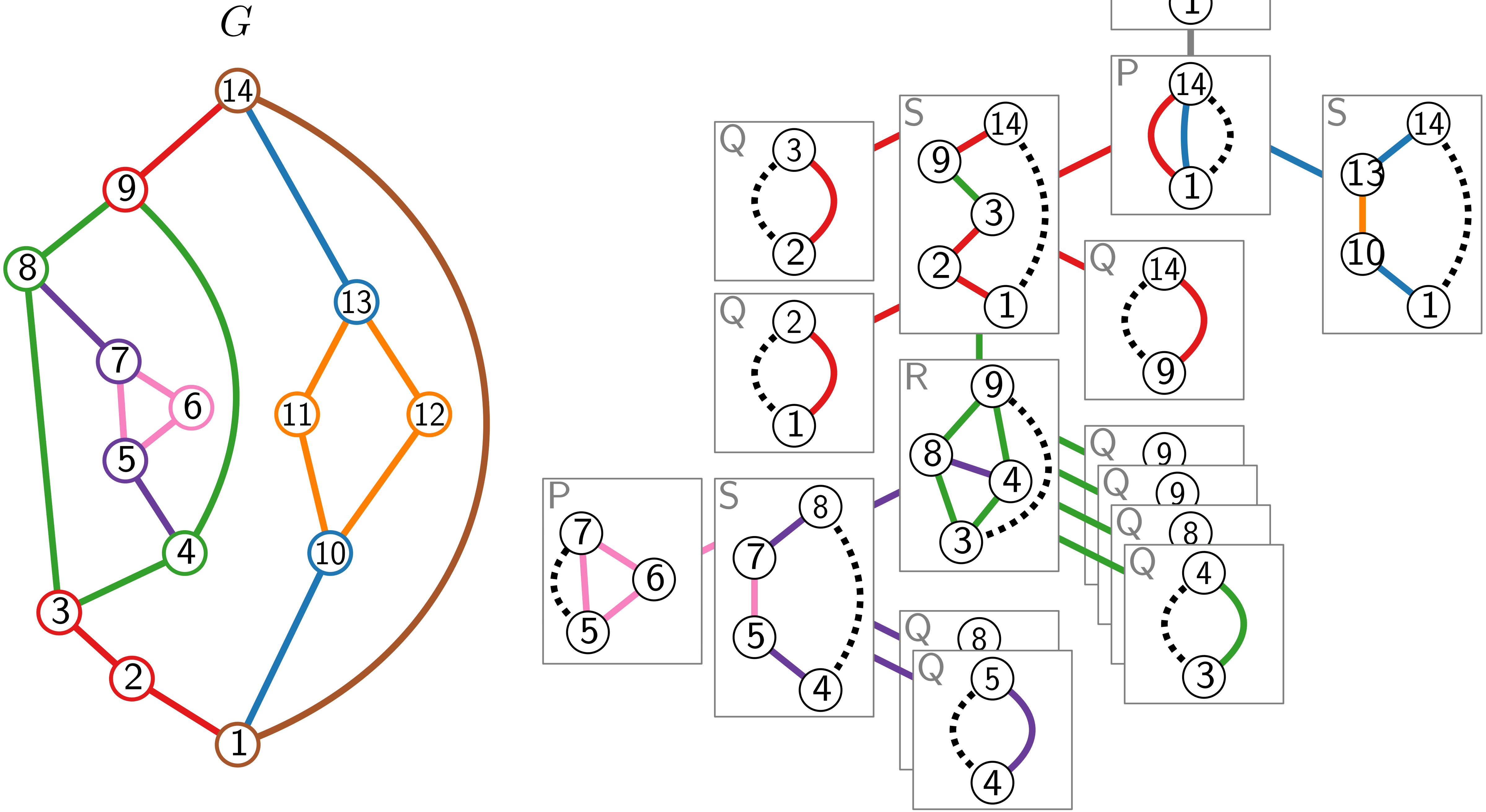

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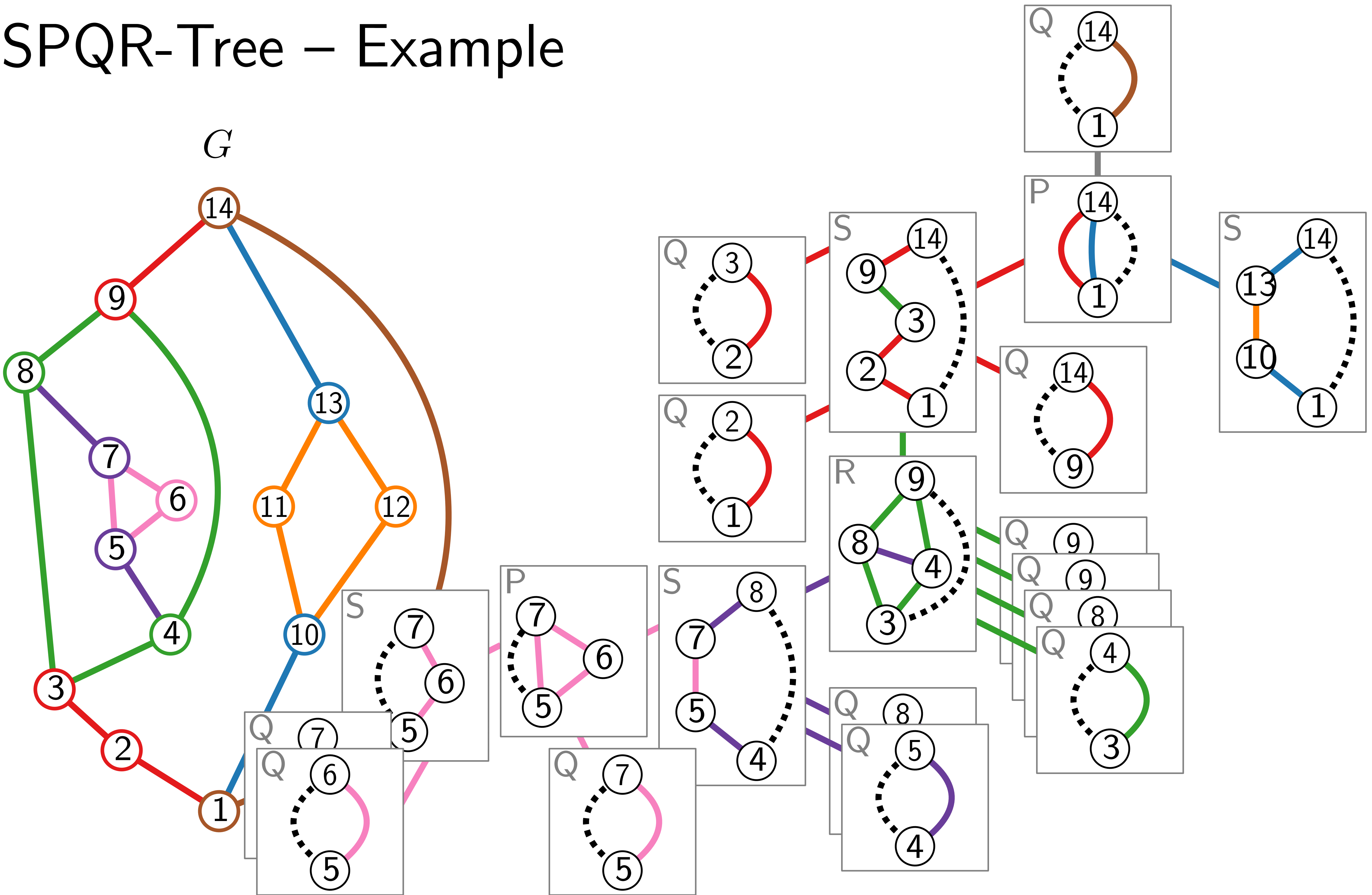

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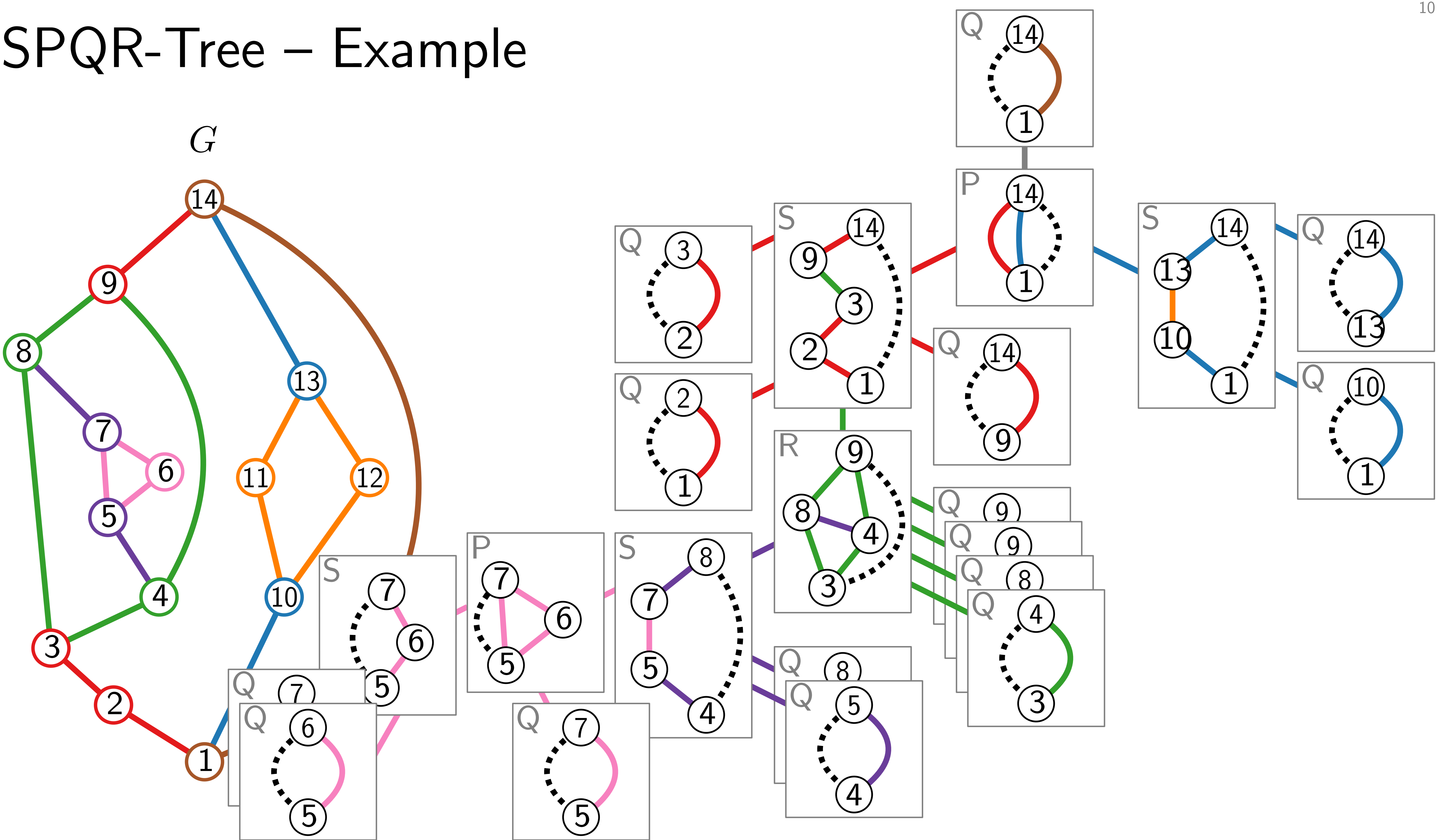

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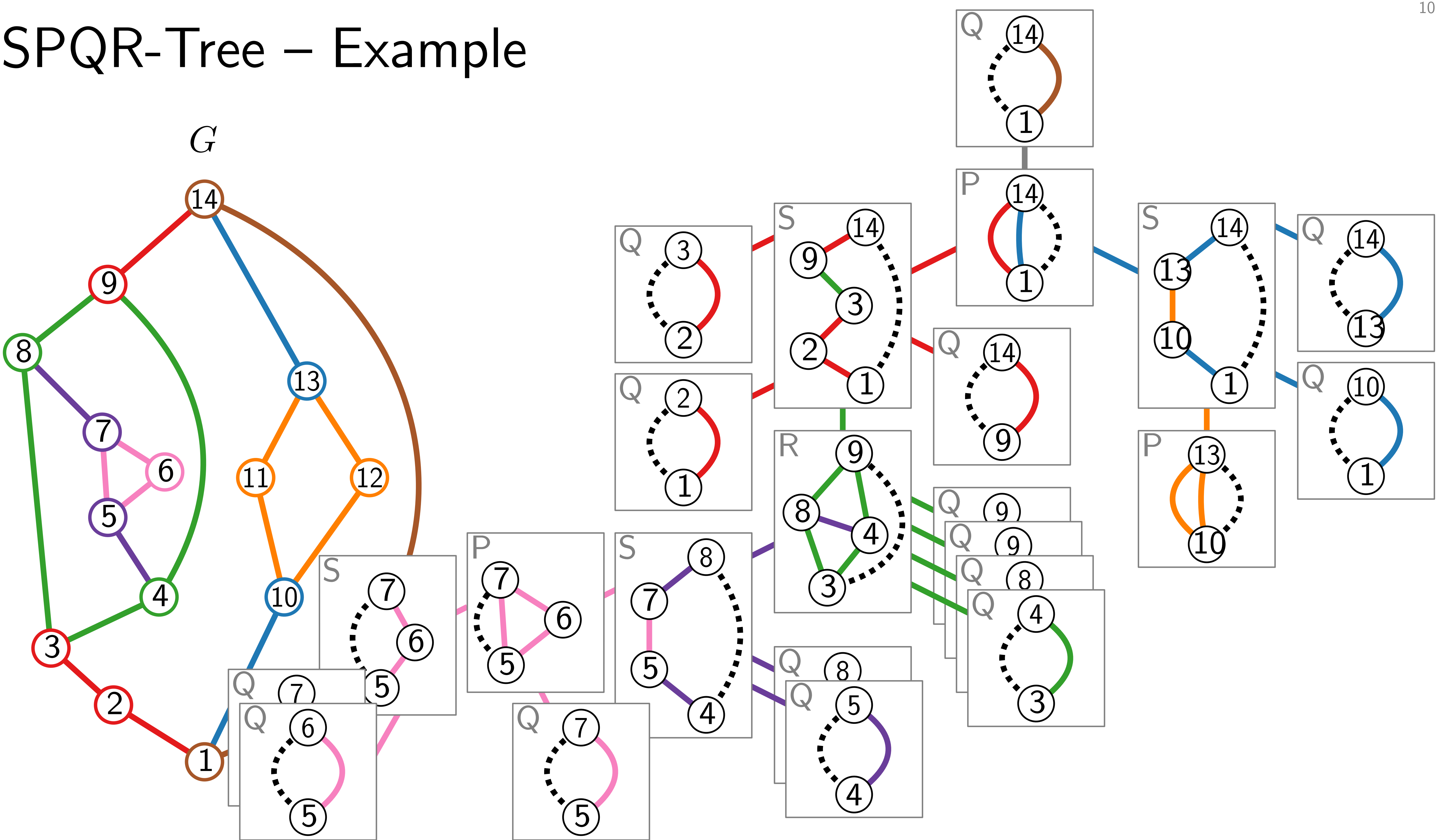

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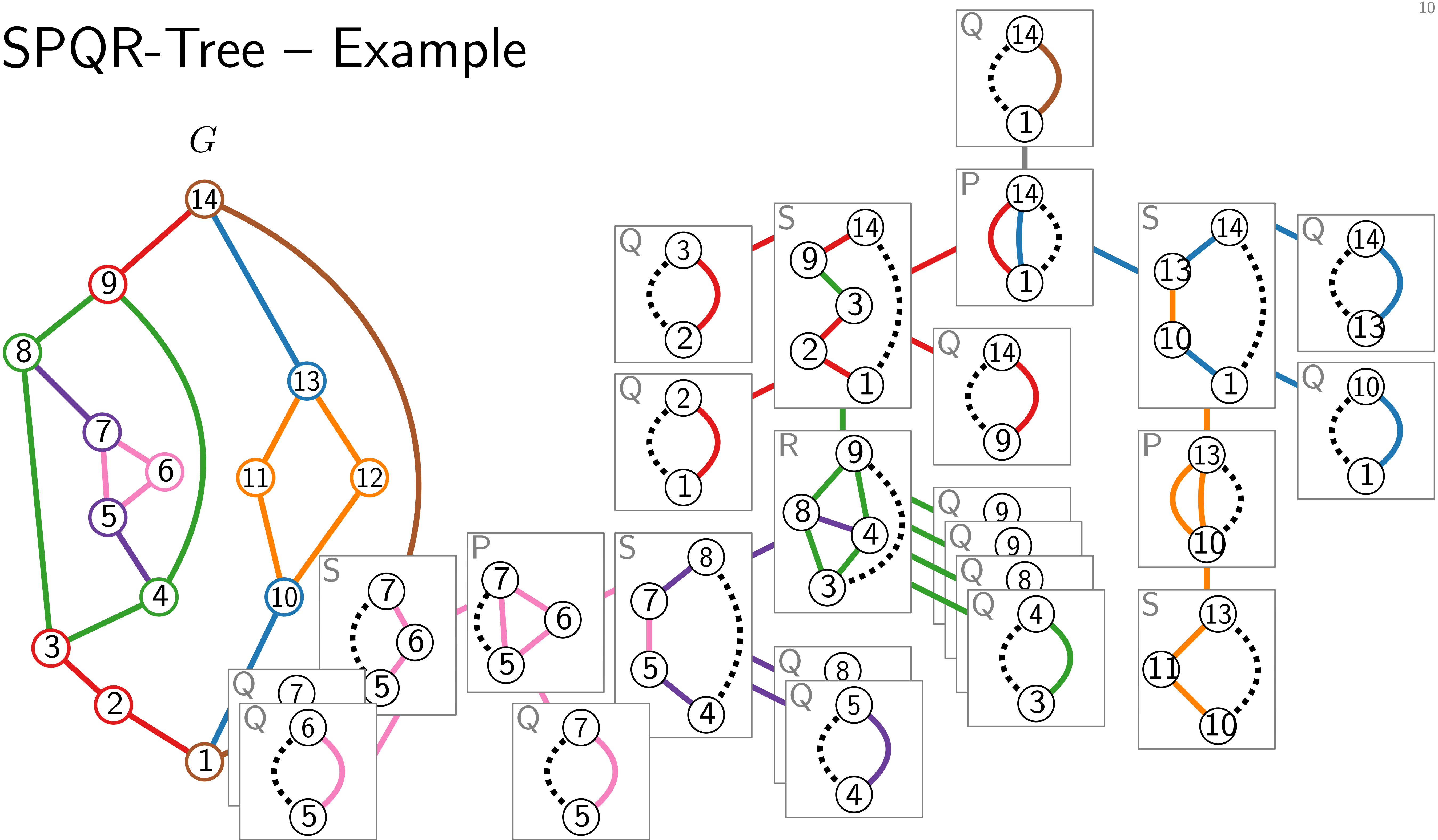

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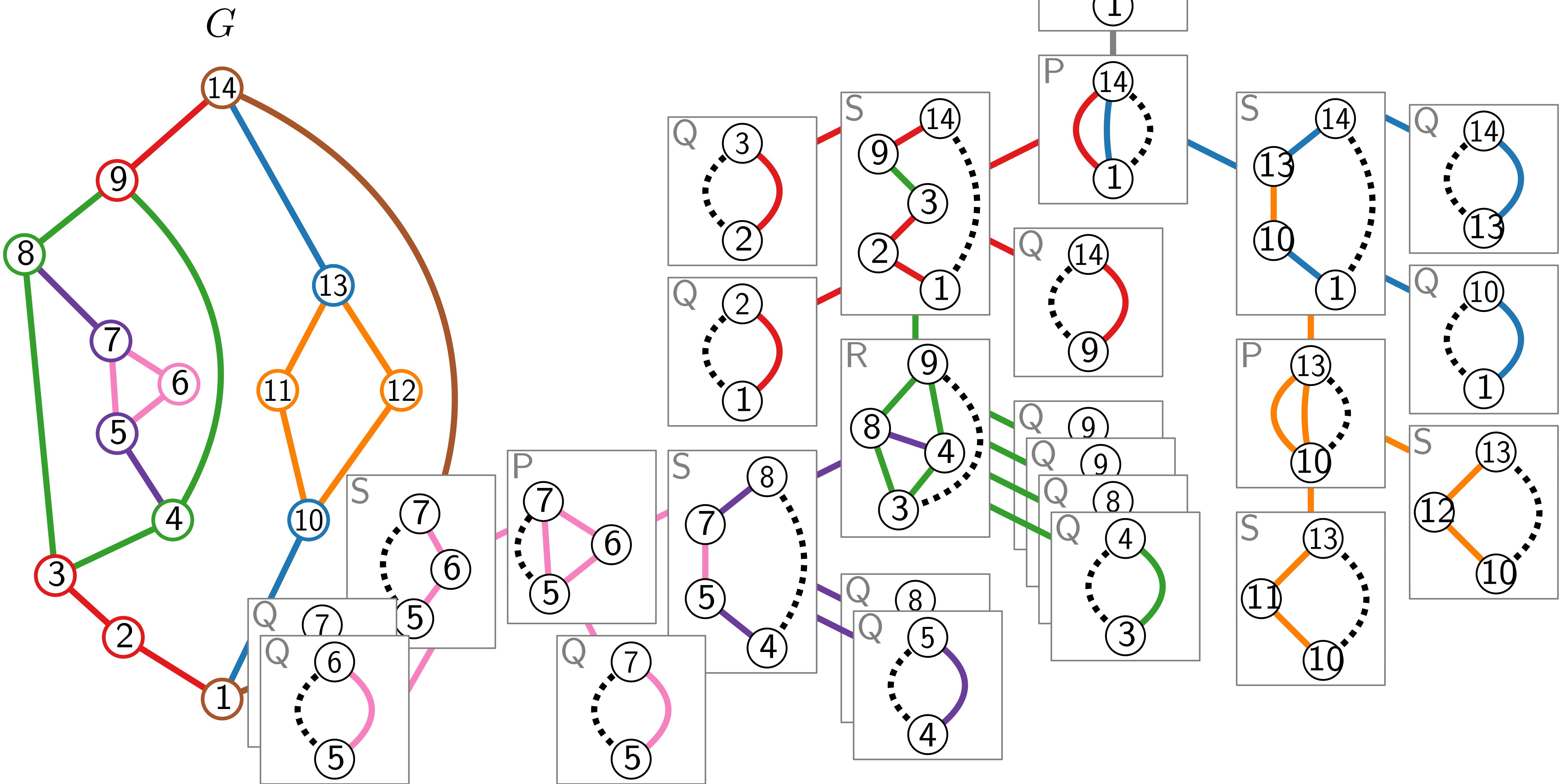

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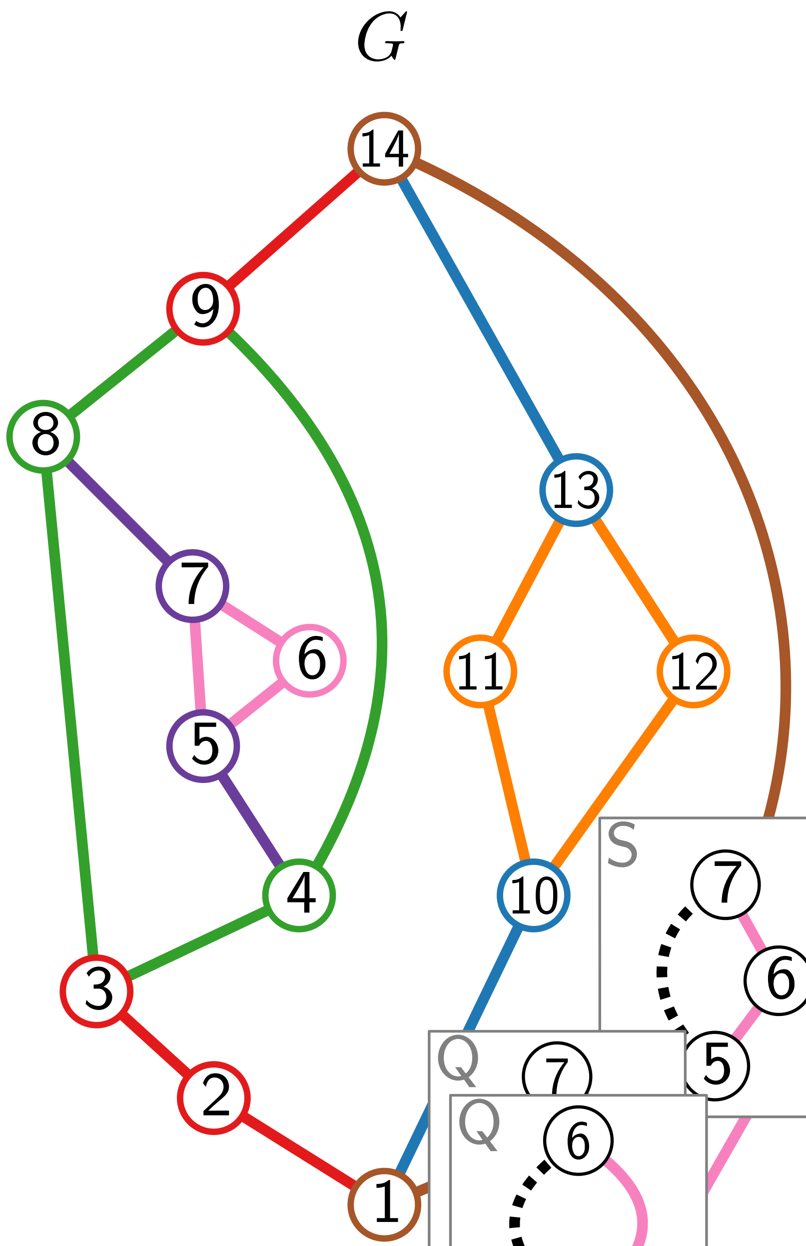

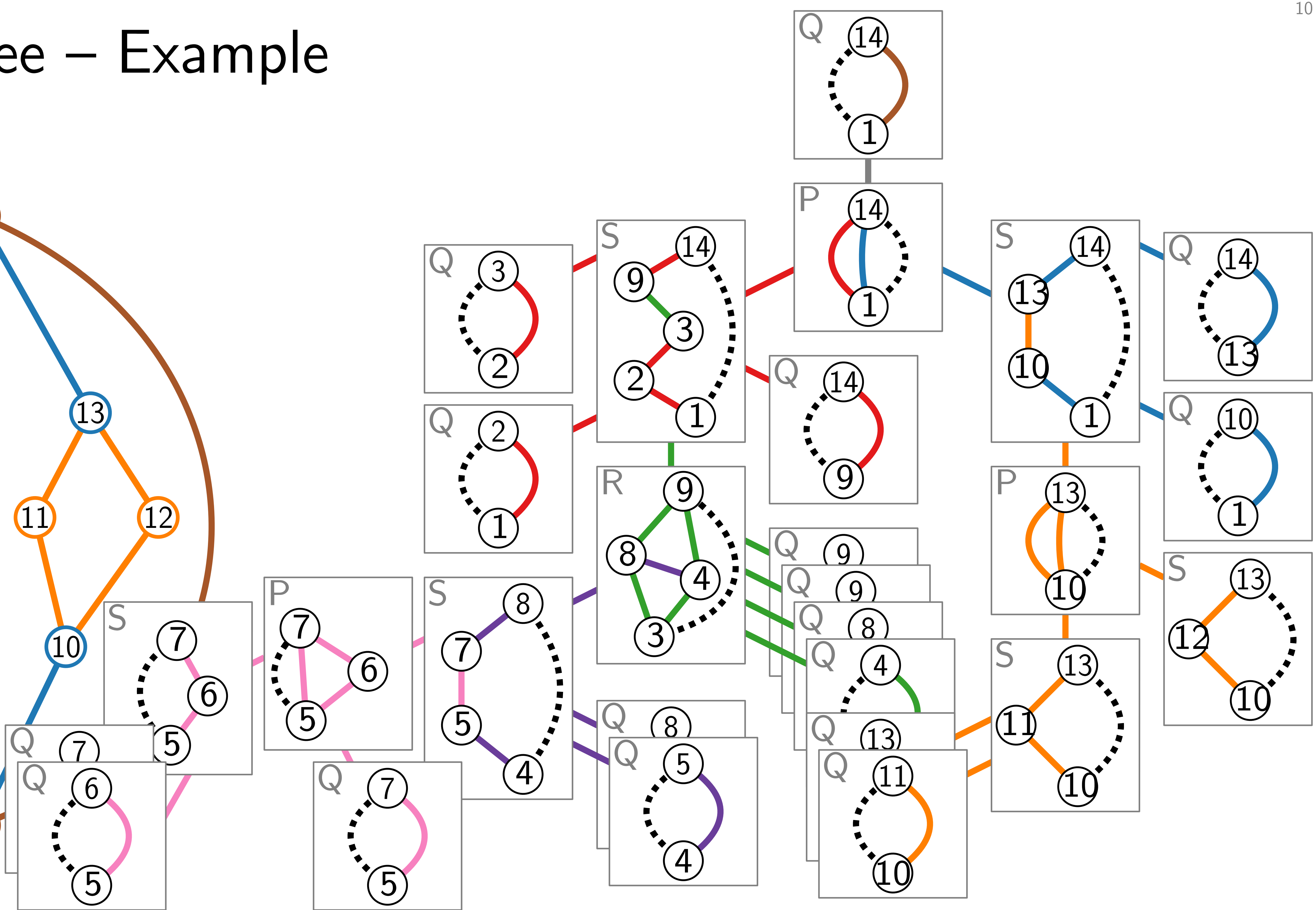

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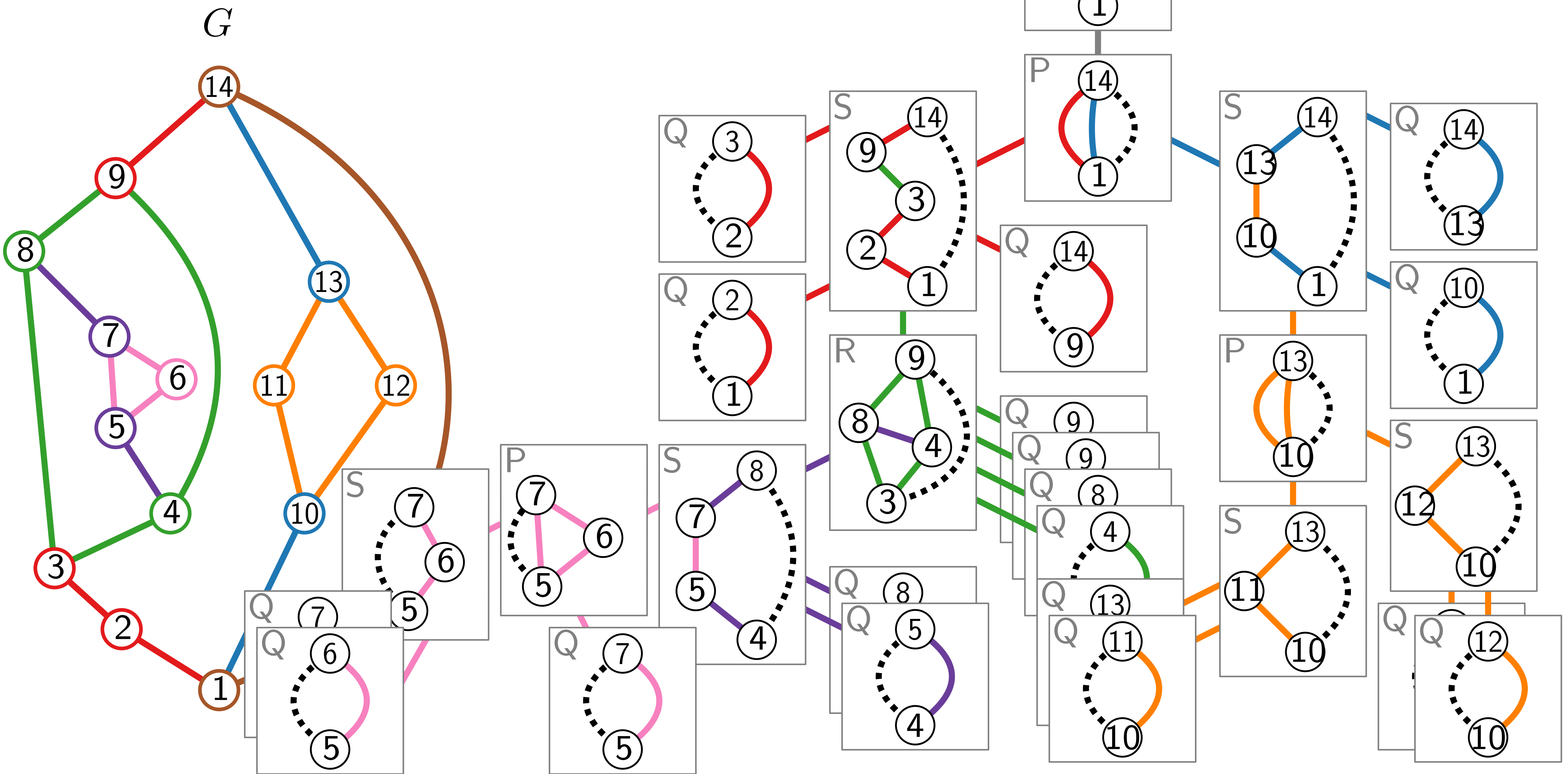
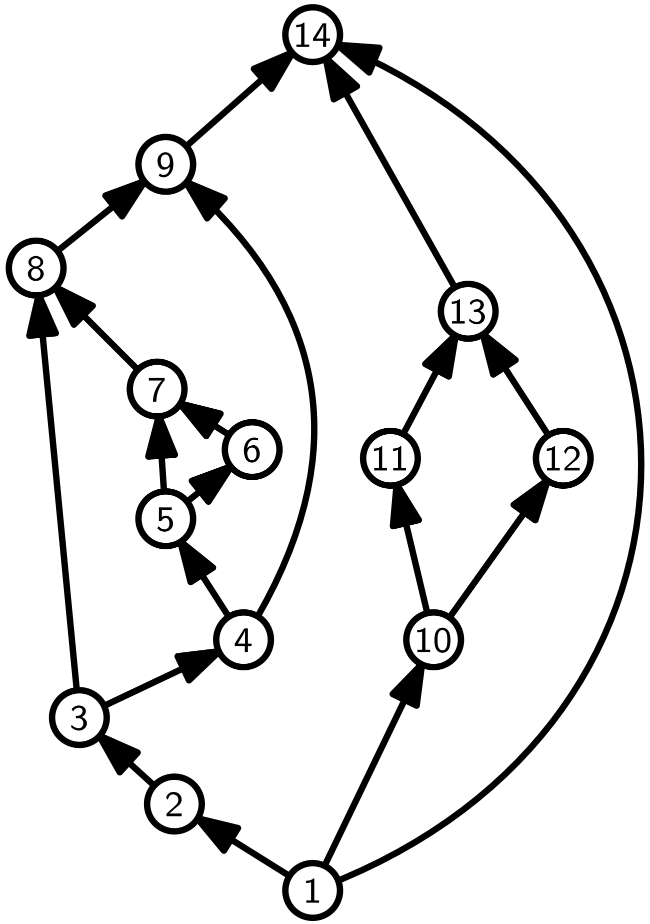


Representation Extension for st-Graphs

Theorem 1'.
Rectangular ε-bar visibility representation extension can be solved in $\mathcal{O}(n^2)$ time for st-graphs.



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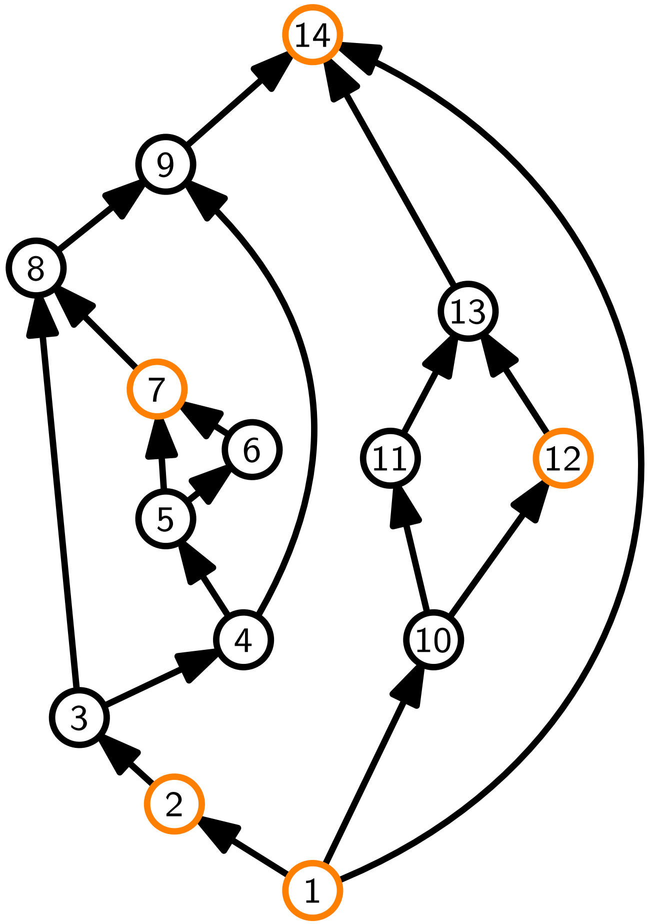

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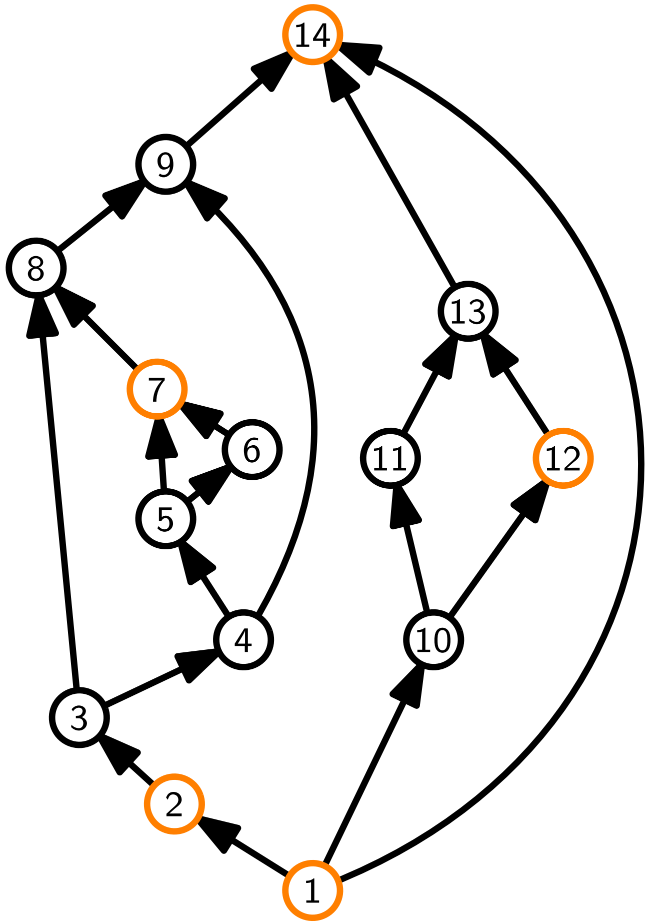

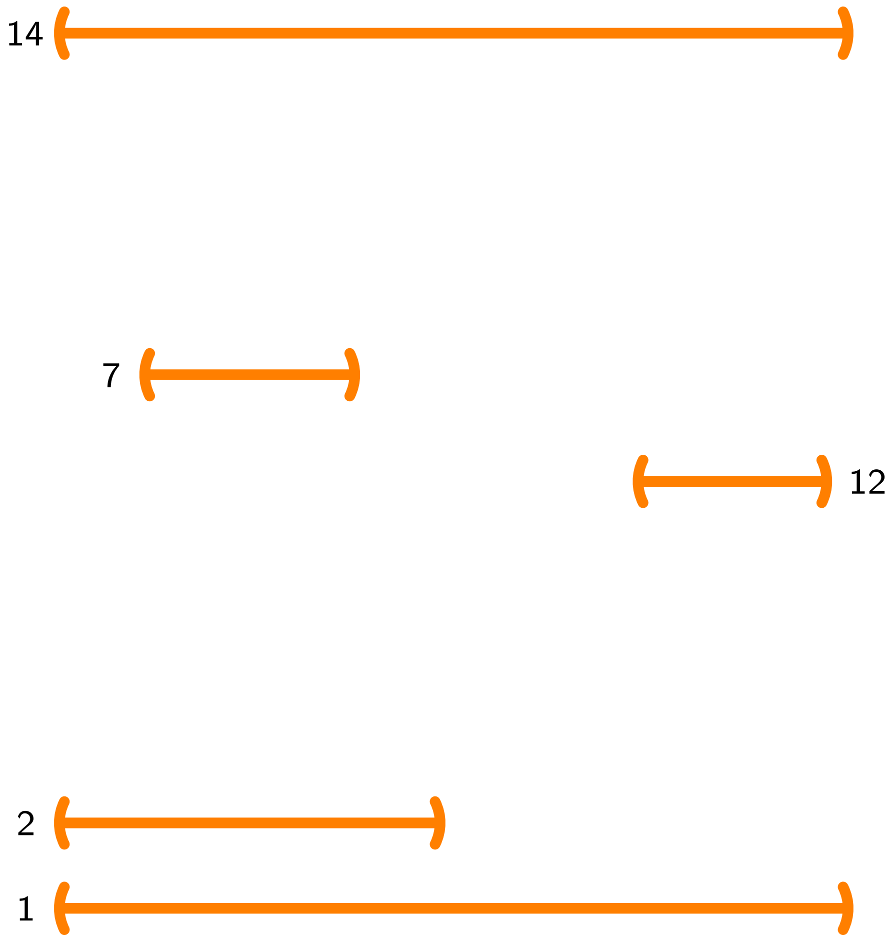

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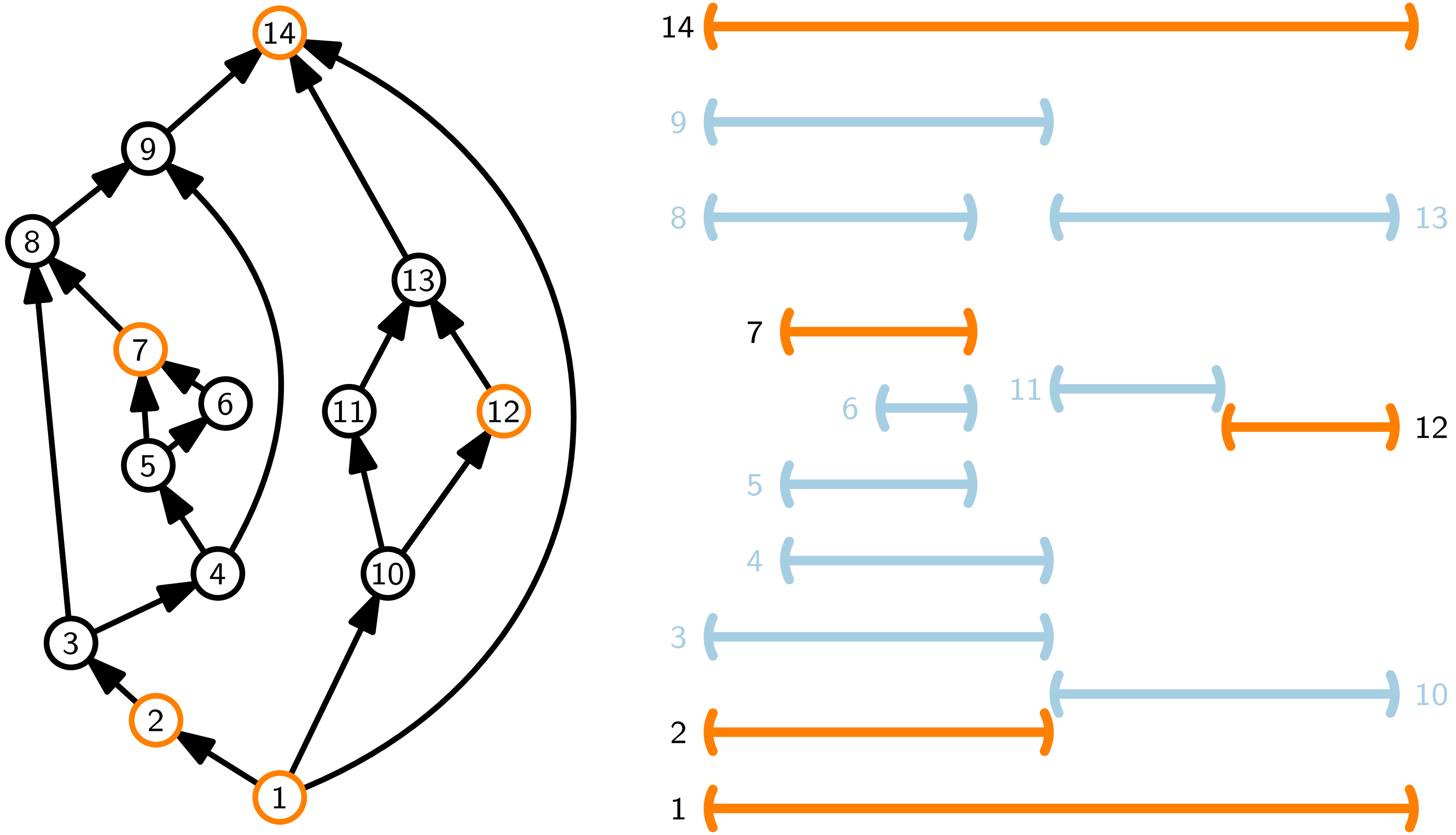

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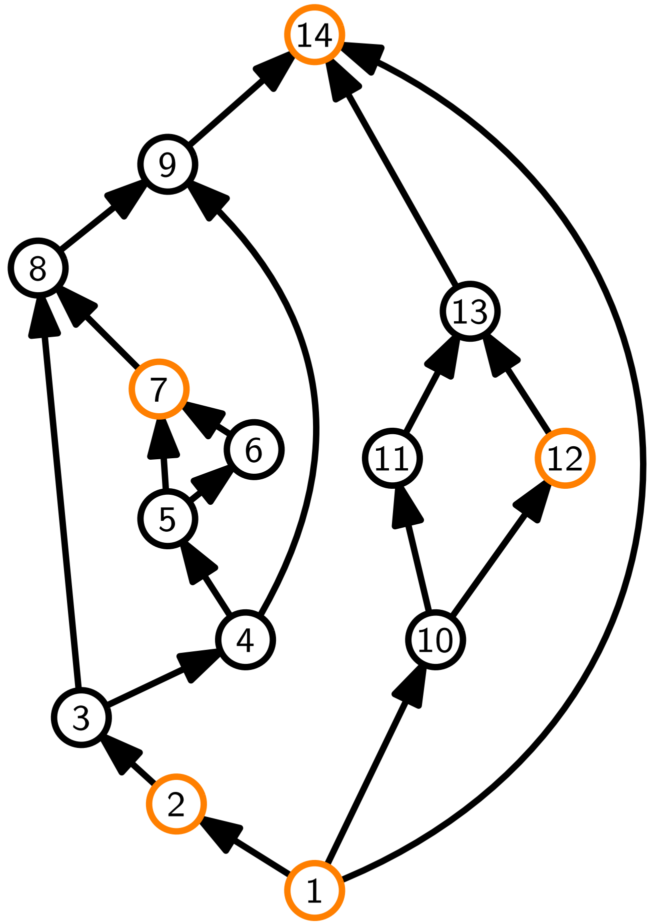

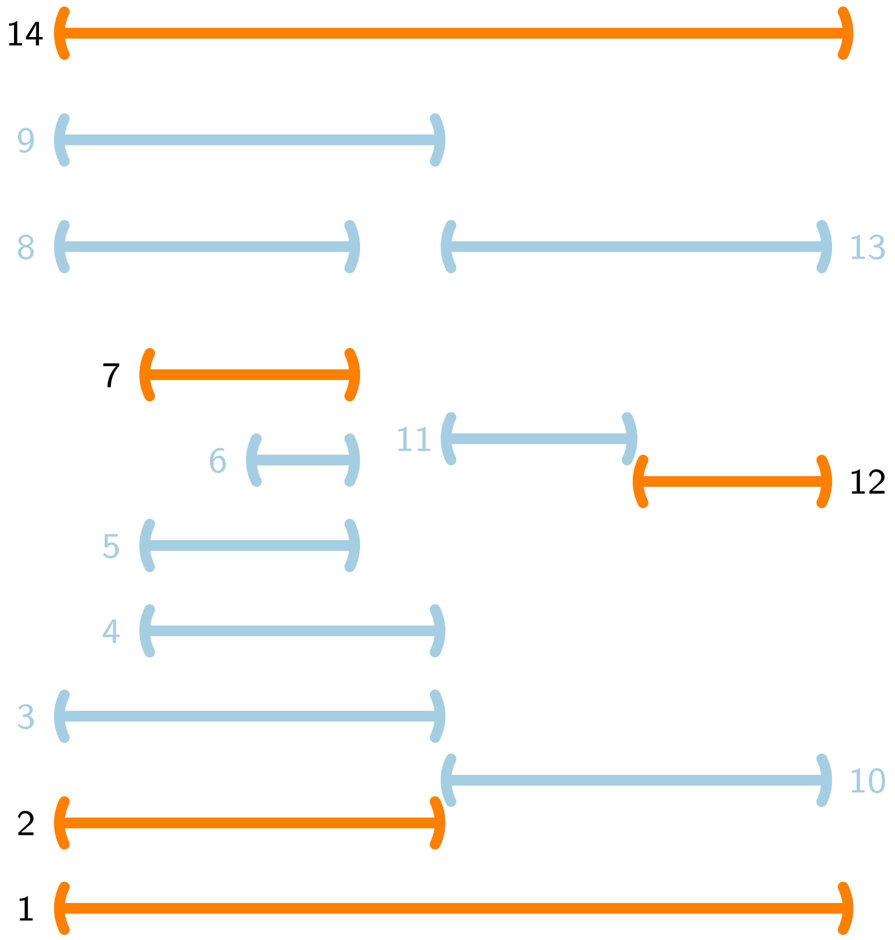

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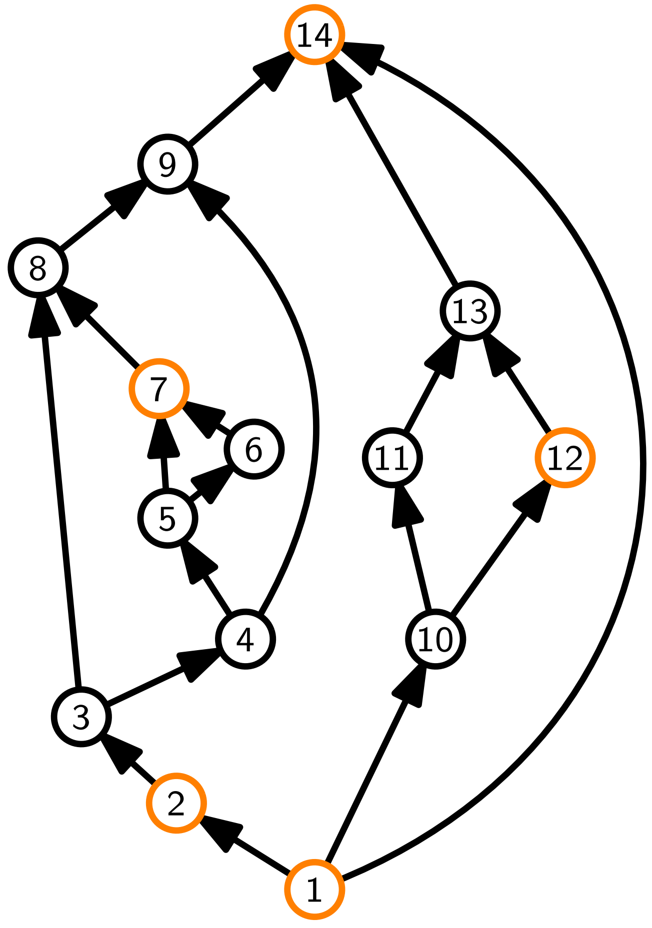

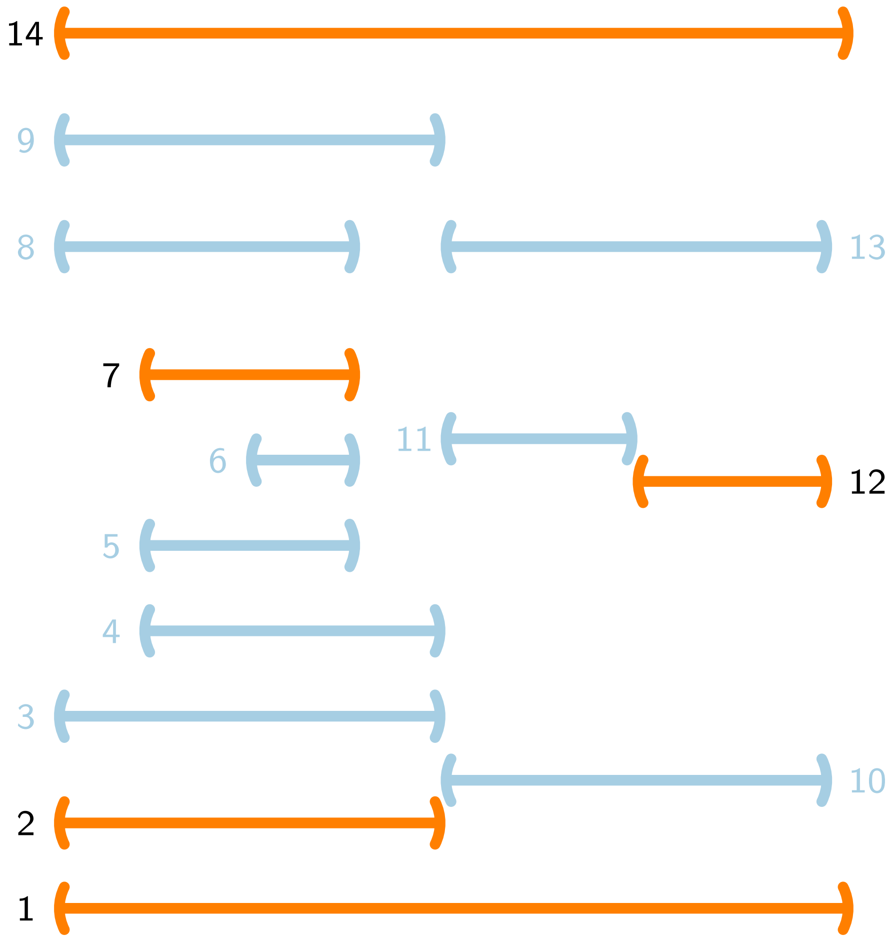

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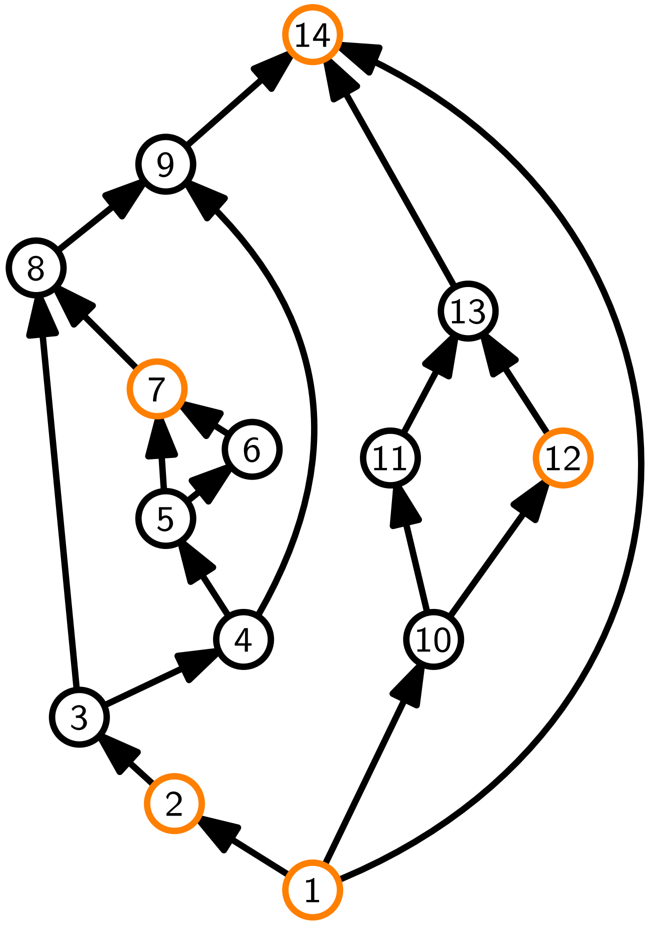

