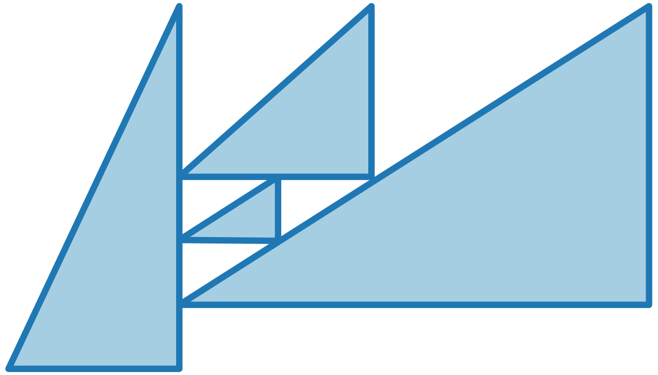
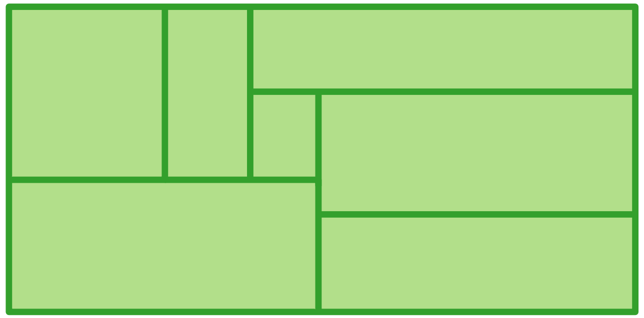
Julius-Maximilians-
UNIVERSITÄT
WÜRZBURG

Visualization of Graphs

Lecture 7:
Contact Representations of Planar Graphs:
Triangle Contacts and Rectangular Duals



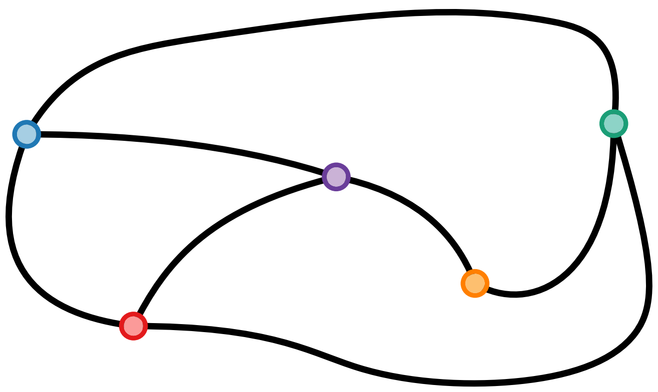


Johannes Zink

Summer semester 2024

Intersection Representation of Graphs

In an **intersection representation** of a graph,
– each vertex is represented by a set



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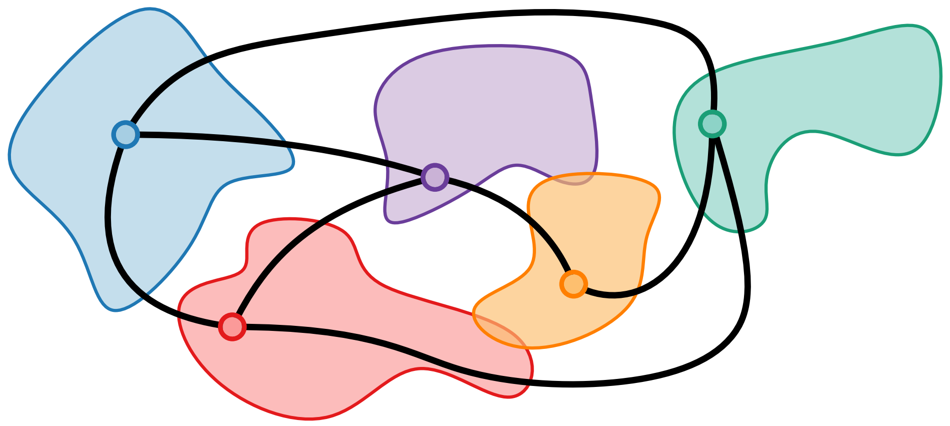

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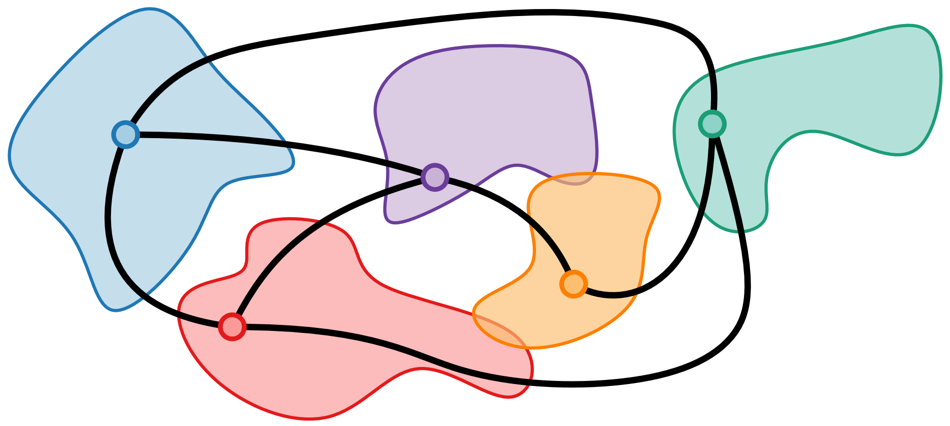