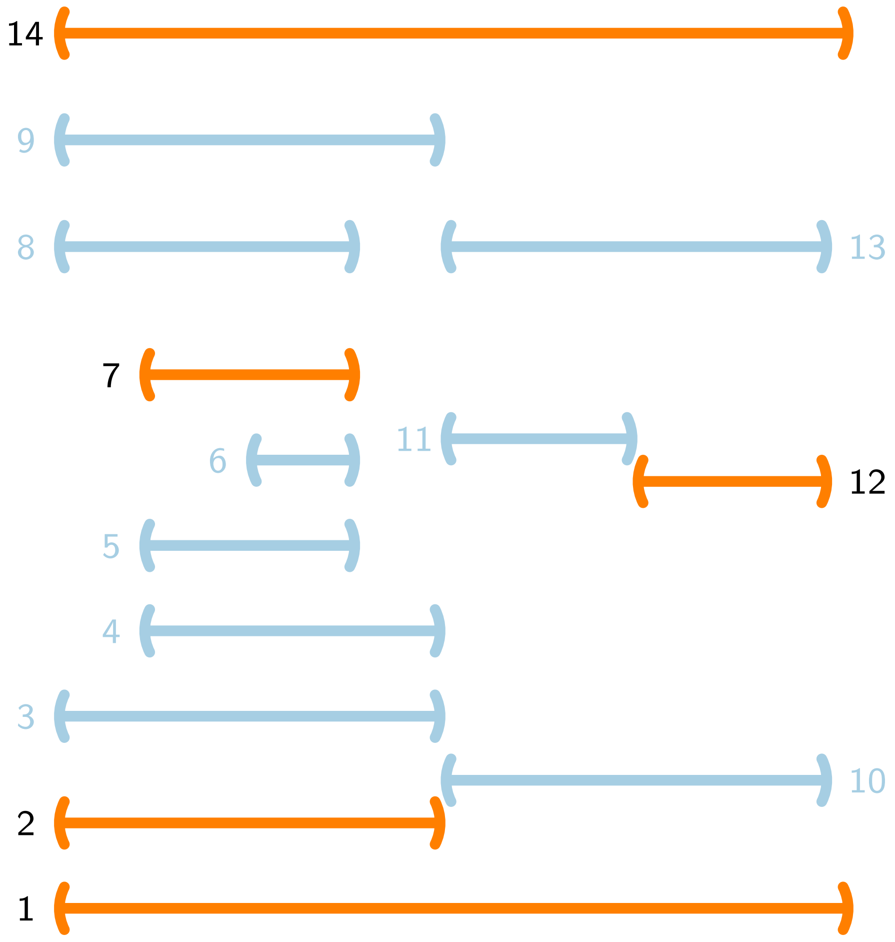

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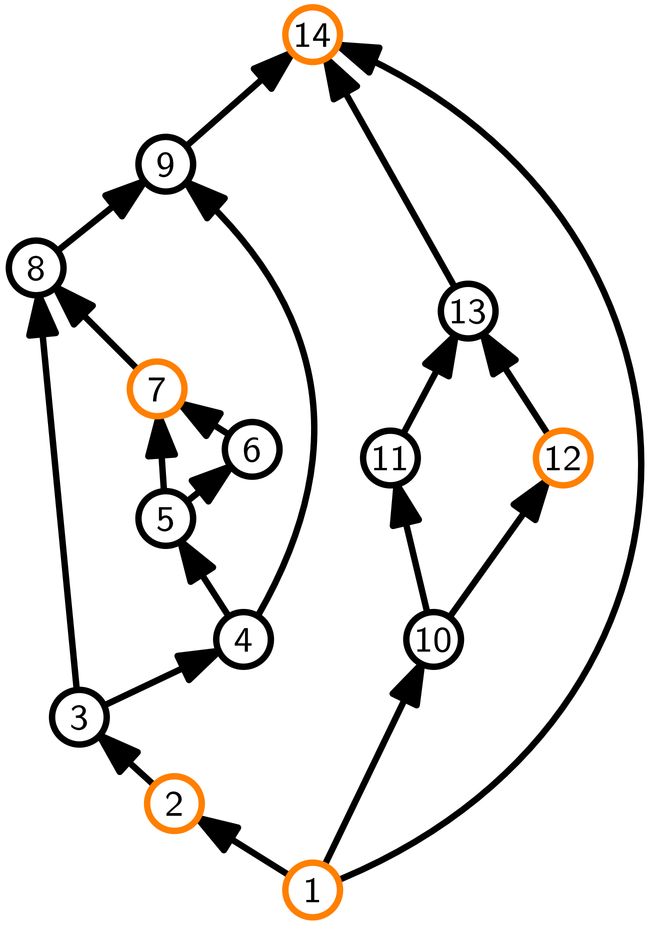

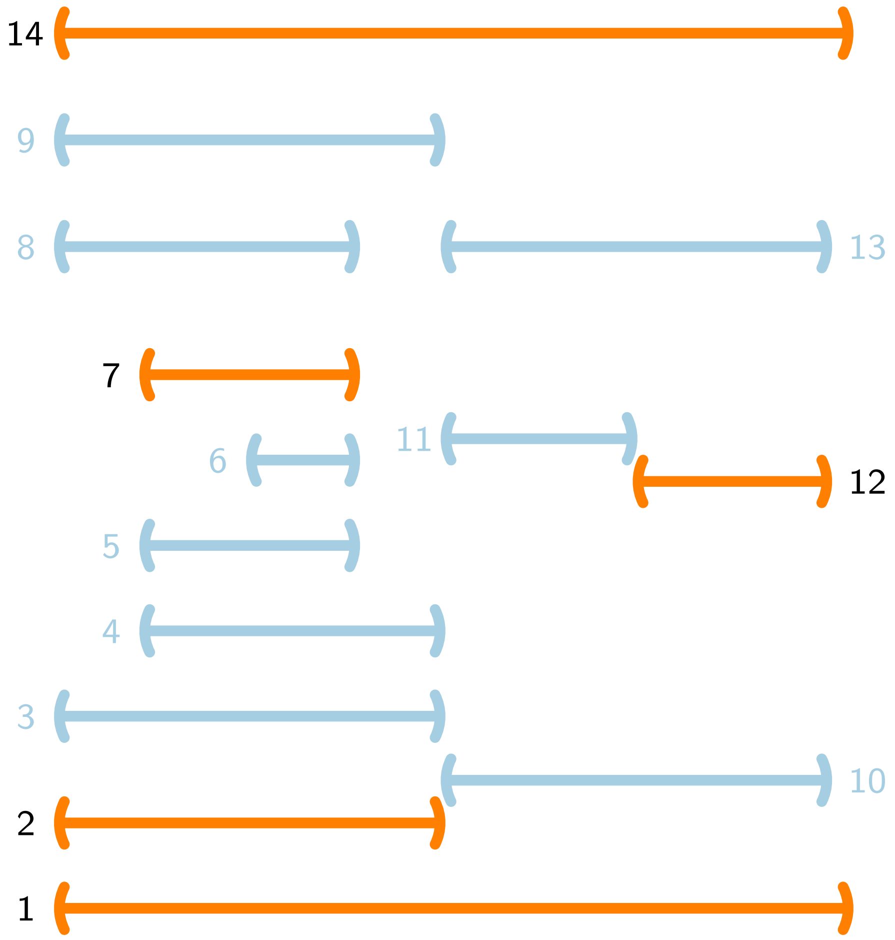

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- Dynamic program via structure of SPQR-tree

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Proof idea. The relative positions of **adjacent** bars must match the order given by y.
So, we can adjust the y-coordinates of any solution to be as in y by sweeping from bottom to top.

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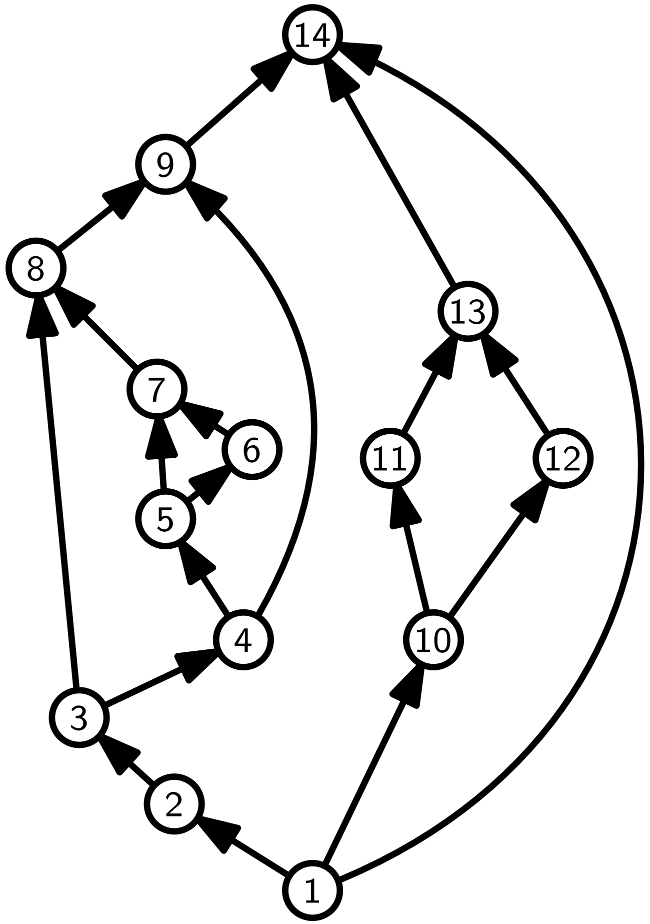
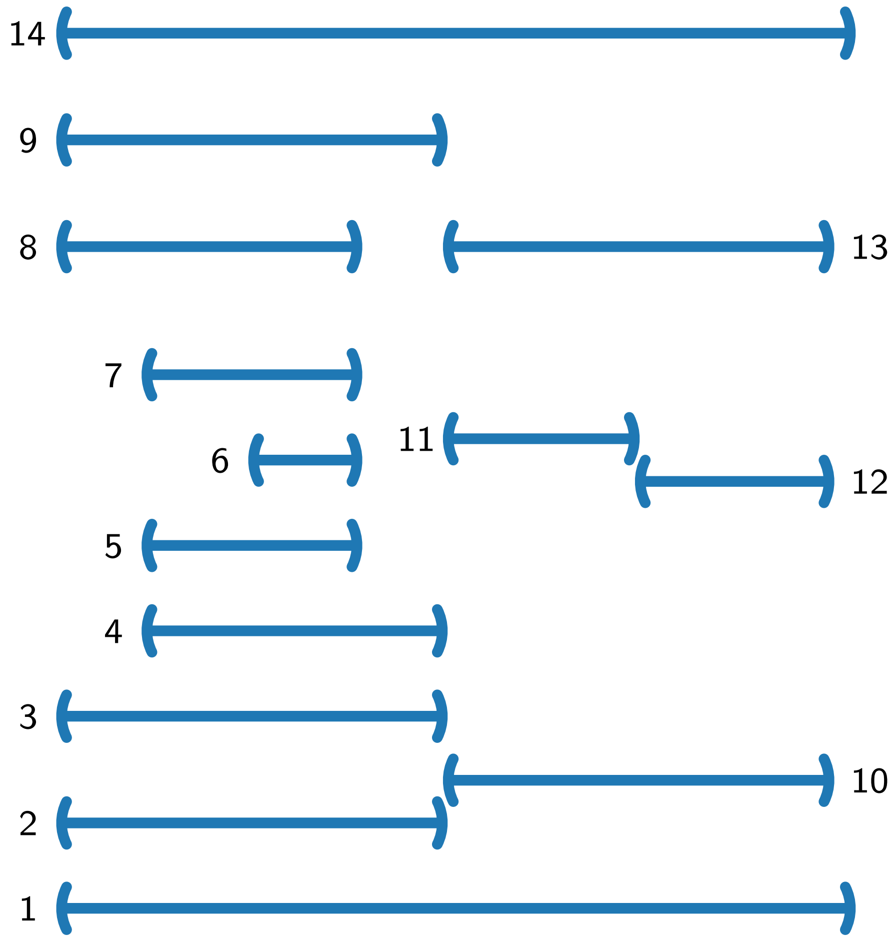
G has a representation extending ψ'
where the y-coordinates of the bars are as in y.

We can now assume that all y-coordinates are given!

Proof idea. The relative positions of **adjacent** bars must match the order given by y.
So, we can adjust the y-coordinates of any solution to be as in y by sweeping from bottom to top.

But Why Do SPQR-Trees Help?





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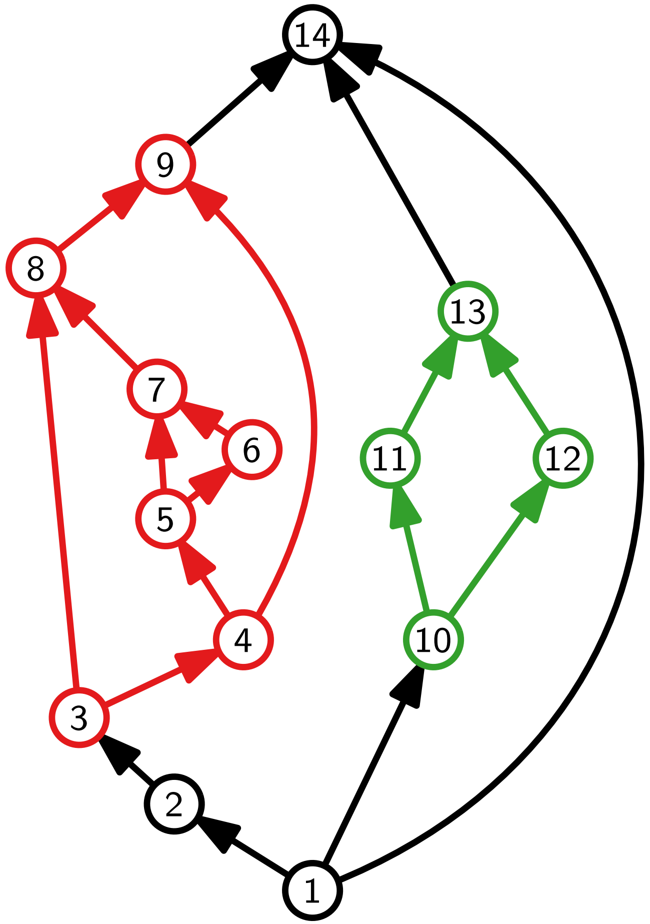

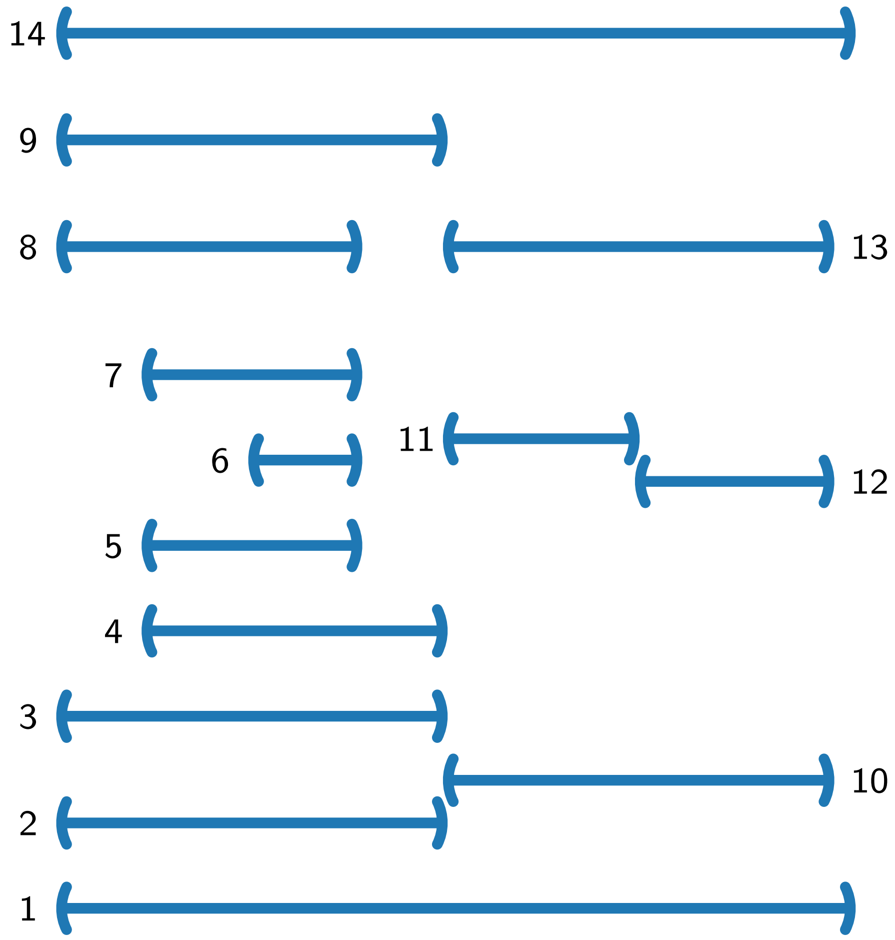

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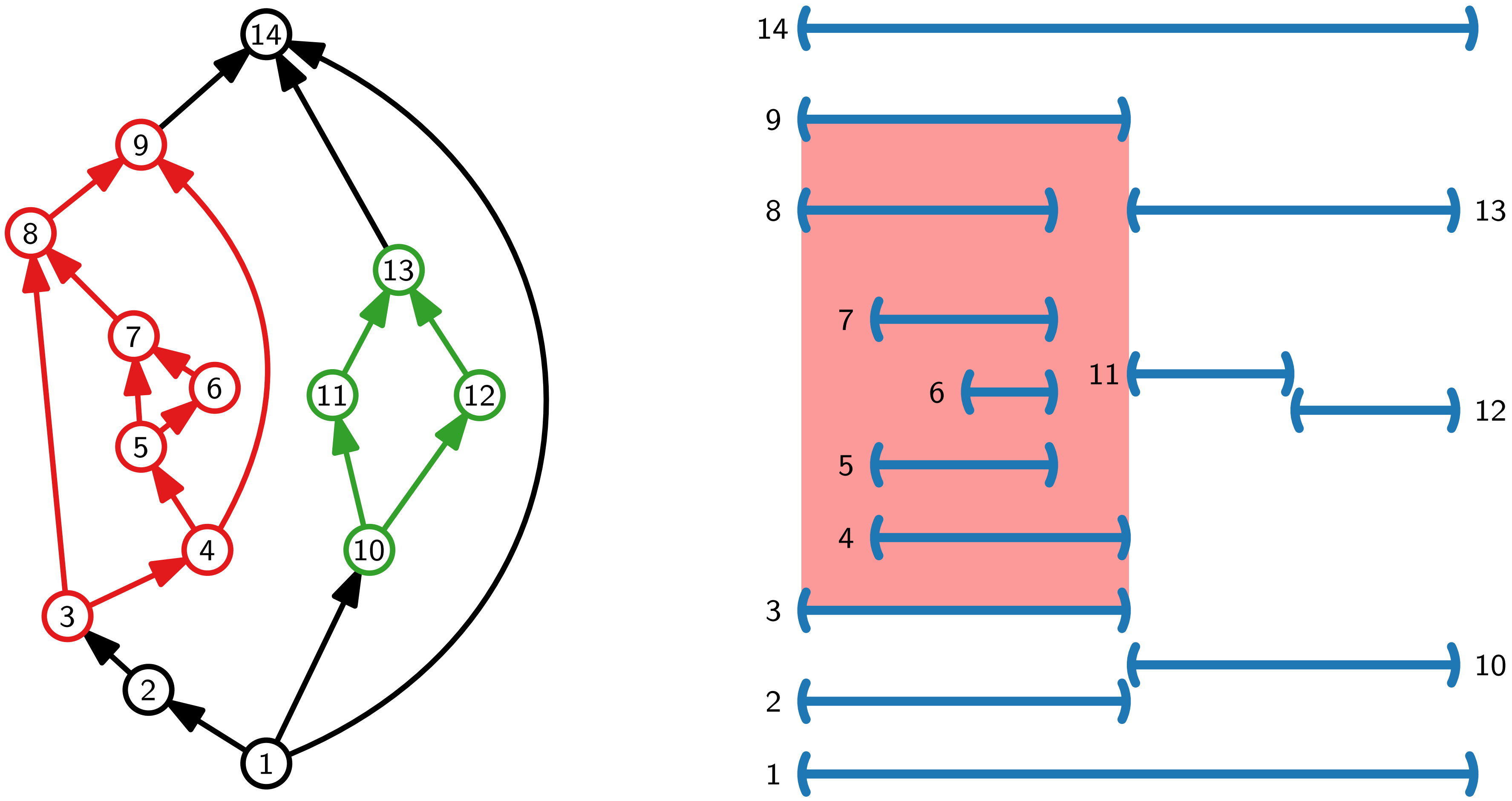

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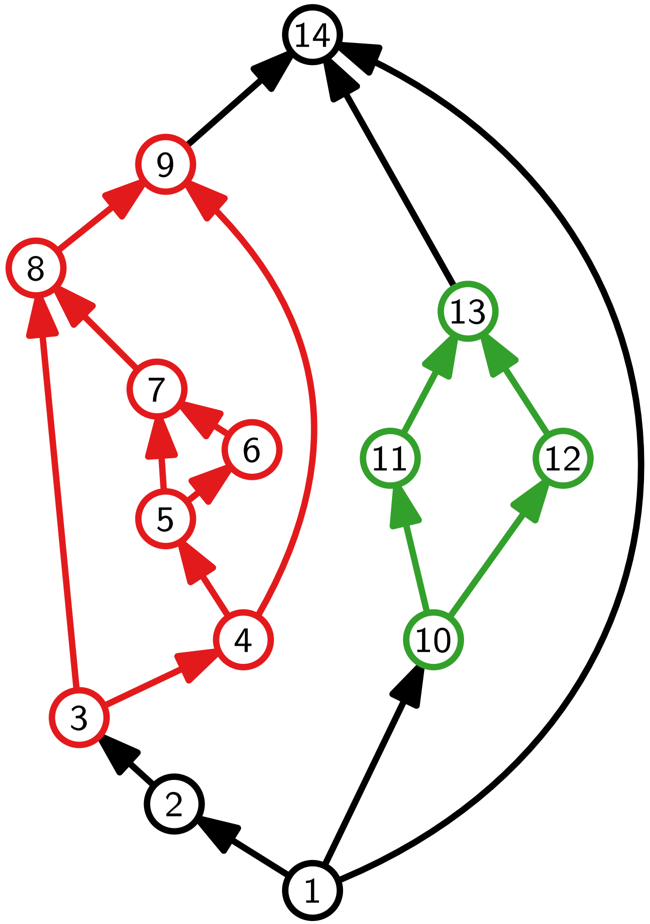
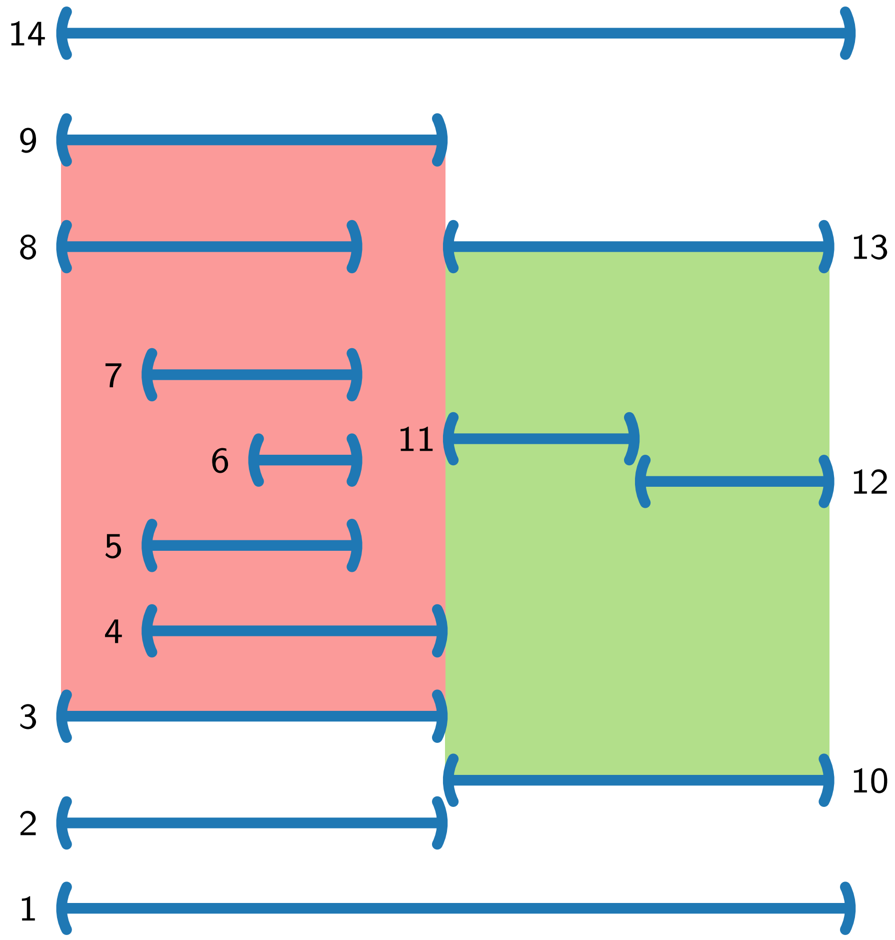
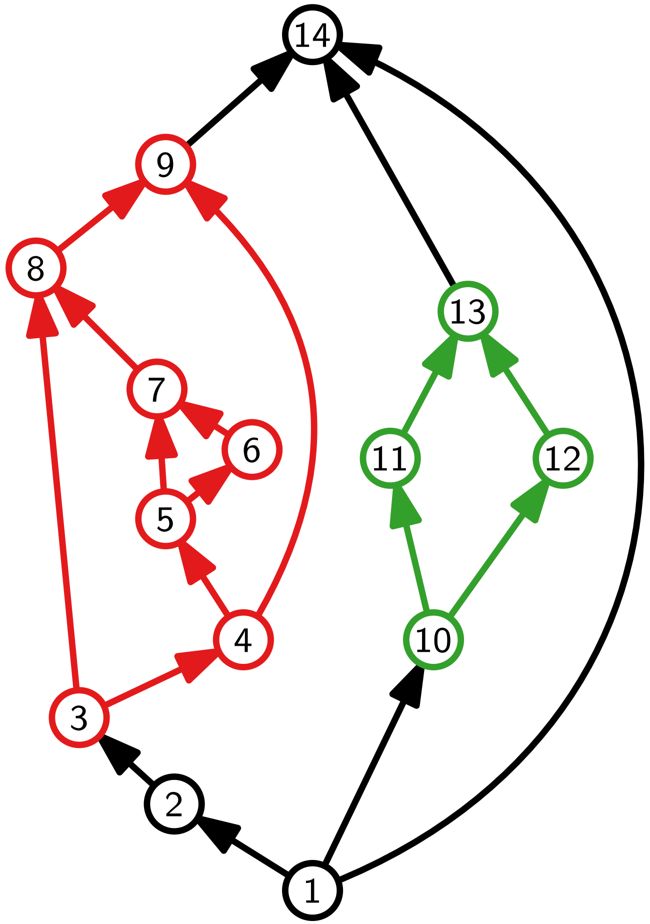
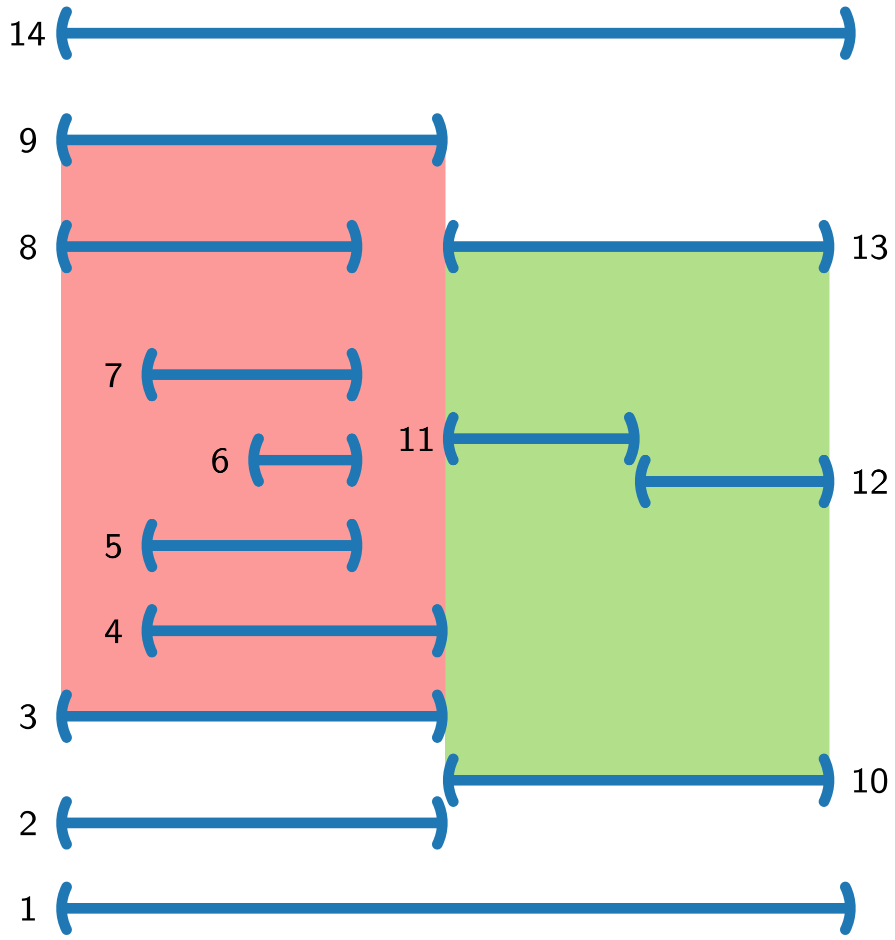




But Why Do SPQR-Trees Help?

Lemma 2.
The SPQR-tree of an st-graph G induces a recursive **tiling** of any ε-bar visibility representation of G.





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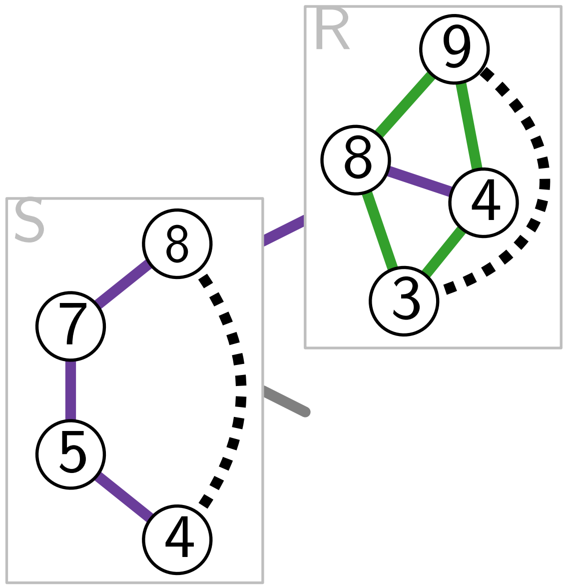
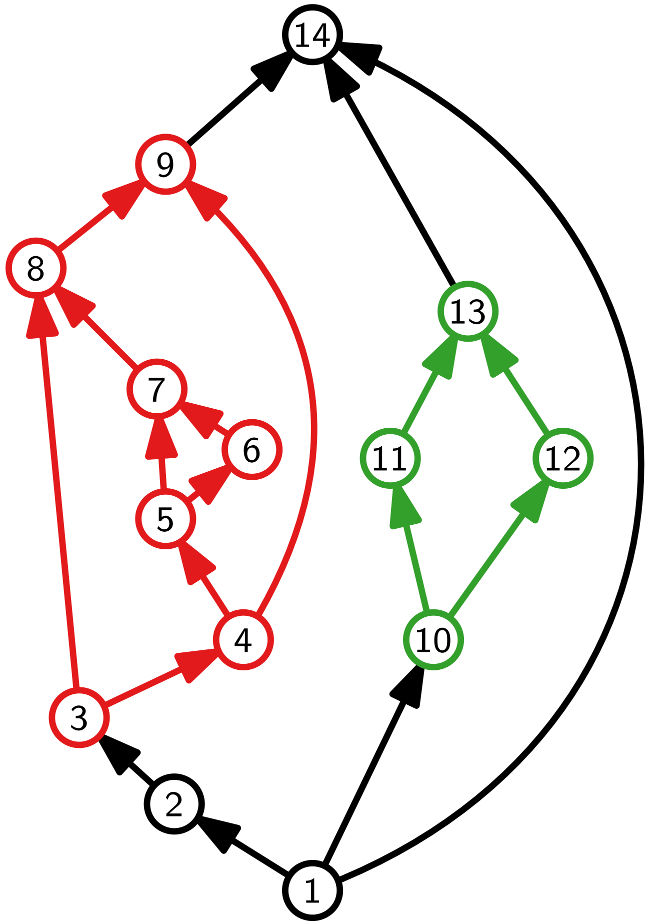
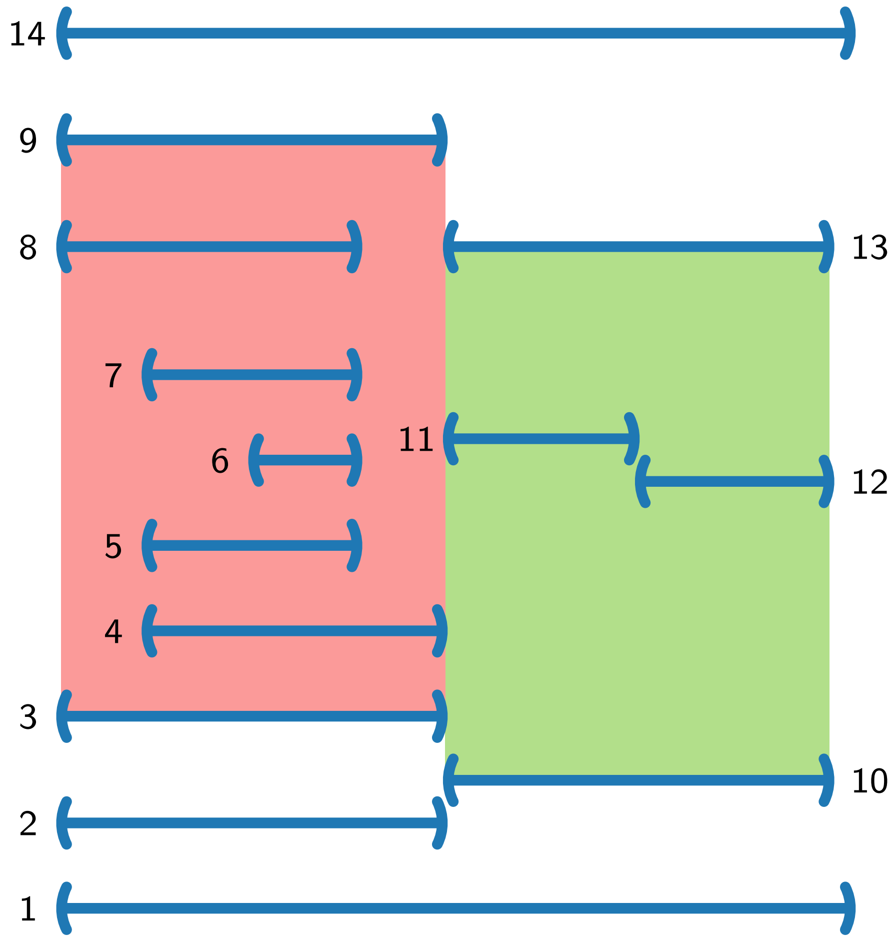


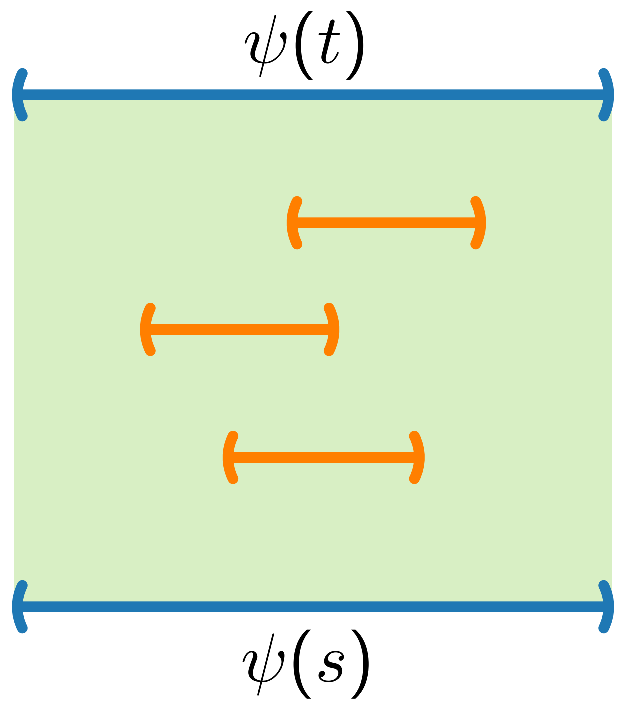
Solve tiles bottom-up.





Tiles

Convention. **Orange** bars are from the given partial representation.



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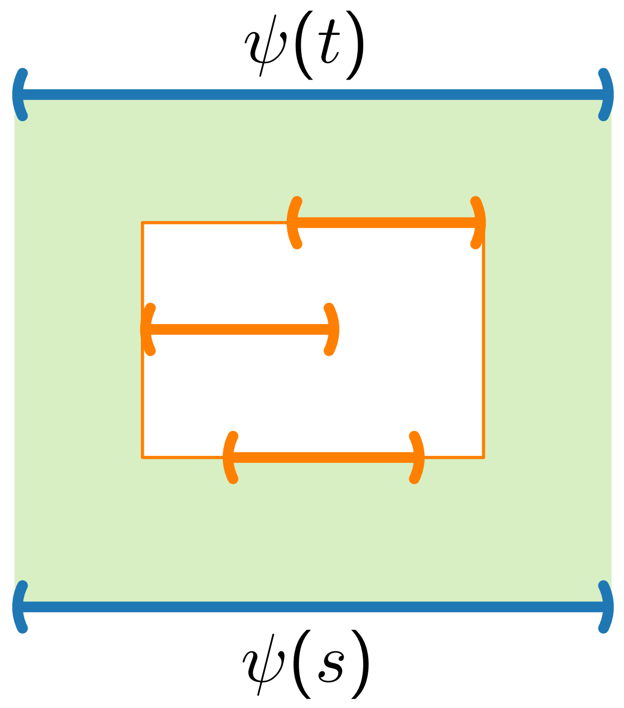

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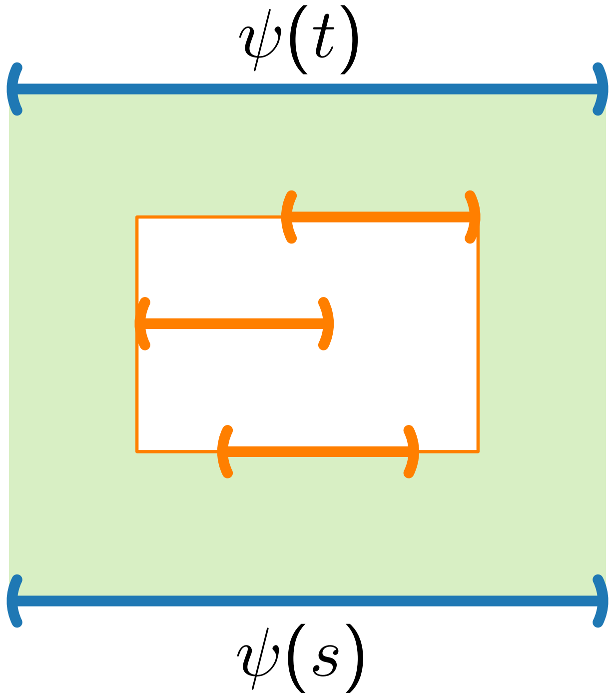

Observation.
The bounding box (tile) of any solution ψ **contains** the bounding box of the partial representation.

Tiles

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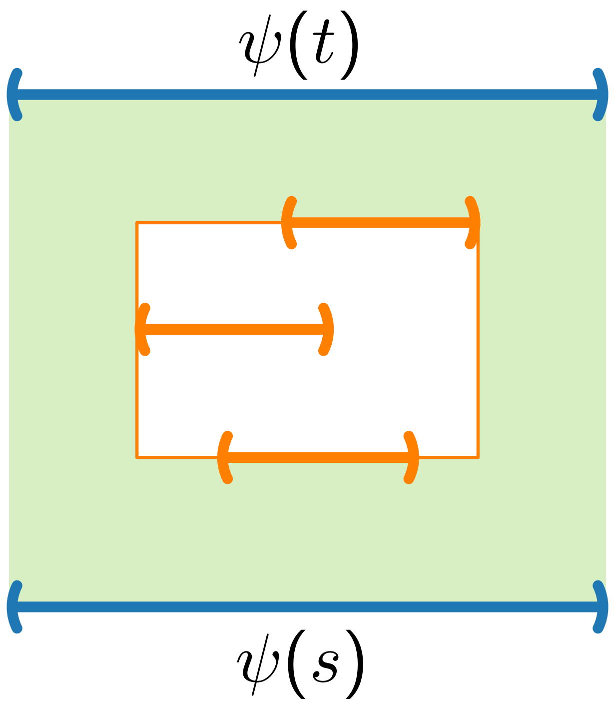
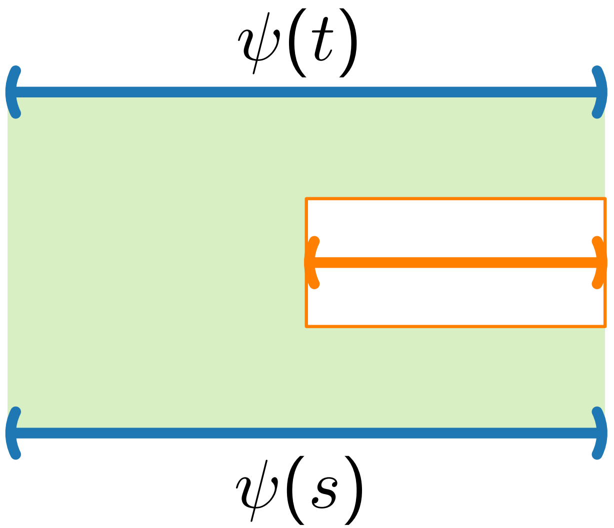


Observation.
The bounding box (tile) of any solution ψ **contains** the bounding box of the partial representation.

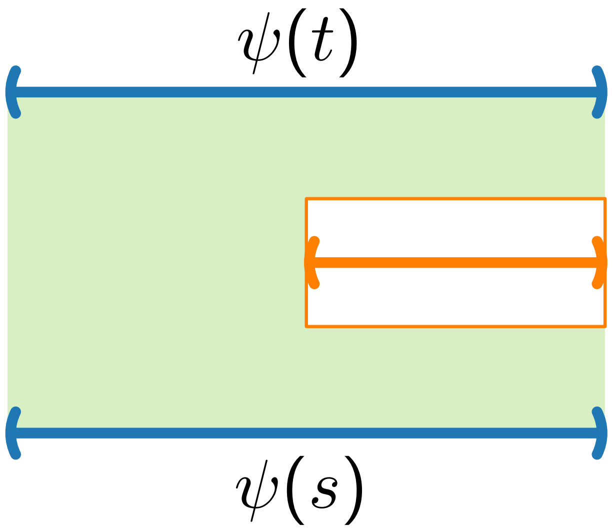
How many different **types** of tiles are there?

Types of Tiles



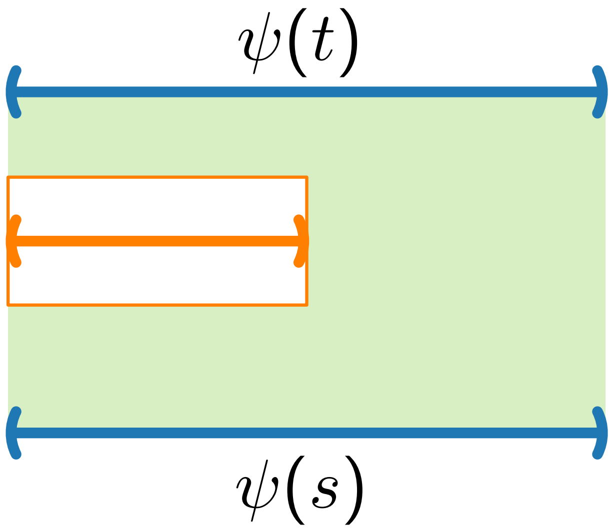
- Right **F**ixed
- Left **L**oose

Types of Tiles



- Right **F**ixed
- Left **L**oose

- Left **F**ixed
- Right **L**oose



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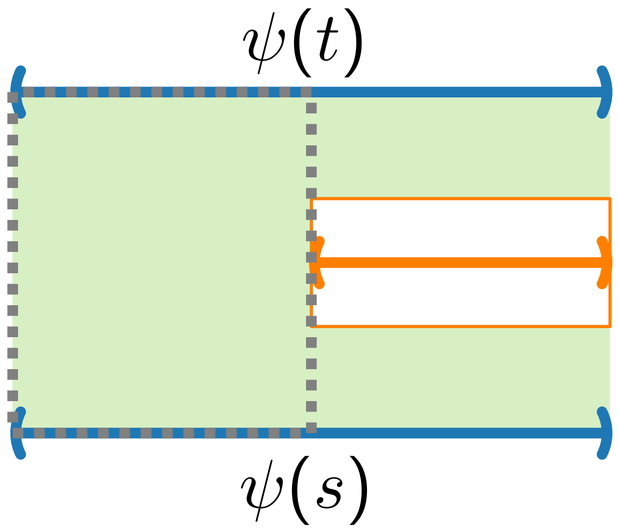

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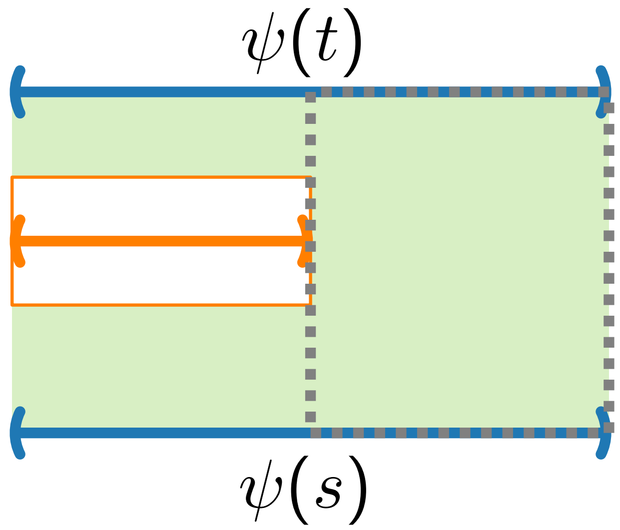

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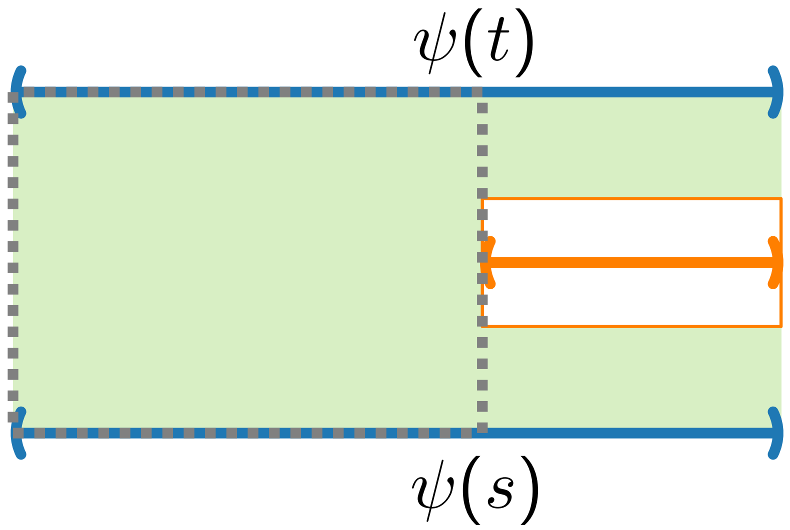

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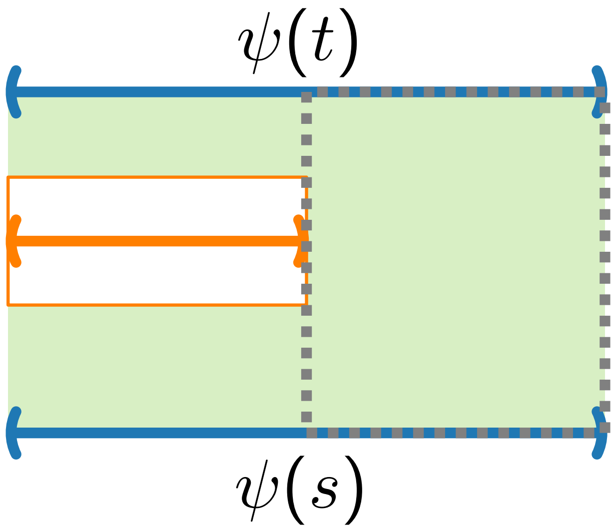

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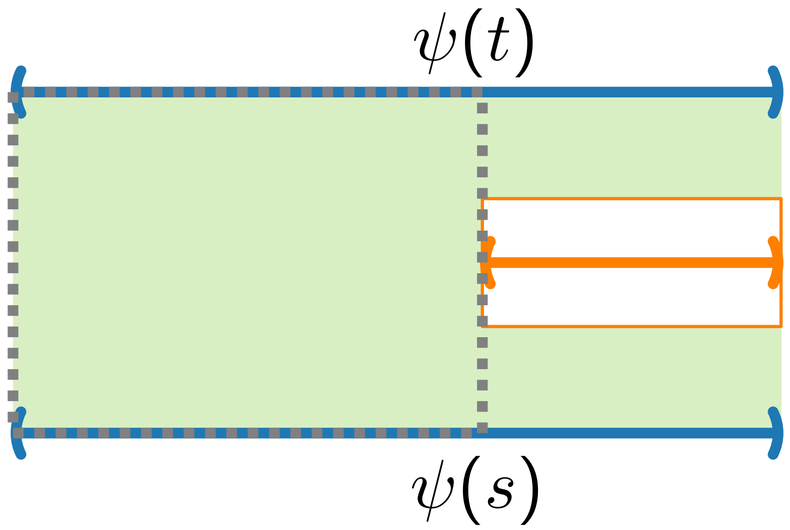

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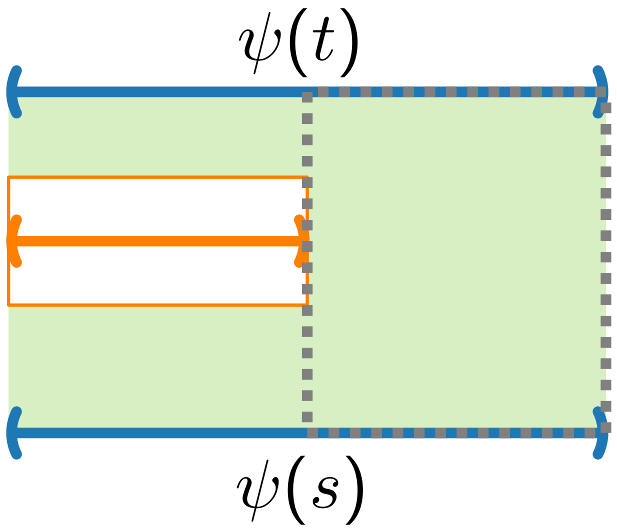
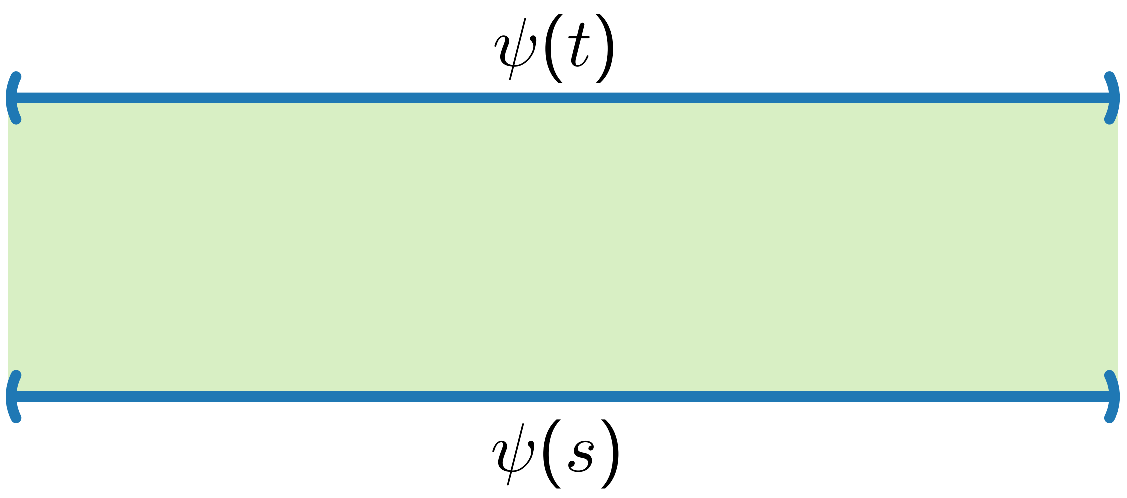
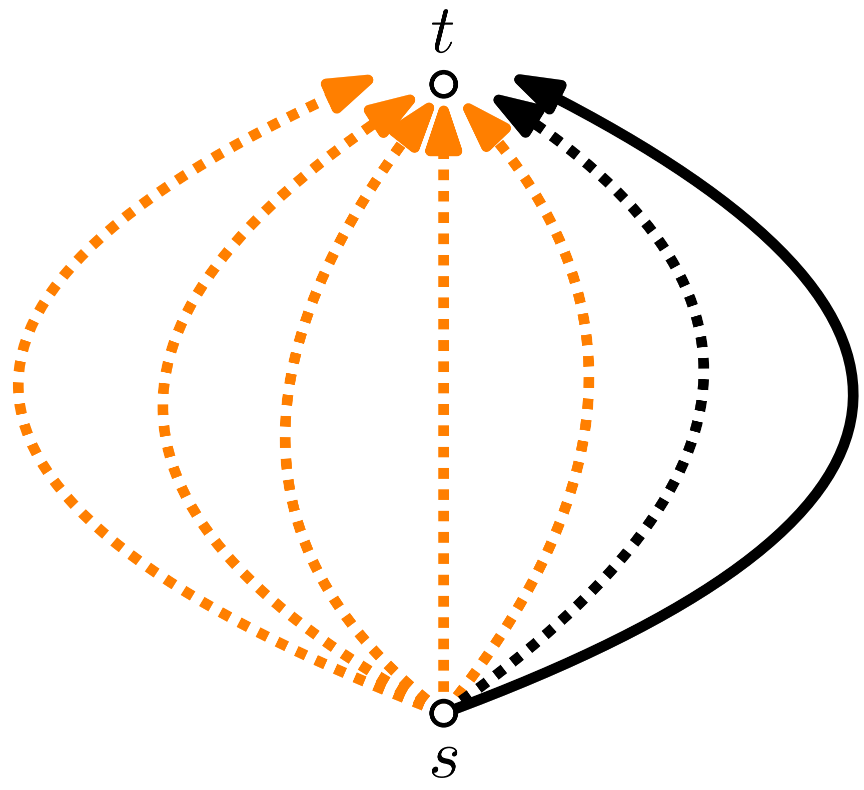


Four different types: **FF, FL, LF, LL**

P-Nodes





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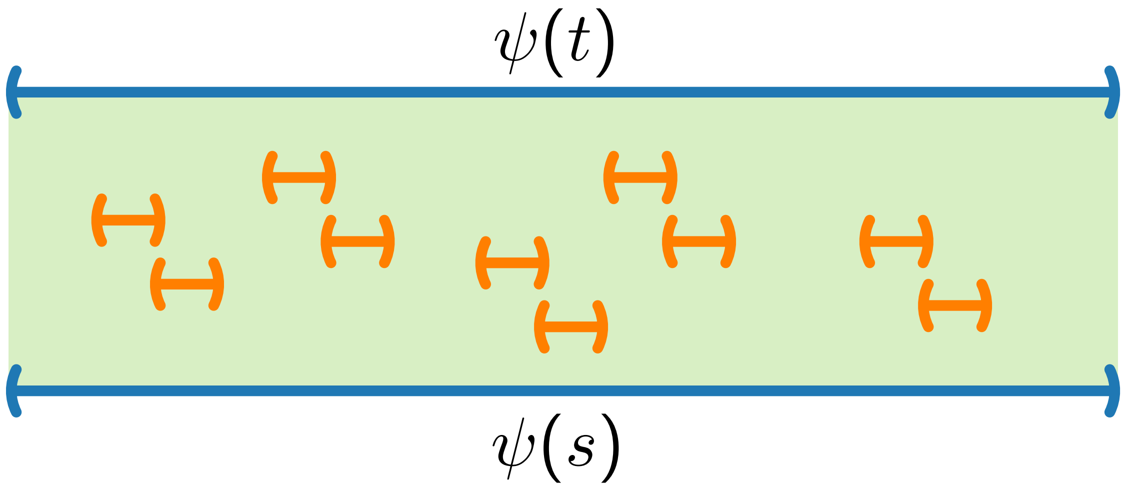

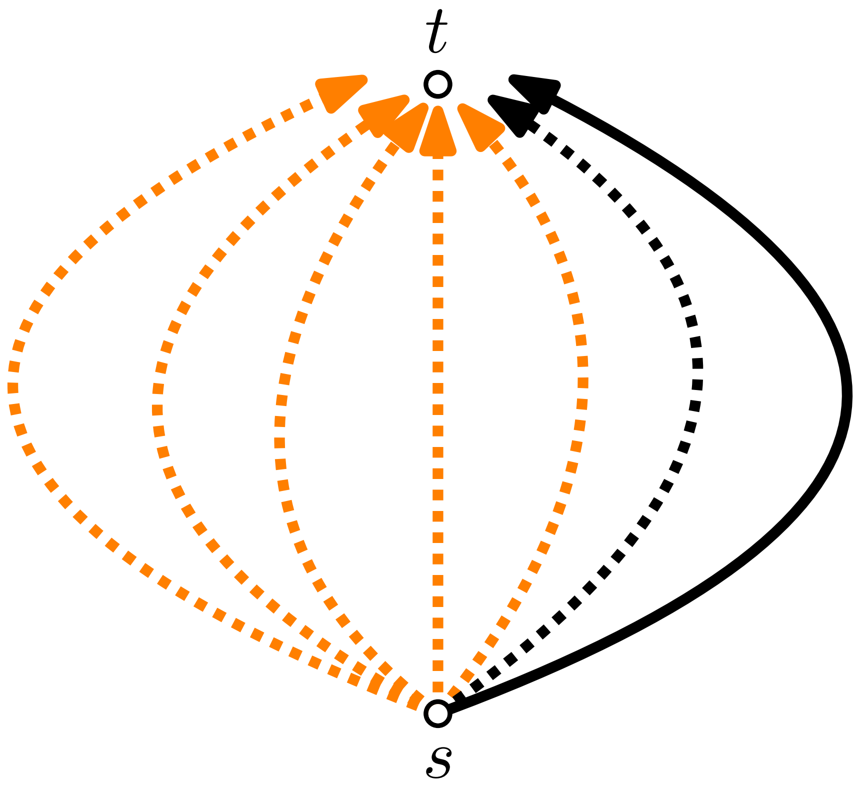

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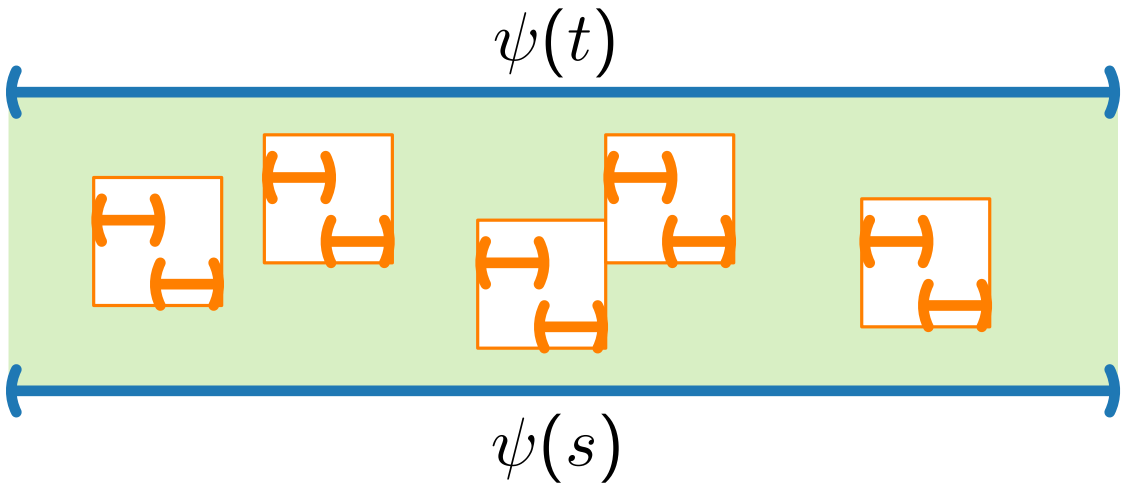

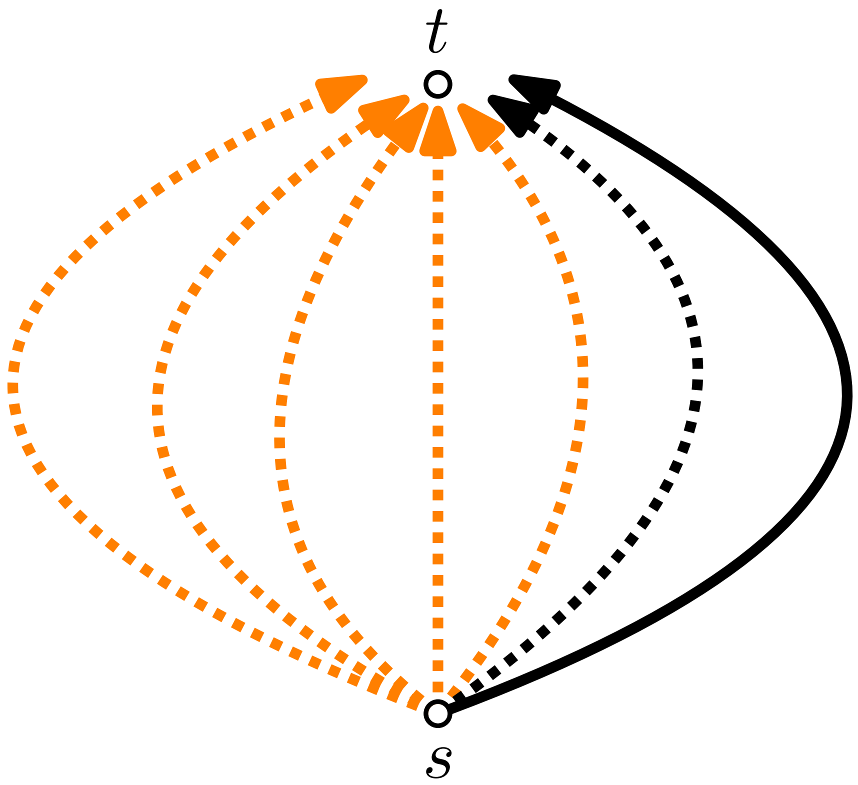

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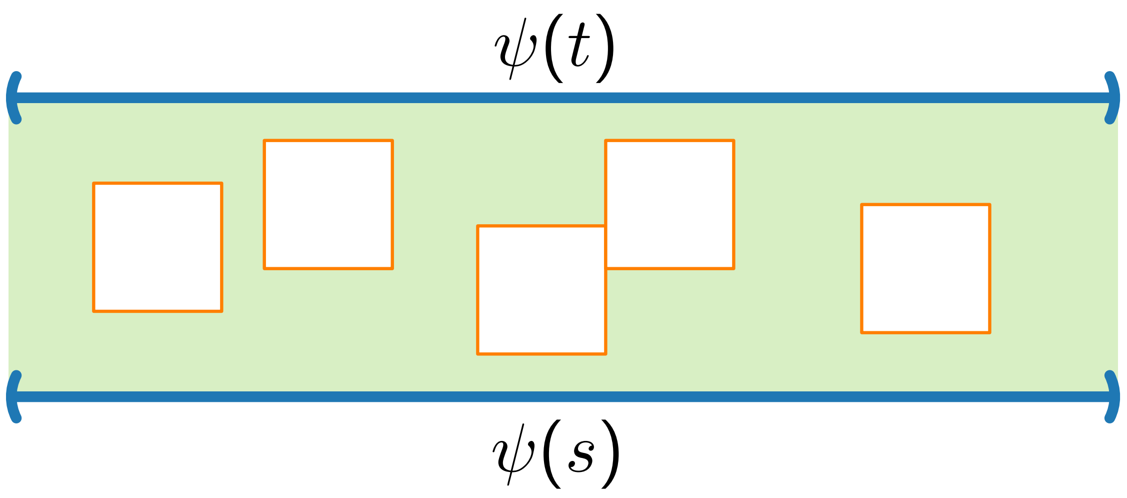

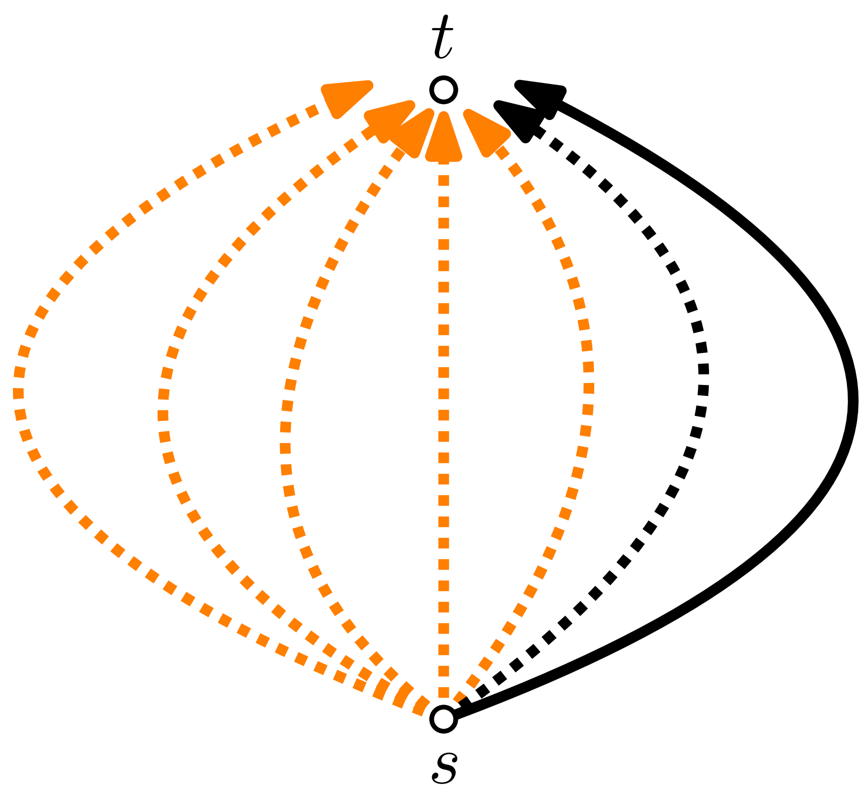

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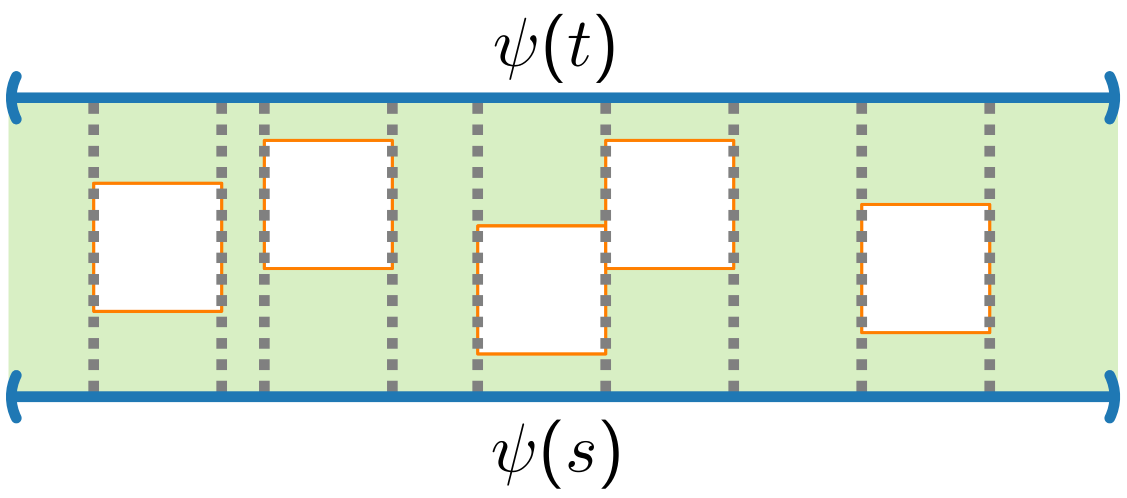

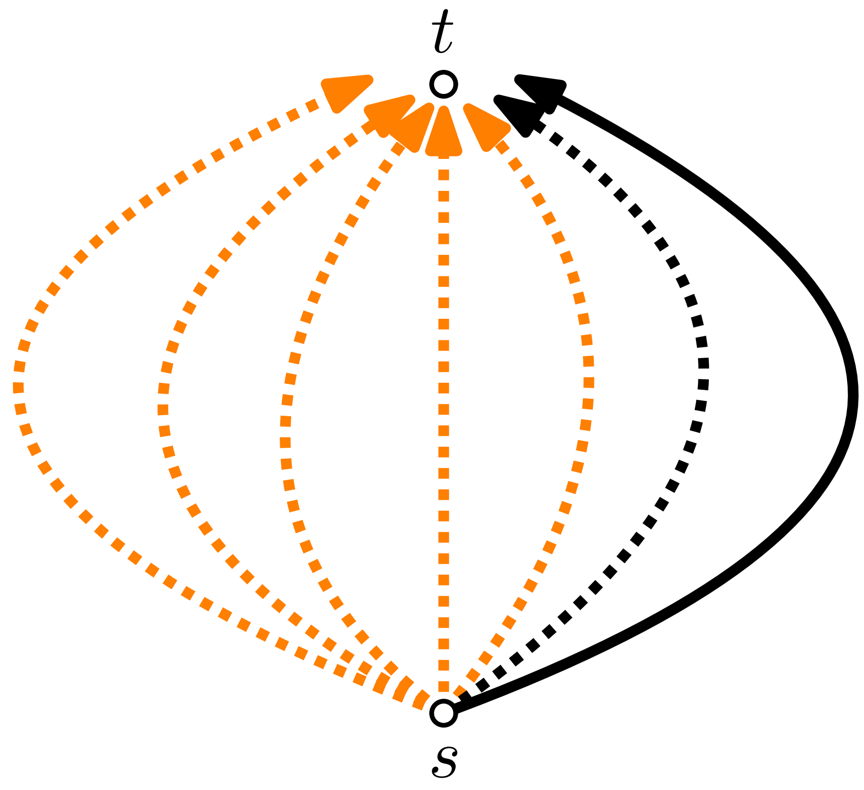

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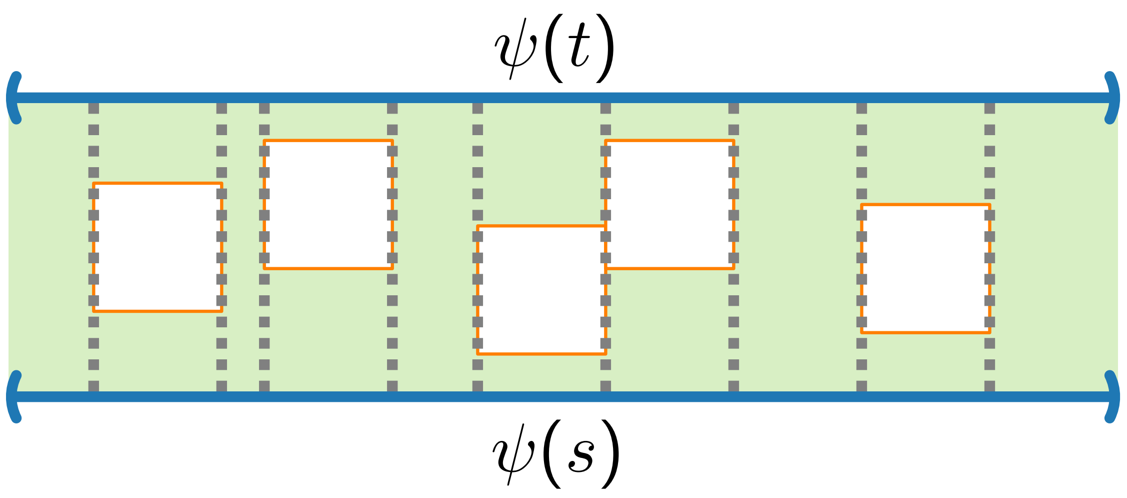
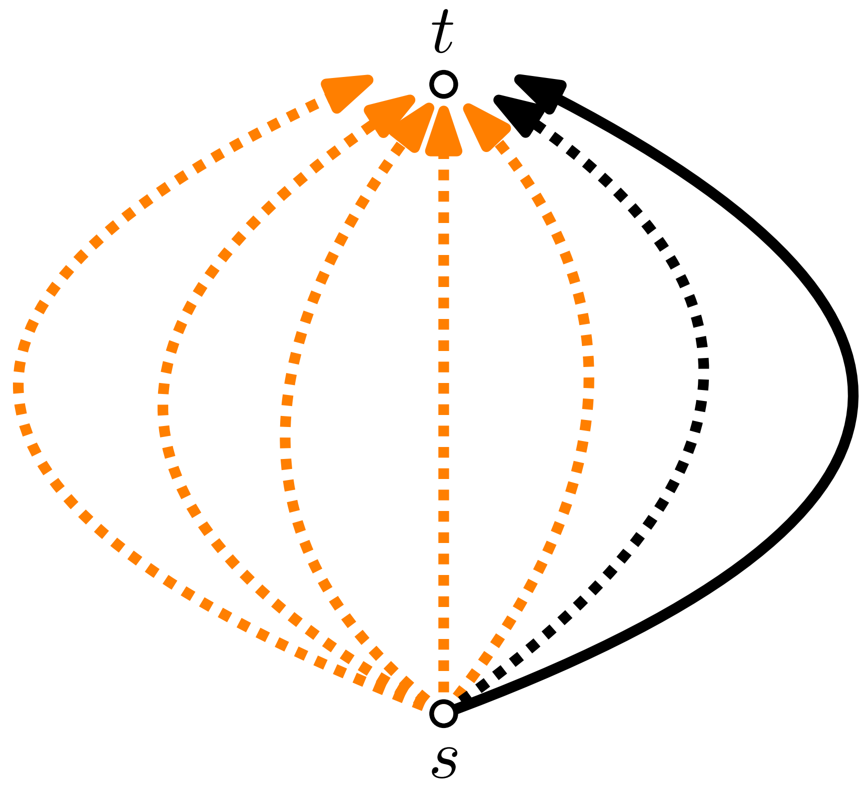
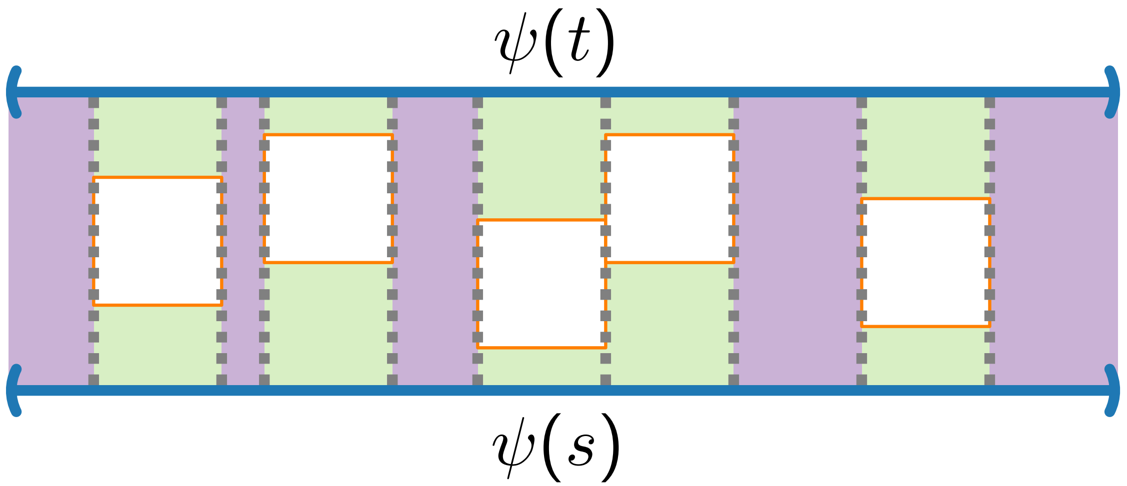
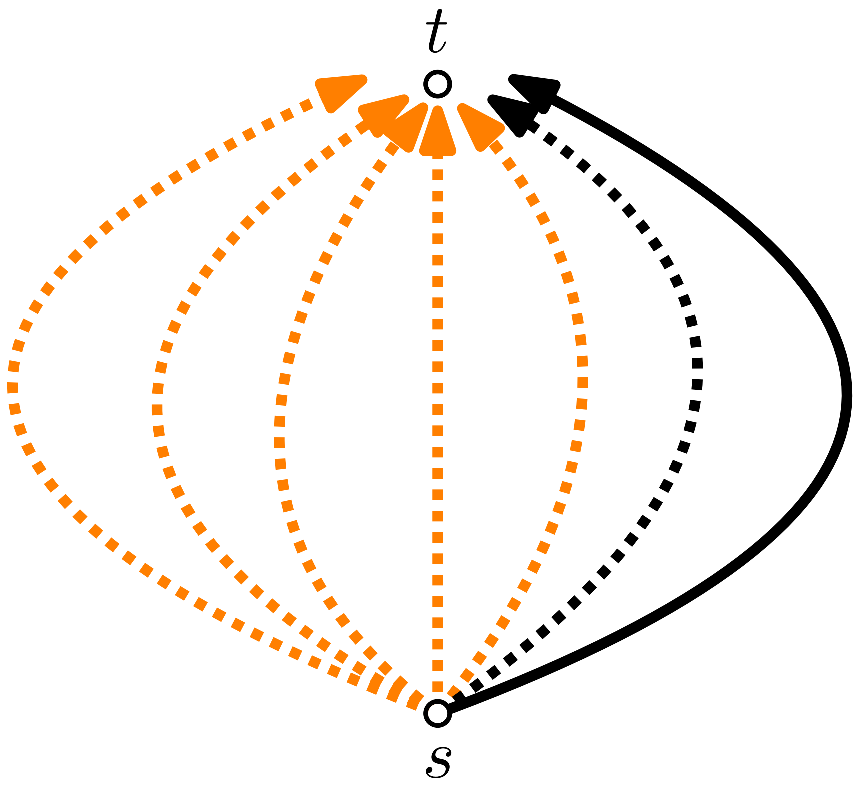




- Children of **P**-node with prescribed bars occur in given left-to-right order

P-Nodes





- Children of **P**-node with prescribed bars occur in given left-to-right order
- But there might be some gaps. . .

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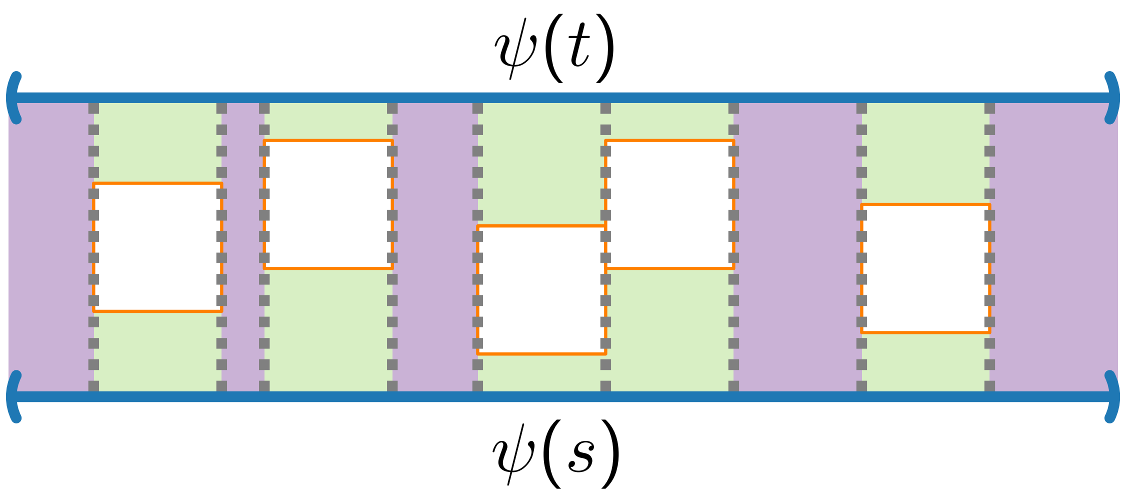

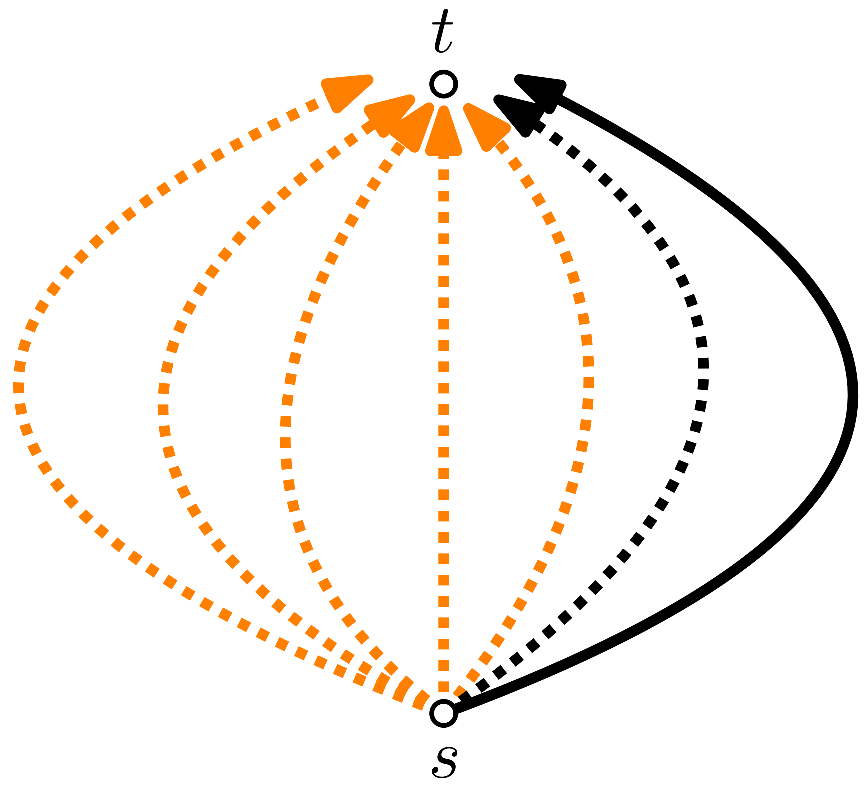

- Children of **P**-node with prescribed bars occur in given left-to-right order
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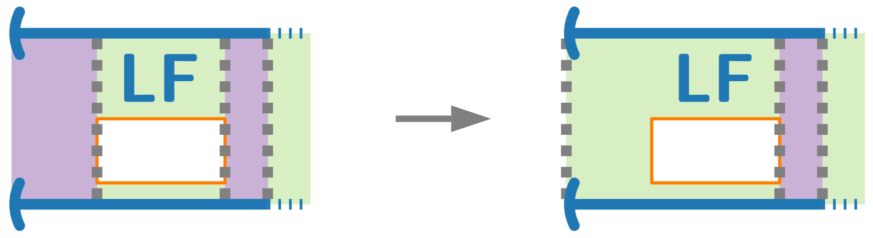
Idea.
Greedily *fill* the gaps by preferring to "stretch" the children with prescribed bars.



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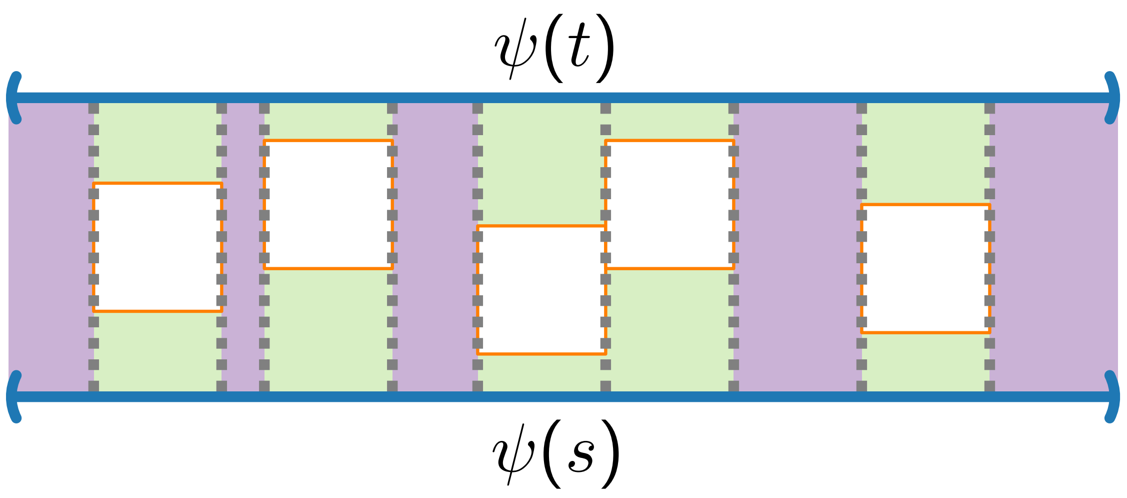

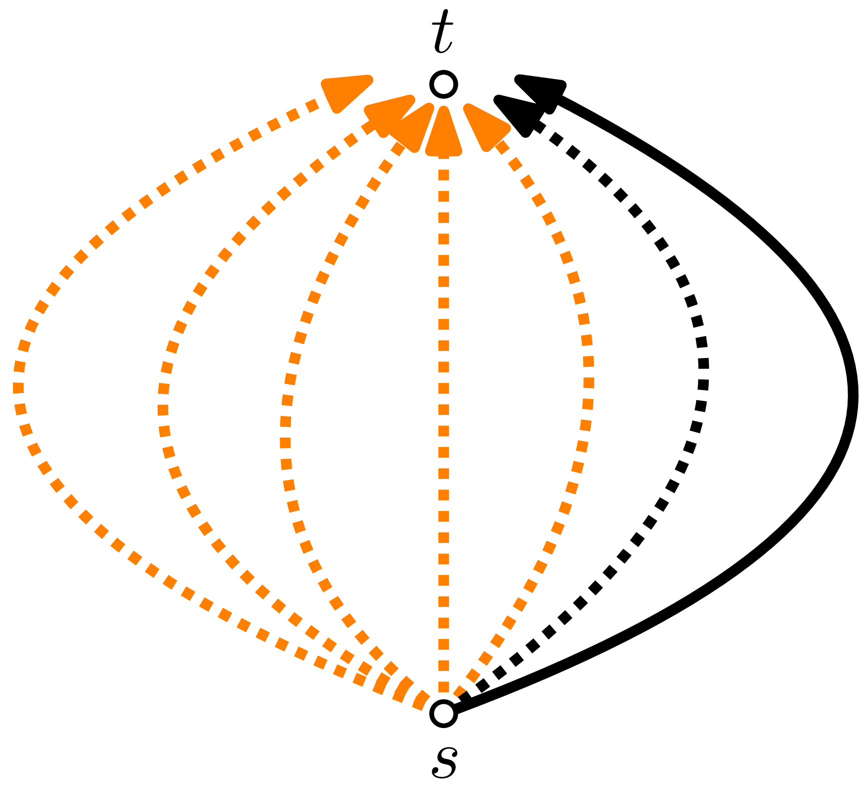

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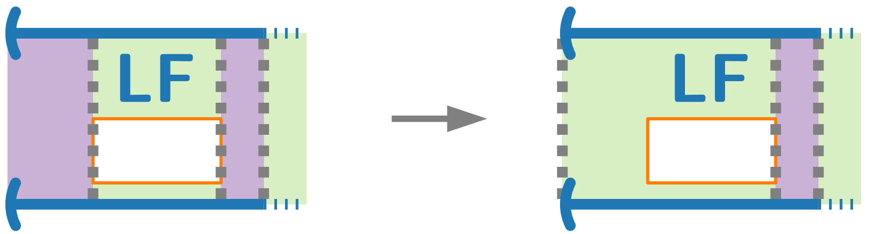
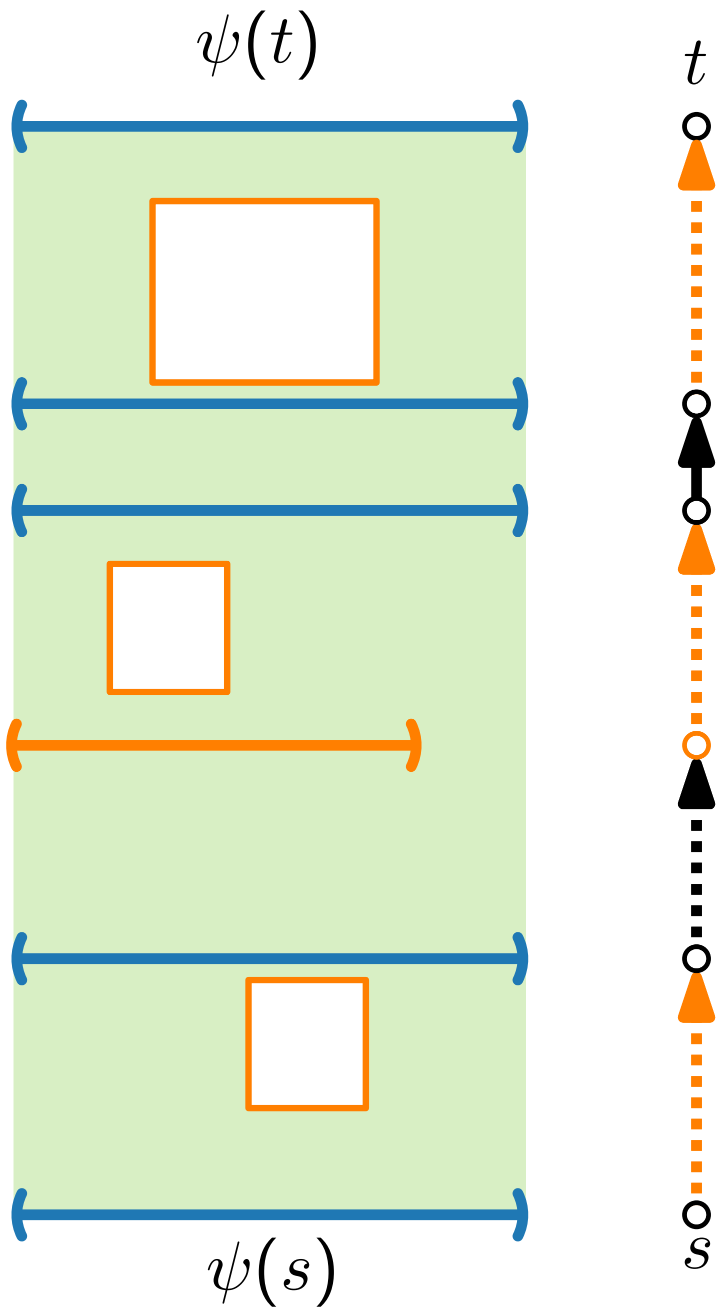
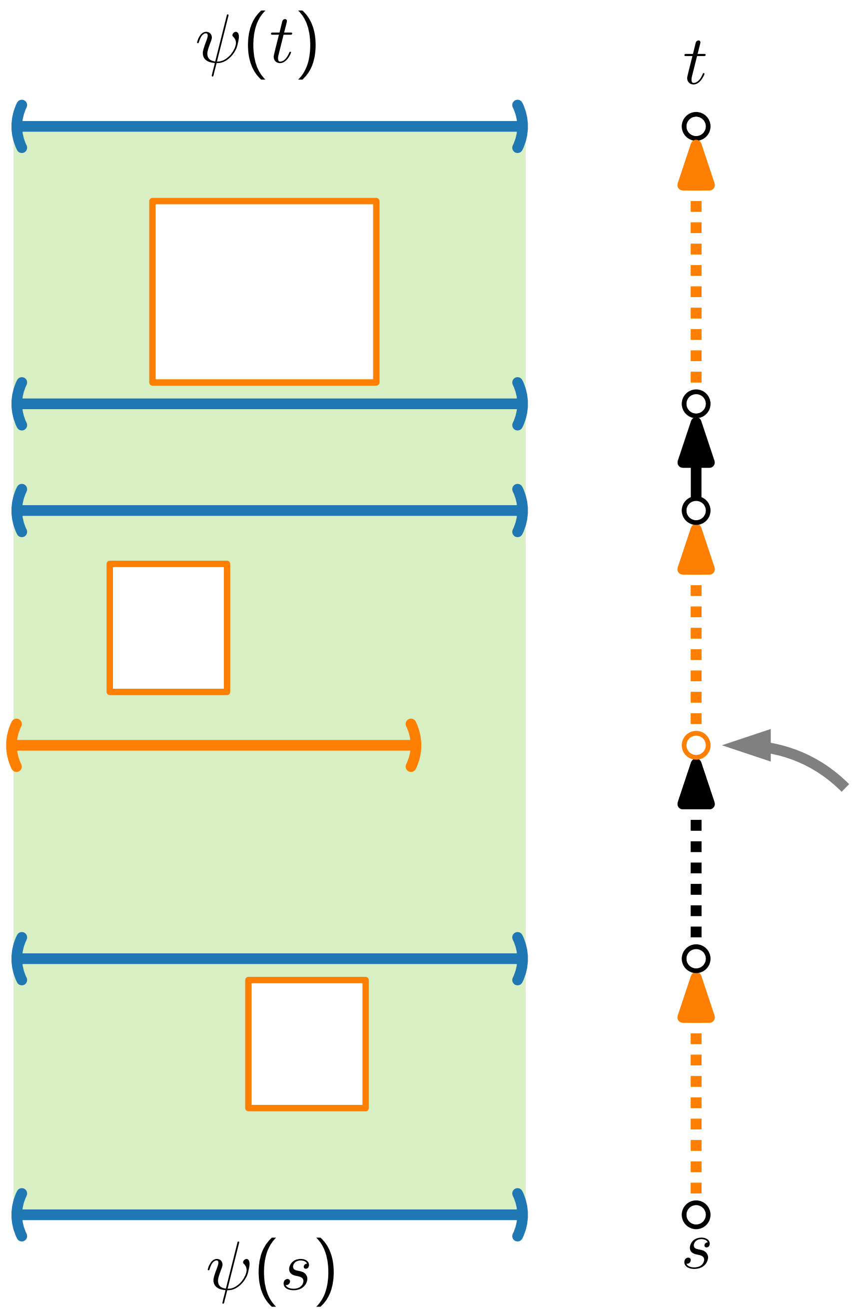


Outcome.
After processing, we must know the valid types for the corresponding subgraphs.

S-Nodes

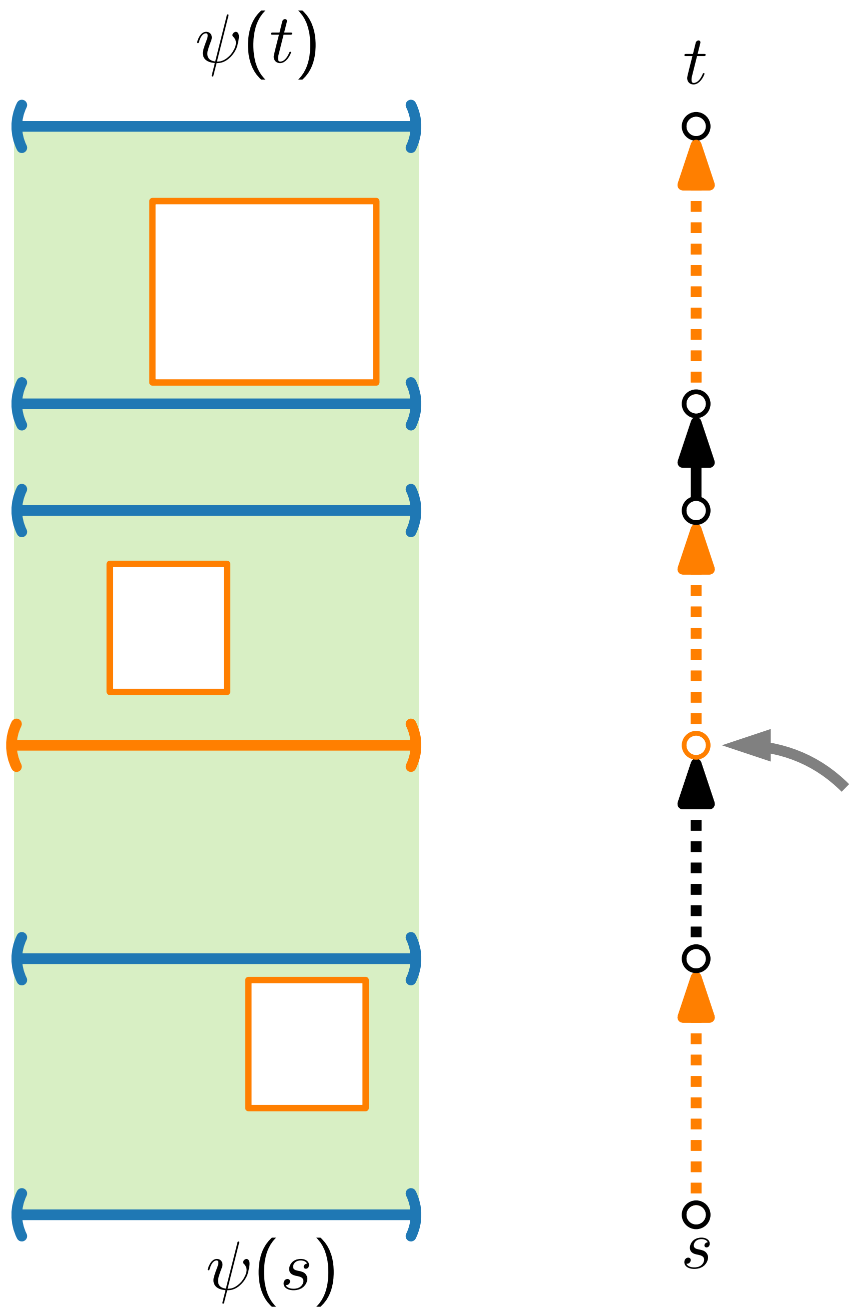


S-Nodes



This fixed vertex means we can only make a **F**ixed-**F**ixed representation!

S-Nodes



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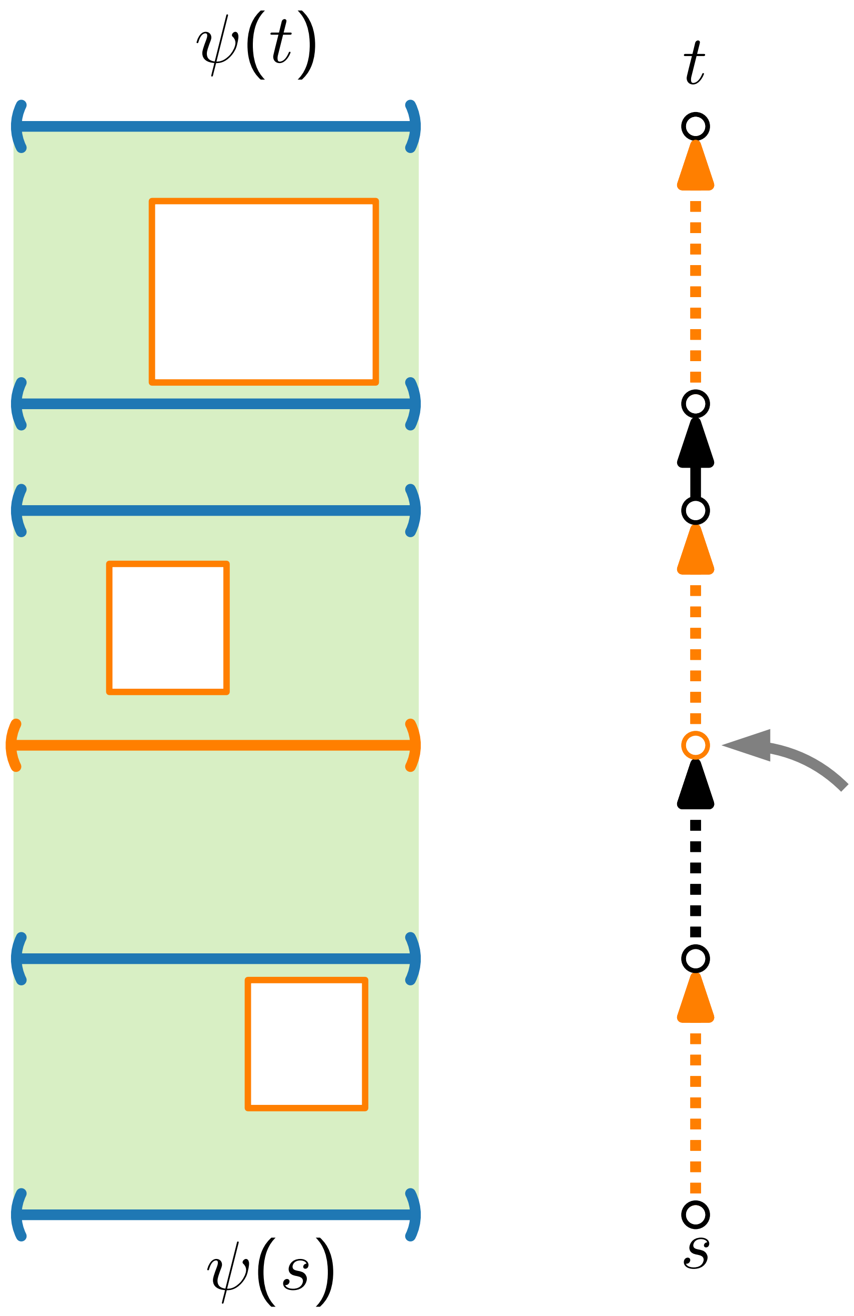

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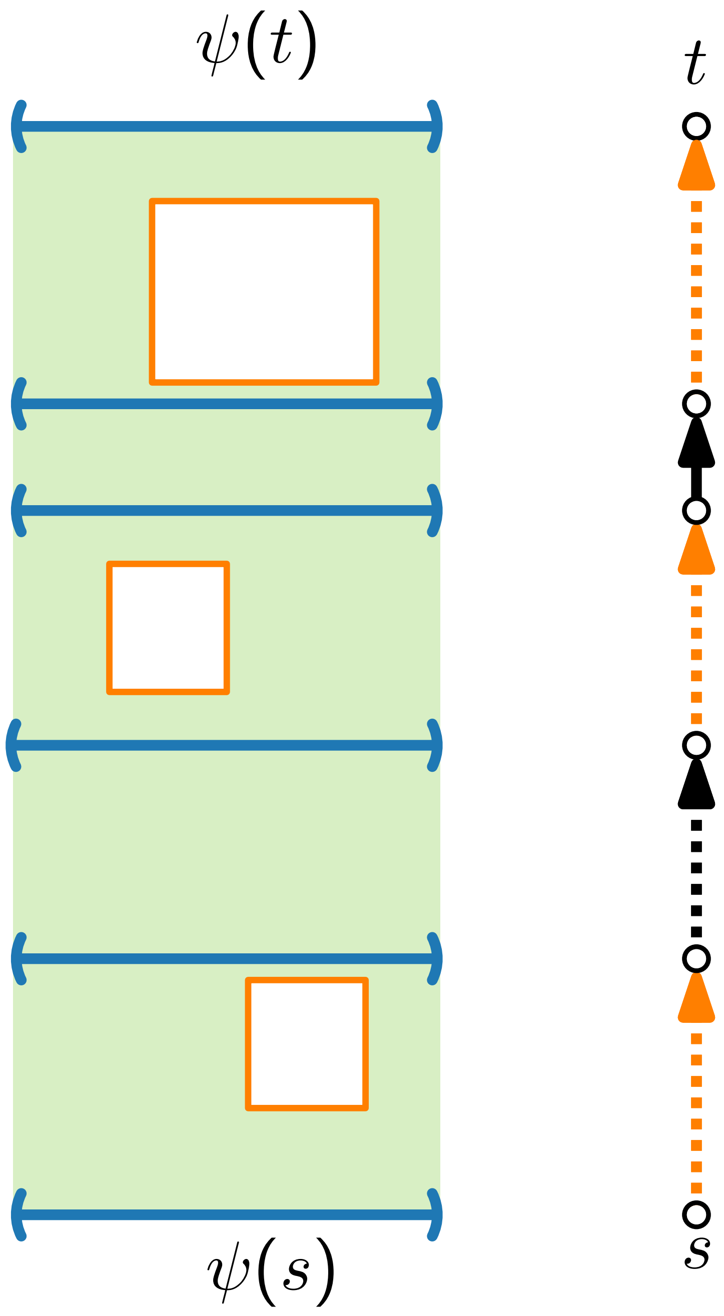
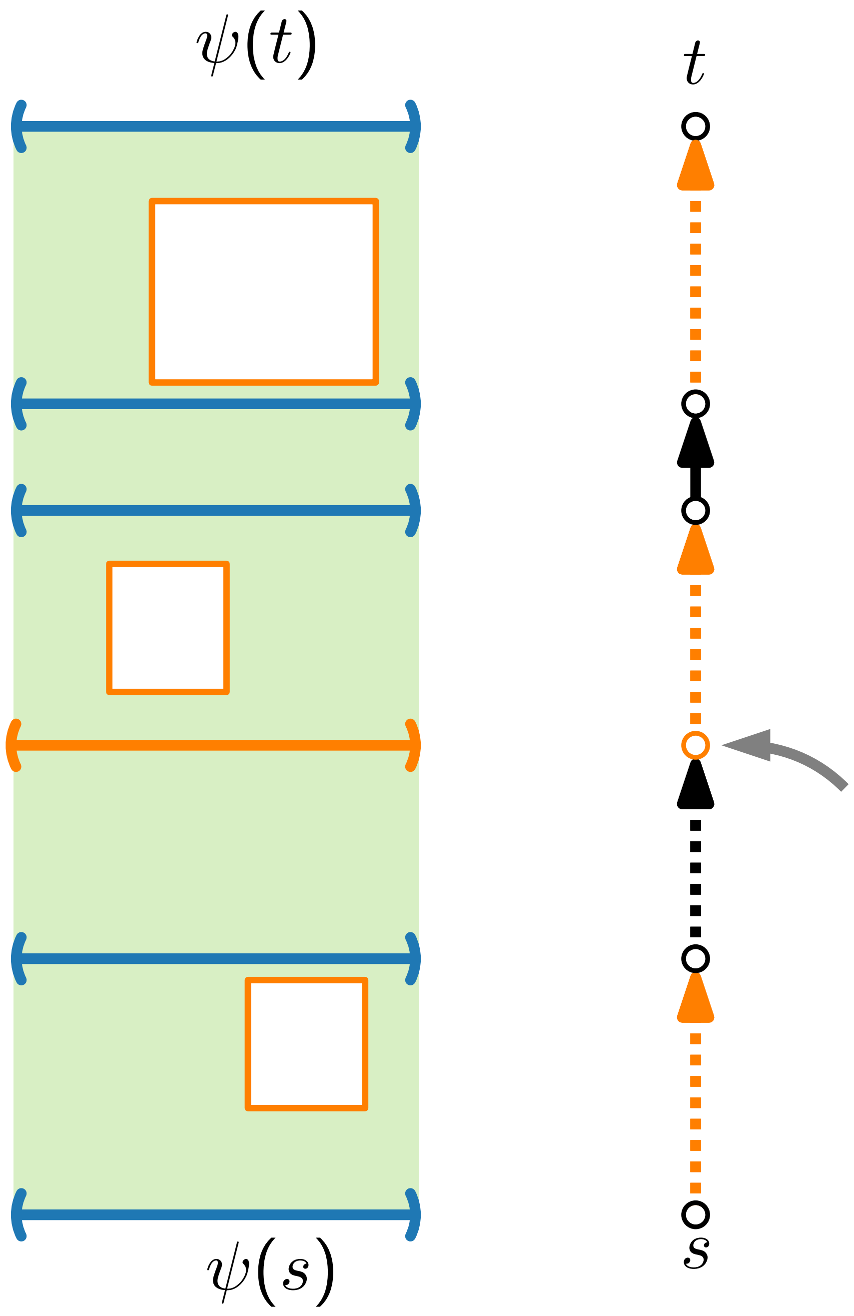
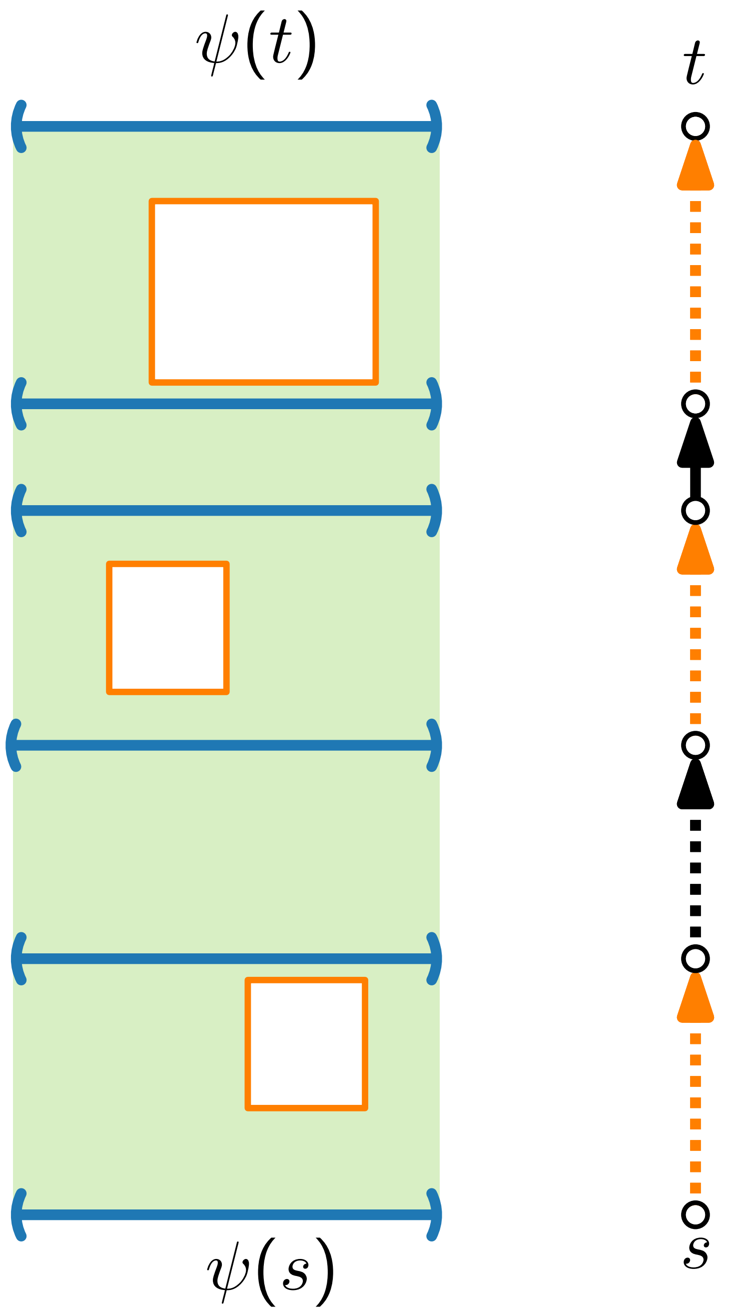


S-Nodes

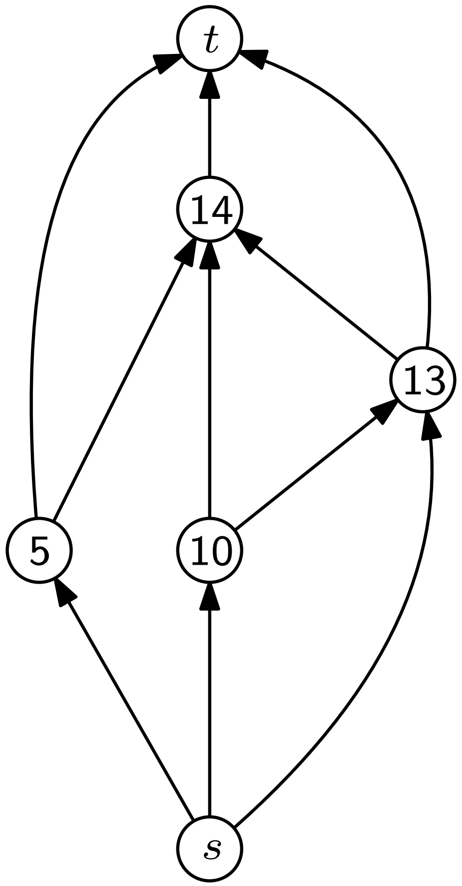


Here we have a chance to make all (**LL, FL, LF, FF**) types.

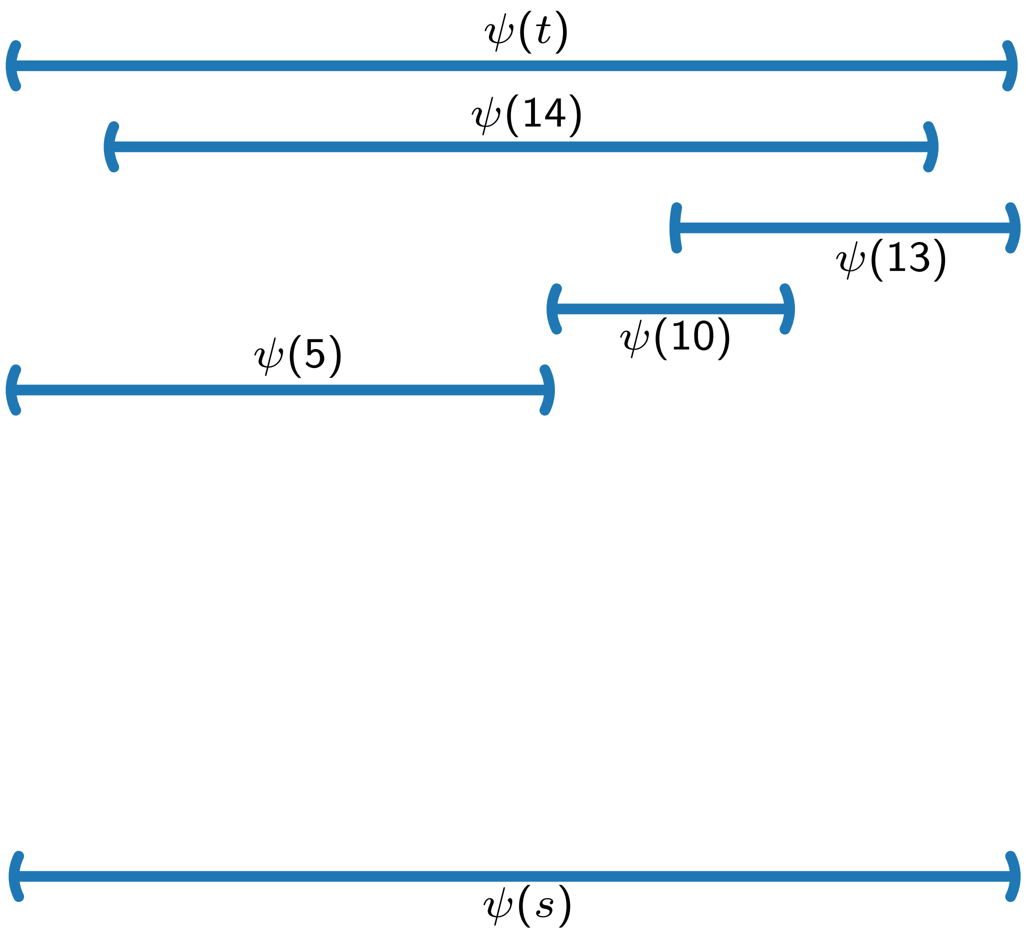
This fixed vertex means we can only make a **F**ixed-**F**ixed representation!

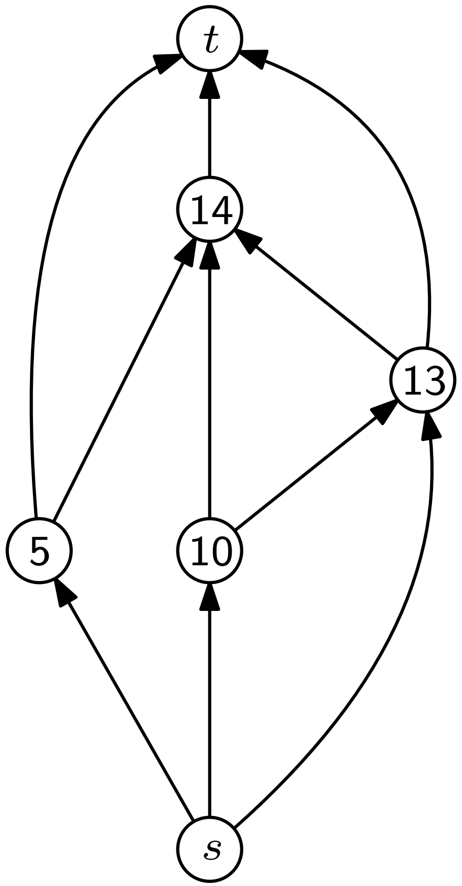


R-Nodes



R-Nodes





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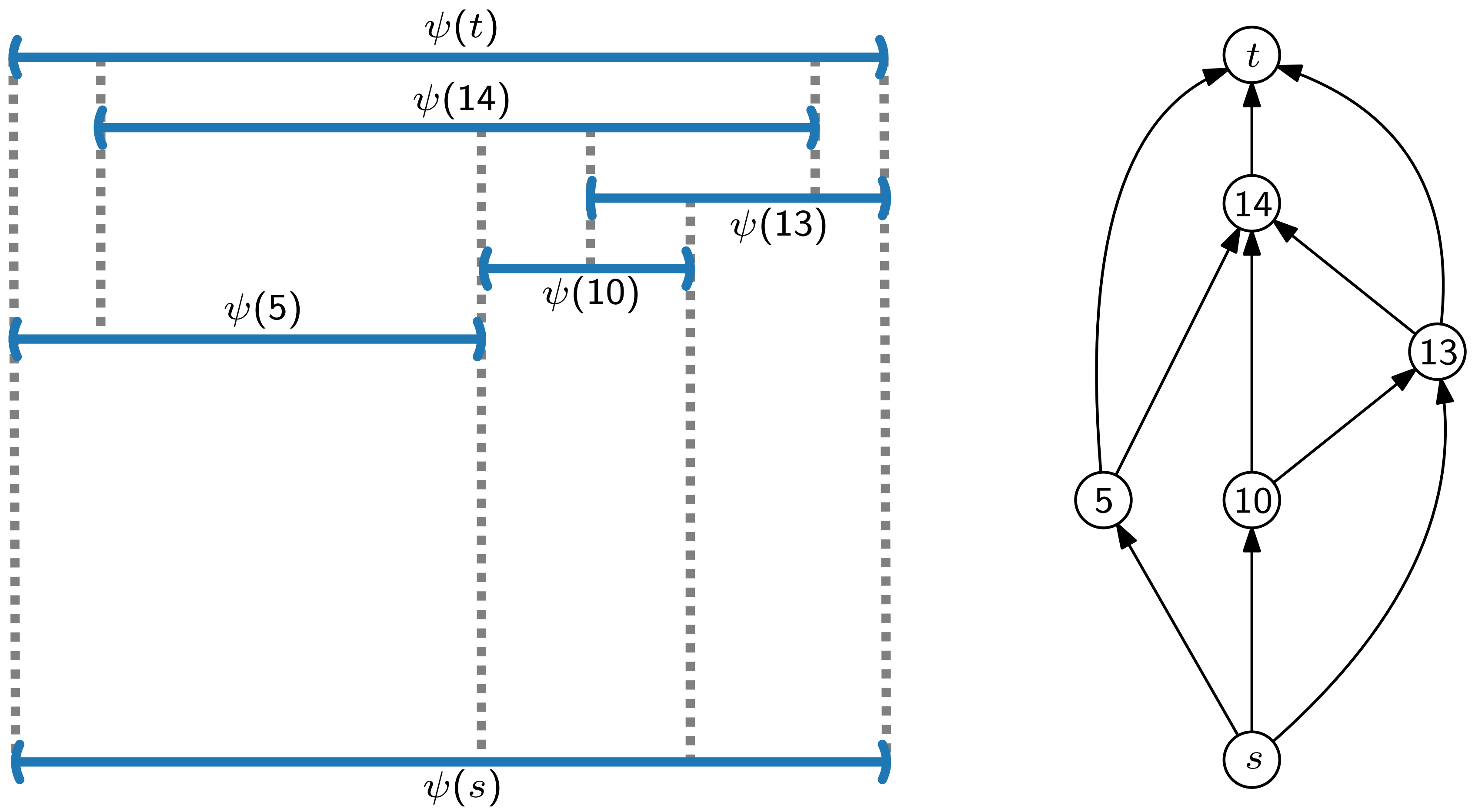

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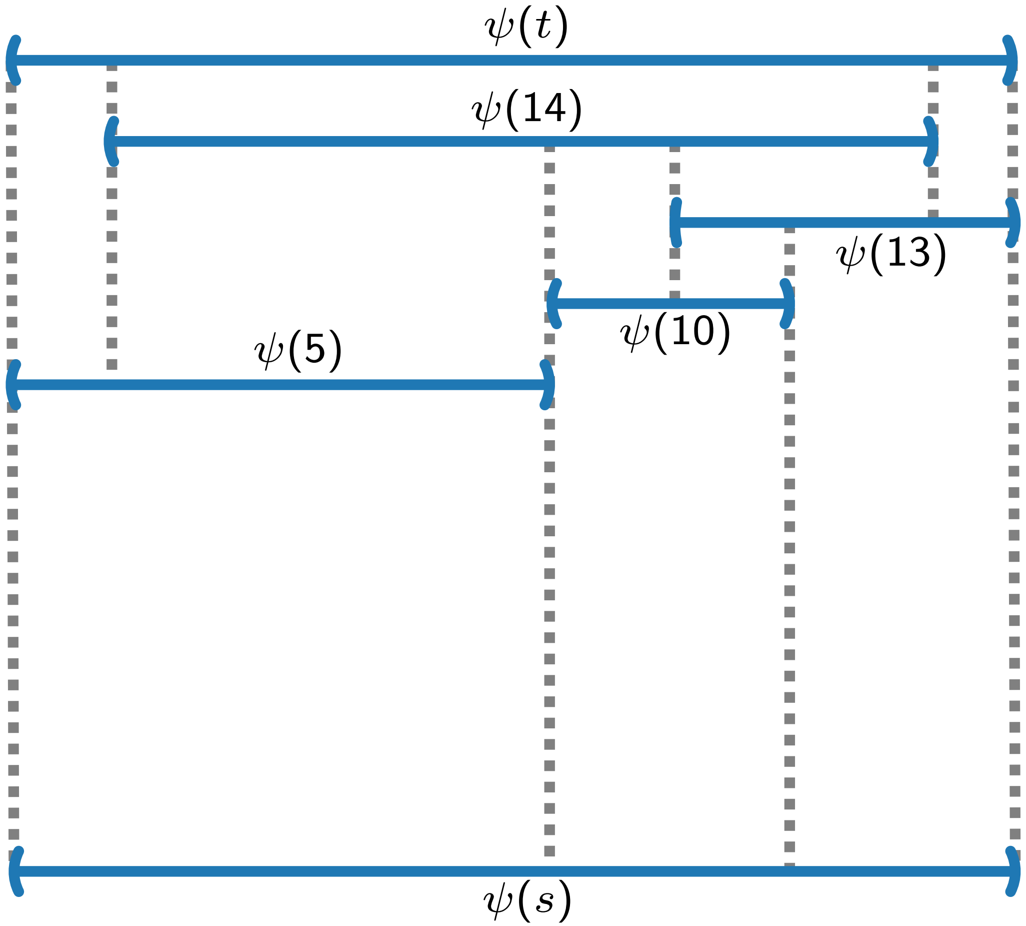

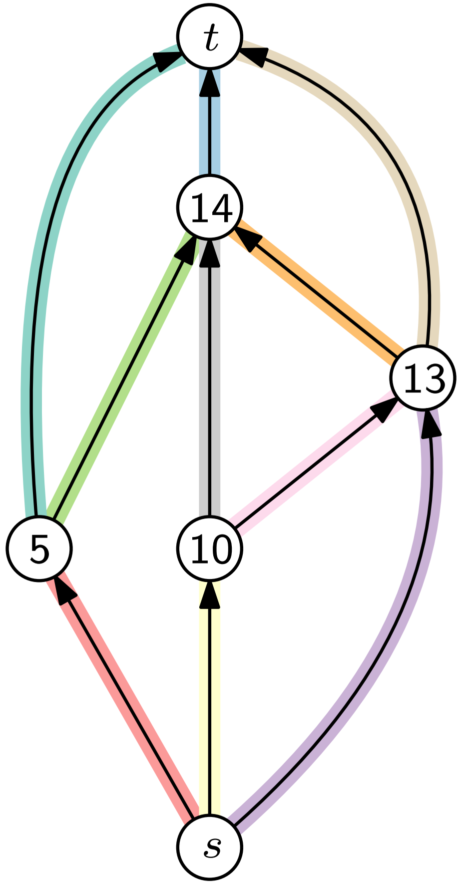

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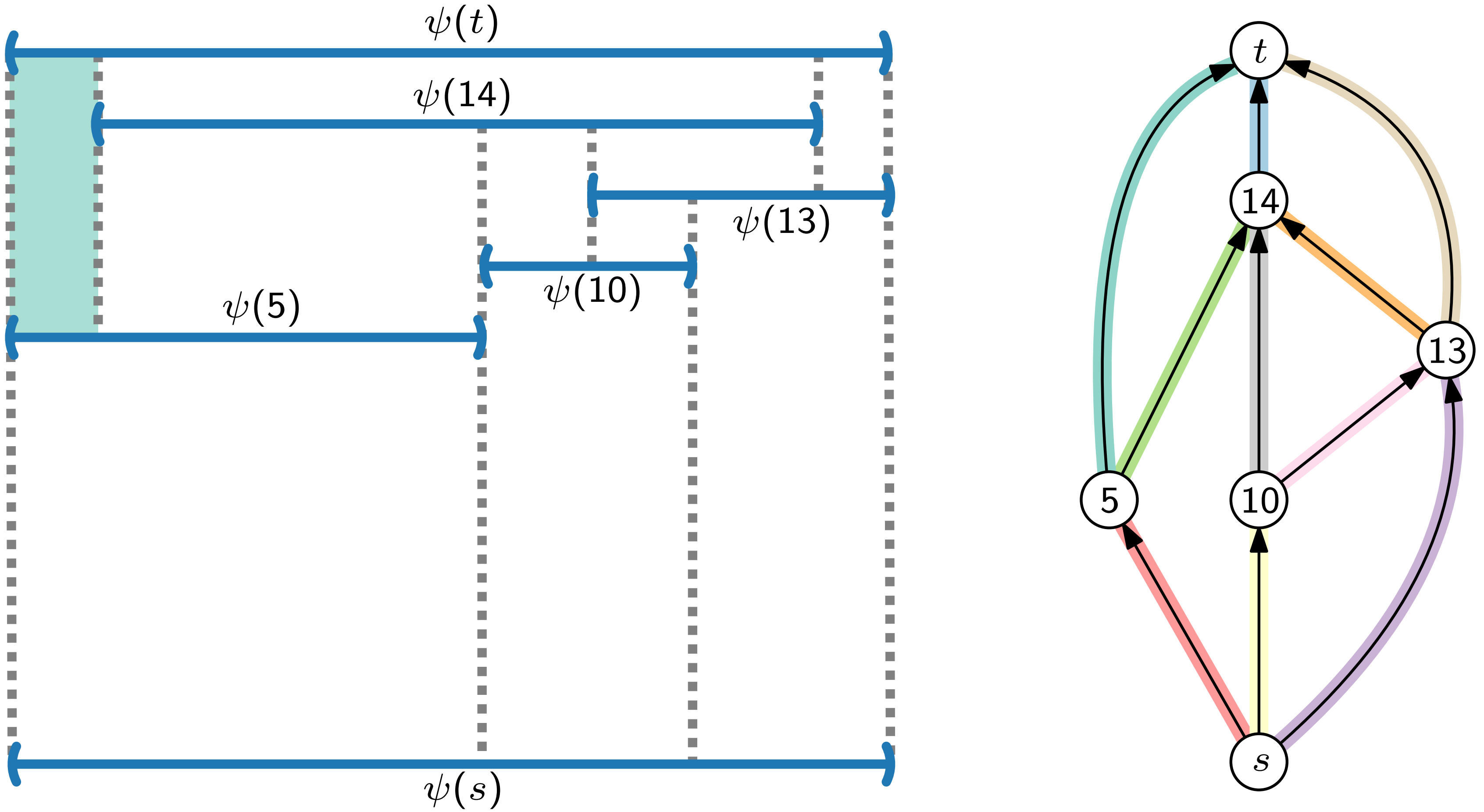

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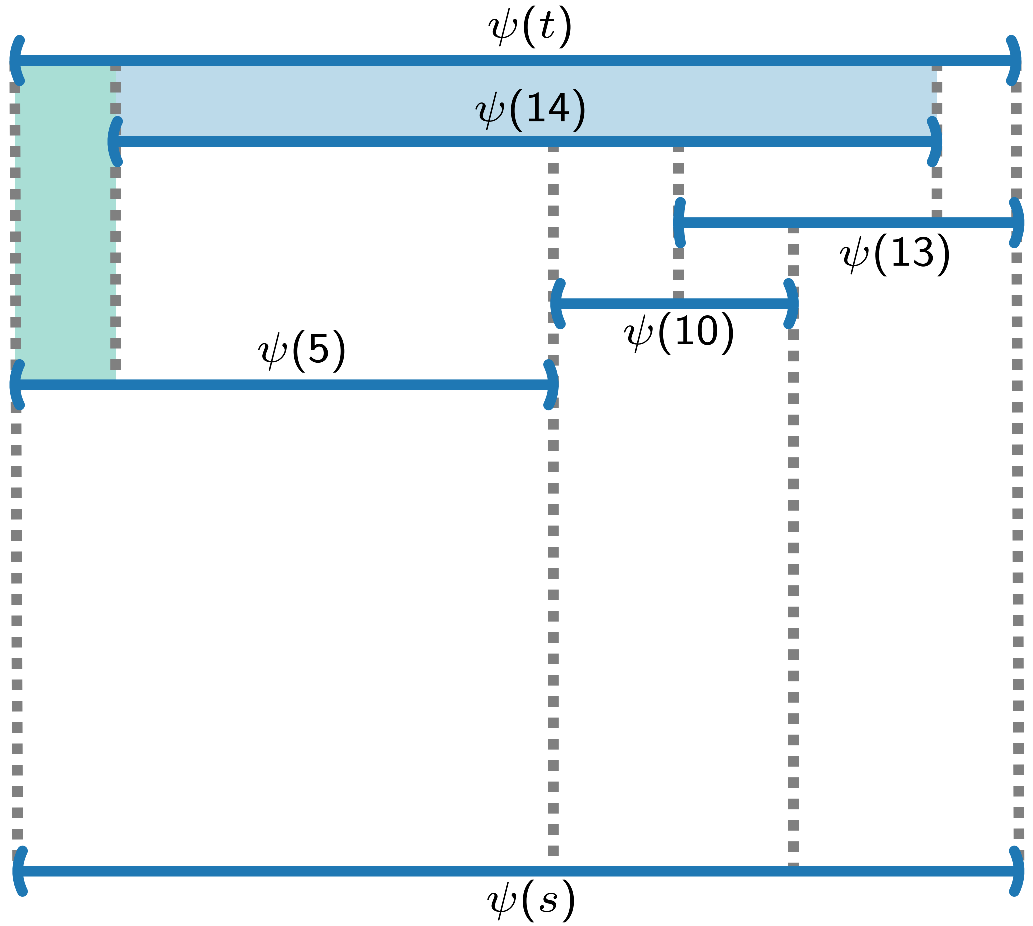

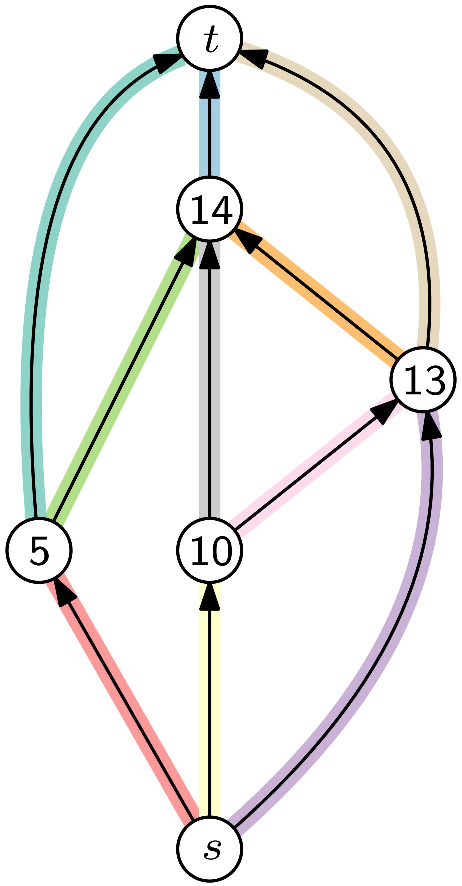

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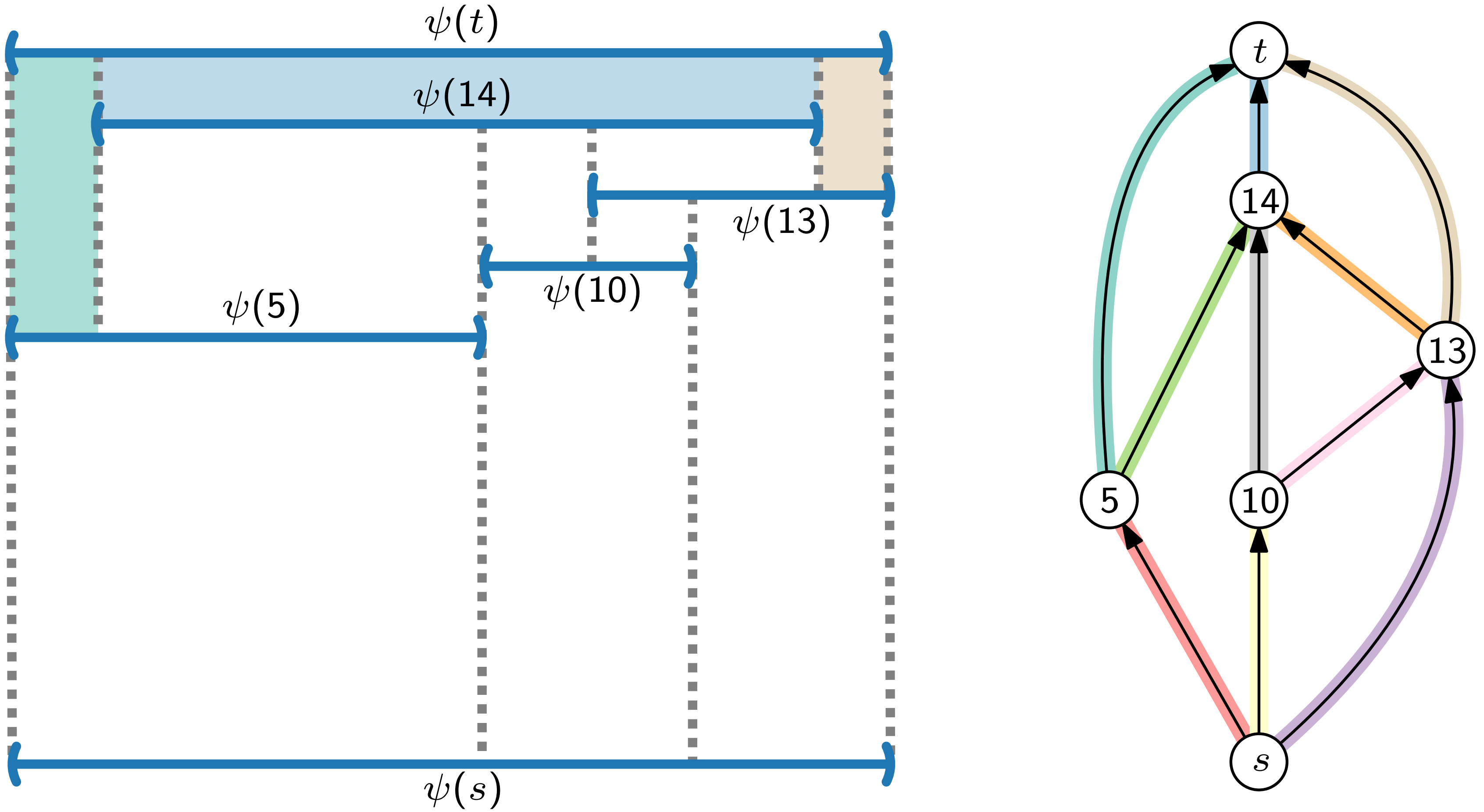

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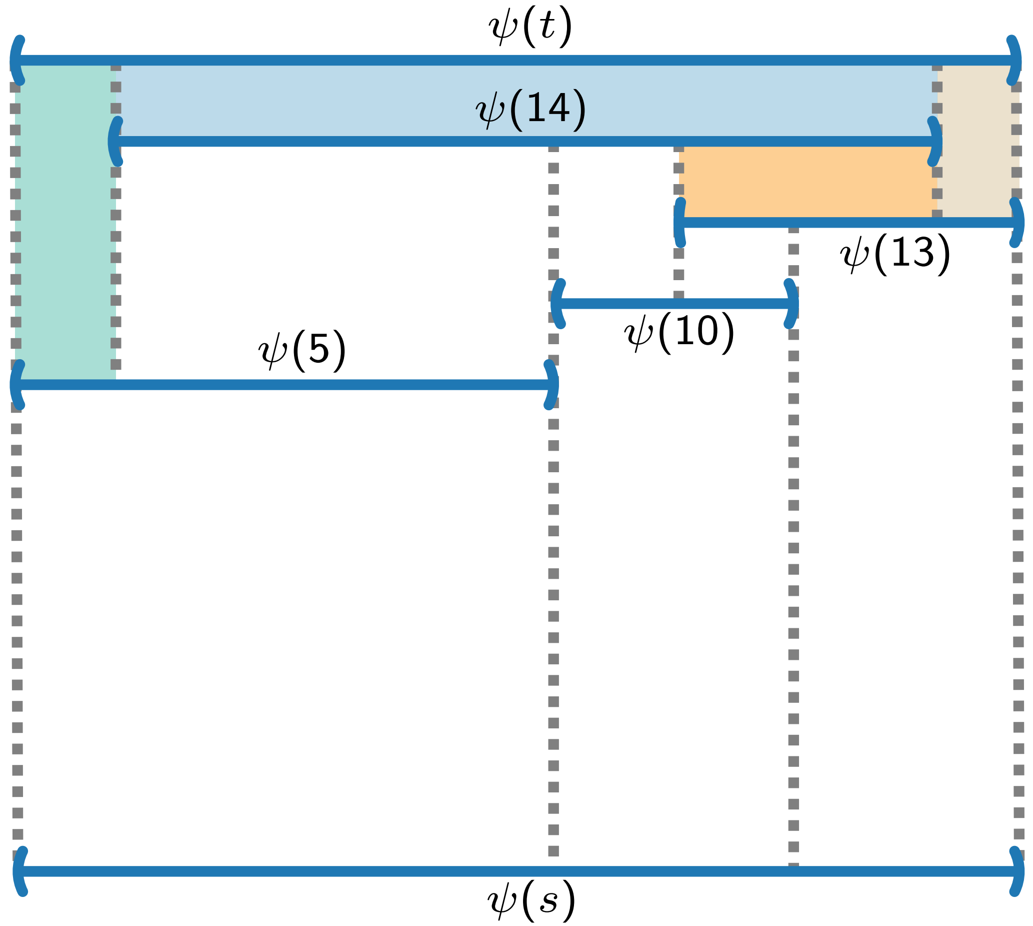

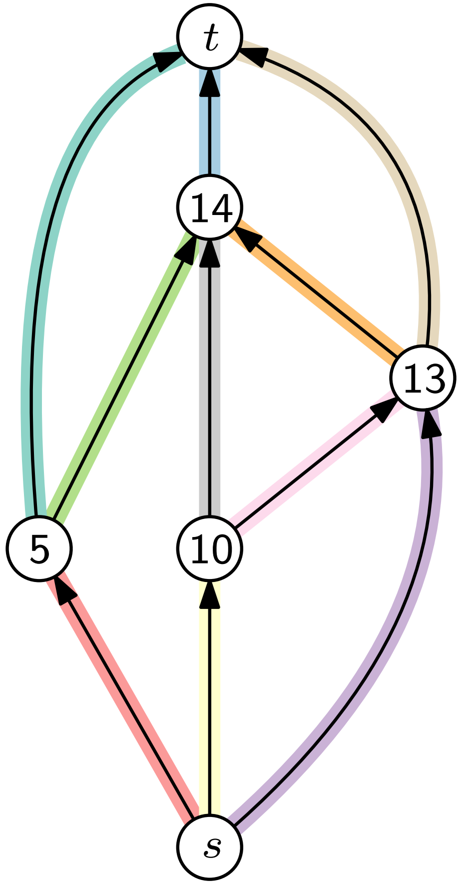

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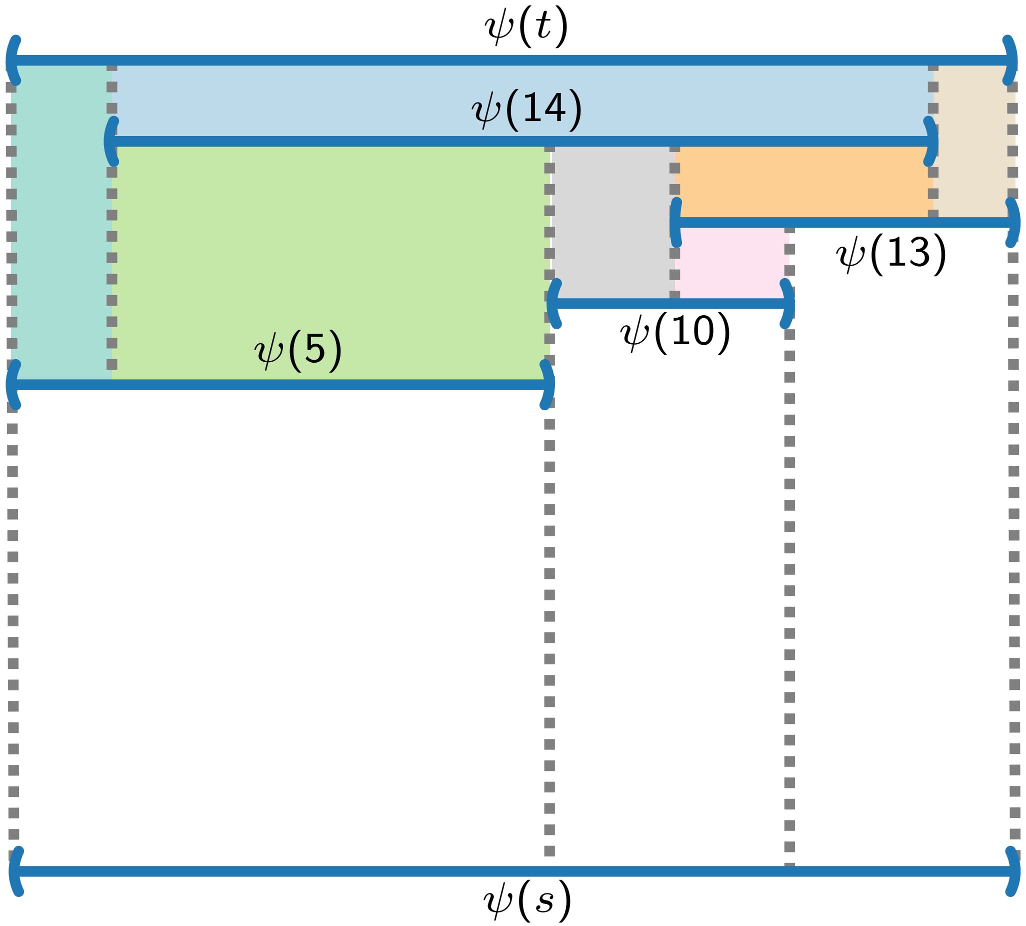

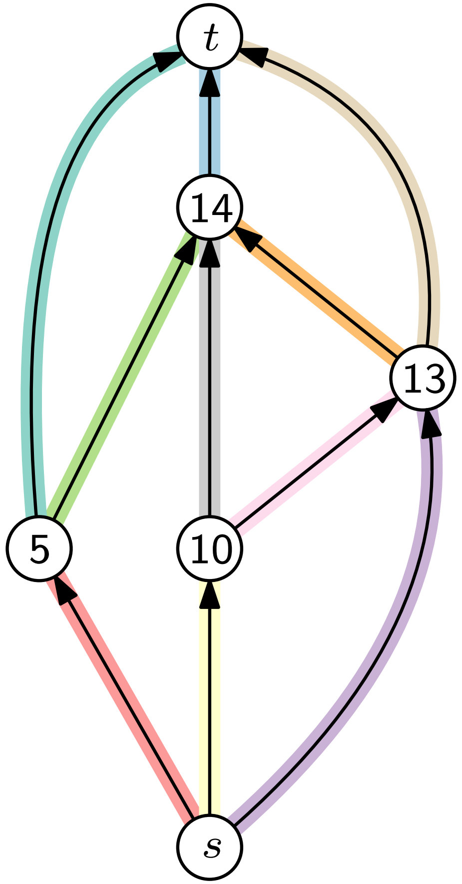

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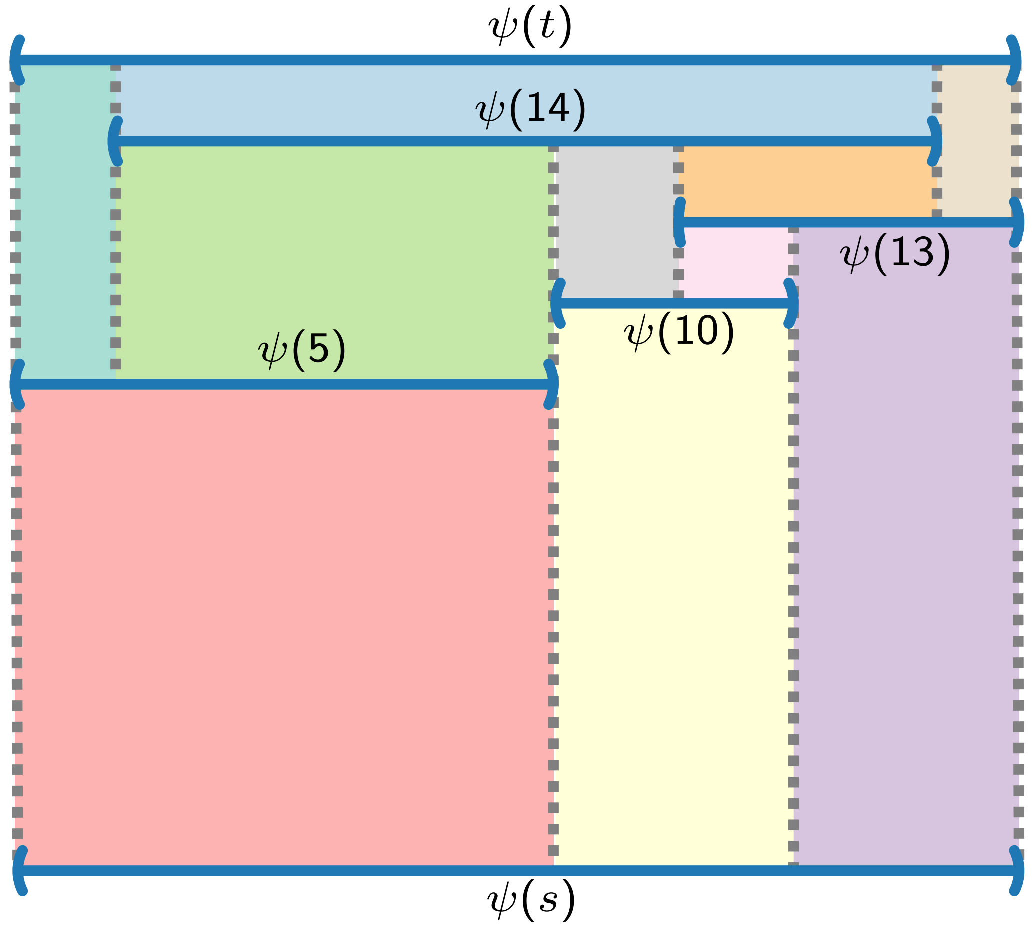
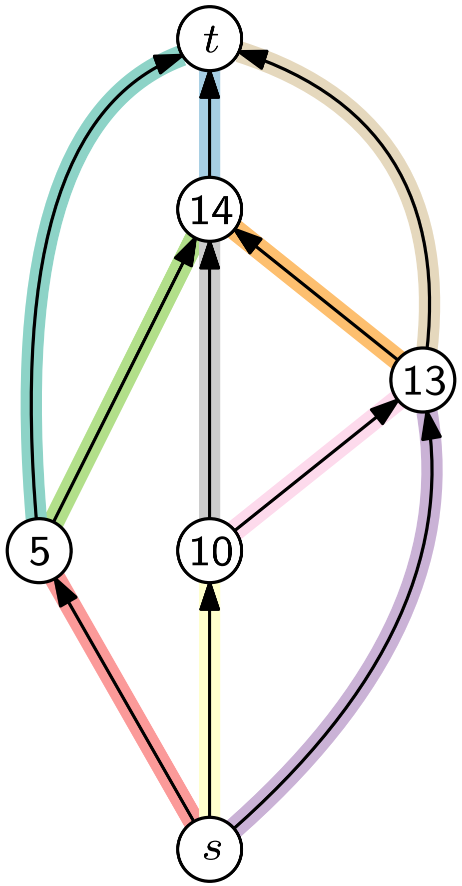
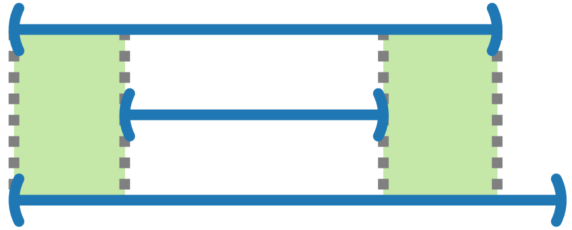
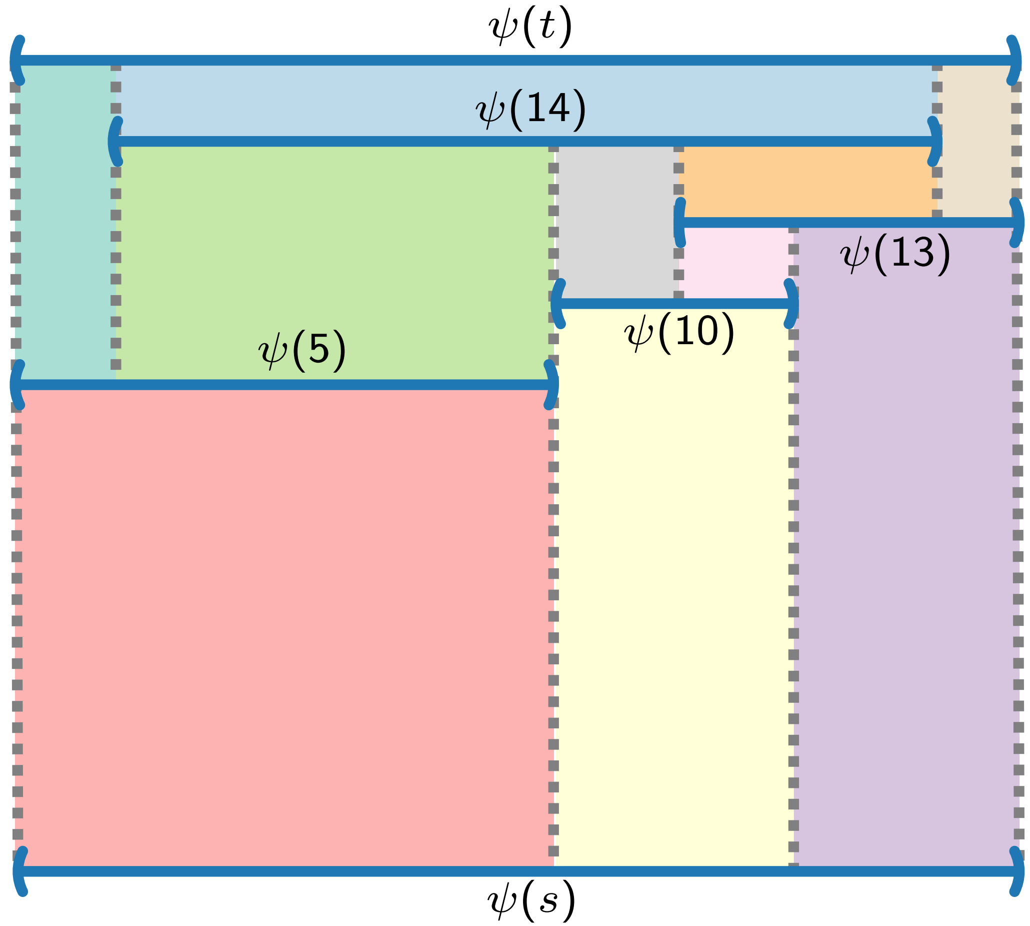
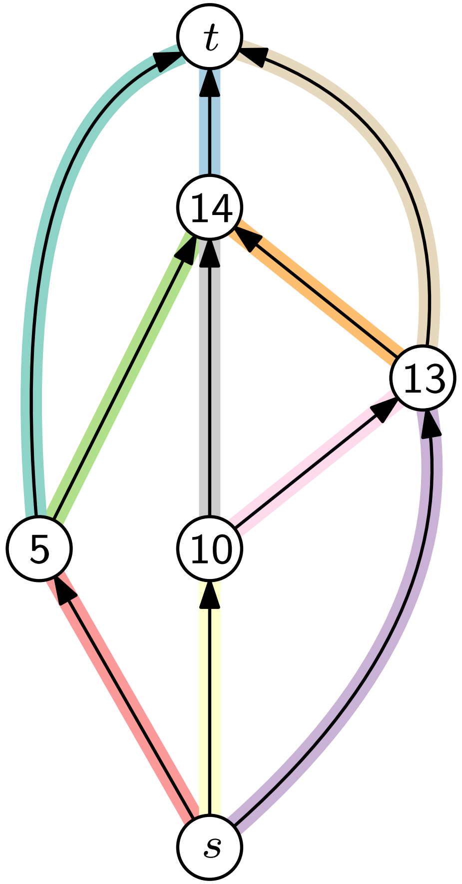




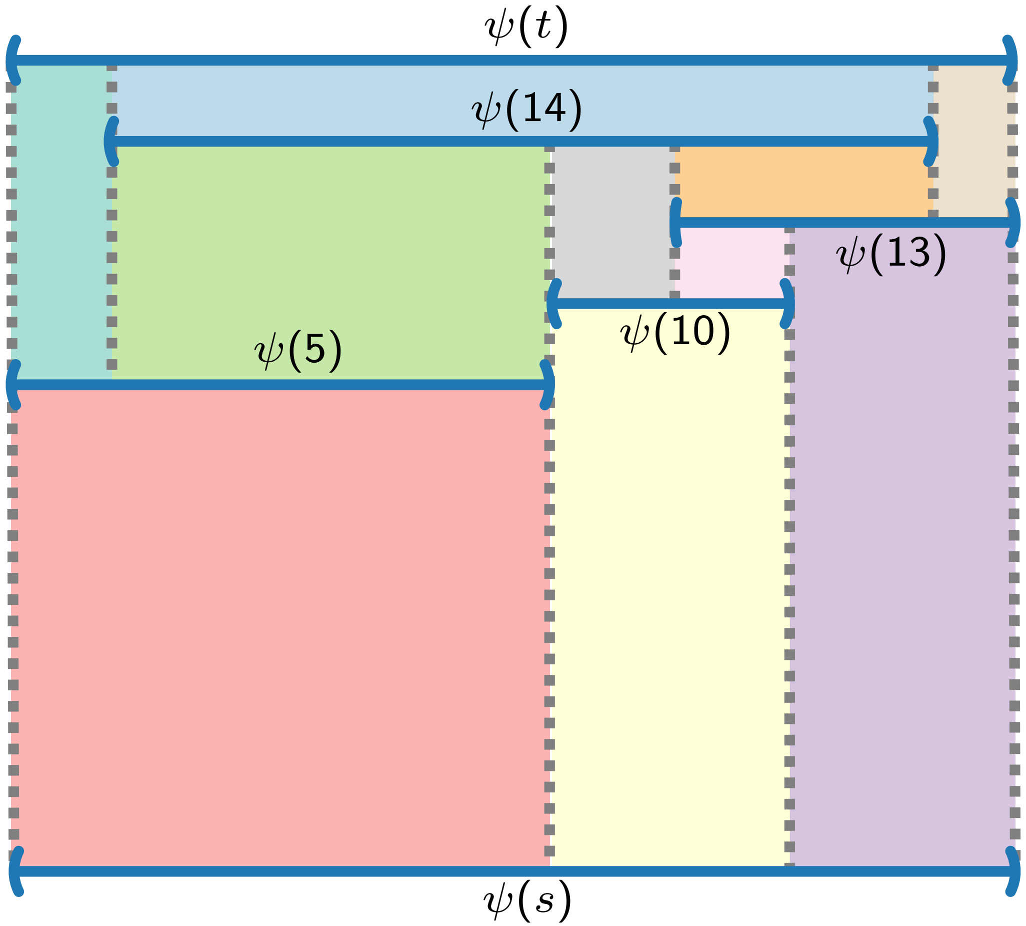
R-Nodes

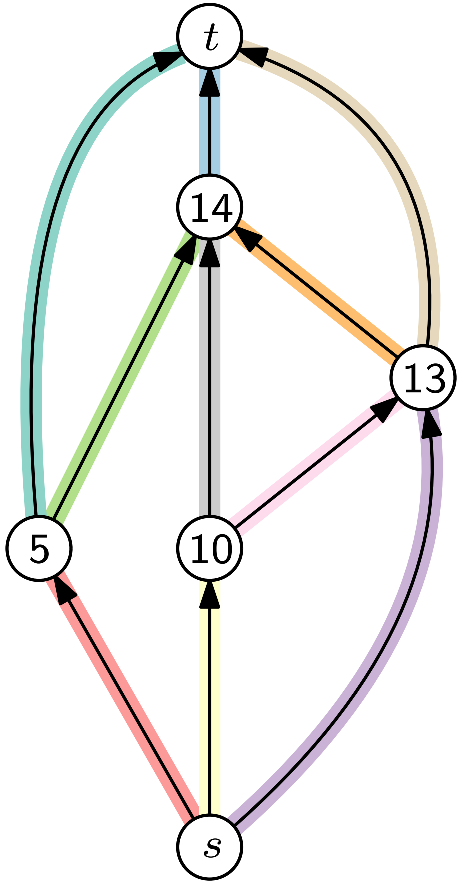


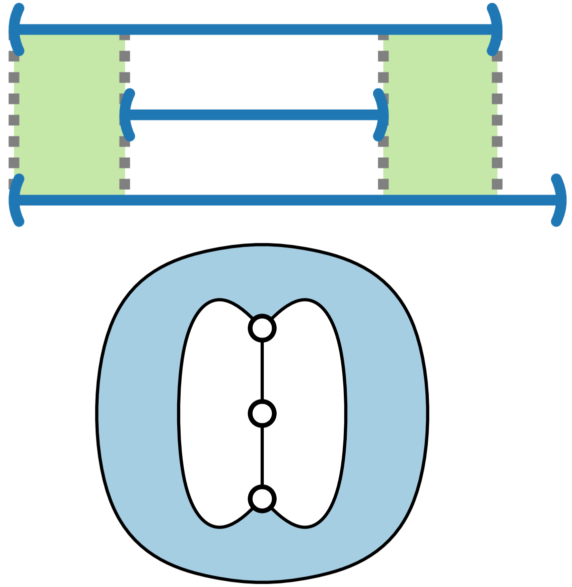




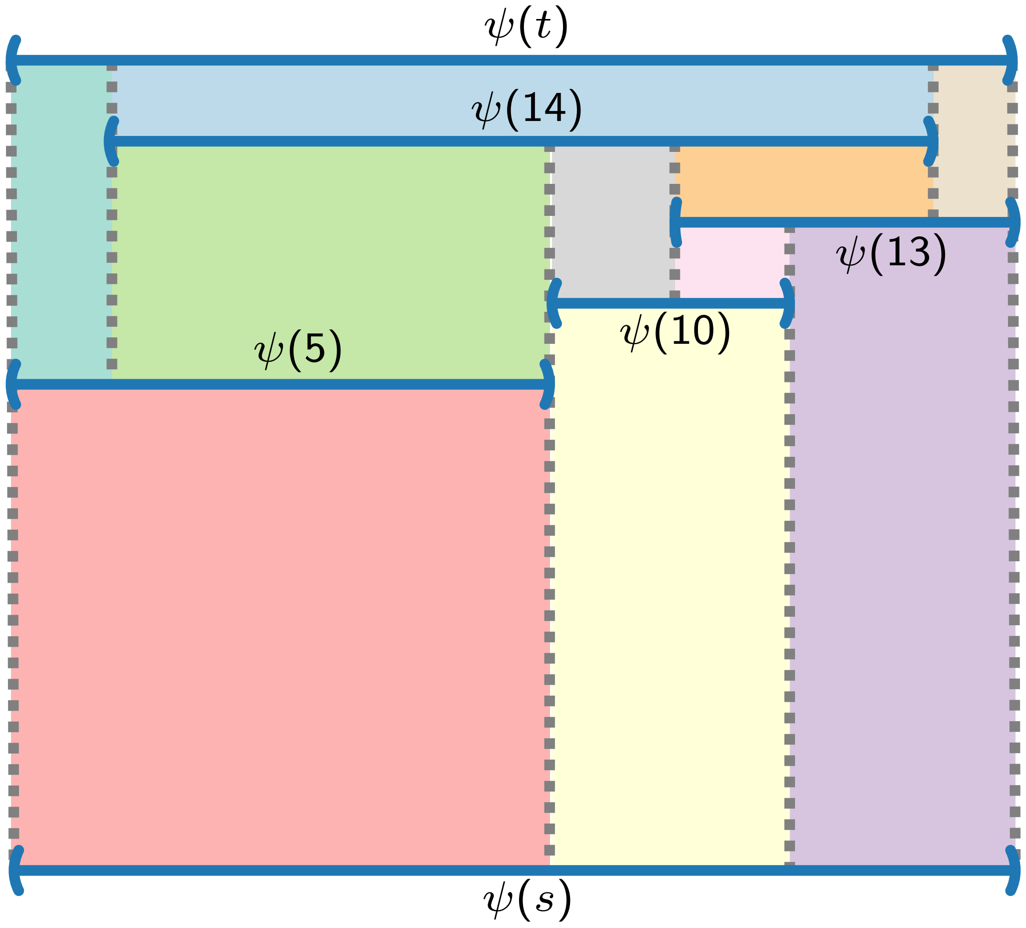
R-Nodes

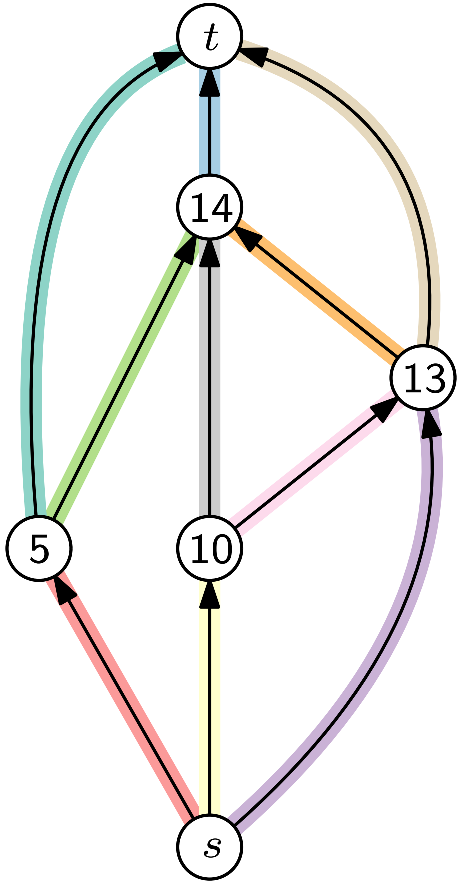


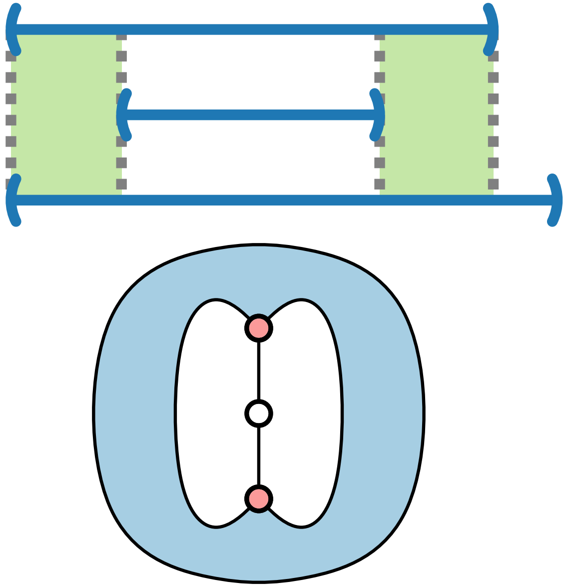




R-Nodes

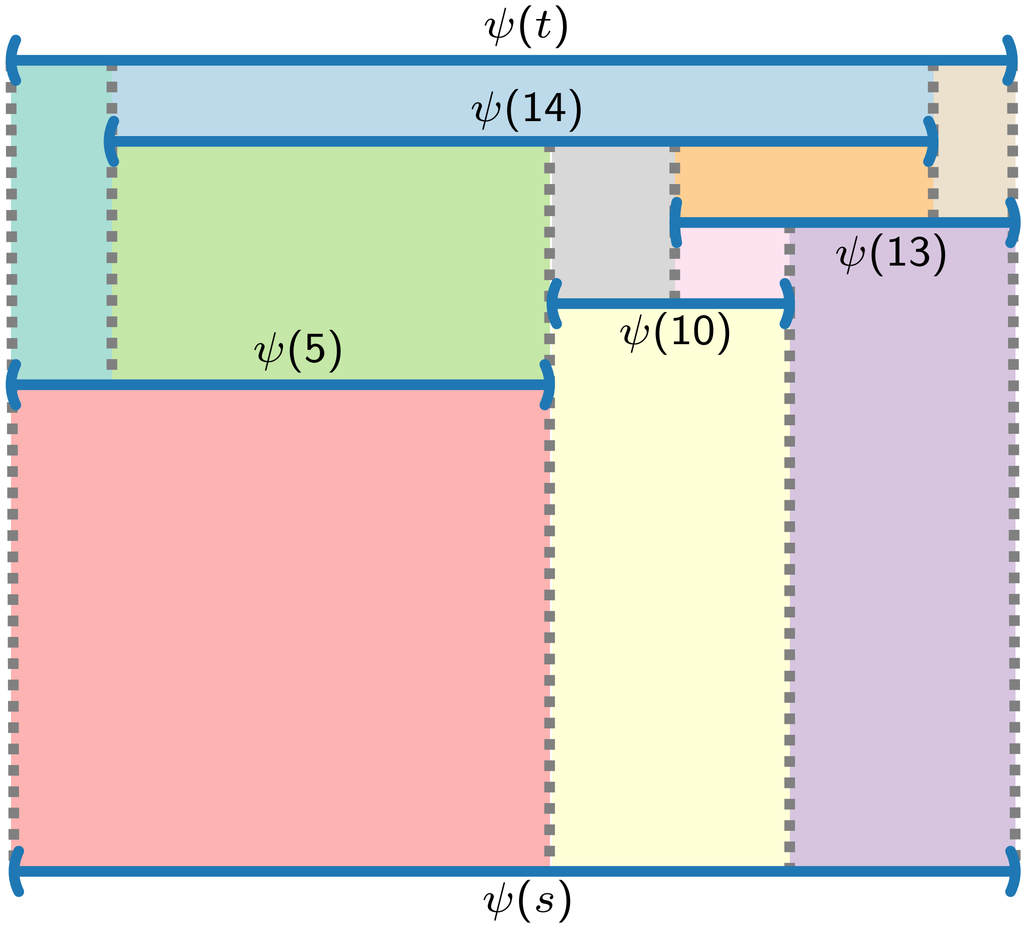


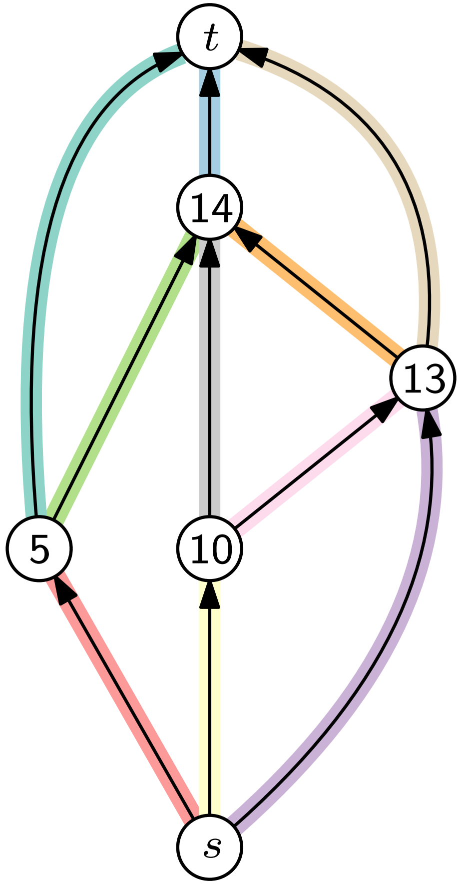


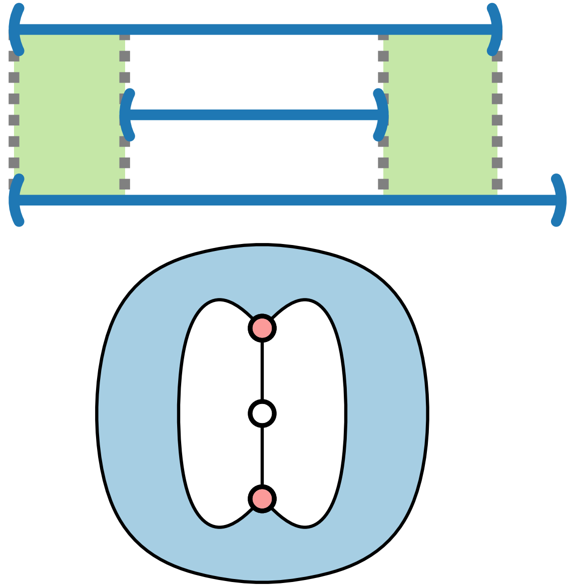


Separation pair!

R-Nodes



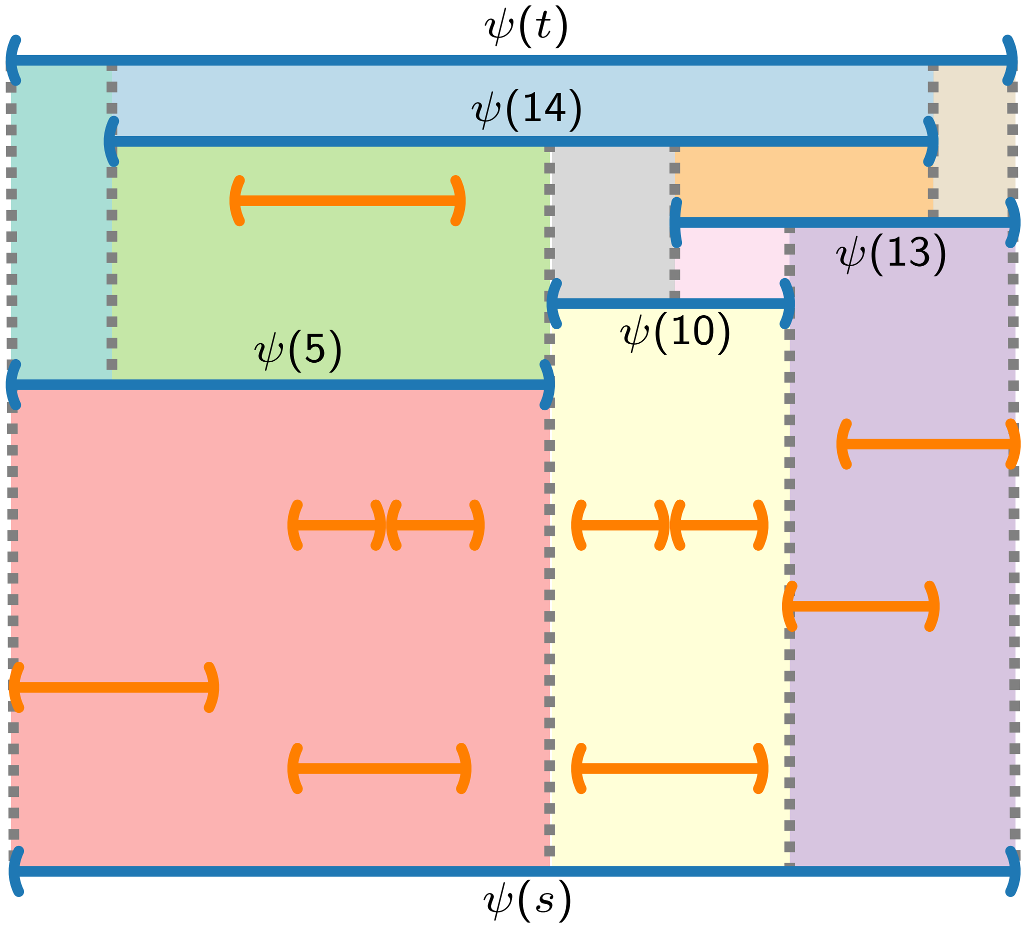


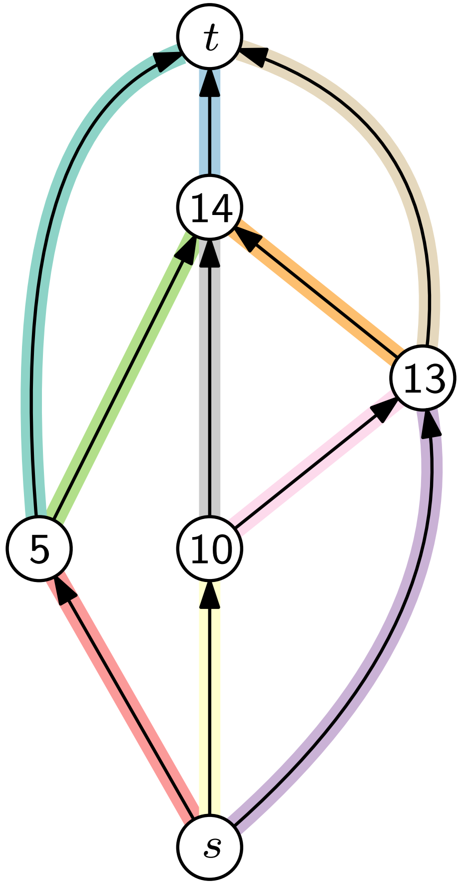


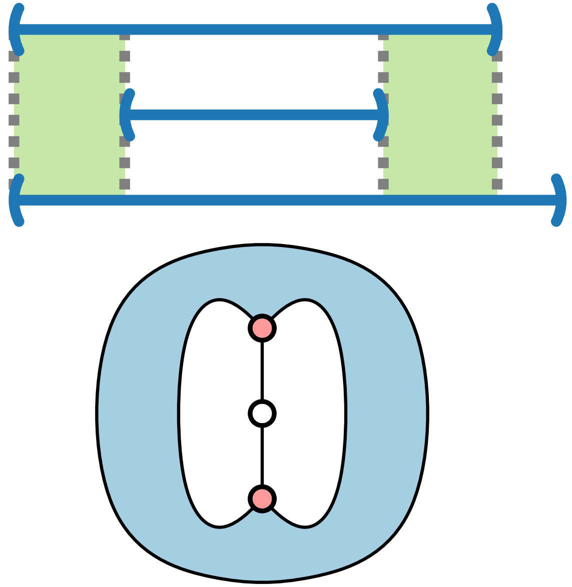
Separation pair!

($\nexists$ in **R**-component.)

R-Nodes





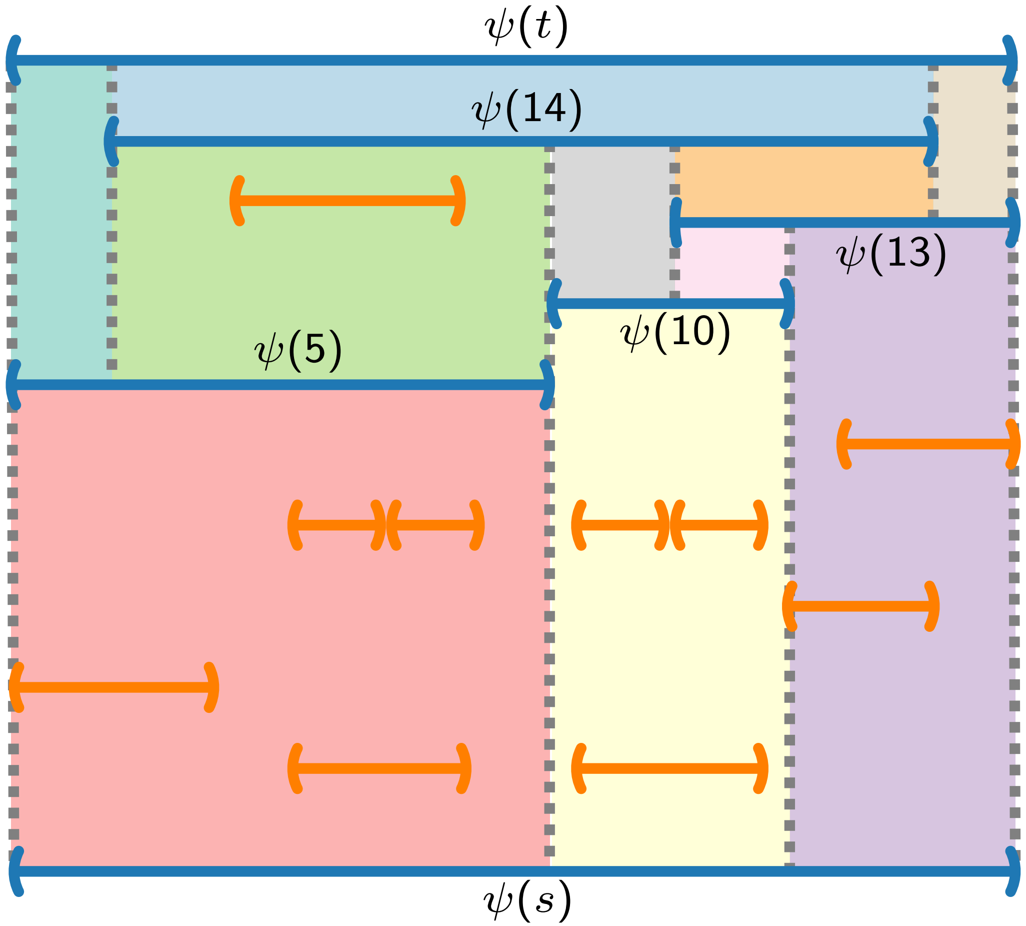


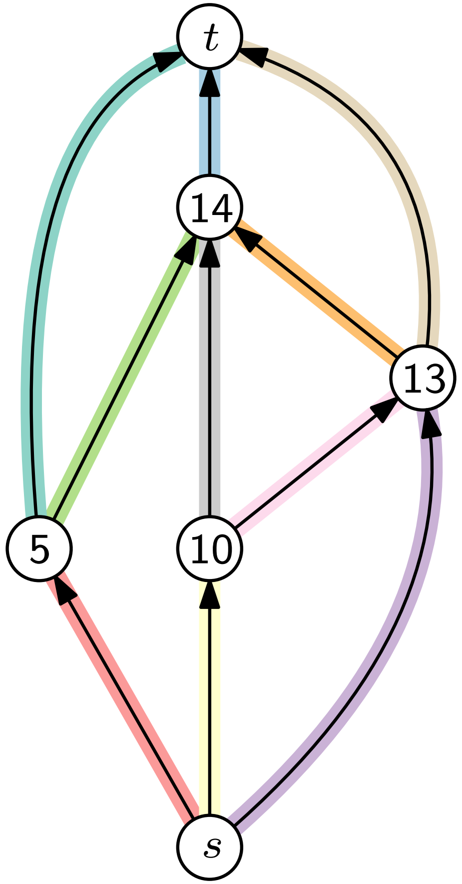
Separation pair!

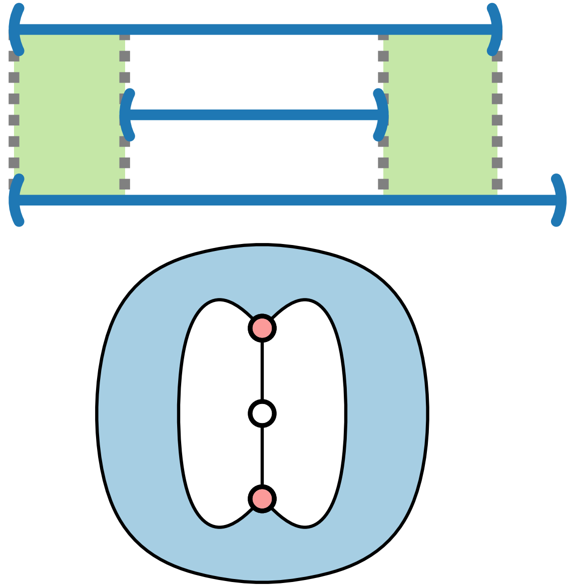
(∄ in **R**-component.)

R-Nodes

- For each child (edge) e:





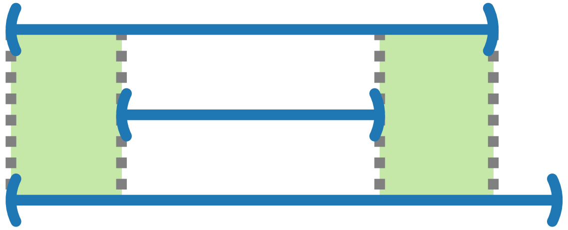


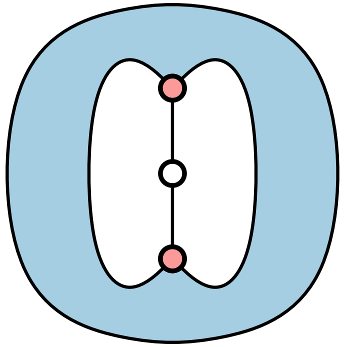
Separation pair!

($\nexists$ in **R**-component.)

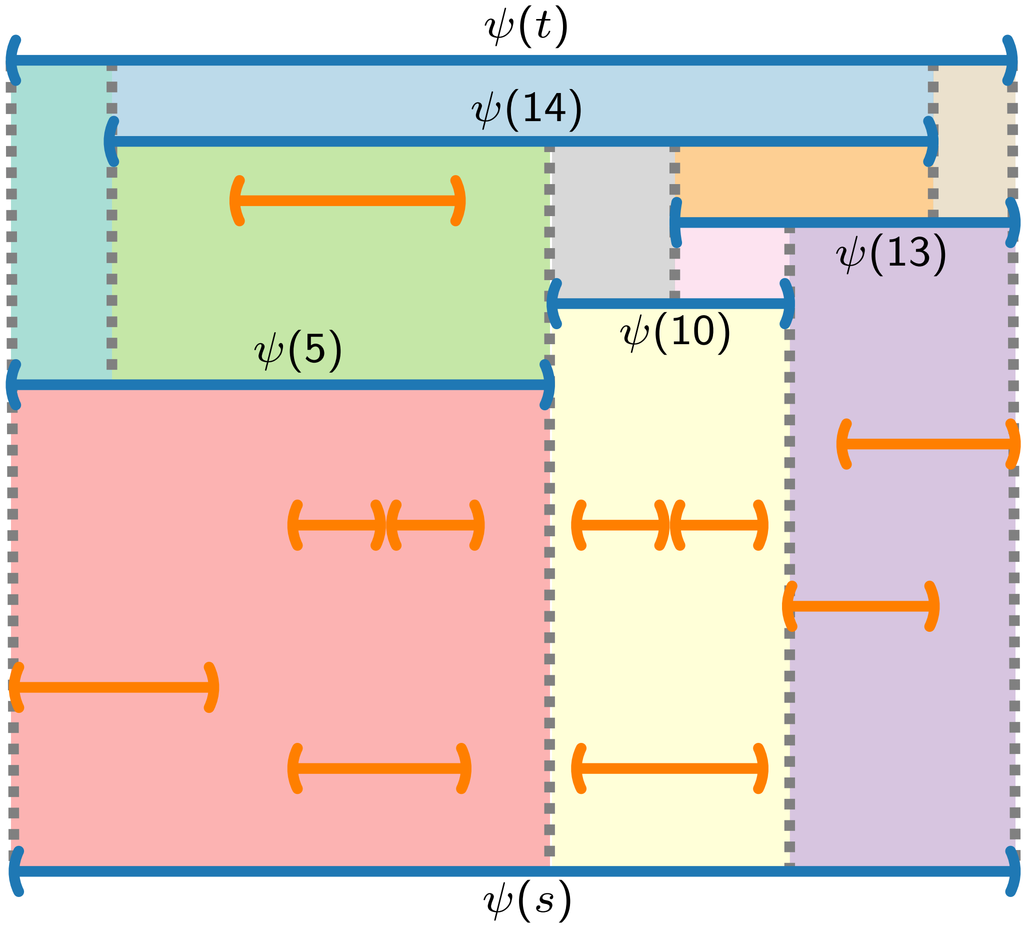
R-Nodes

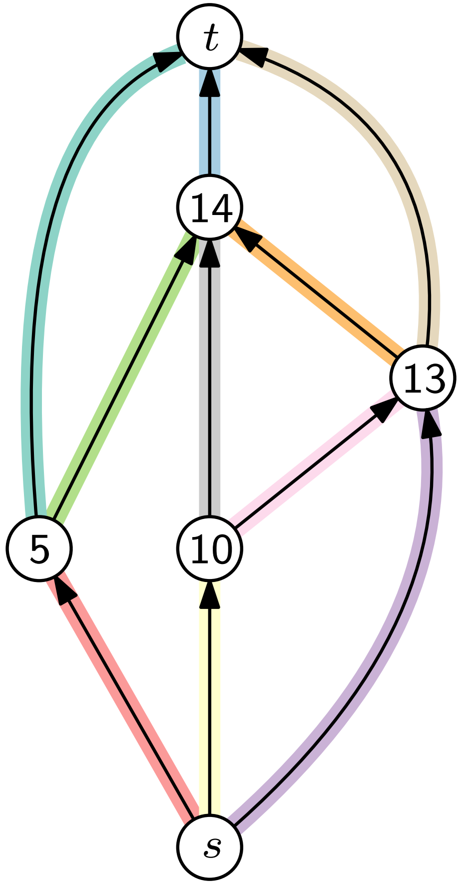
- For each child (edge) e:
  - Find all types of {**FF, FL, LF, LL**} that admit a drawing.





Separation pair!
($\nexists$ in **R**-component.)





R-Nodes with 2-SAT Formulation

- For each child (edge) e:
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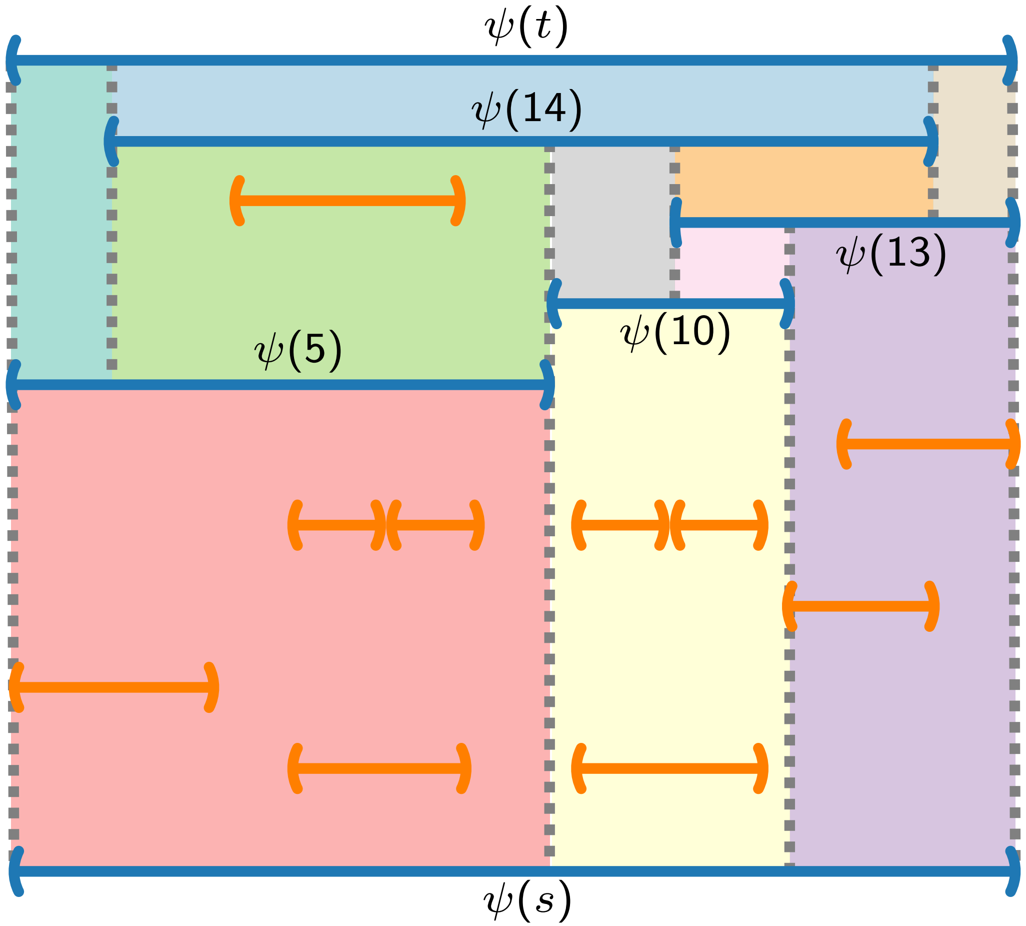
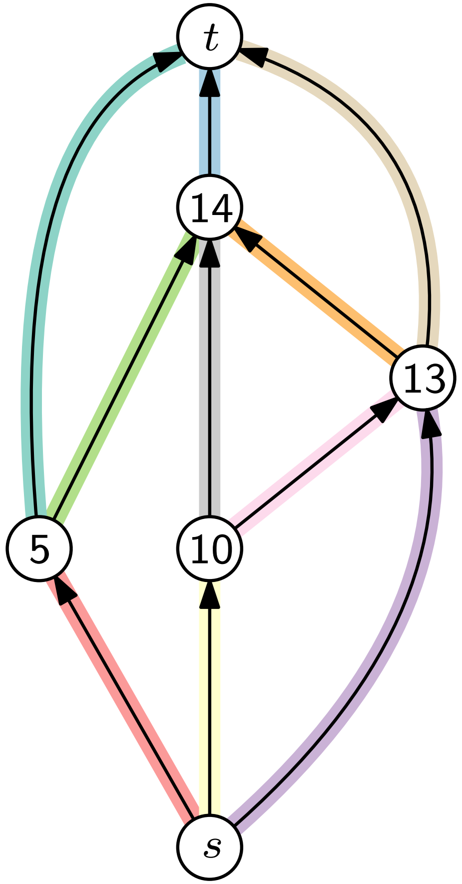
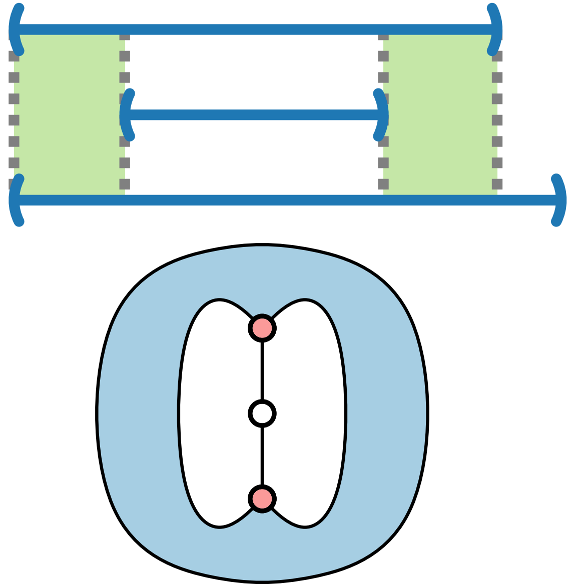




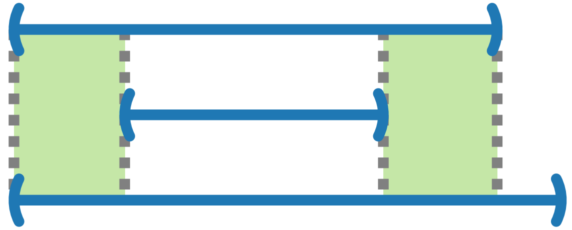


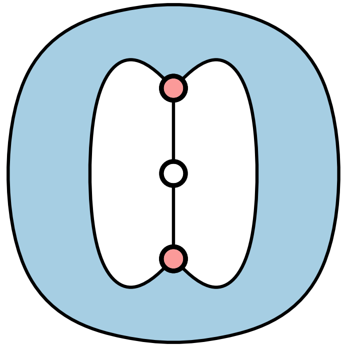
Separation pair!

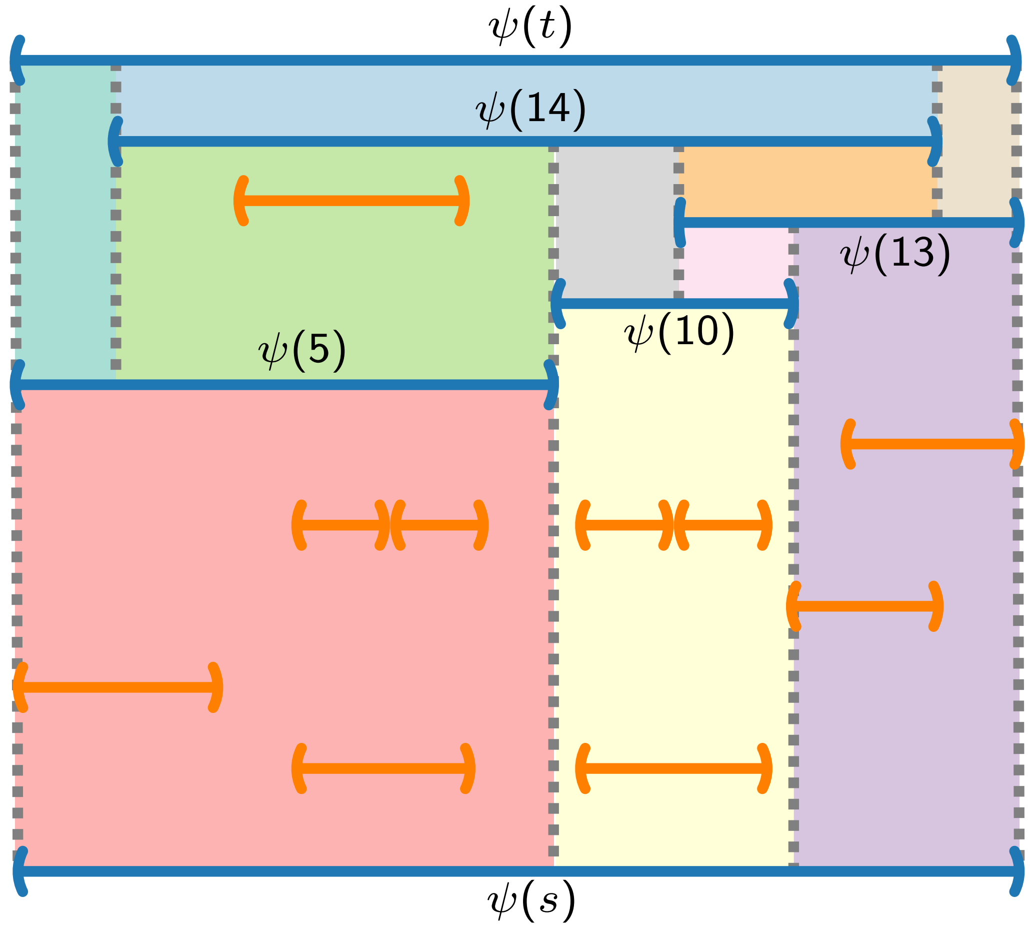
($\nexists$ in **R**-component.)

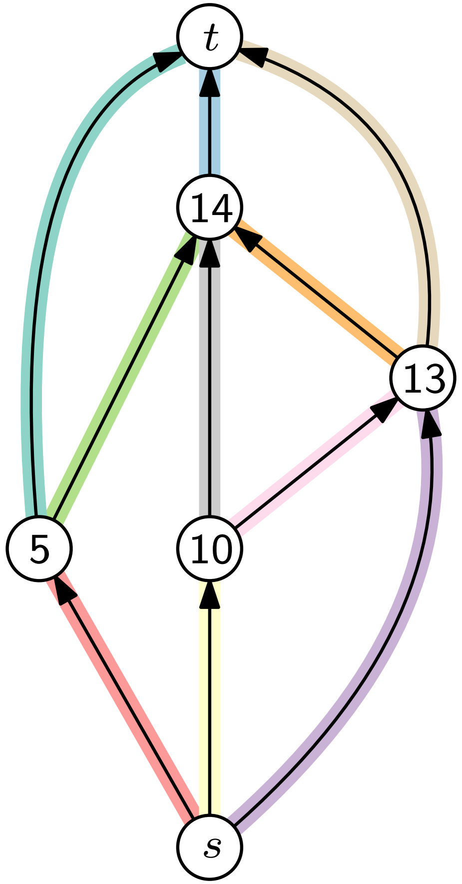
R-Nodes with 2-SAT Formulation

- For each child (edge) e:
  - Find all types of $\{$**FF**, **FL**, **LF**, **LL**$\}$ that admit a drawing.
  - Use two variables (l_e and r_e) to encode the type of its tile (**F** $= 0$).









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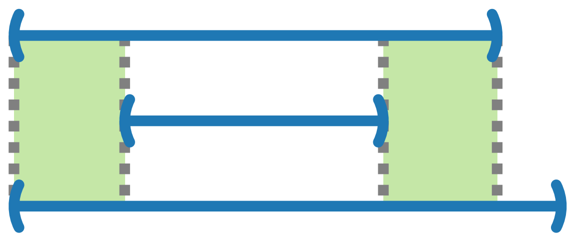
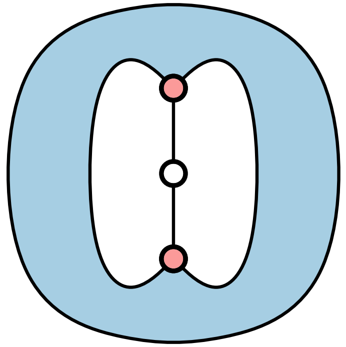
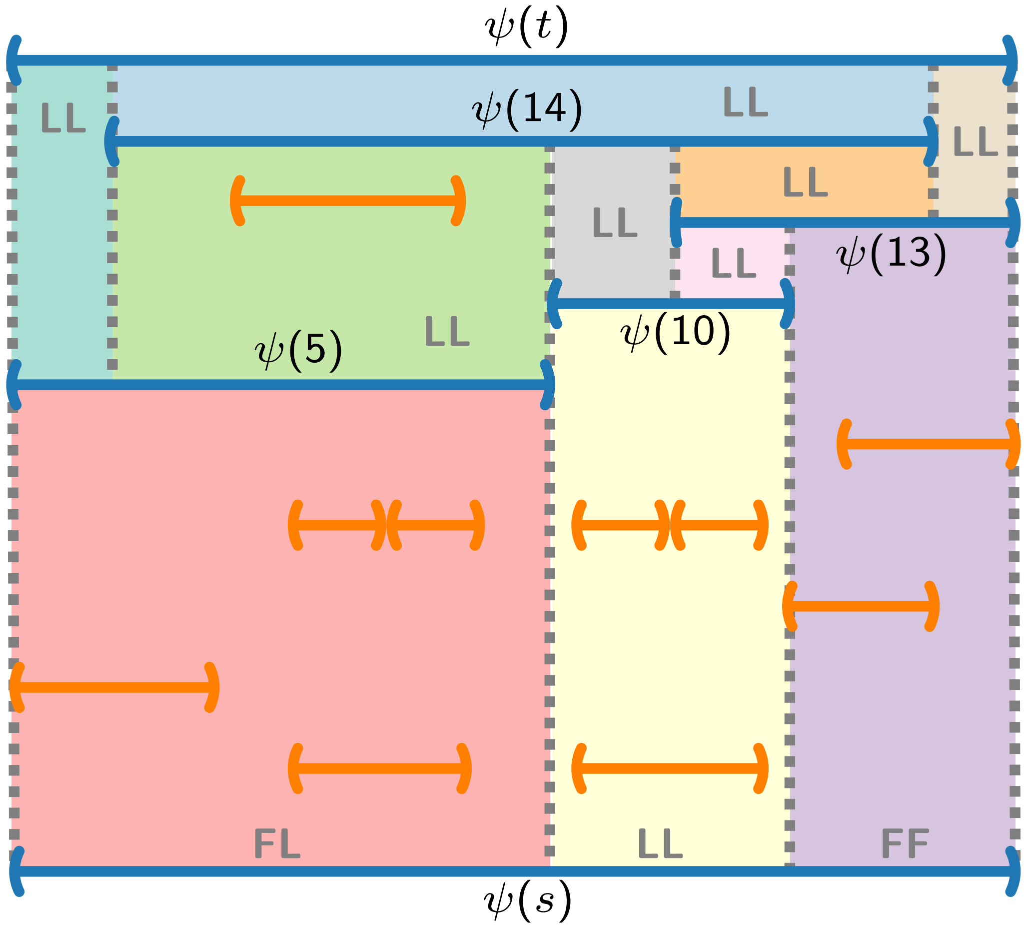
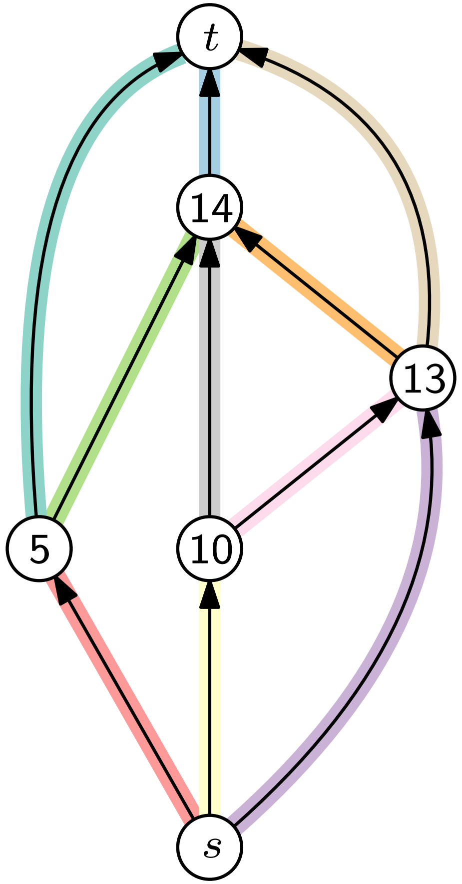



Separation pair!
($\nexists$ in **R**-component.)





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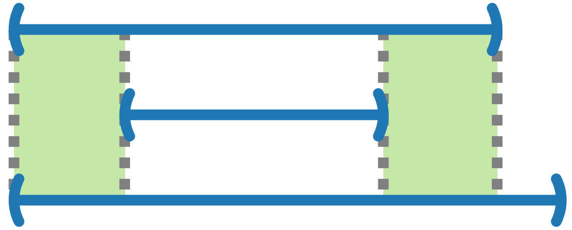

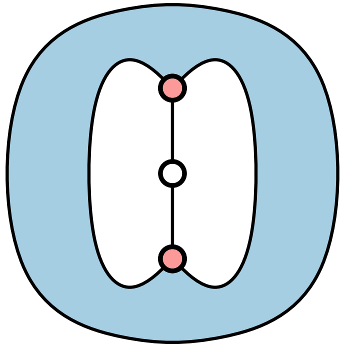

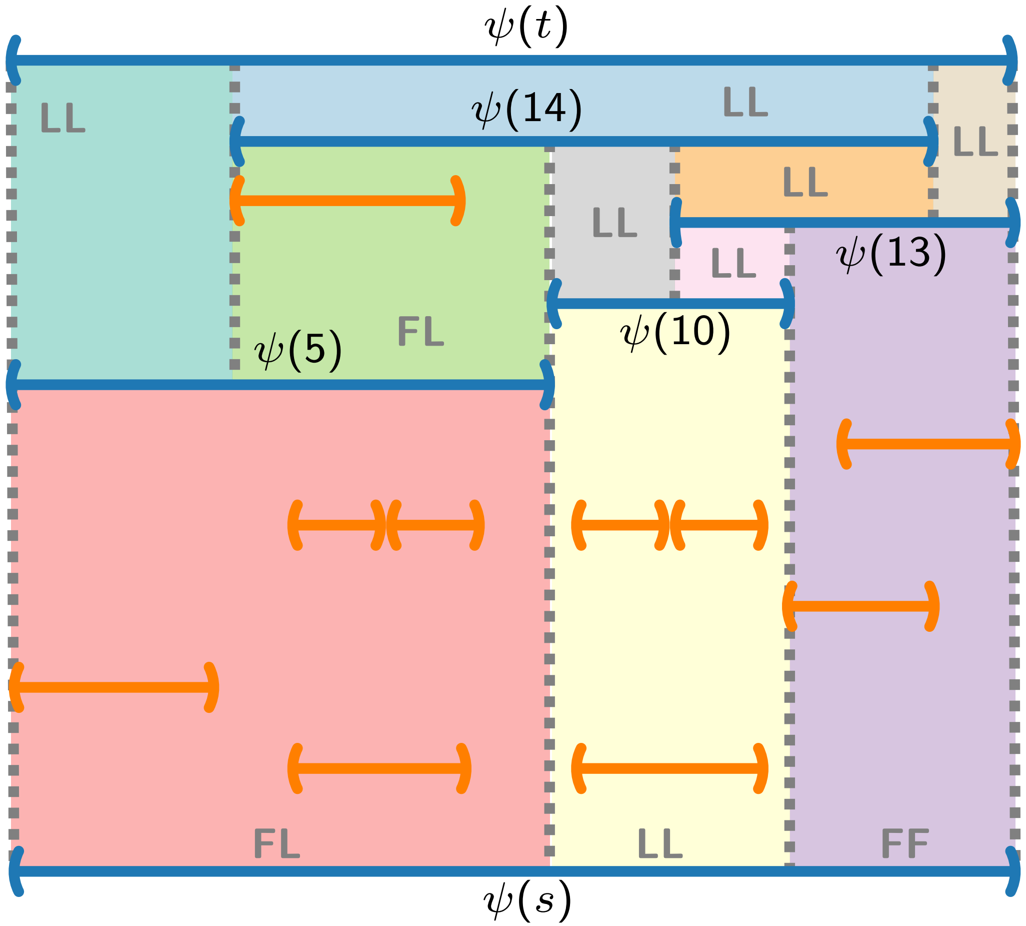

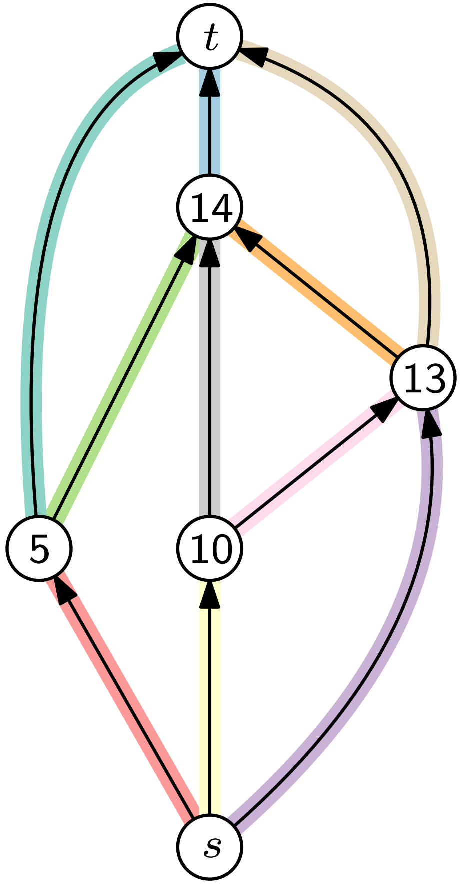

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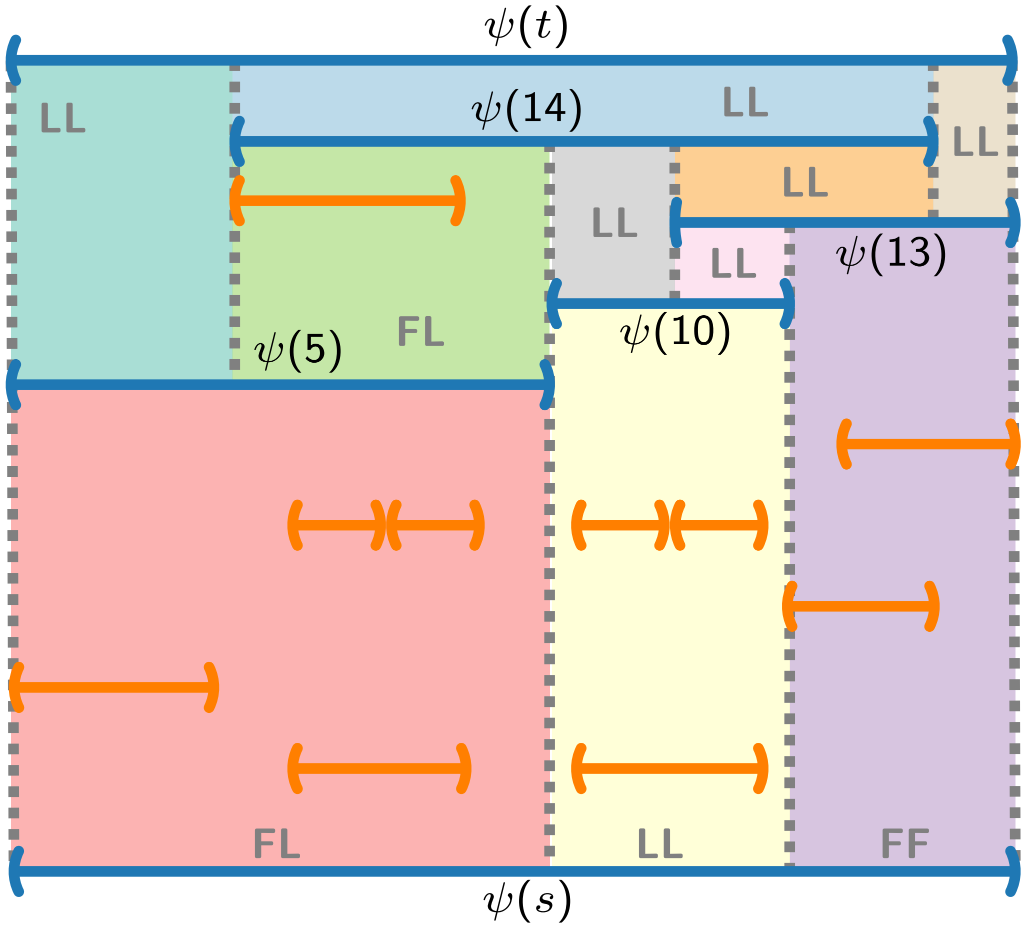
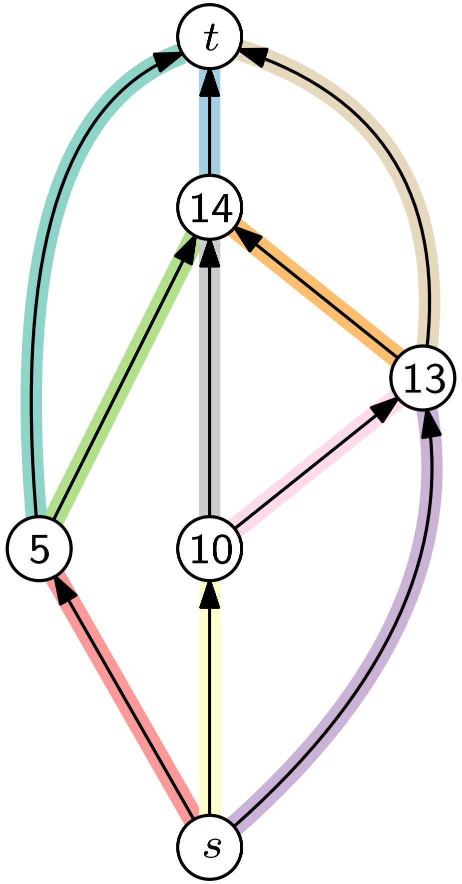
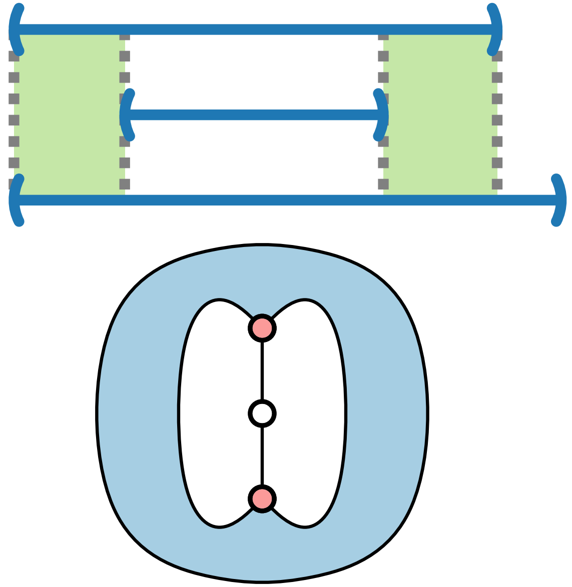
  - Add *consistency clauses*







Separation pair!

(∄ in **R**-component.)

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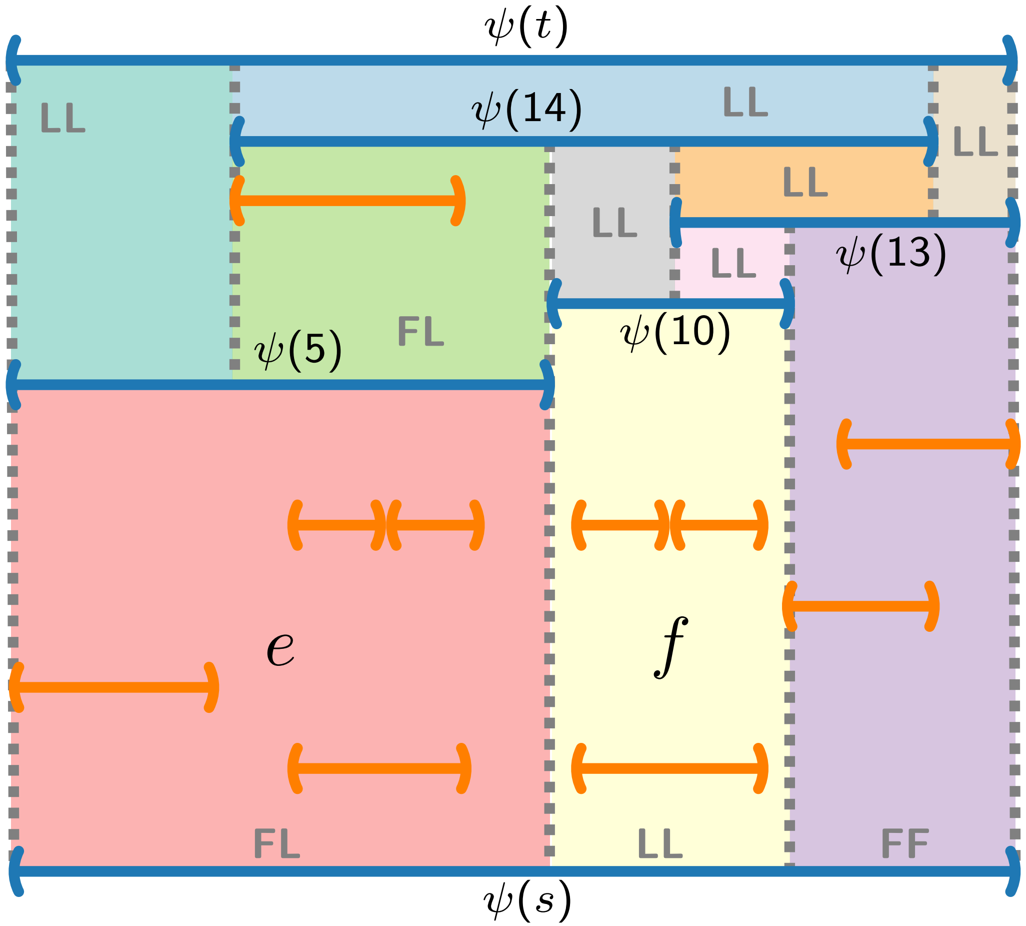

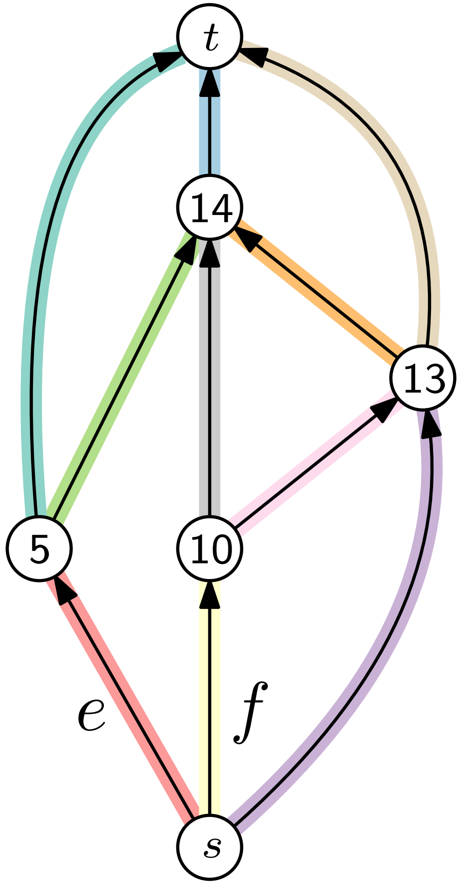

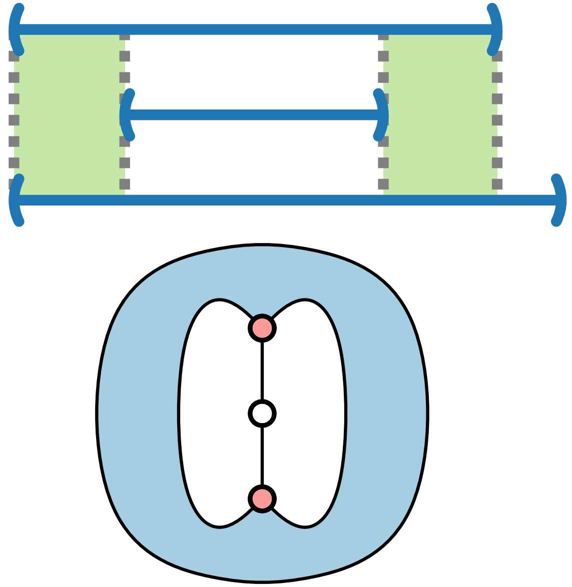

Separation pair!
($\nexists$ in **R**-component.)

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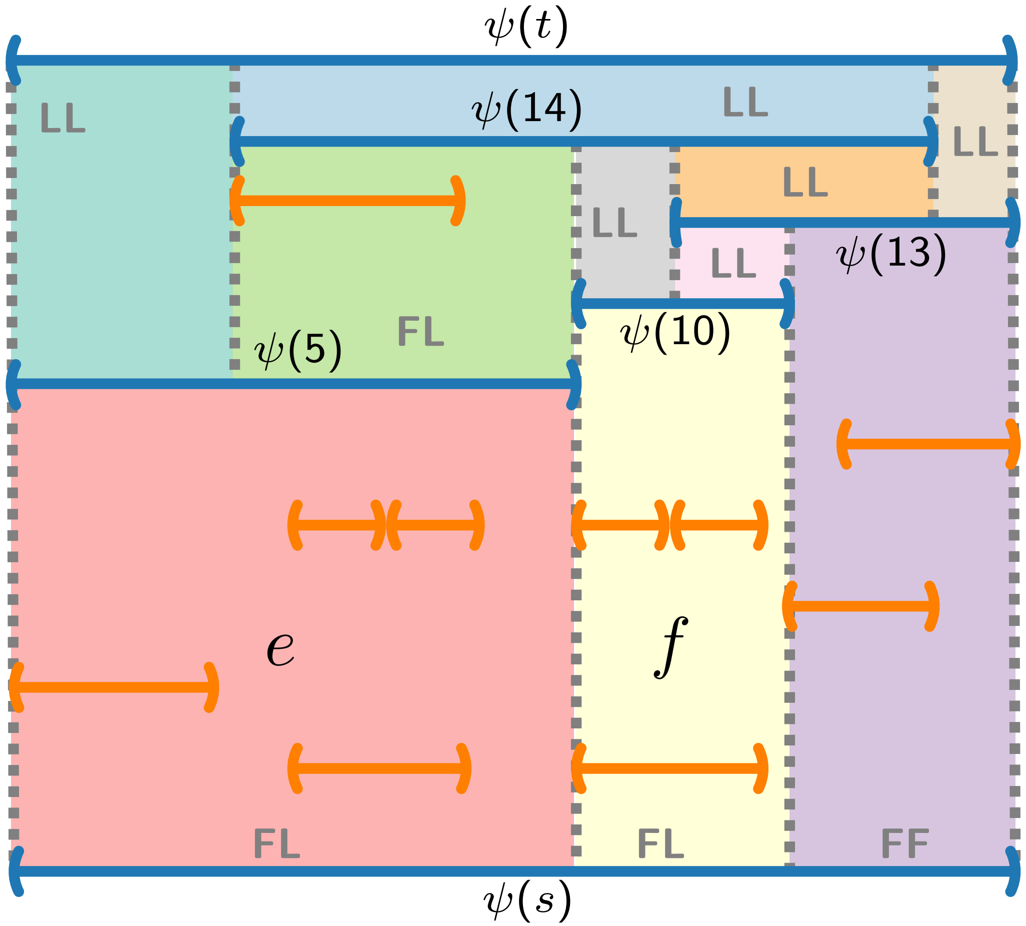

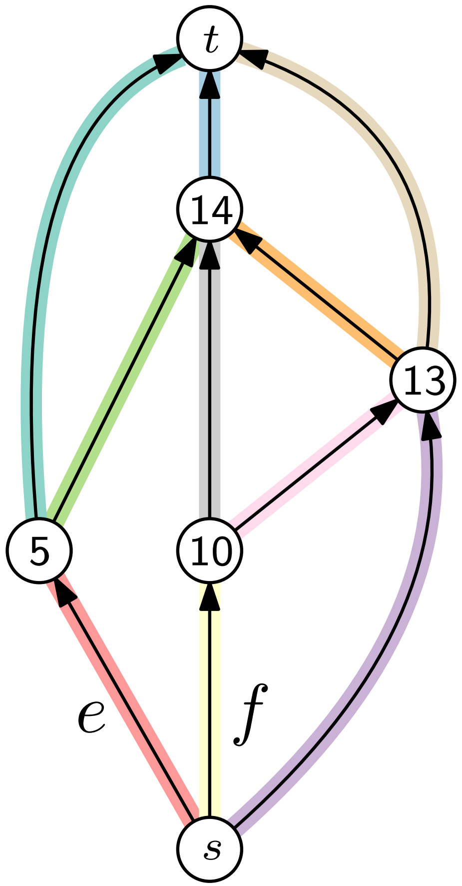

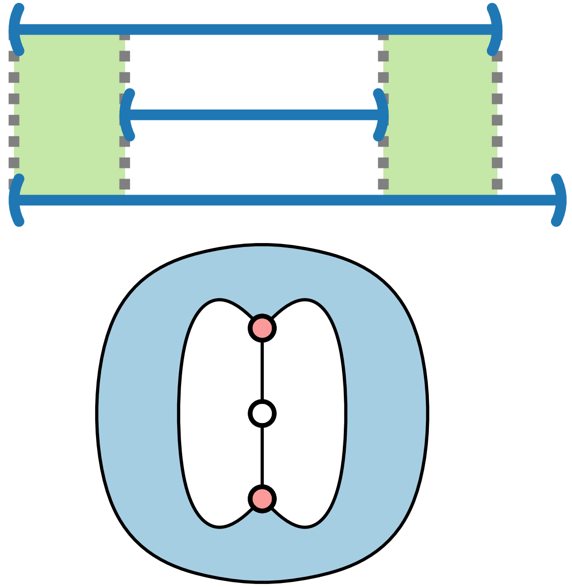

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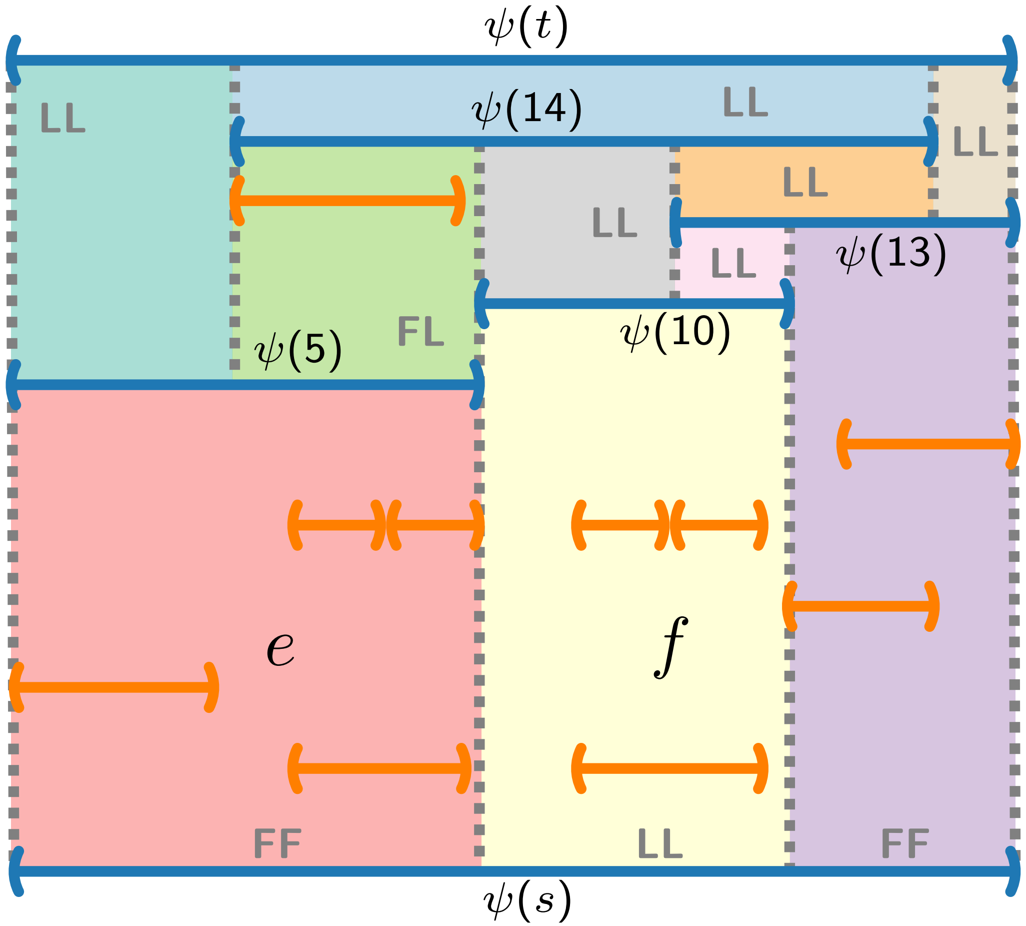

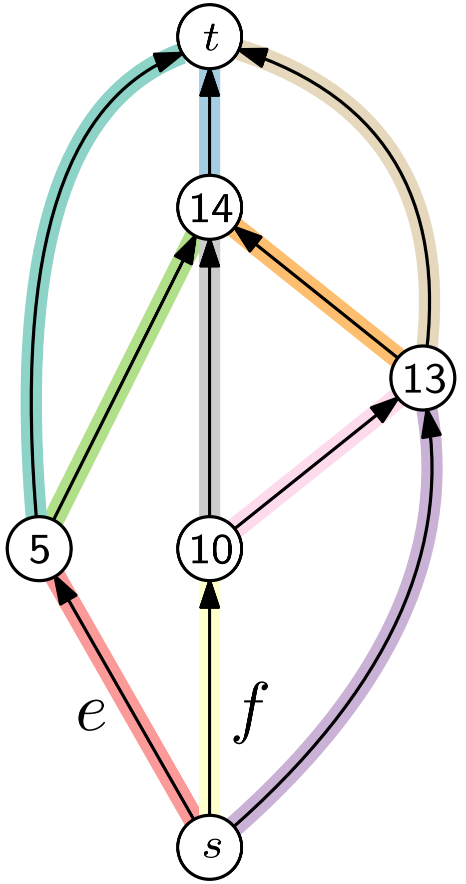

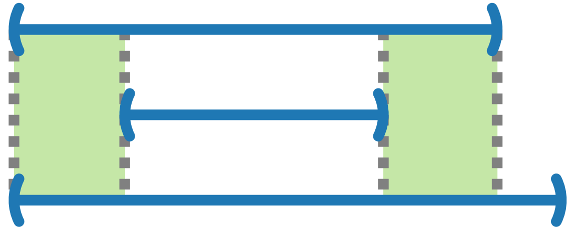

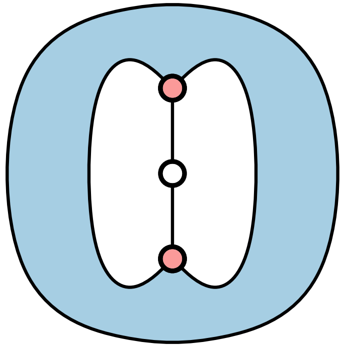

Separation pair!

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R-Nodes with 2-SAT Formulation

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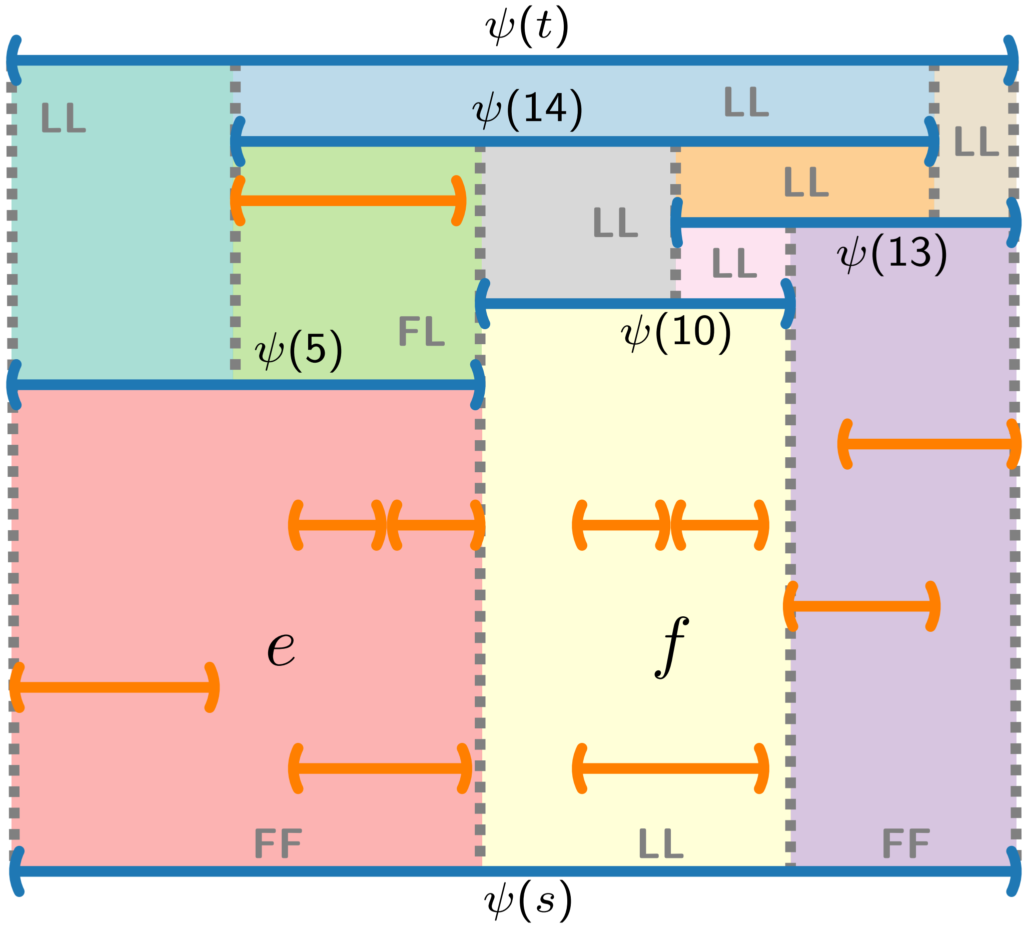

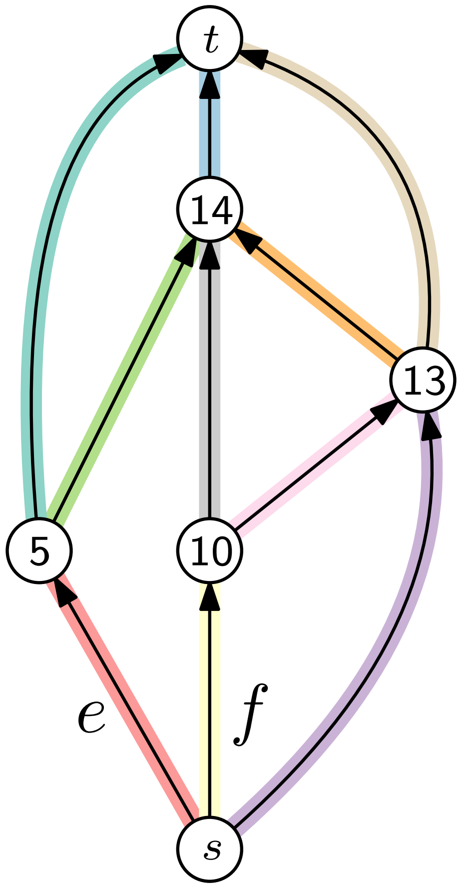

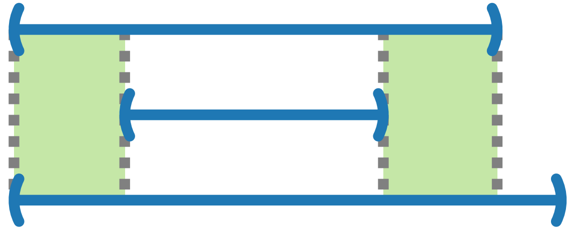

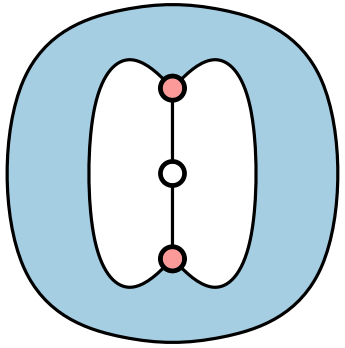

Separation pair!

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R-Nodes with 2-SAT Formulation

- For each child (edge) e:
  - Find all types of {**FF, FL, LF, LL**} that admit a drawing.
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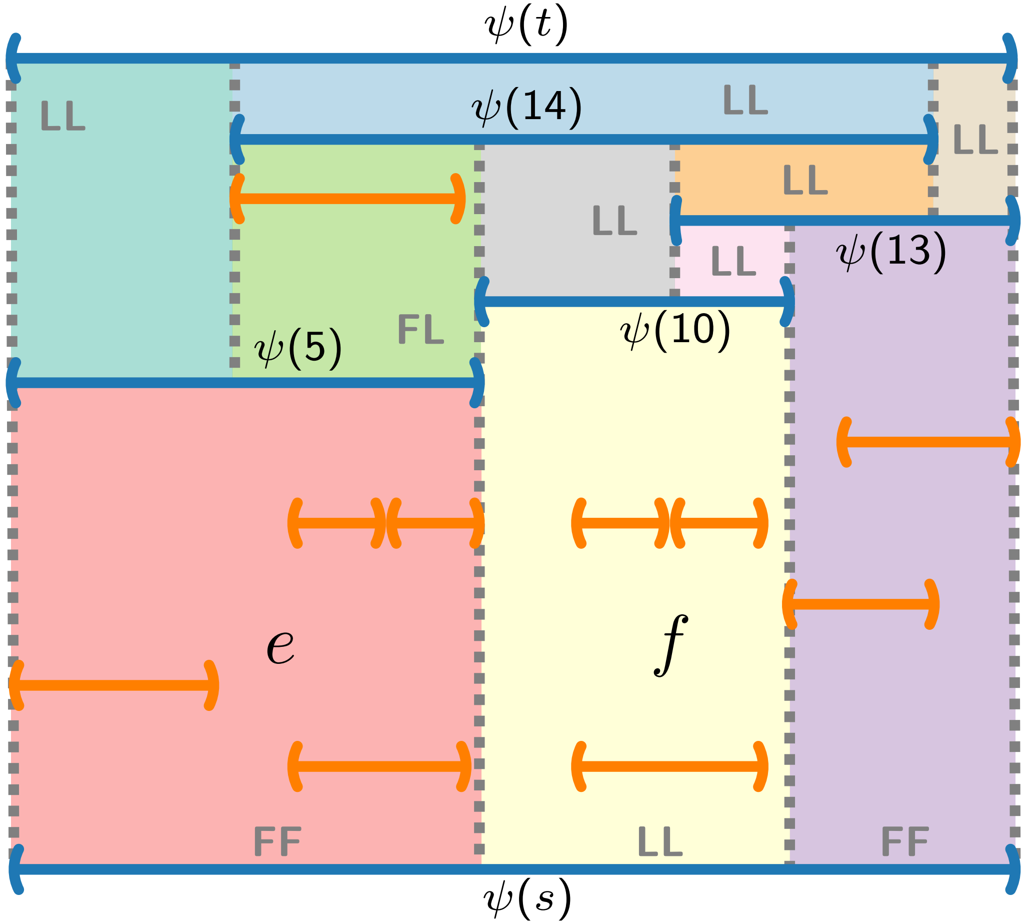
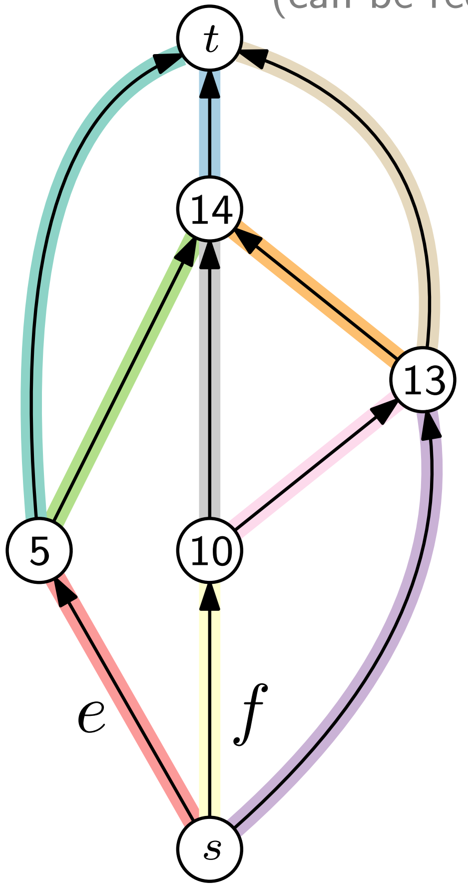
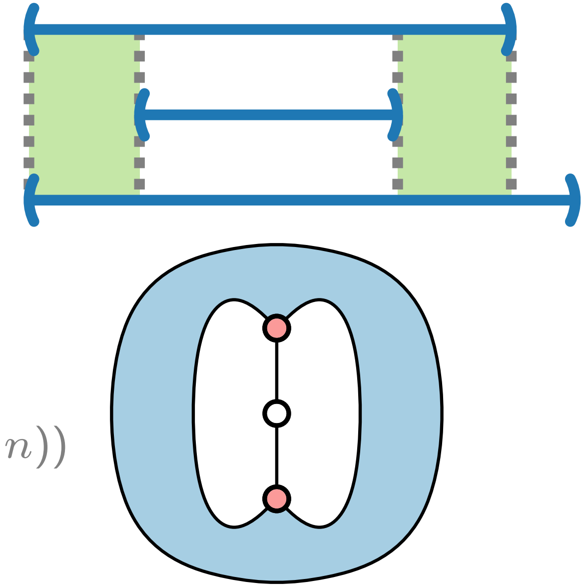
  - Add *consistency clauses*: e.g., $\neg(\neg r_e \wedge \neg l_f)$ $\rightarrow O(n^2)$ many.

(can be reduced to $O(n \log^2 n)$)







Separation pair!

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R-Nodes with 2-SAT Formulation

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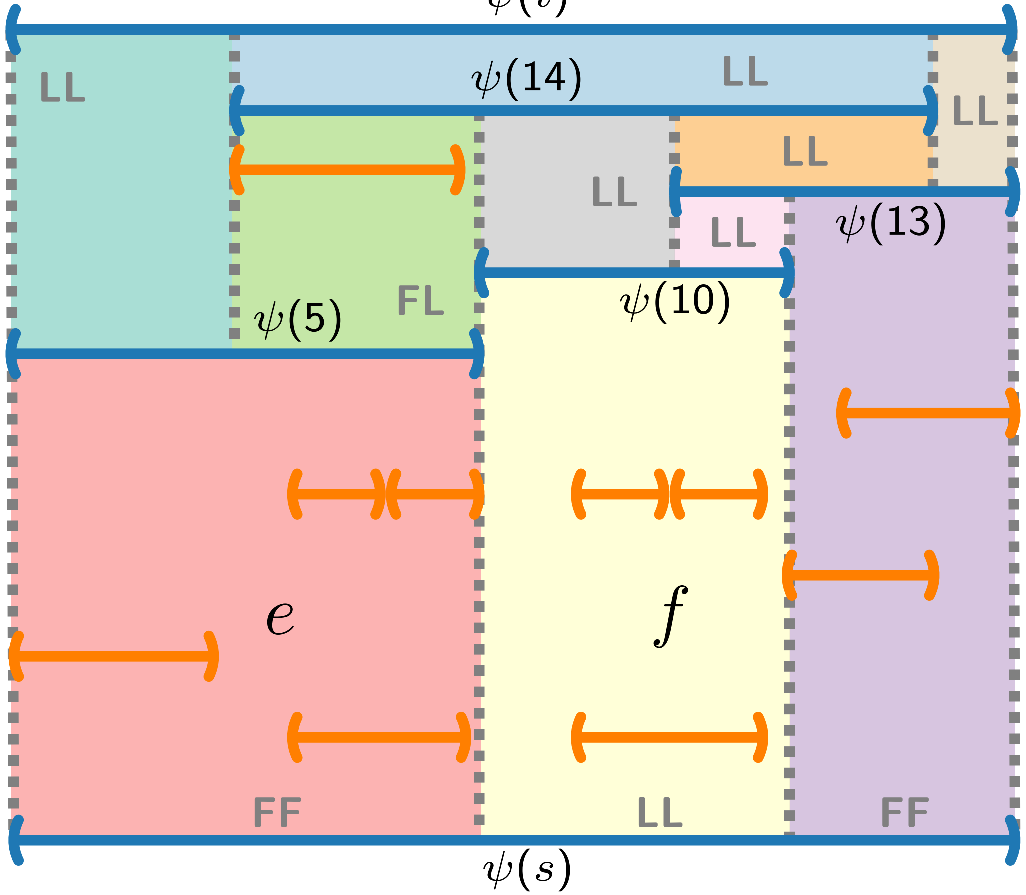

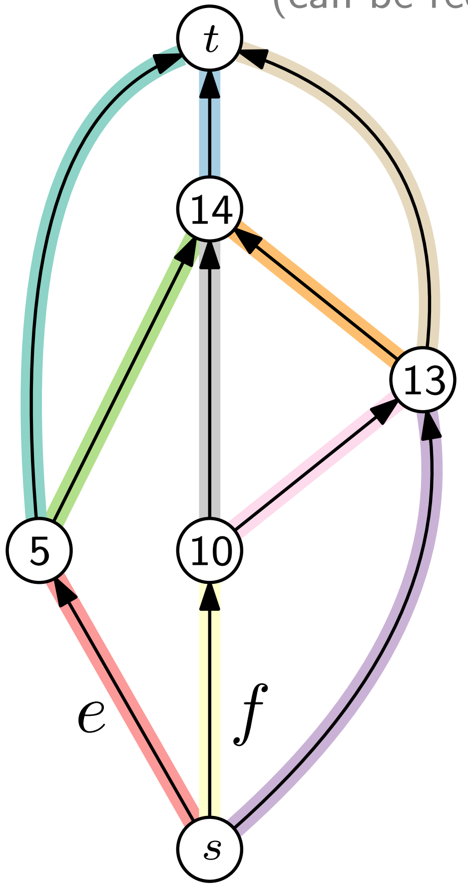

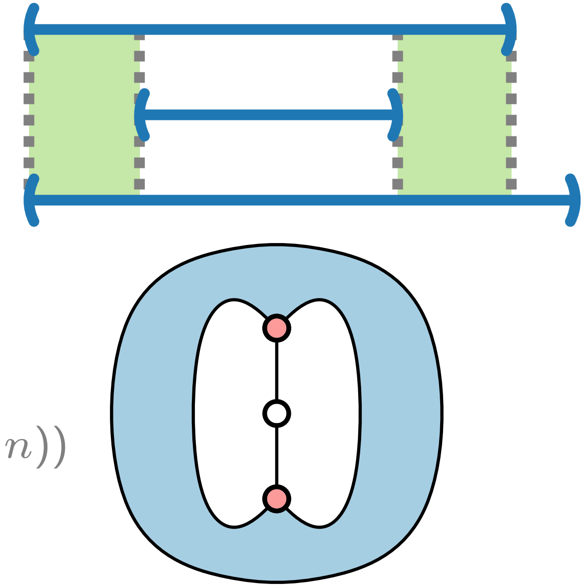

Separation pair!
(∄ in **R**-component.)

- Finding a satisfying assignment of a 2-SAT formula can be done in linear time!

R-Nodes with 2-SAT Formulation

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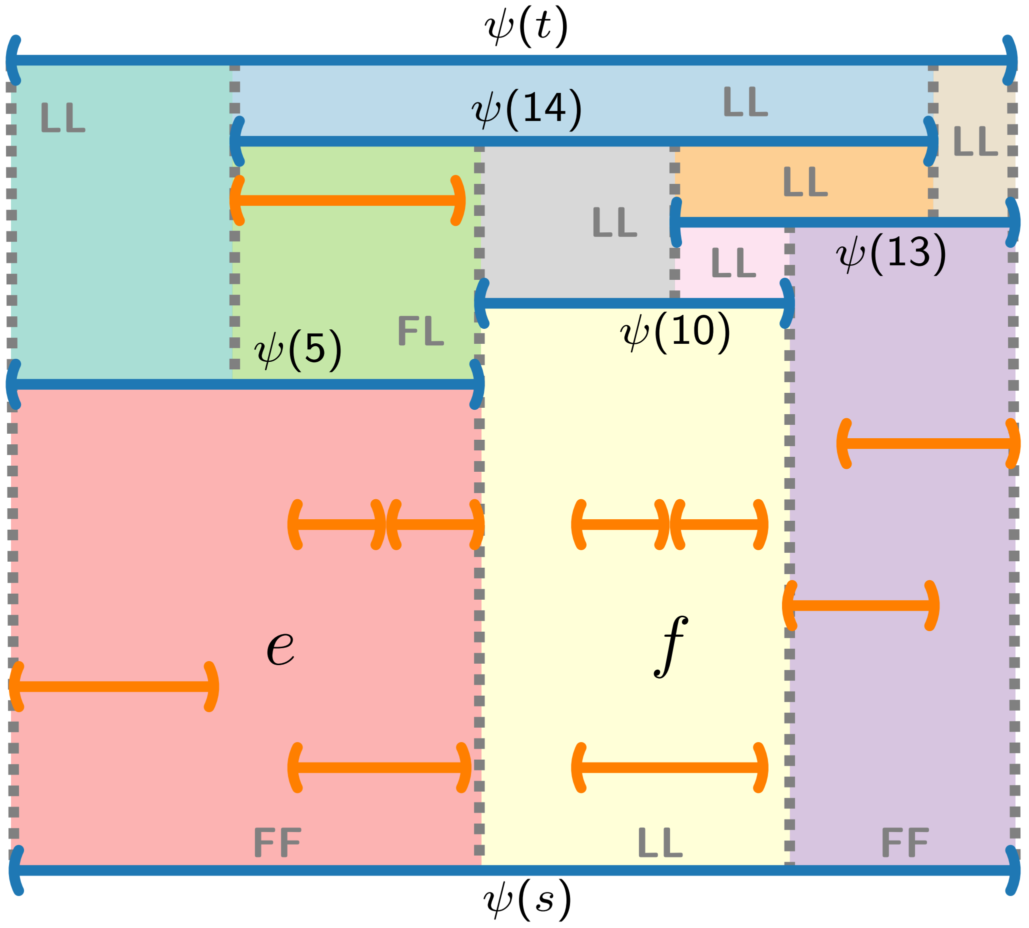
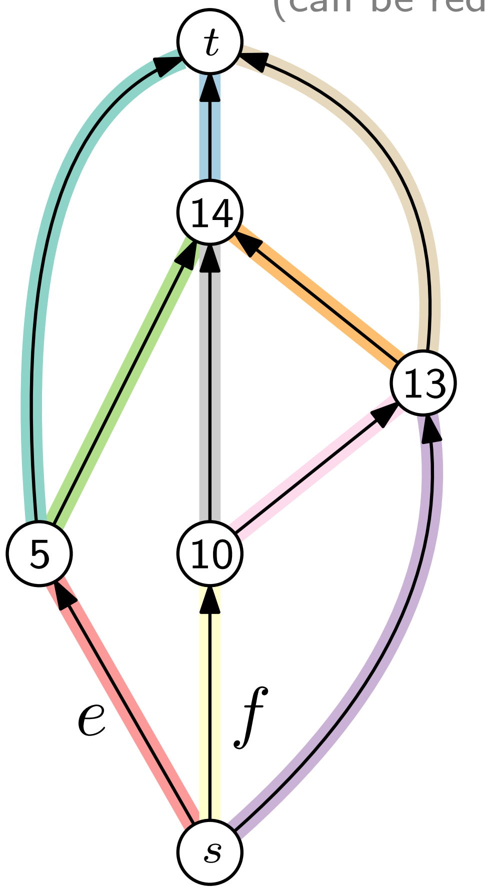
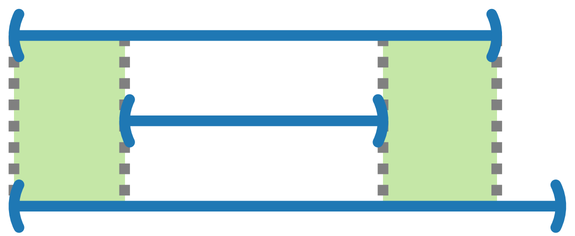
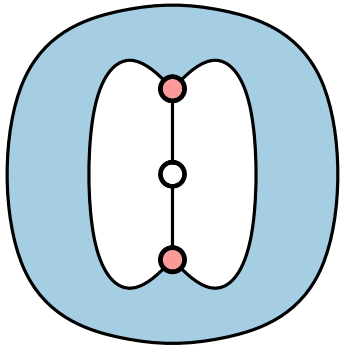








Separation pair!
($\nexists$ in **R**-component.)

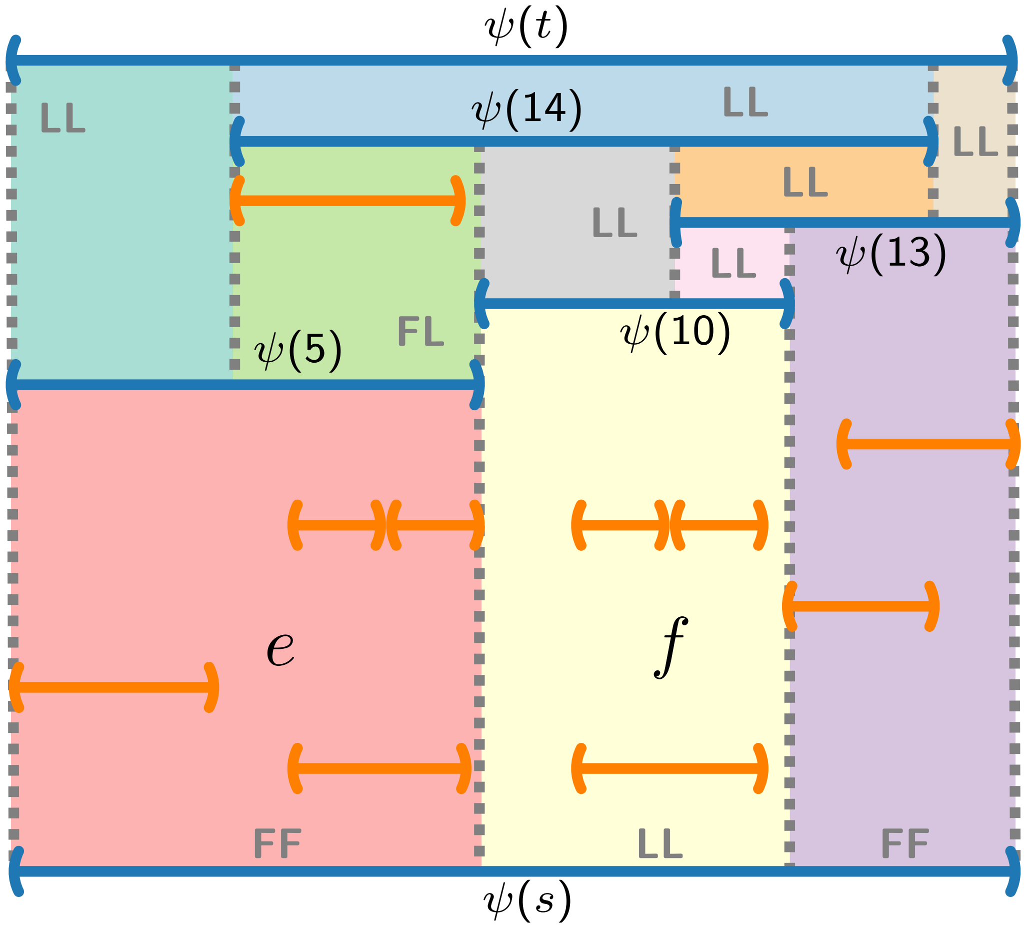
- Finding a satisfying assignment of a 2-SAT formula can be done in linear time!

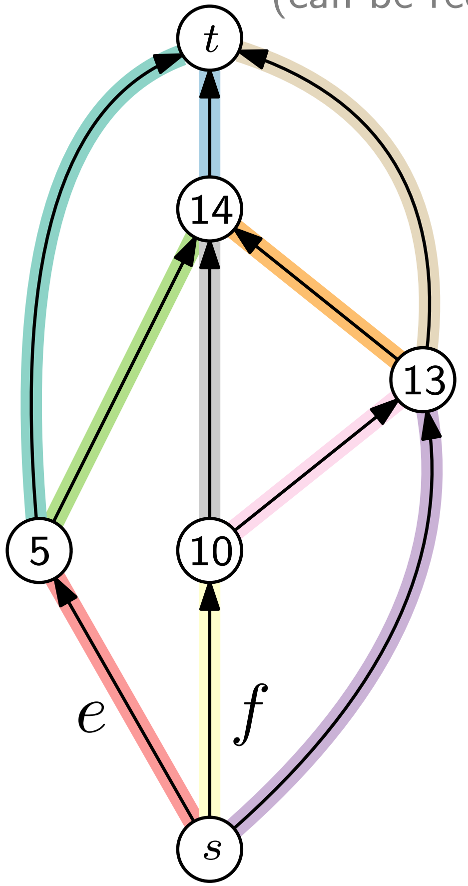
$\Rightarrow O(n^2)$ time in total

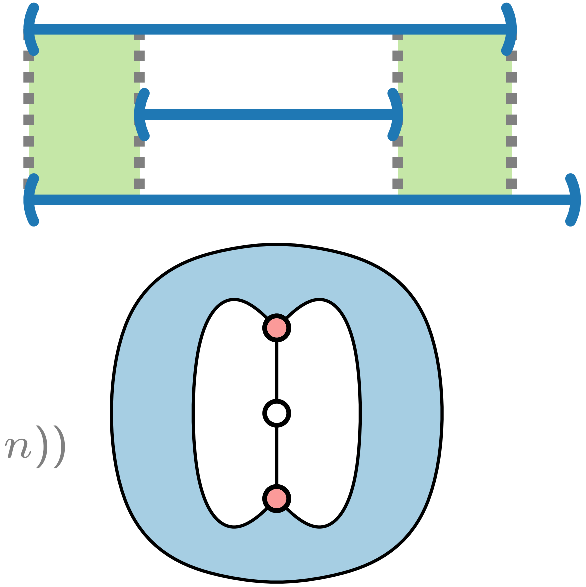
R-Nodes with 2-SAT Formulation

- For each child (edge) e:
  - Find all types of {**FF, FL, LF, LL**} that admit a drawing.
  - Use two variables (l_e and r_e) to encode the type of its tile (**F** $= 0$).
  - Add *consistency clauses*: e.g., $\neg(\neg r_e \wedge \neg l_f)$ $\rightarrow O(n^2)$ many.

(can be reduced to $O(n \log^2 n)$)







Separation pair!
($\nexists$ in **R**-component.)

- Finding a satisfying assignment of a 2-SAT formula can be done in linear time!

$\Rightarrow O(n^2)$ time in total or $O(n \log^2 n)$

Results and Outline

[Chaplick, Guśpiel, Gutowski, Krawczyk, Liotta '18]

Theorem 1.
Rectangular ε-bar visibility representation extension can be solved in $\mathcal{O}(n \log^2 n)$ time *for st-graphs*.

- Dynamic program via SPQR-trees
- Easier version: $\mathcal{O}(n^2)$

Theorem 2.
ε-bar visibility representation extension is NP-complete.

- Reduction from Planar Monotone 3-SAT

Theorem 3.
ε-bar visibility representation extension is NP-complete even for (series-parallel) st-graphs when restricted to the *integer grid* (or if any fixed $\varepsilon > 0$ is specified).

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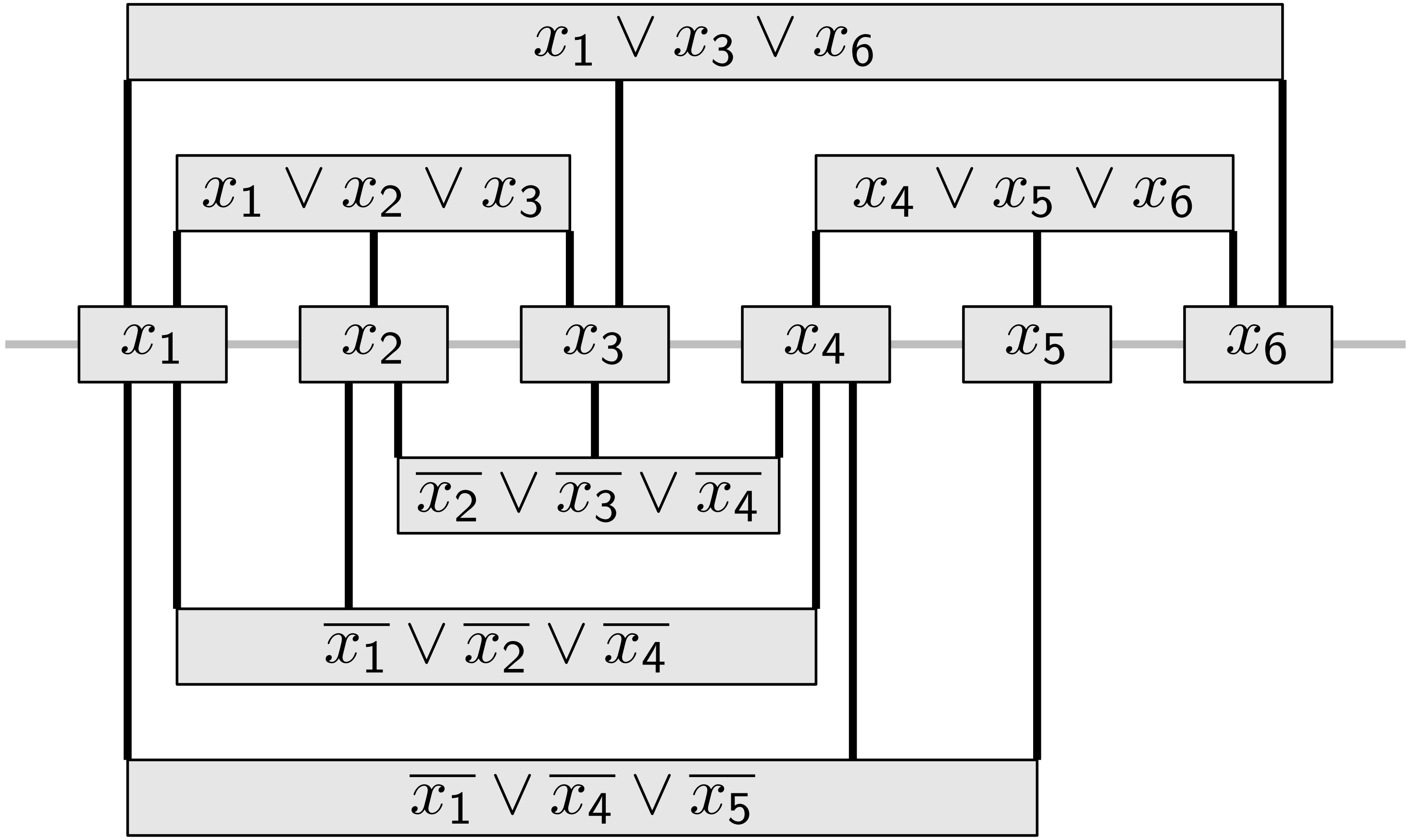

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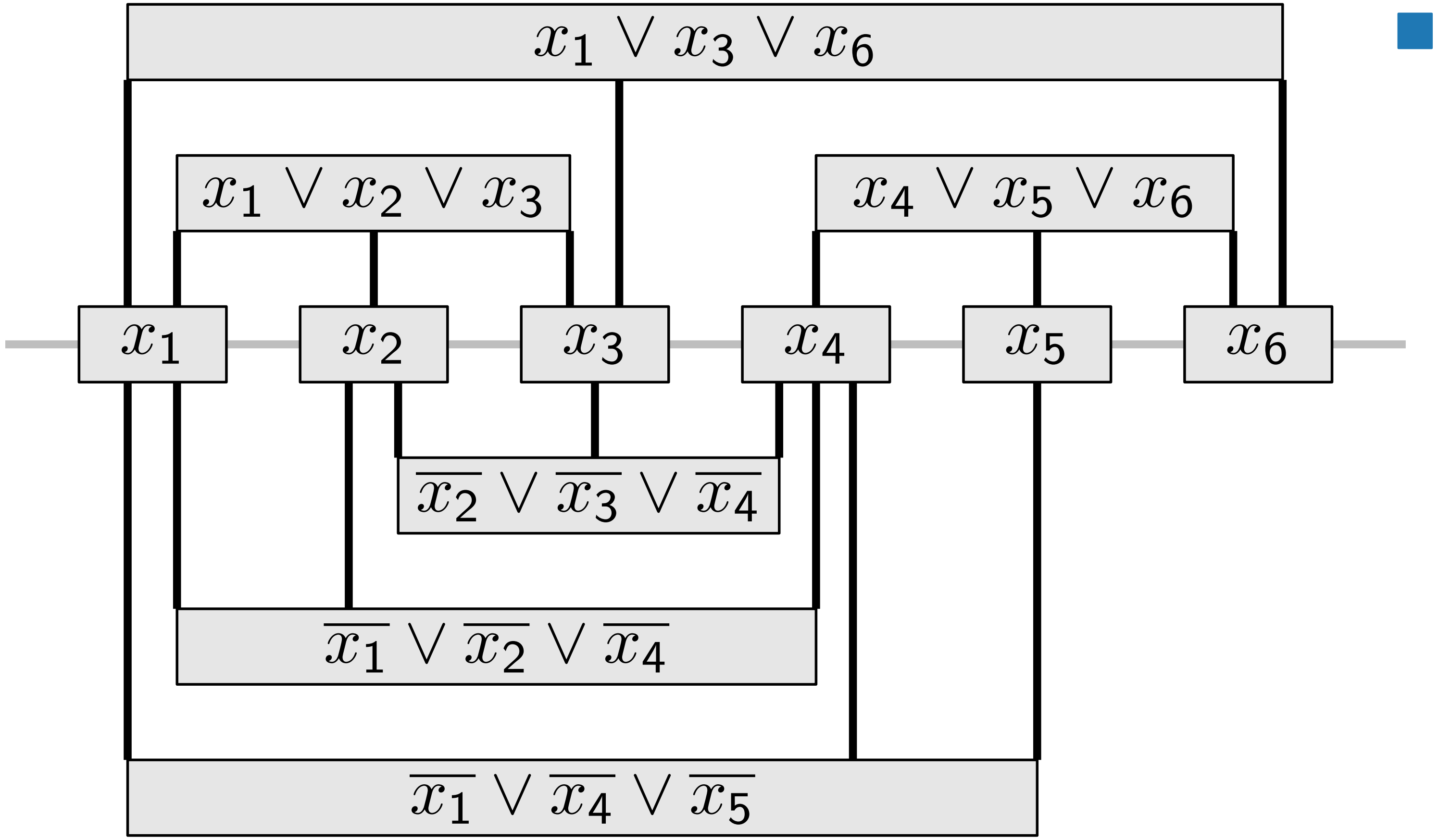

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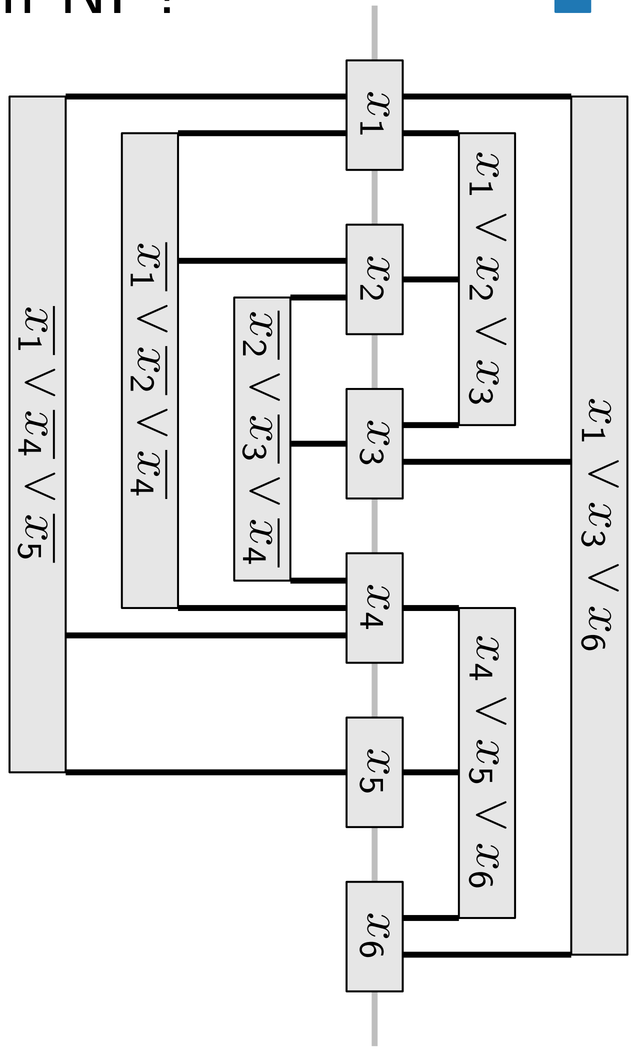

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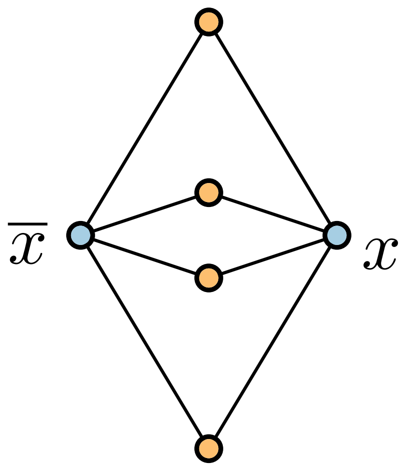

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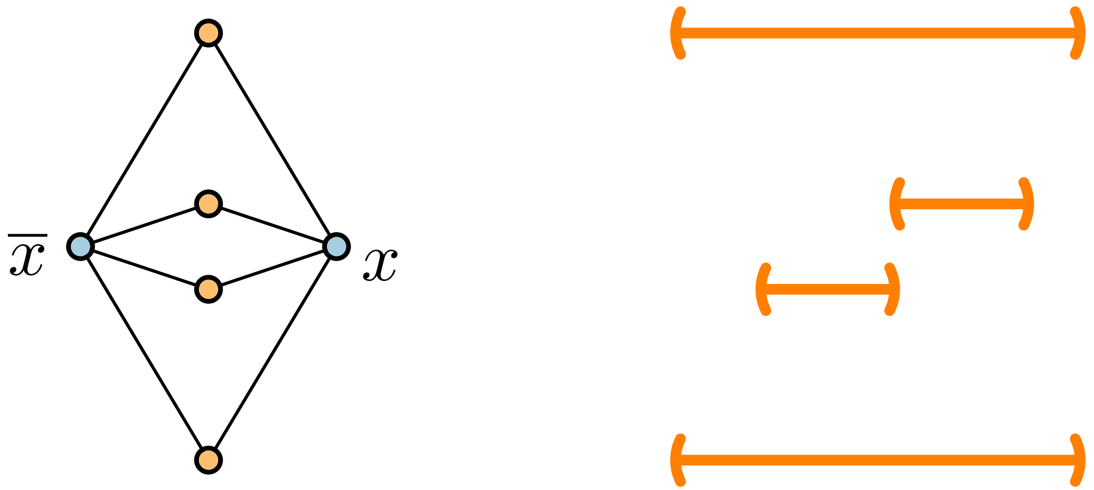

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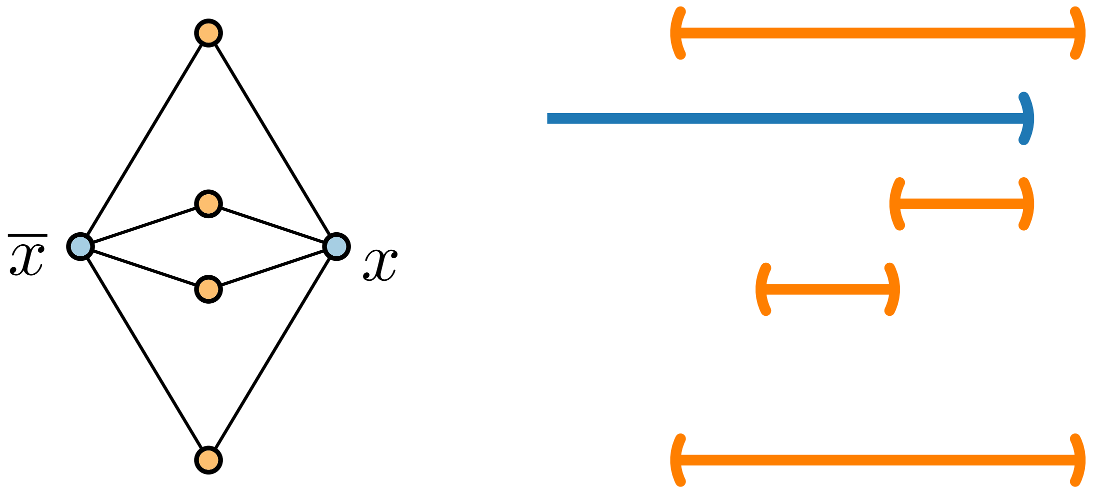

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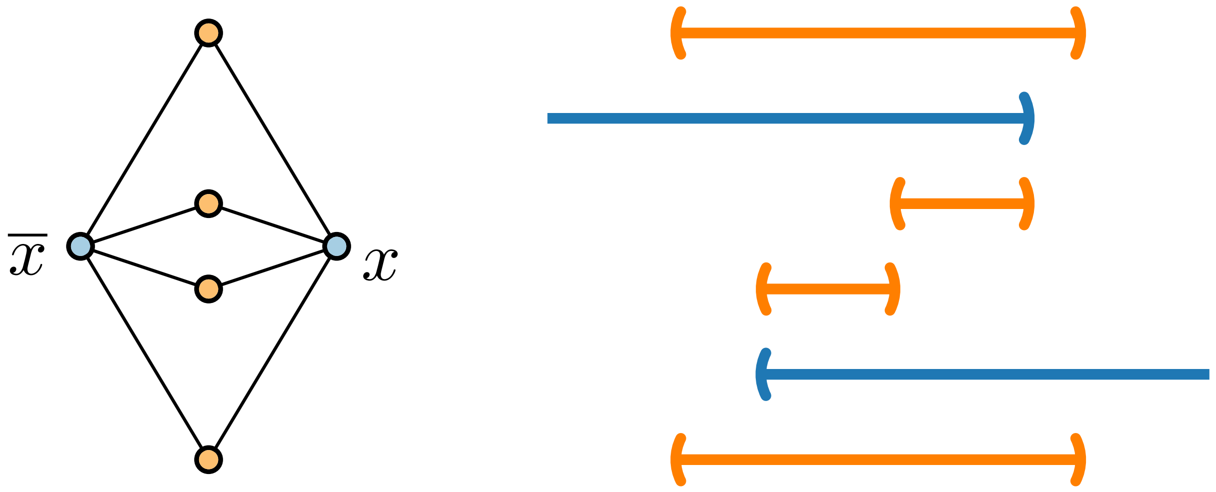

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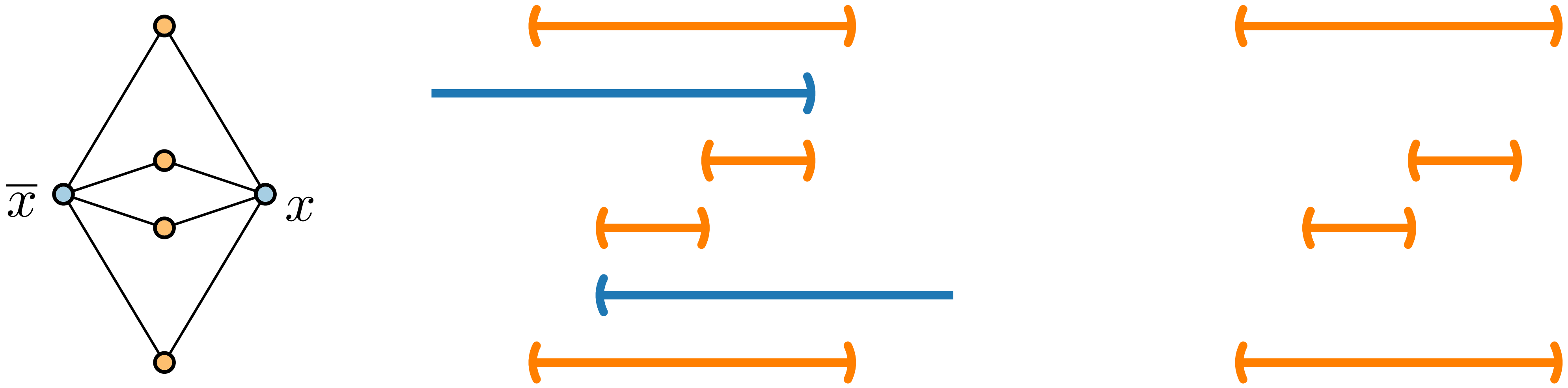

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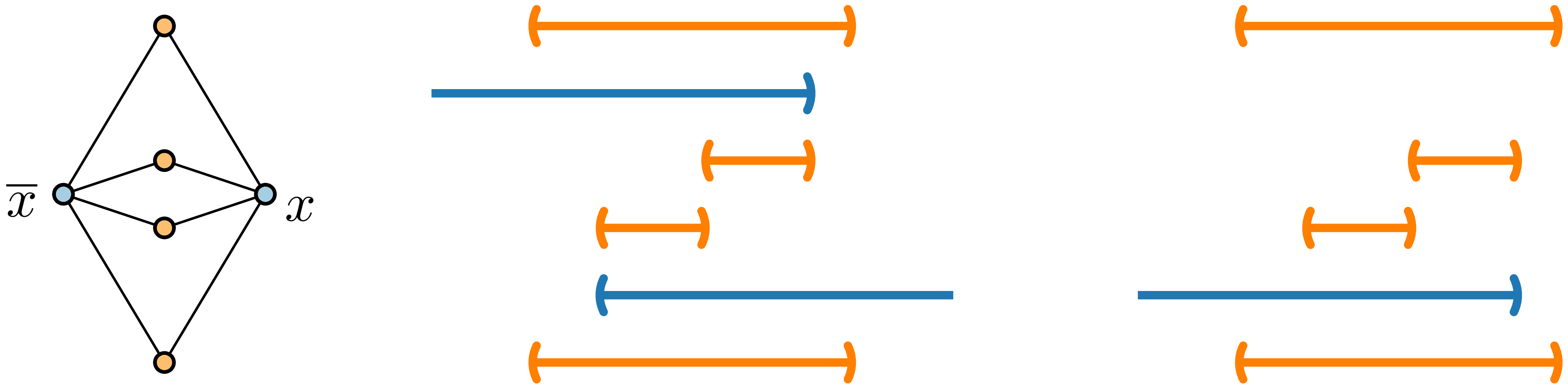

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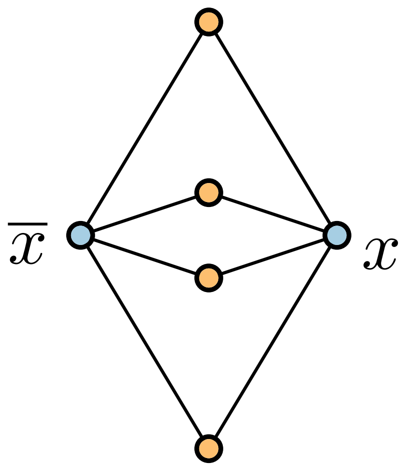

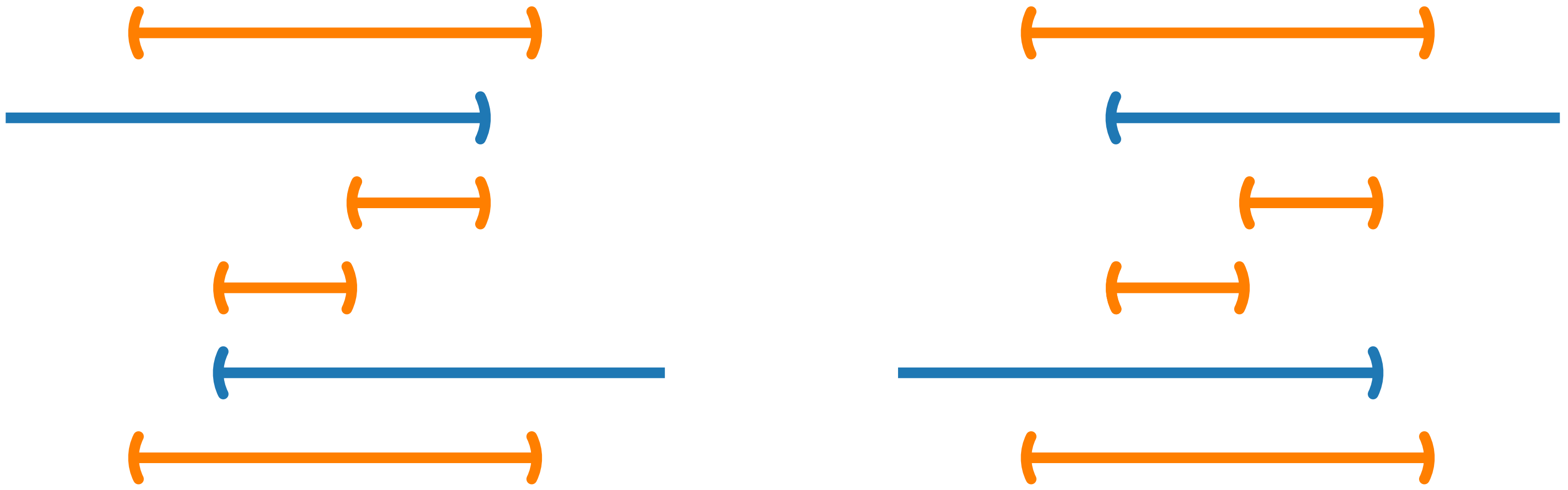

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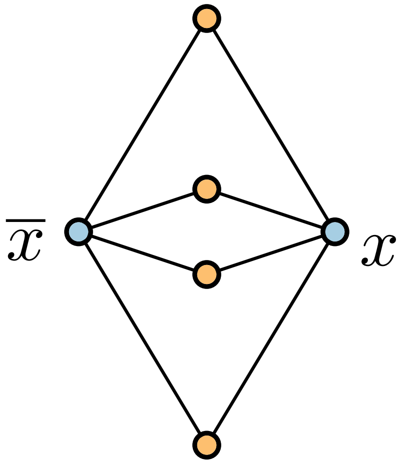

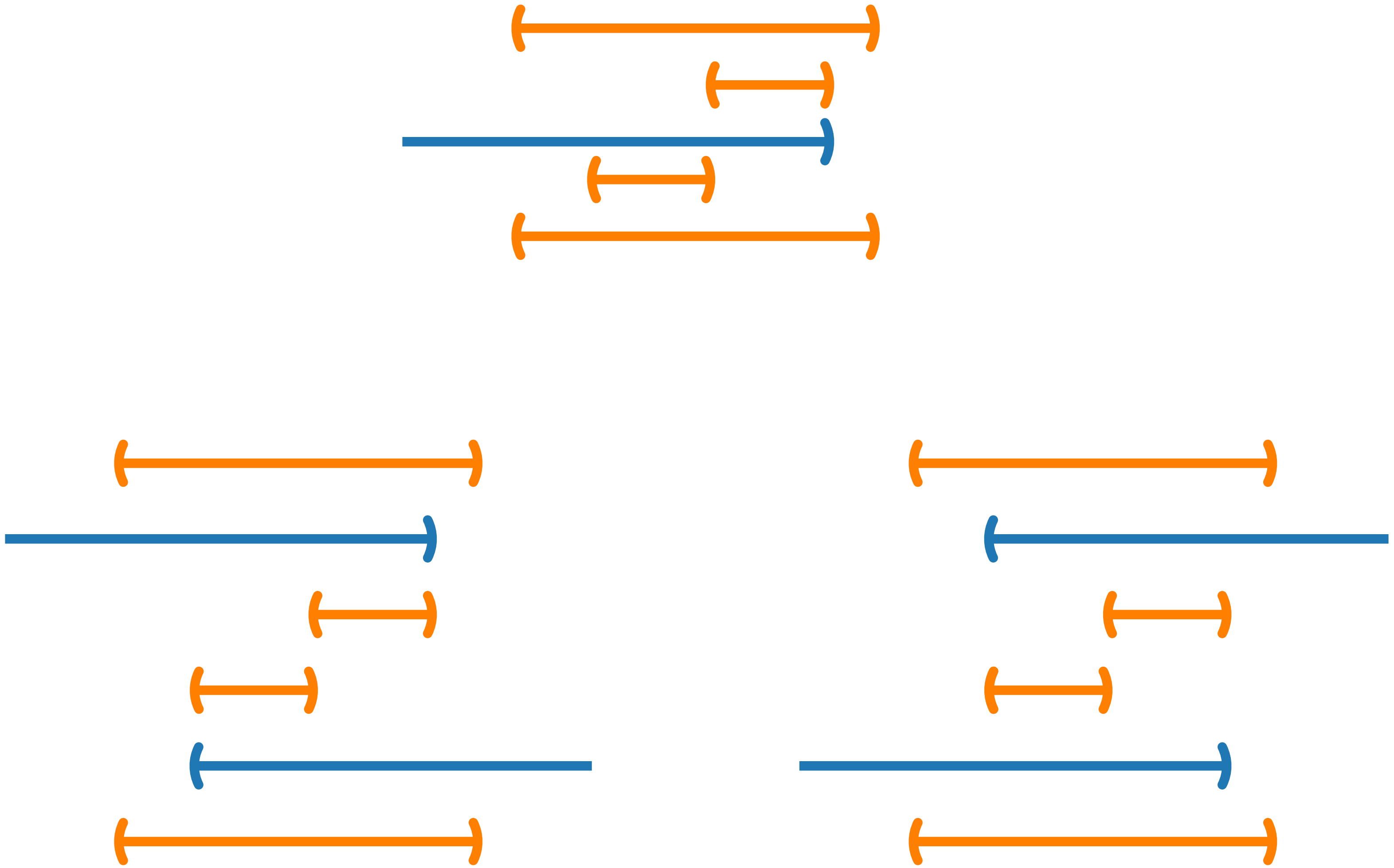

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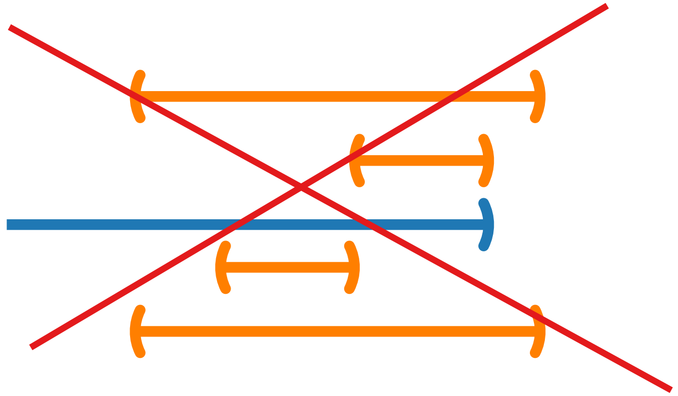

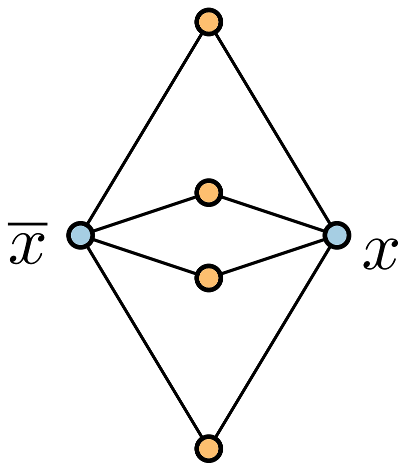

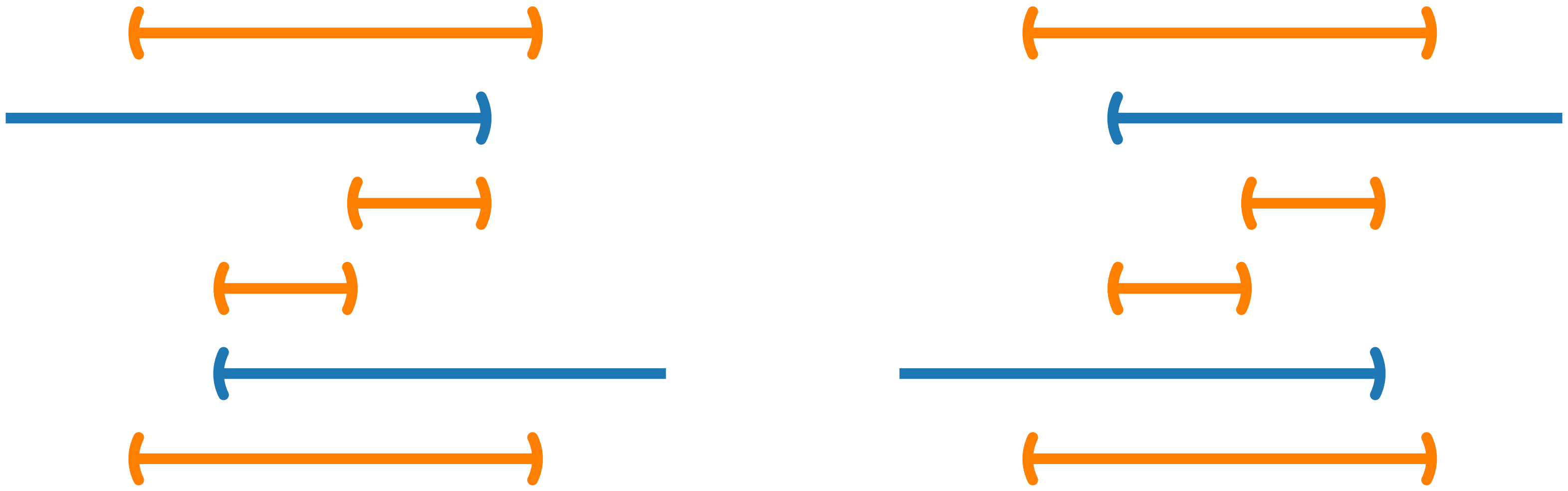

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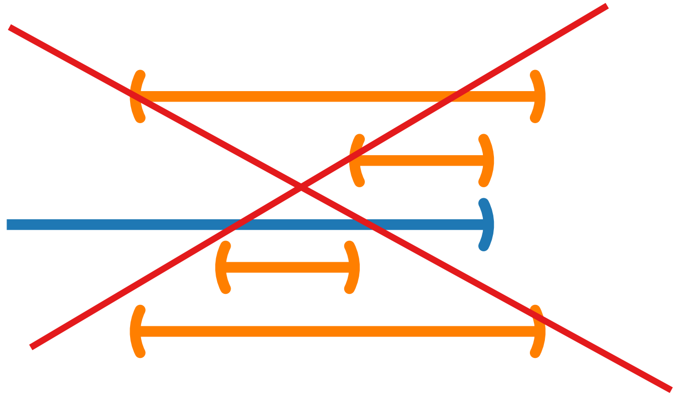
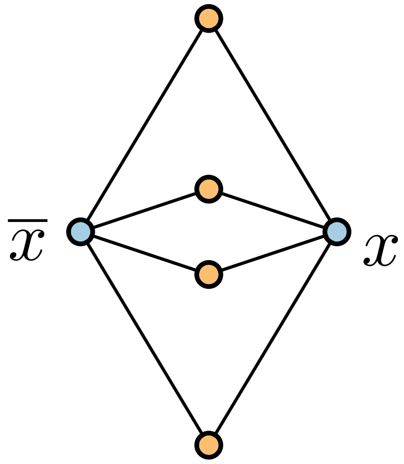
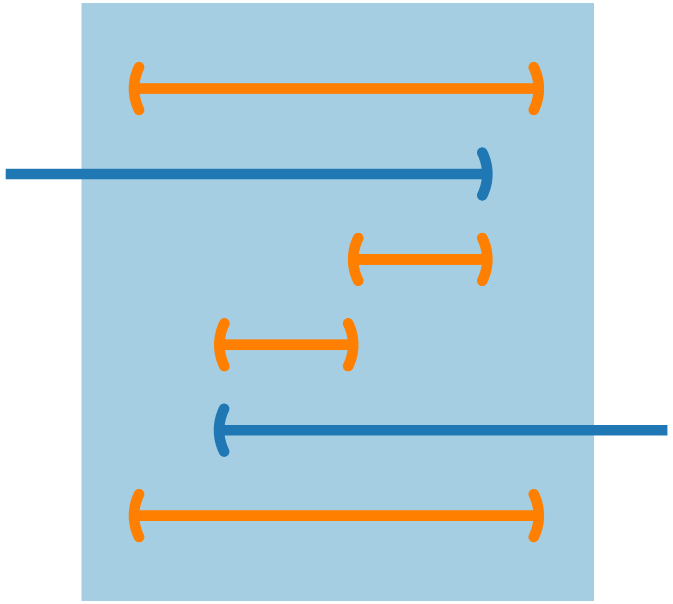




$x = \textsc{False}$



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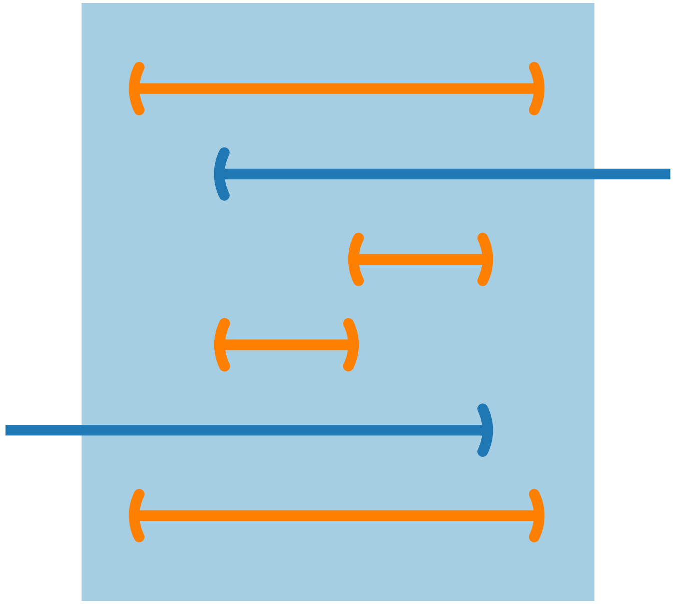

Clause Gadget

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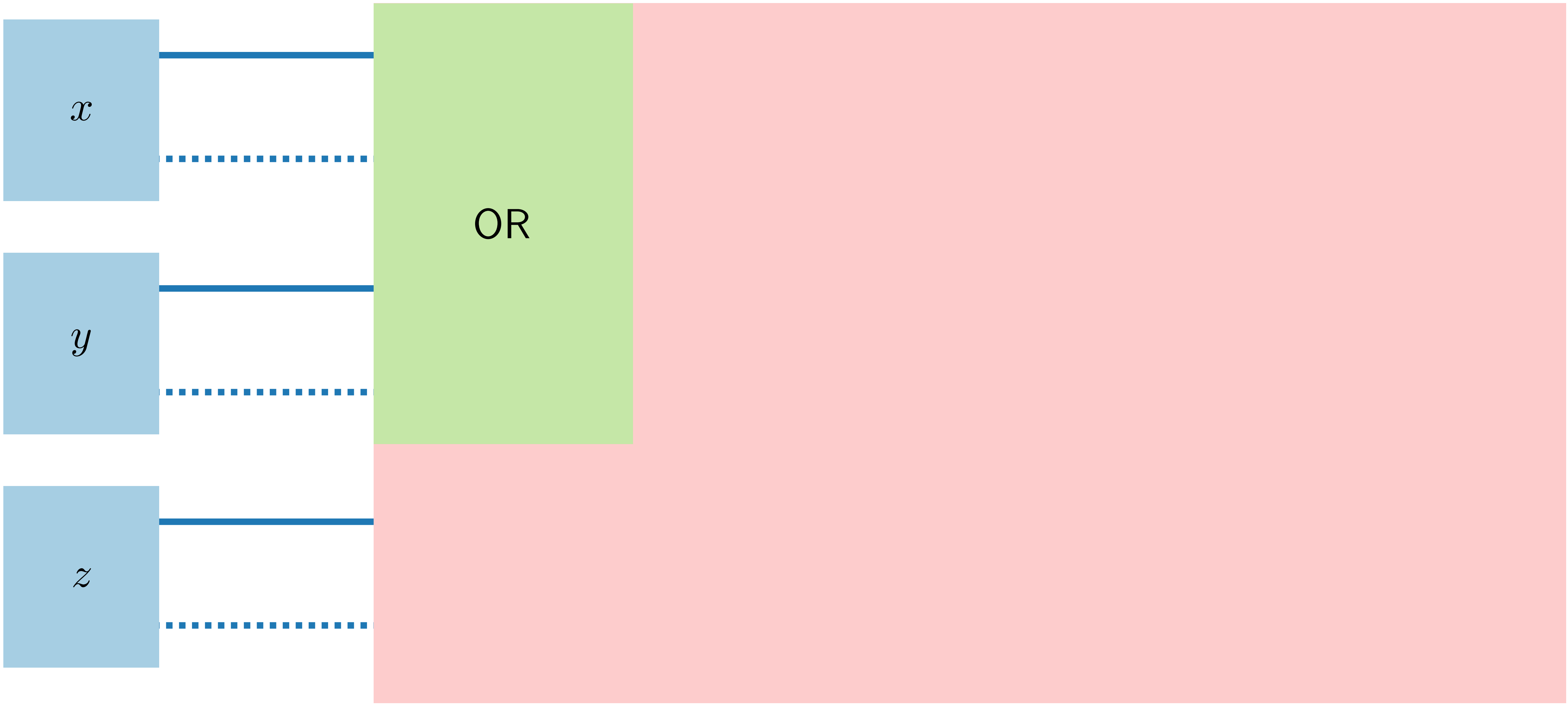

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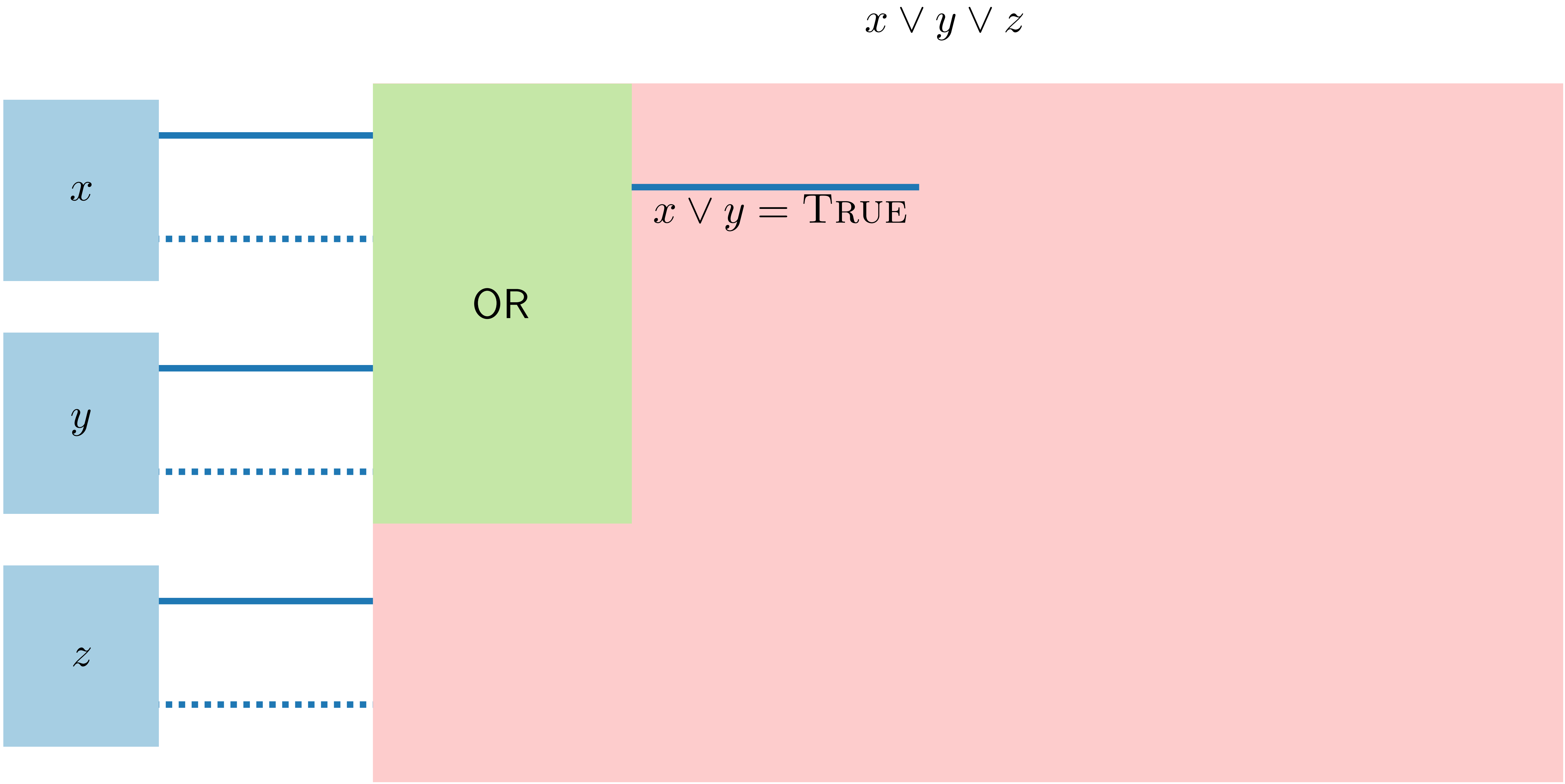

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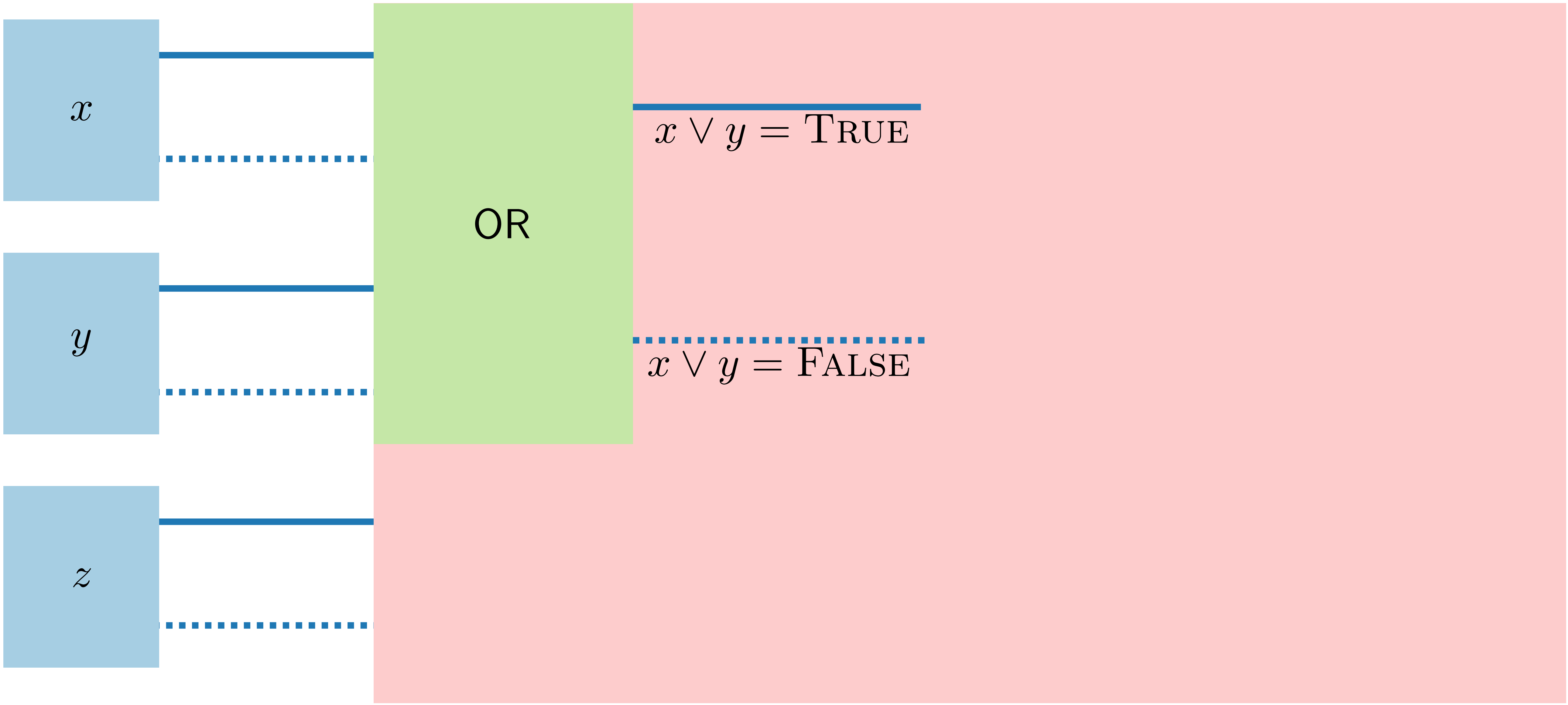

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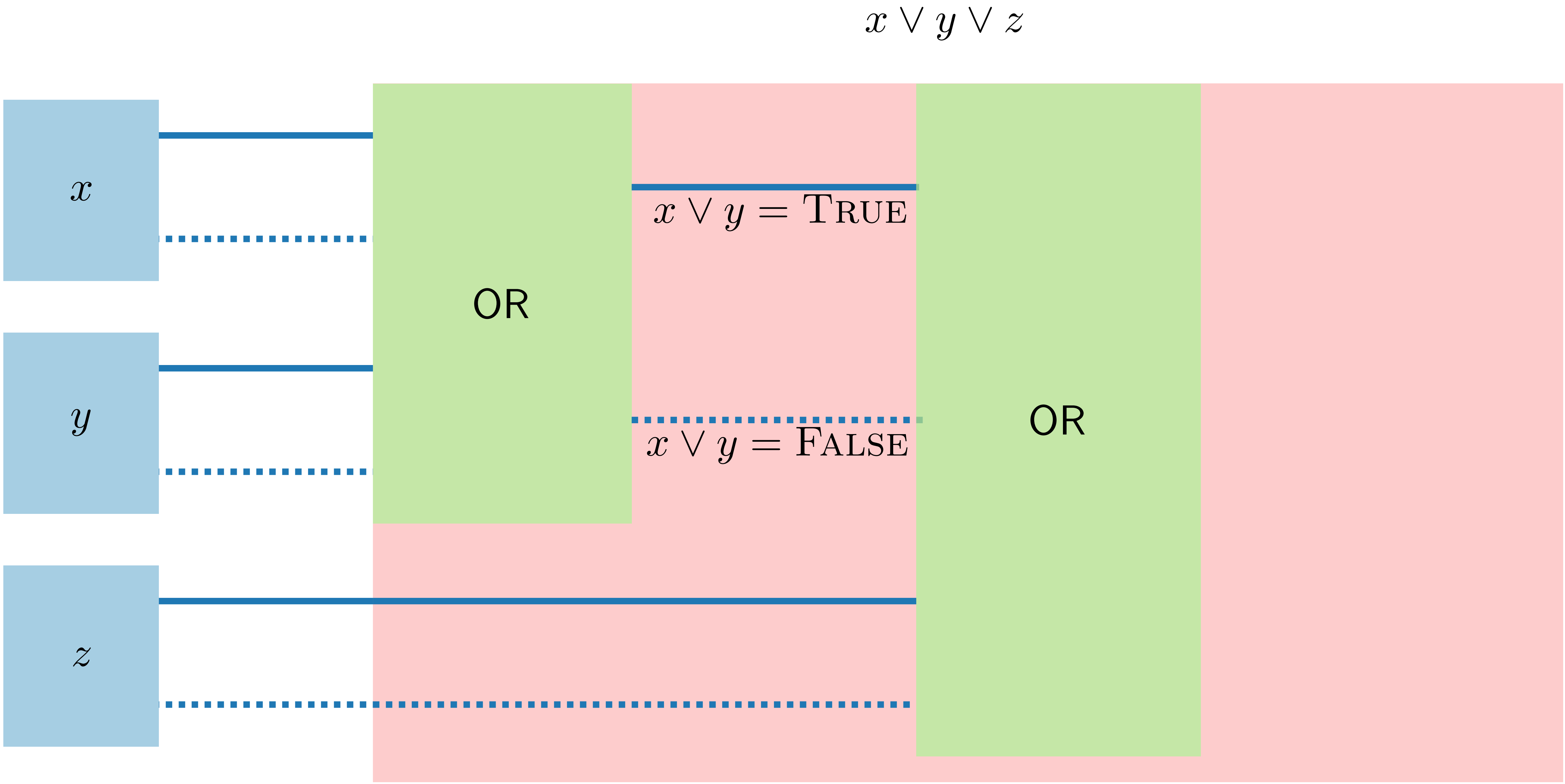

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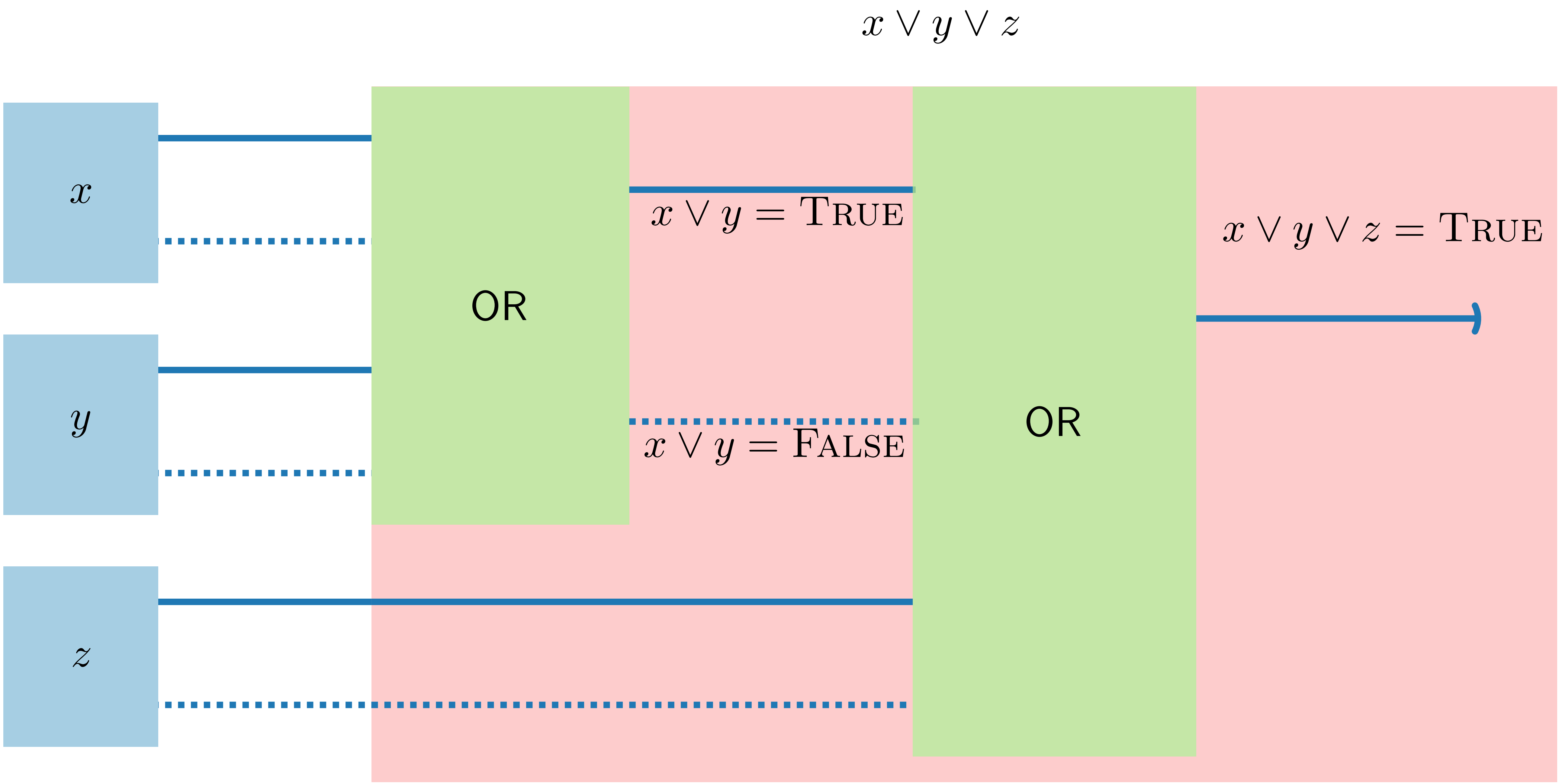

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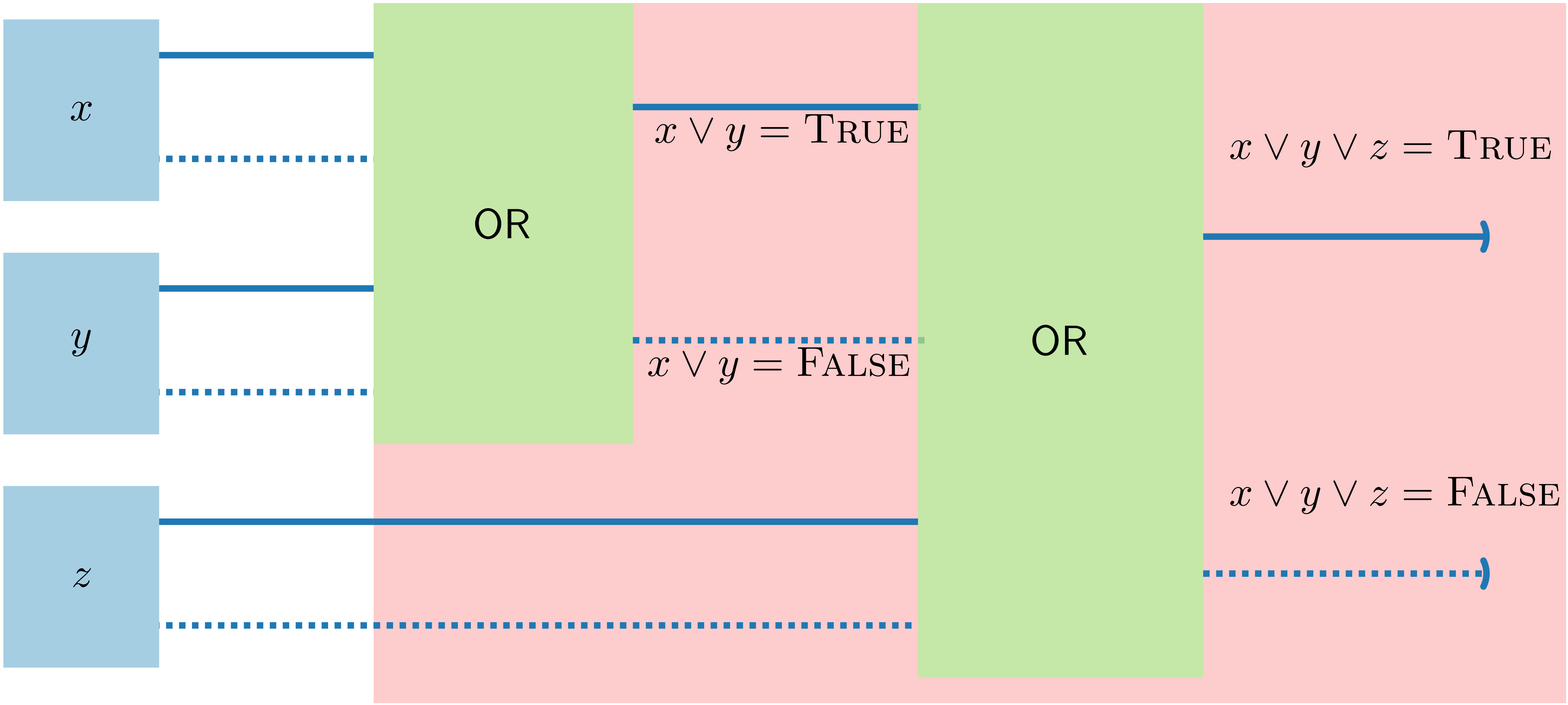

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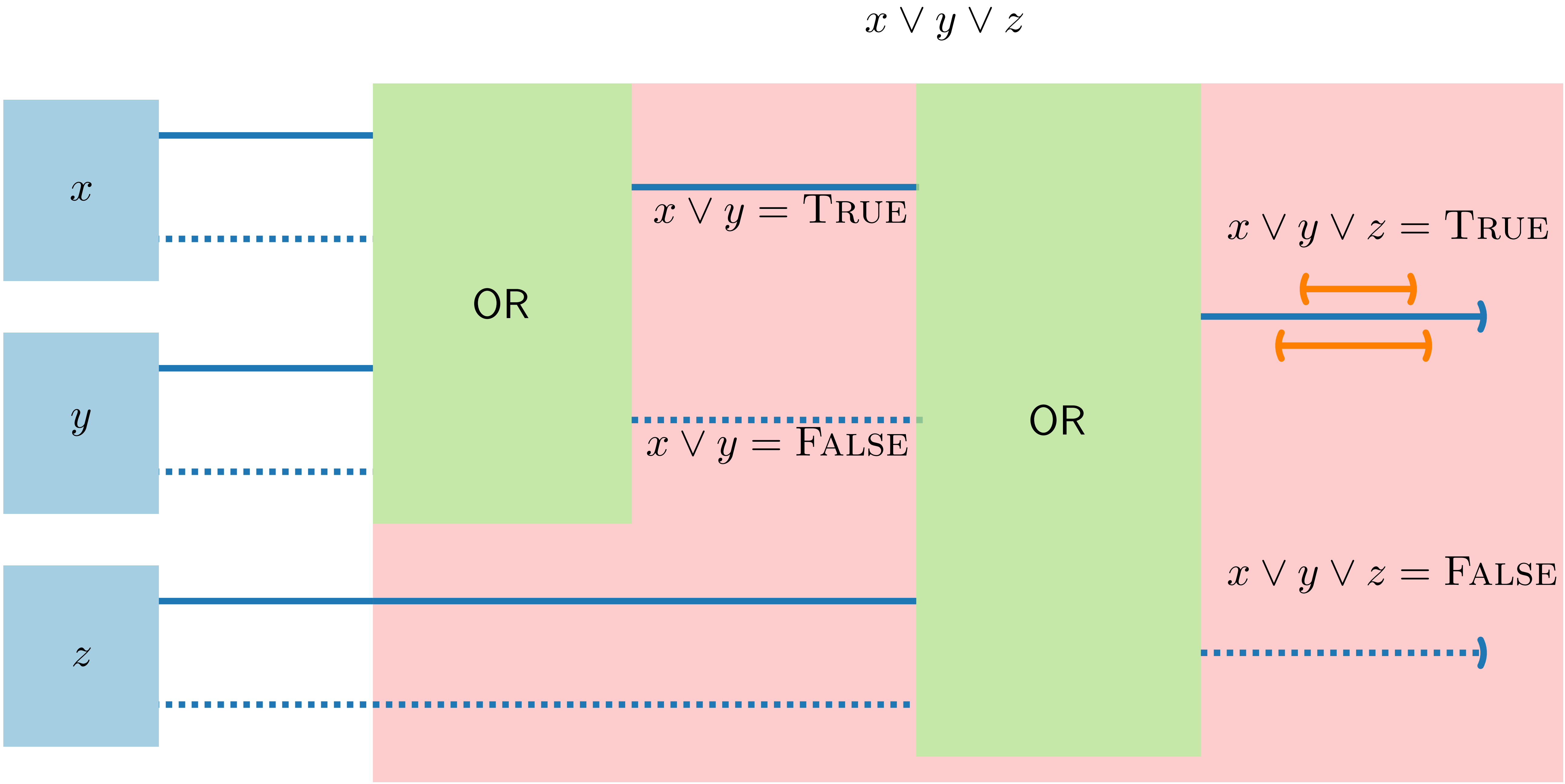

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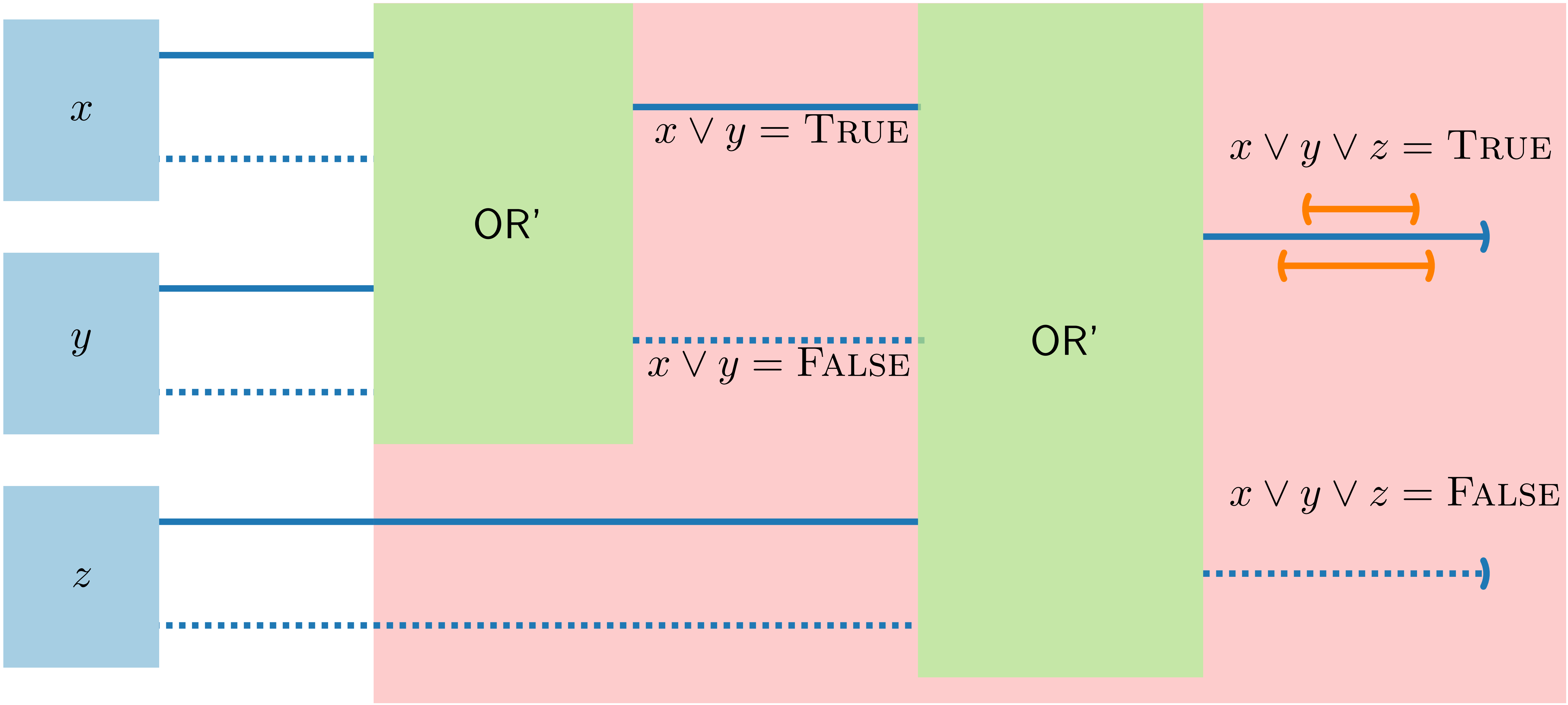

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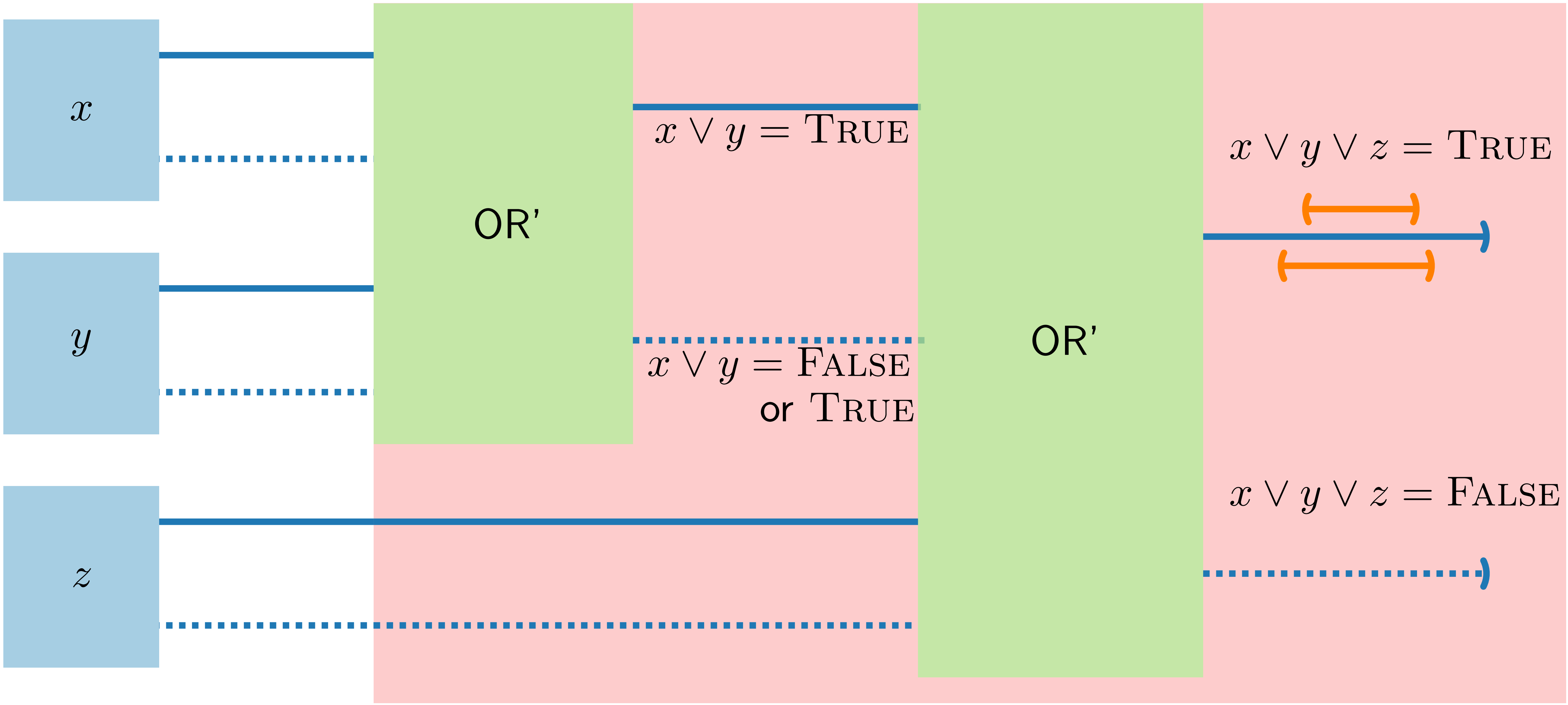

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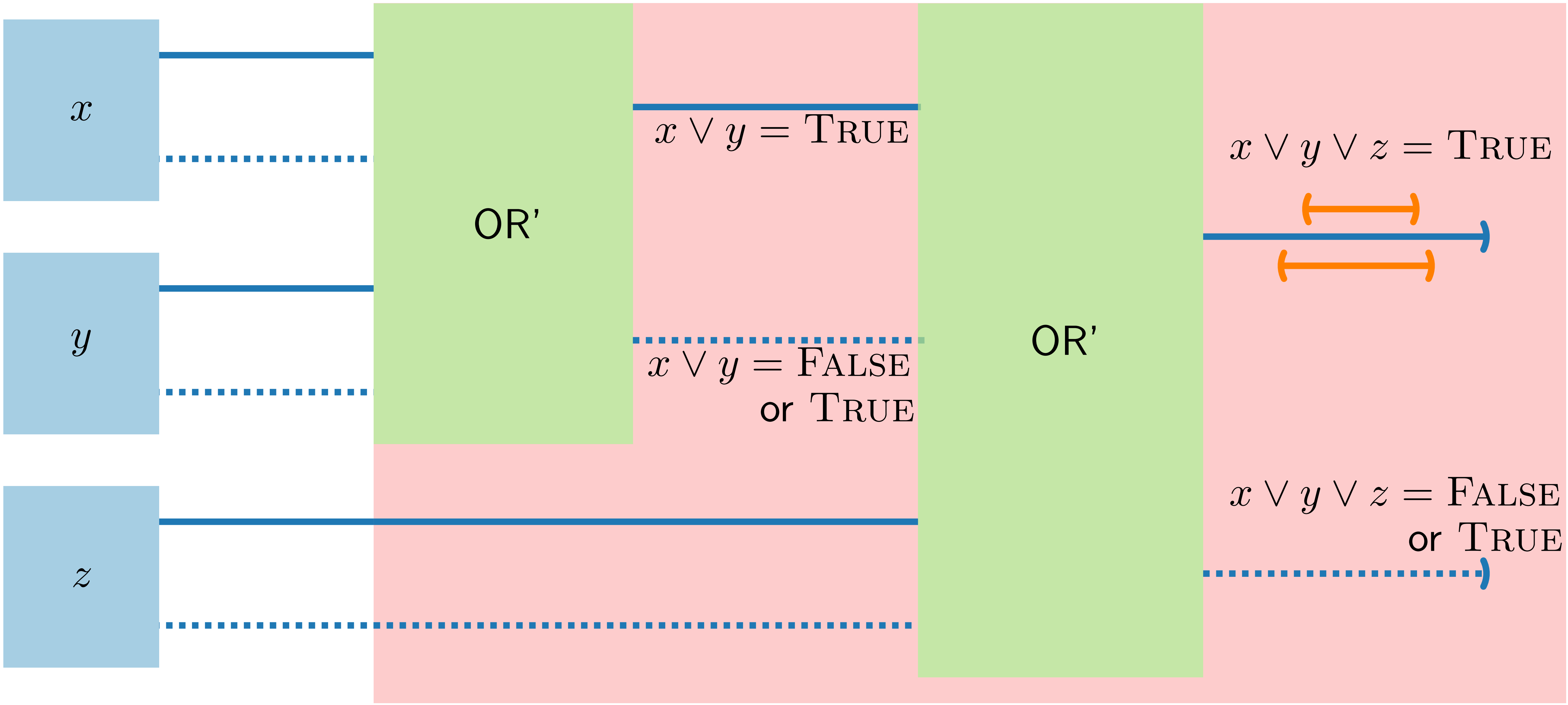

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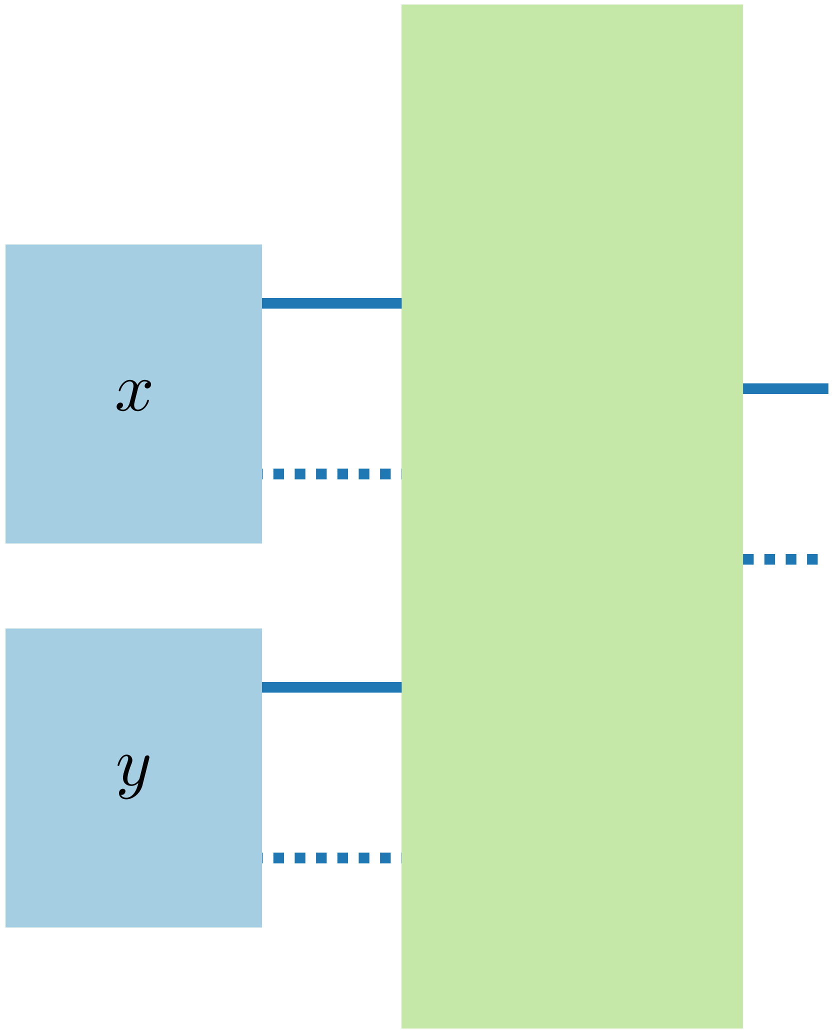

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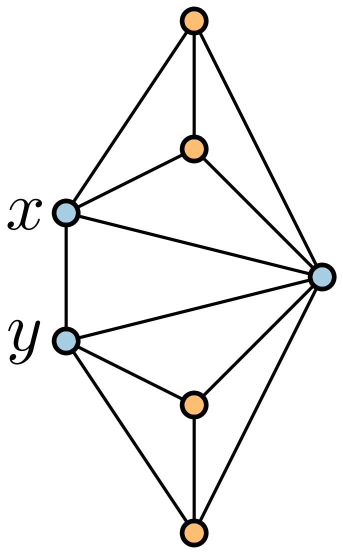

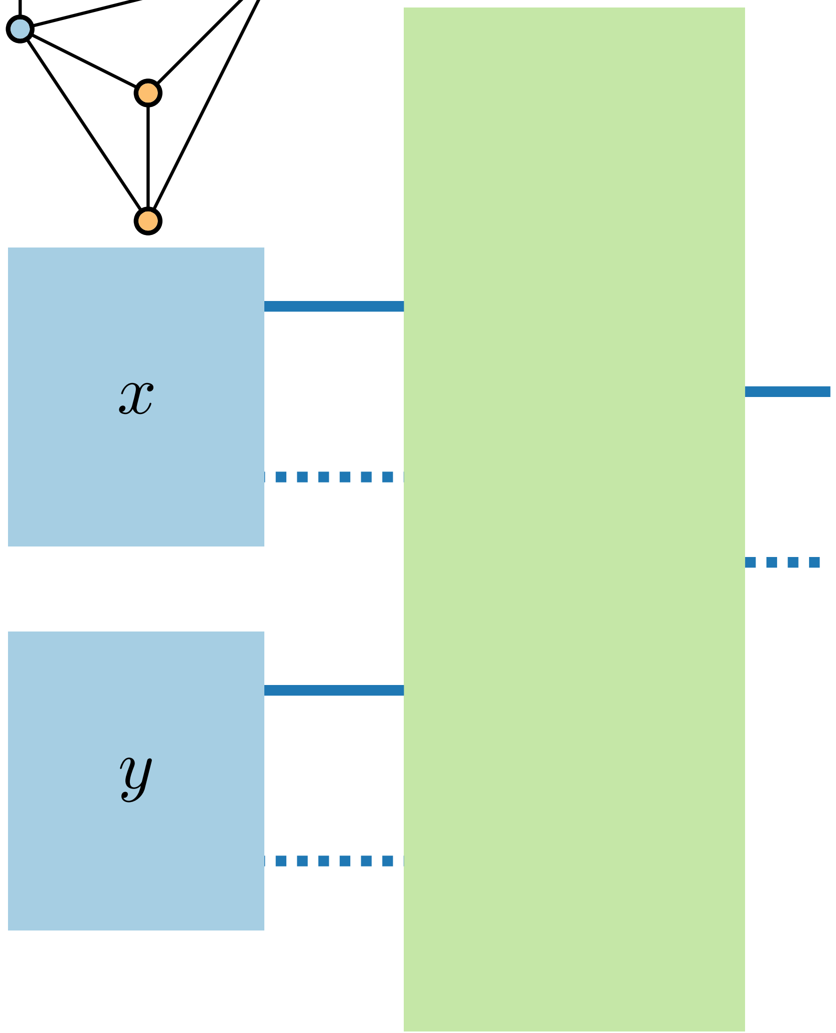

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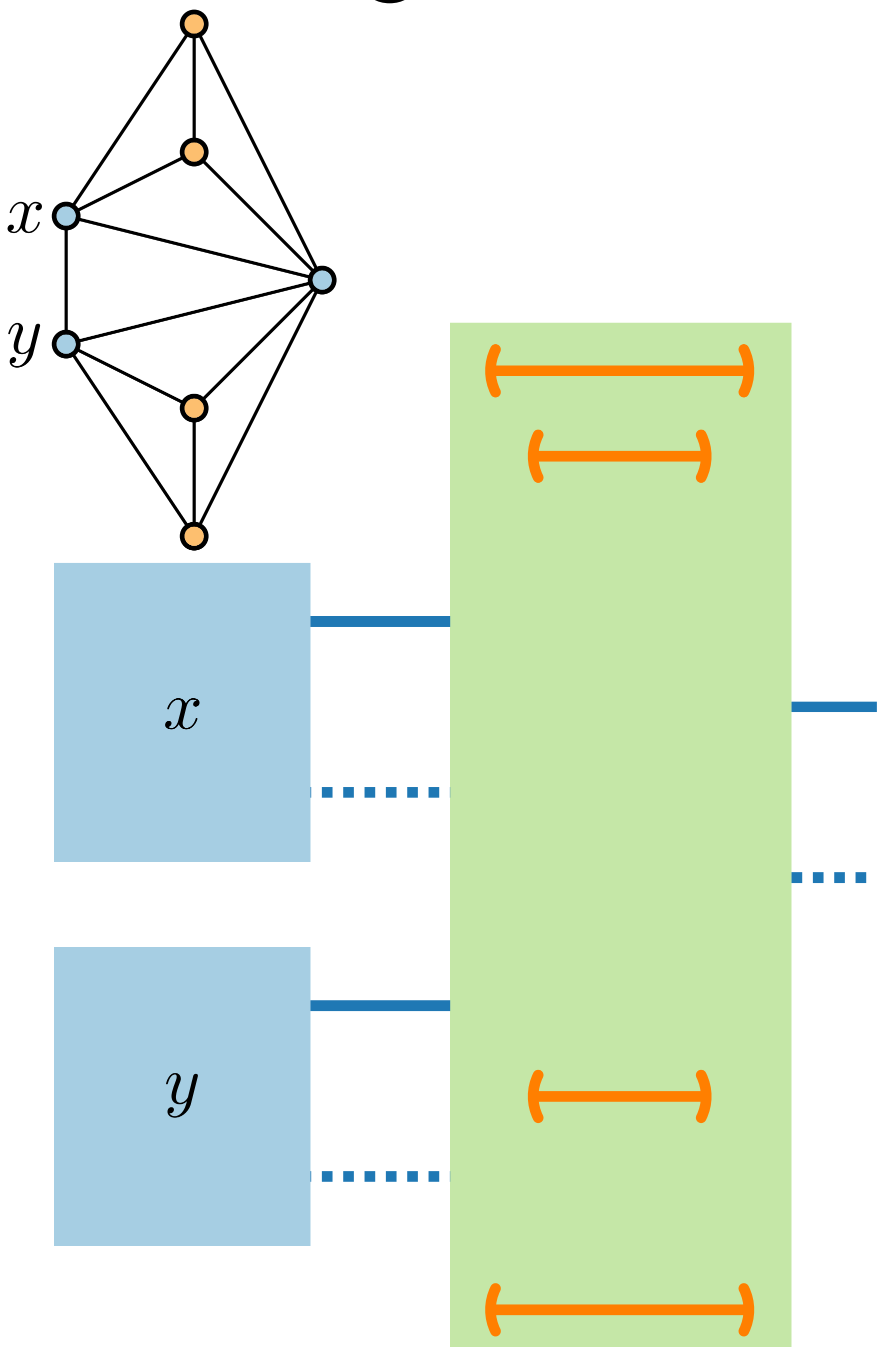

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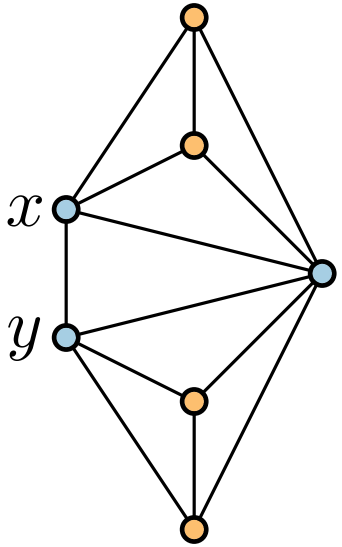

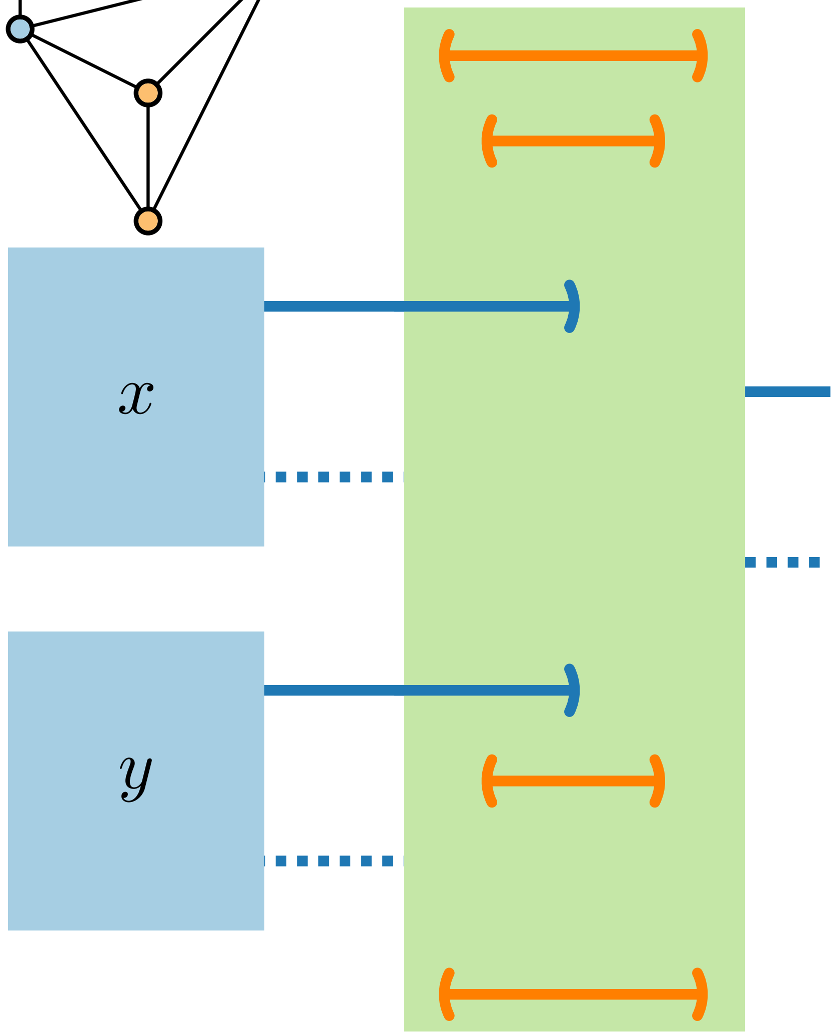

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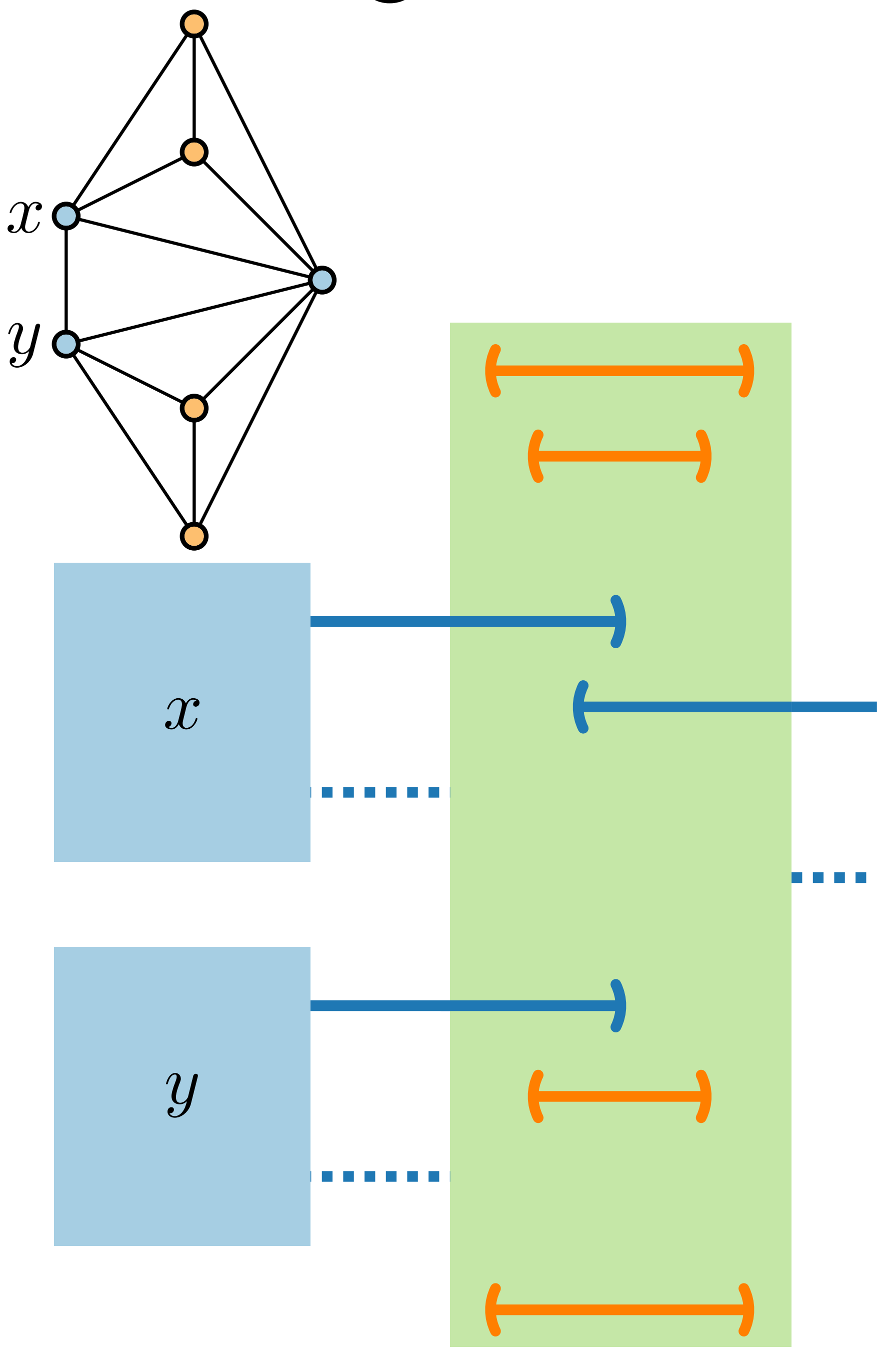

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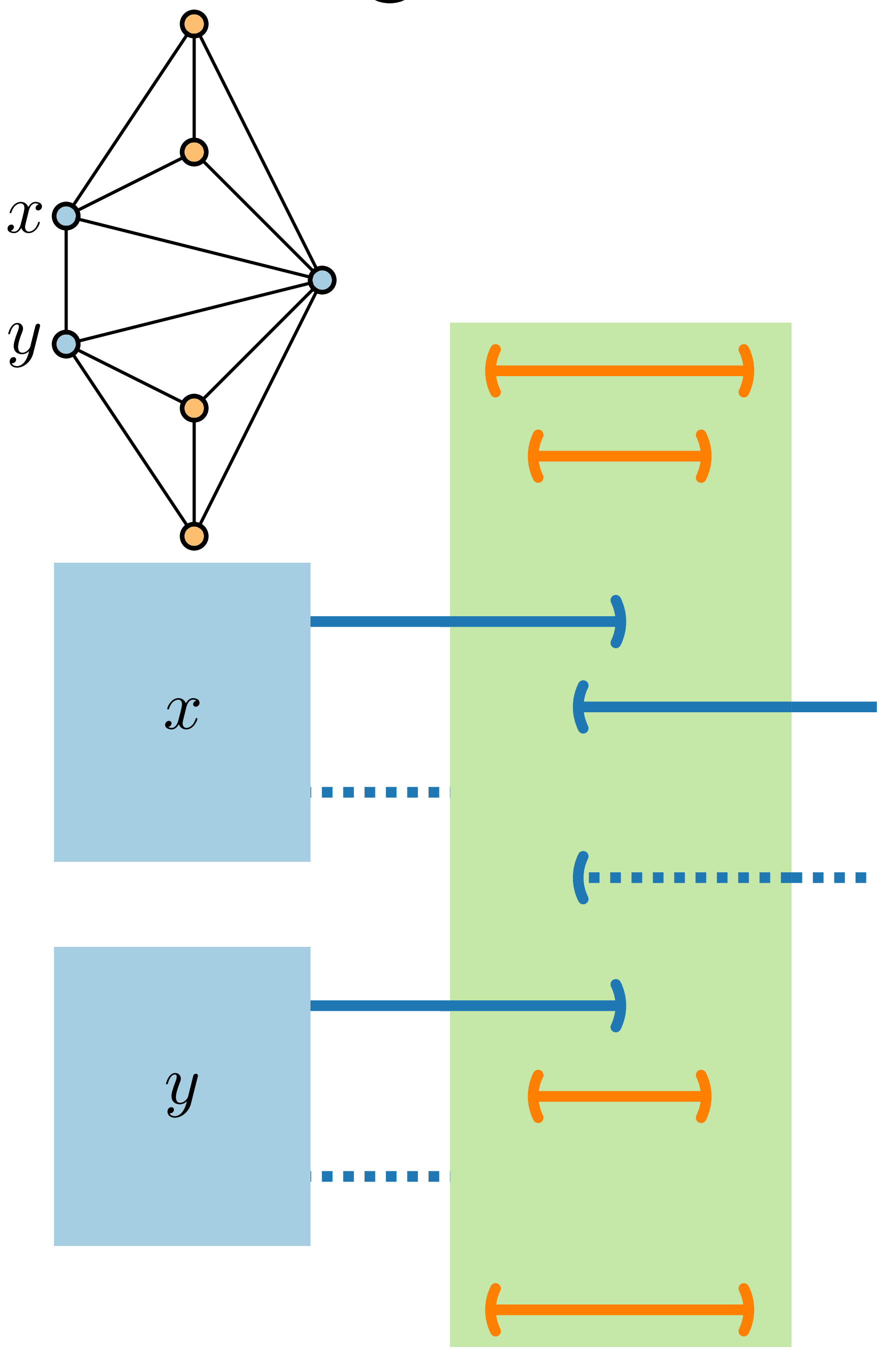

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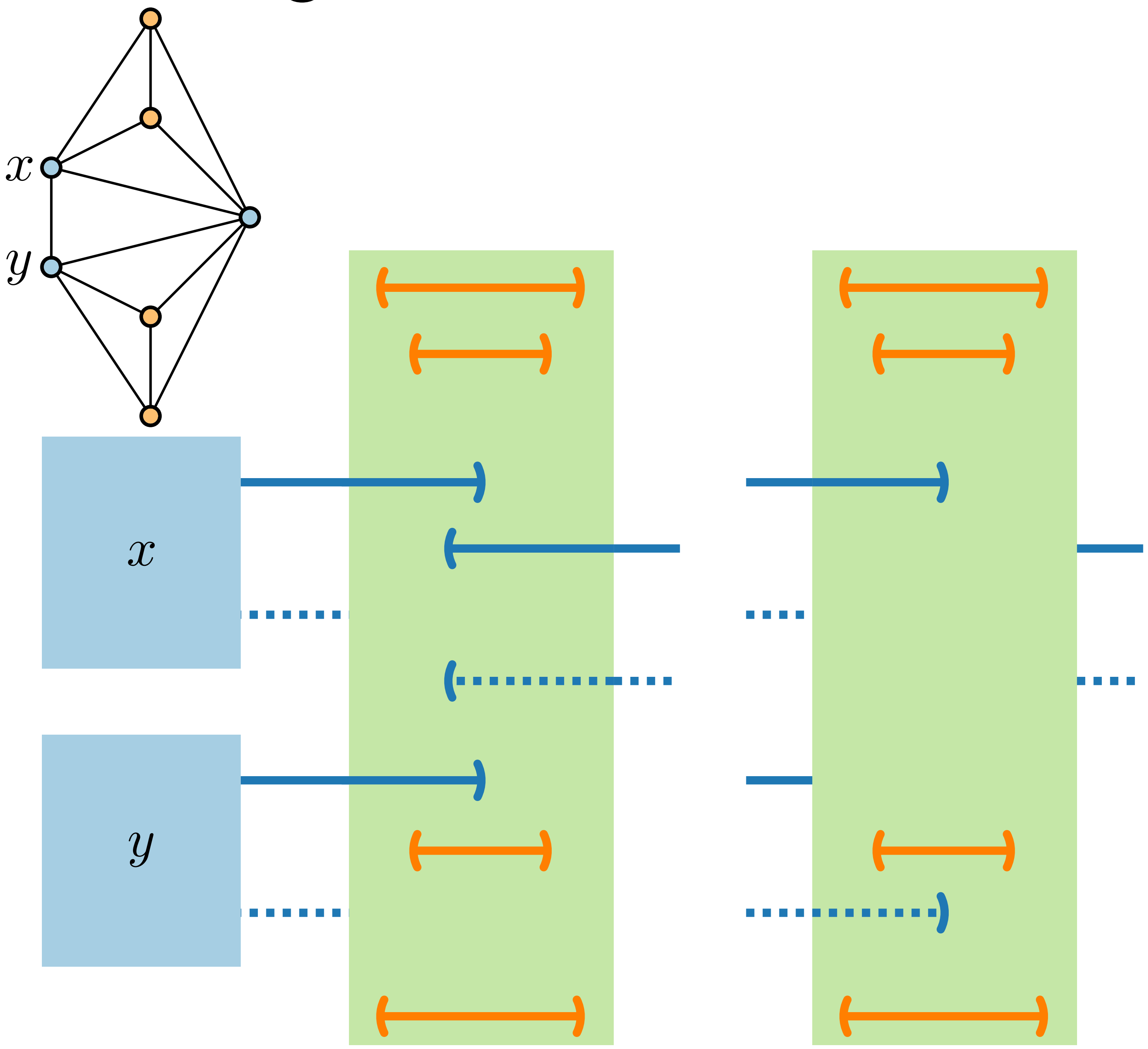

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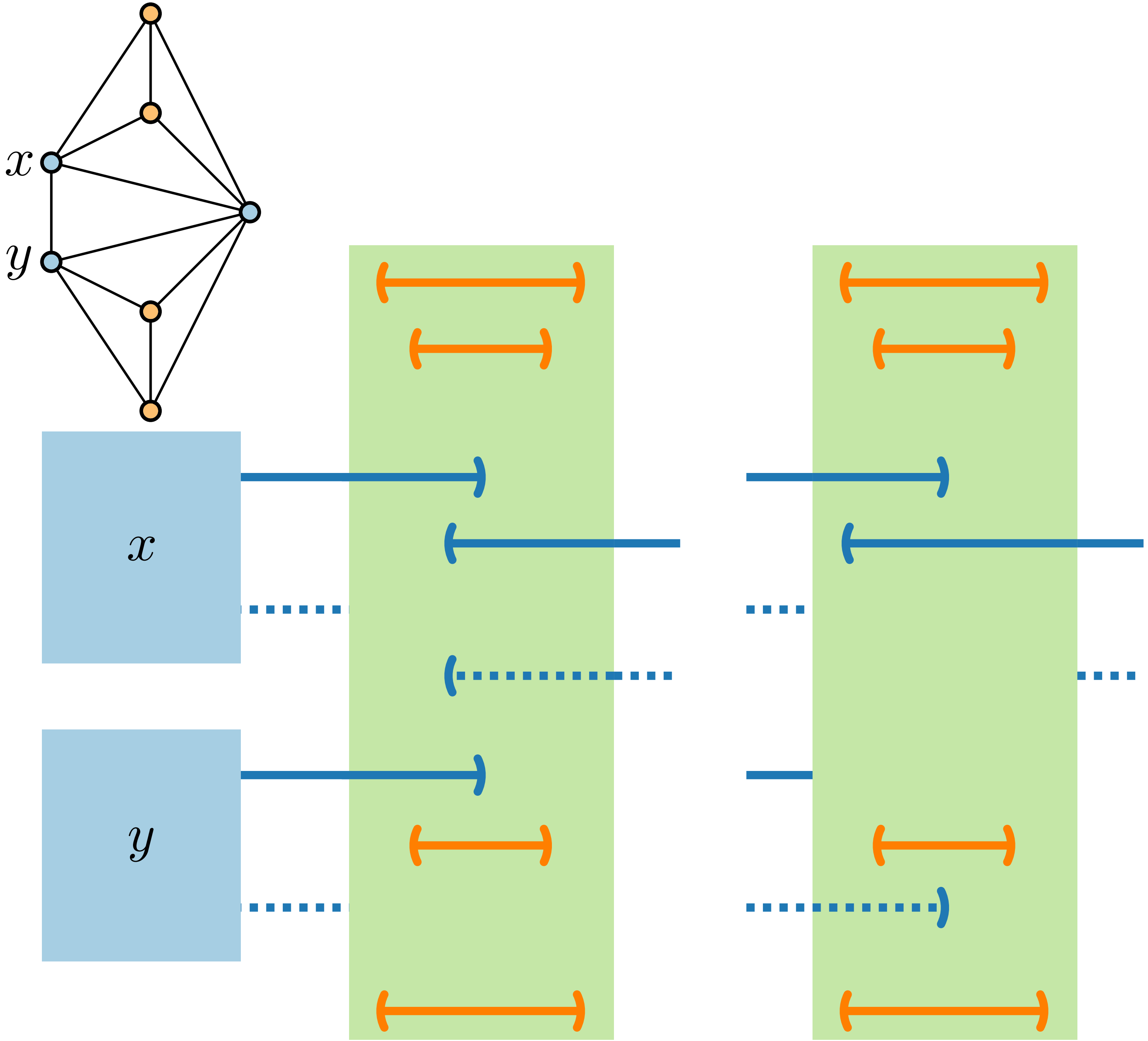

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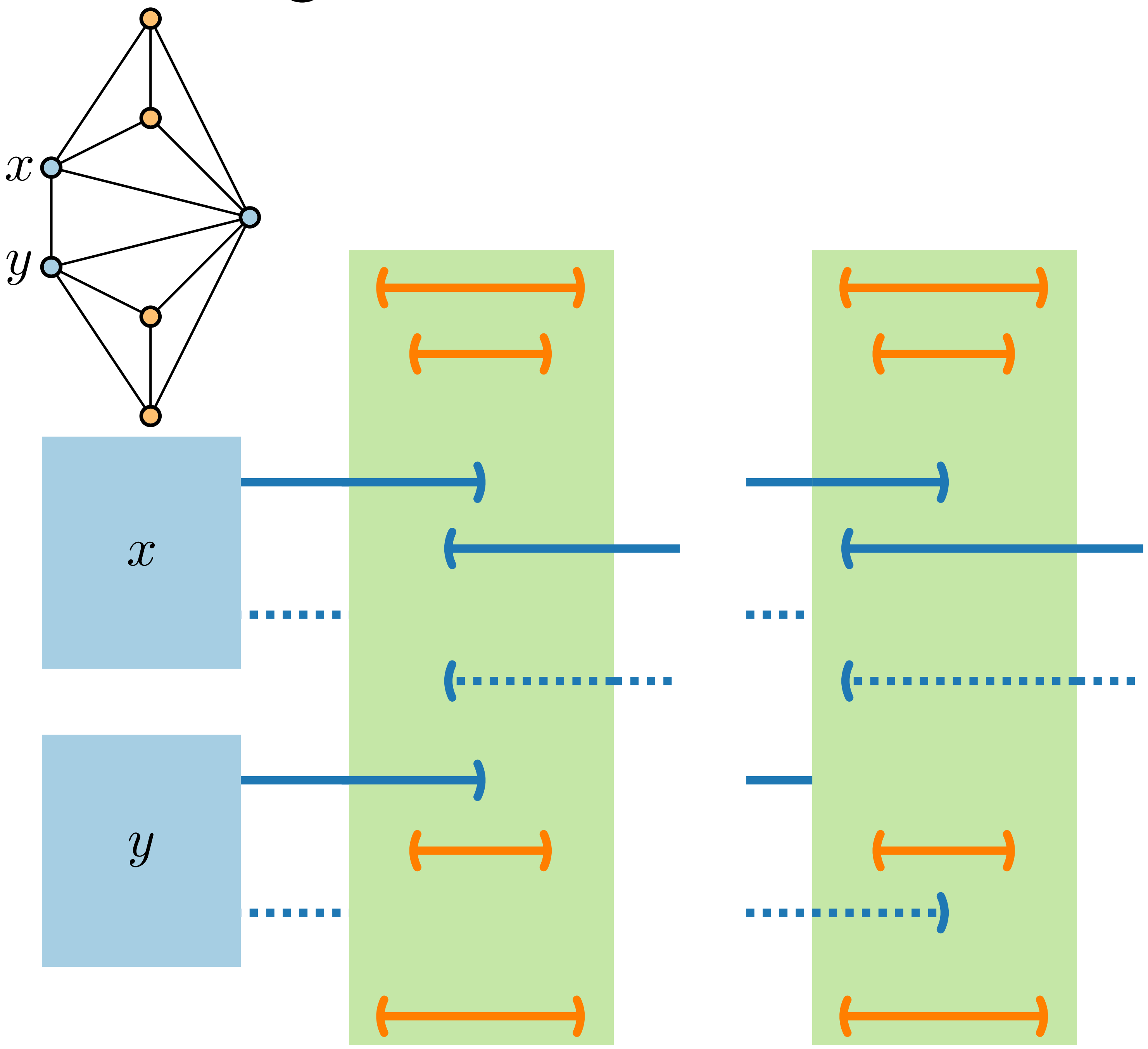

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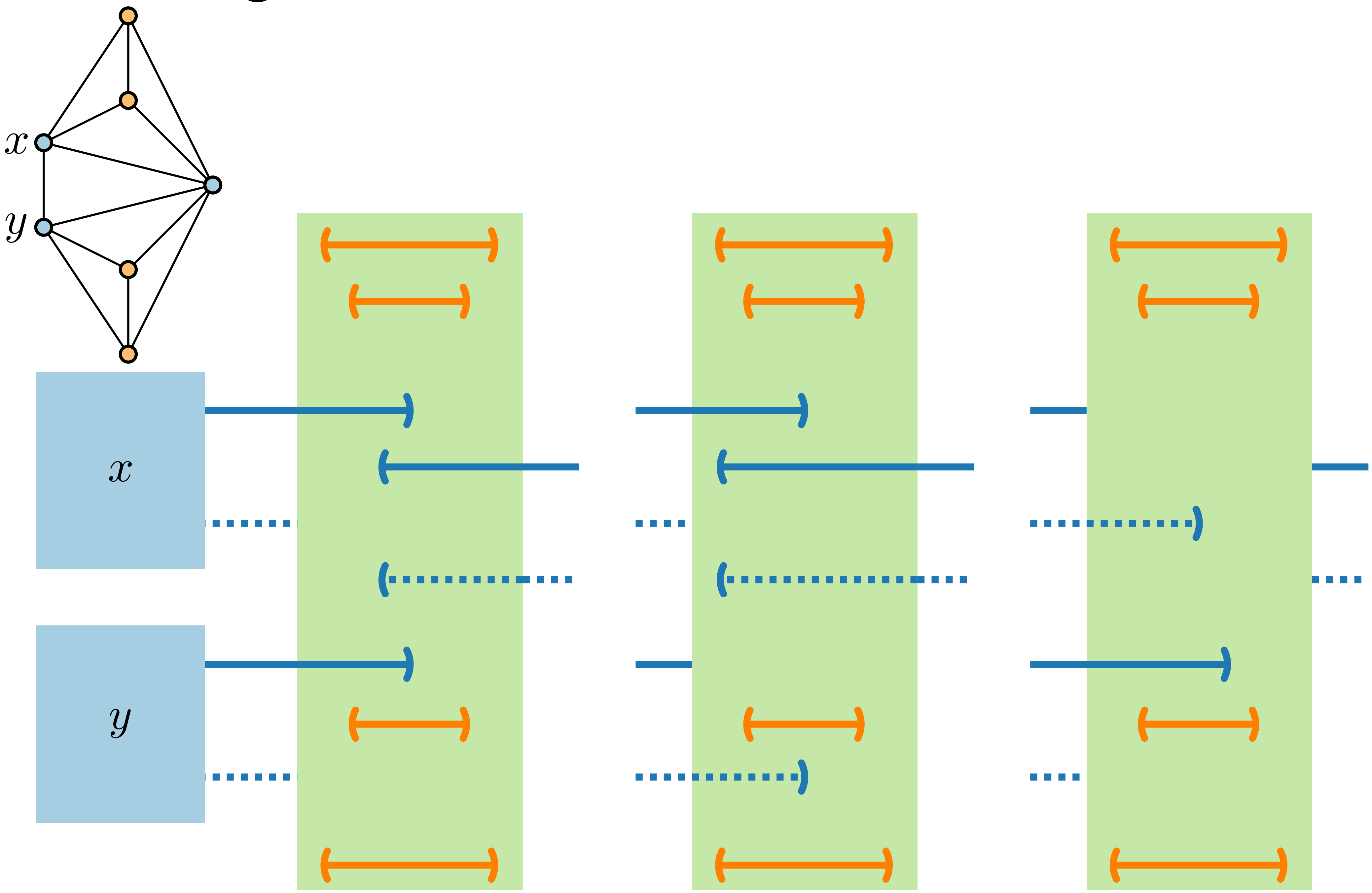

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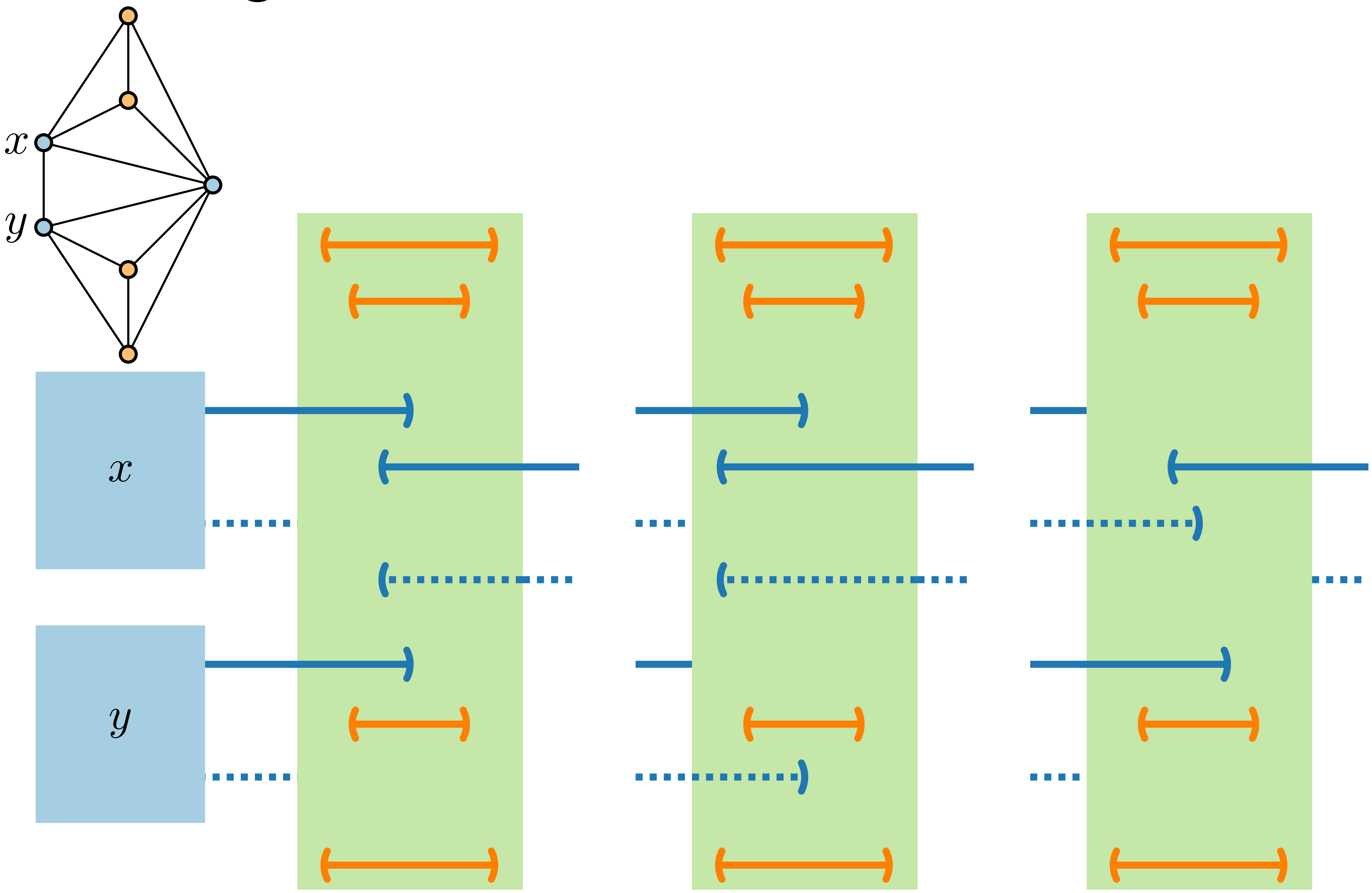

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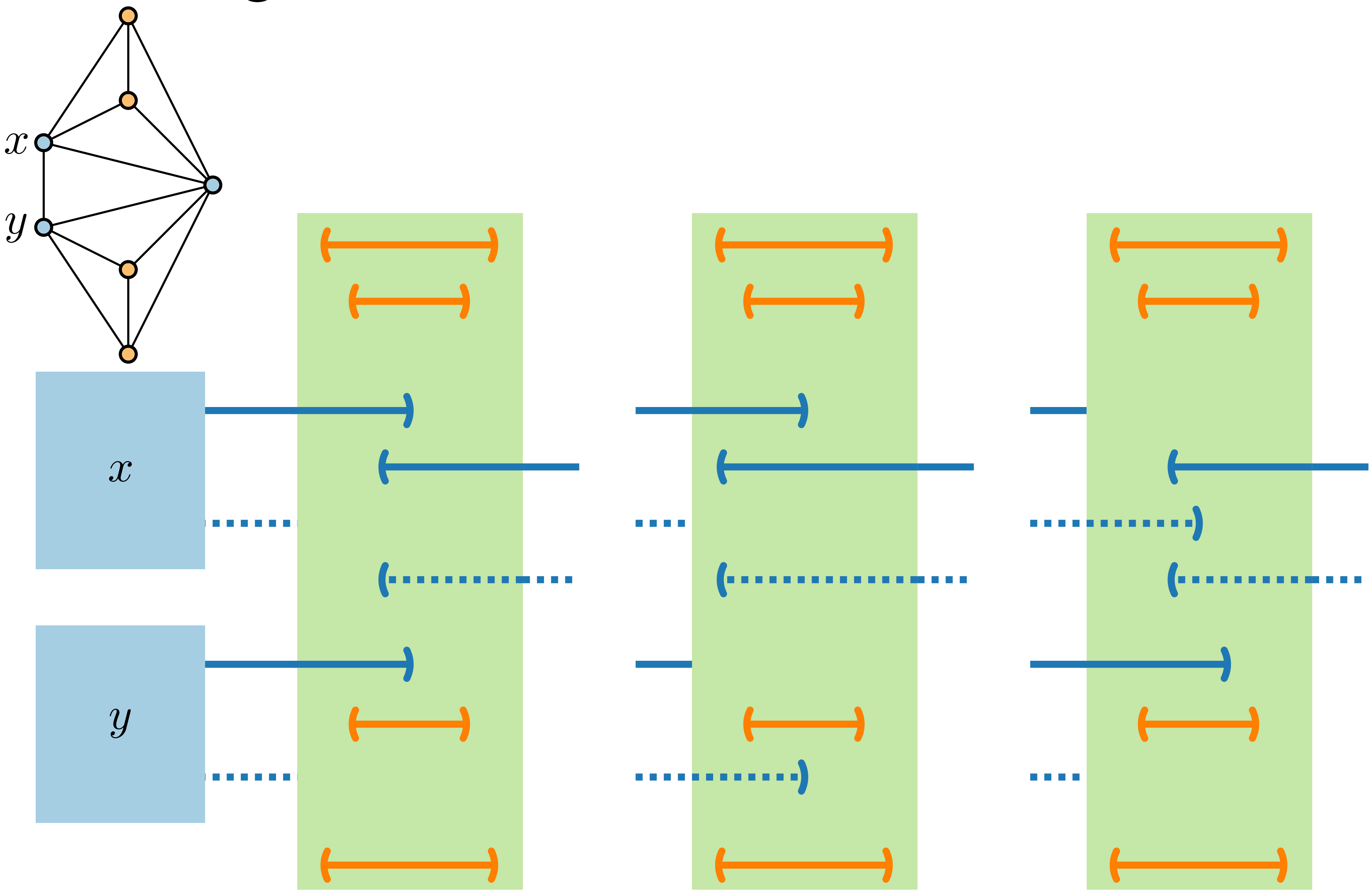

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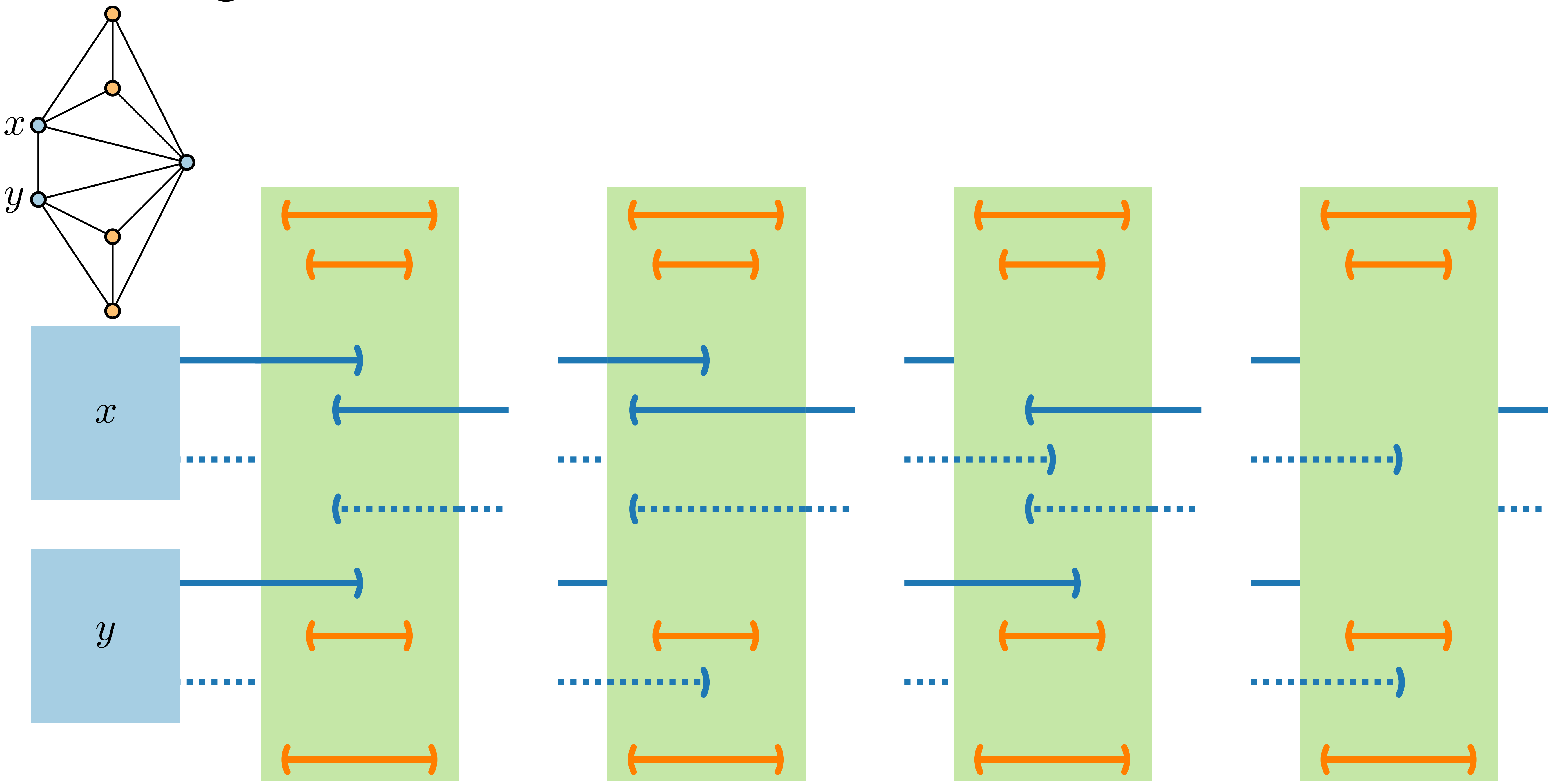

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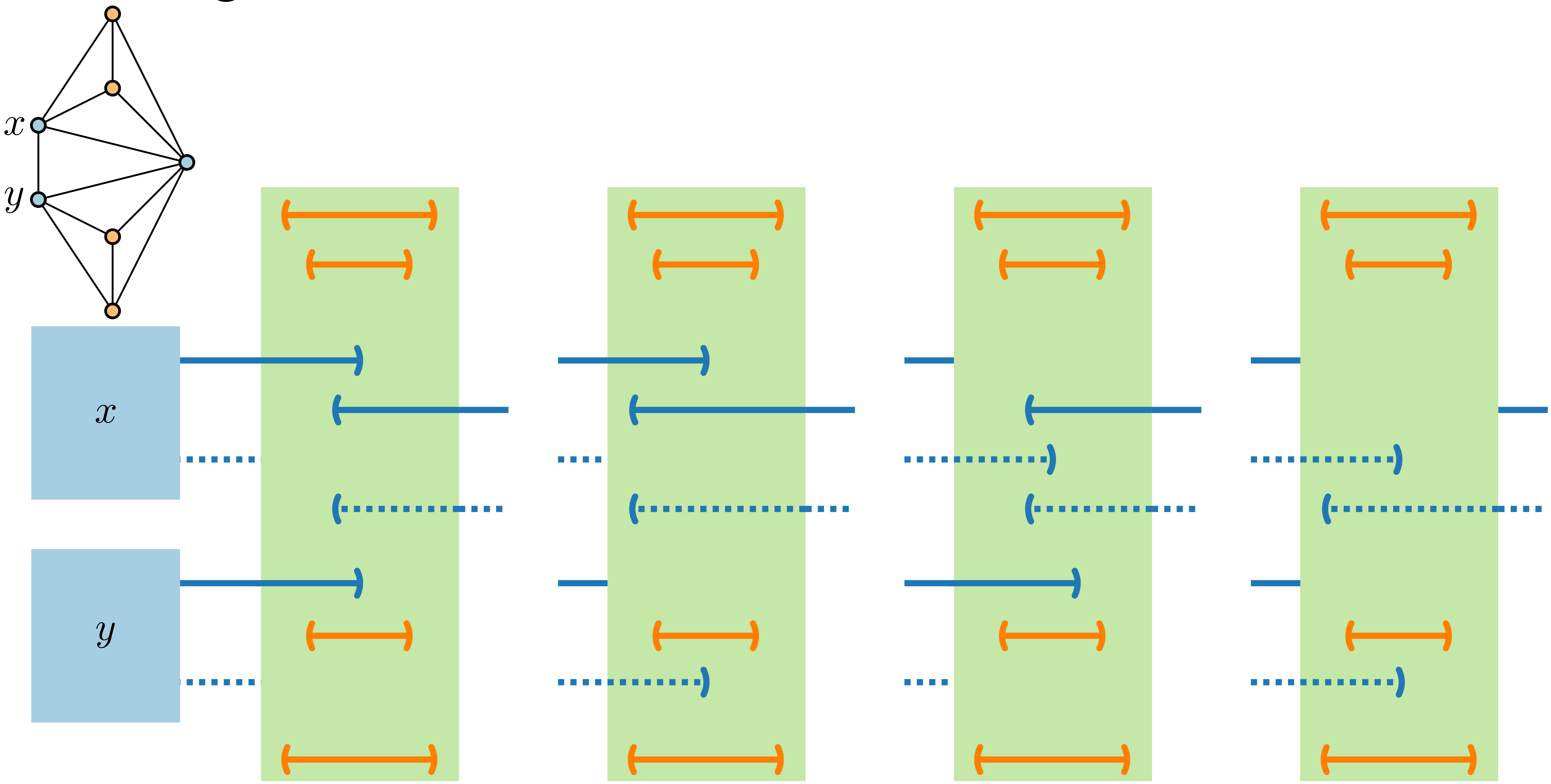

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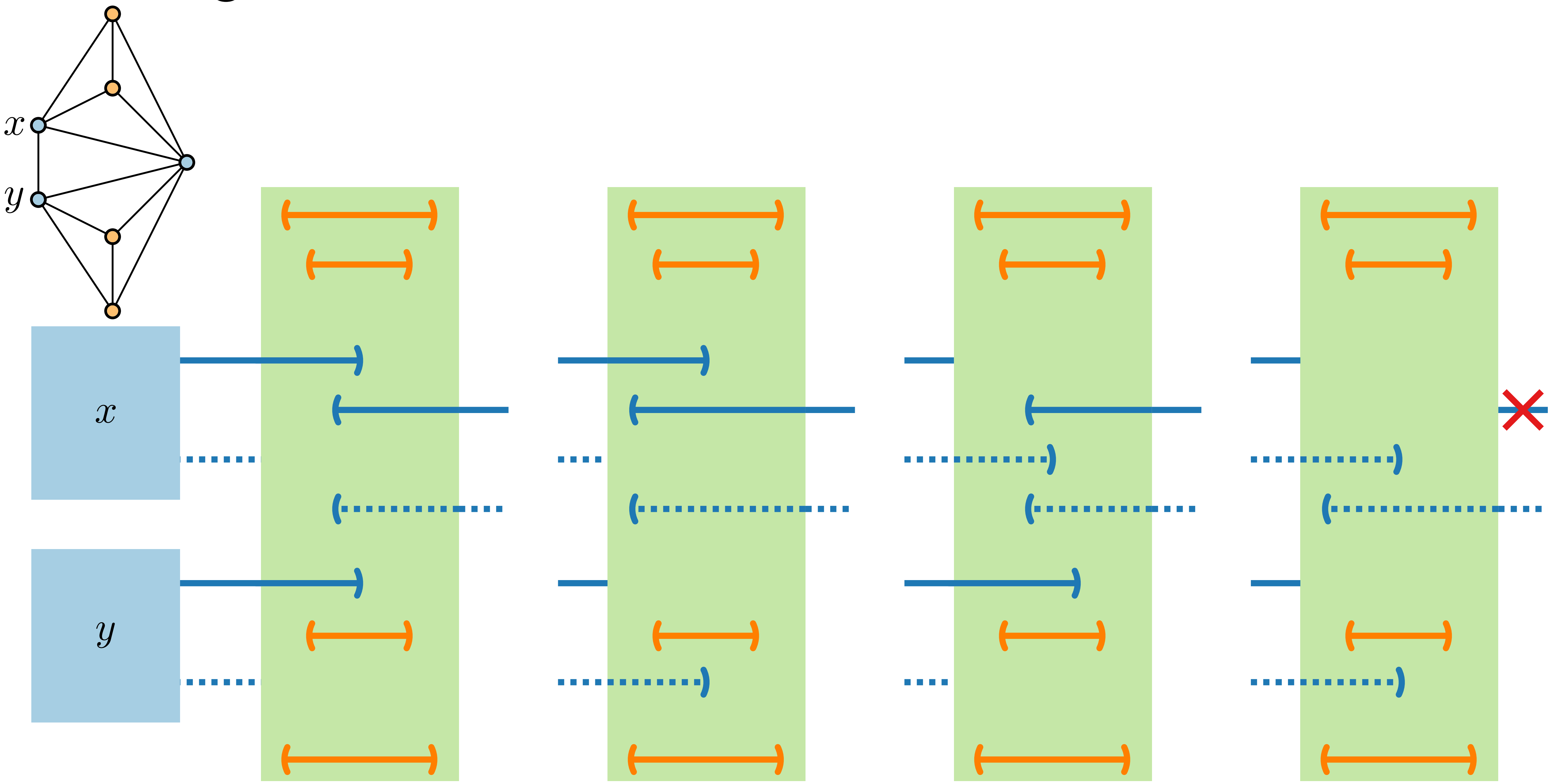

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- Can *strong* bar visibility recognition / representation extension be solved in polynomial time for st-graphs?

Literature

Main source:

- [Chaplick, Guśpiel, Gutowski, Krawczyk, Liotta '18]
  The Partial Visibility Representation Extension Problem

Referenced papers:

- [Tamassia, Tollis '86] Algorithms for visibility representations of planar graphs
- [Wismath '85] Characterizing bar line-of-sight graphs
- [Chaplick, Dorbec, Kratochvíl, Montassier, Stacho '14]
  Contact representations of planar graphs: Extending a partial representation is hard
- [Andreae '92] Some results on visibility graphs
- [Garg, Tamassia '01]
  On the Computational Complexity of Upward and Rectilinear Planarity Testing
- [Gutwenger, Mutzel '01] A Linear Time Implementation of SPQR-Trees
- [de Berg, Khosravi '10] Optimal Binary Space Partitions in the Plane