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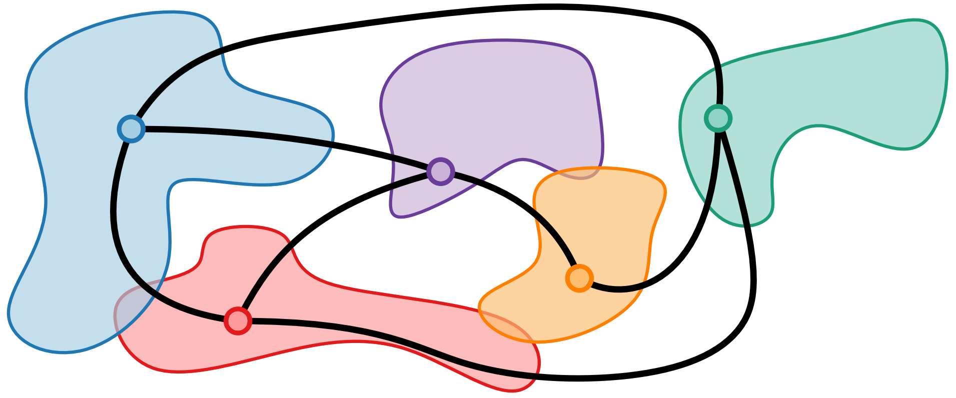

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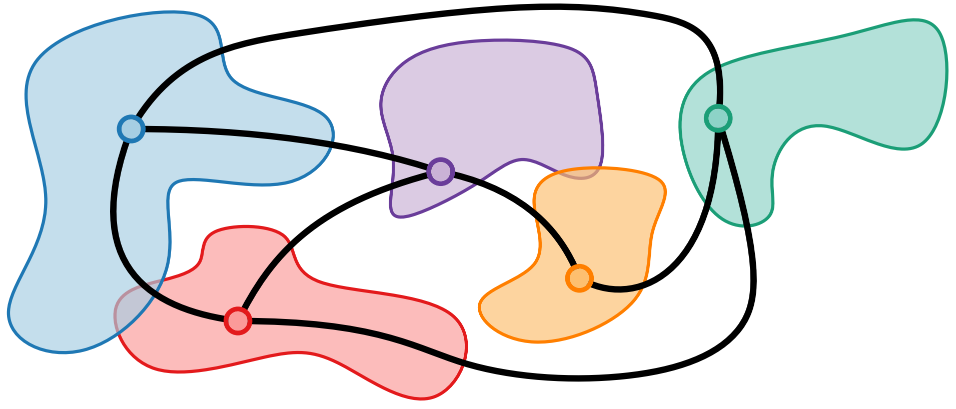

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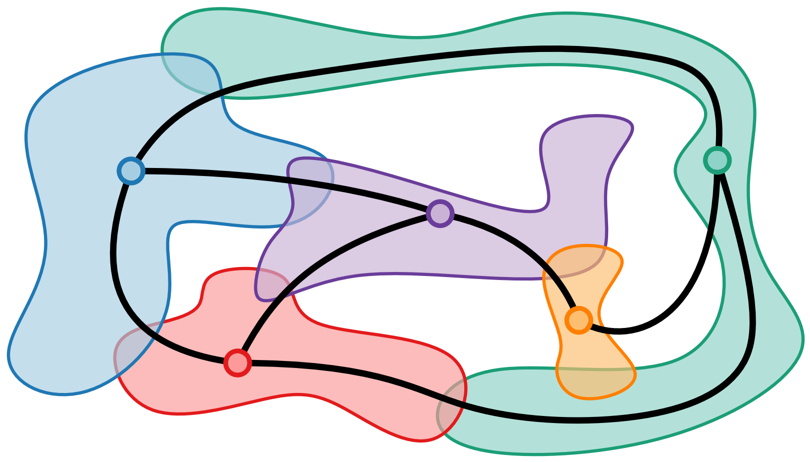
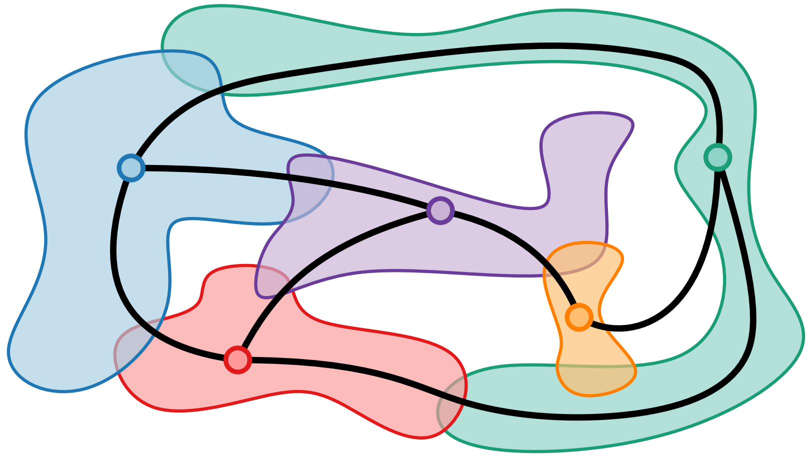


Intersection Representation of Graphs

In an **intersection representation** of a graph,
– each vertex is represented by a set
– such that two sets intersect $\Leftrightarrow$ the corresponding vertices are adjacent.

For a collection $\mathcal{S}$ of sets, the **intersection graph** $G(\mathcal{S})$ of $\mathcal{S}$ has vertex set $\mathcal{S}$ and edge set $\{\{S, S'\} \colon S, S' \in \mathcal{S}, S \neq S',$ and $S \cap S' \neq \emptyset\}$.



Contact Representation of Graphs

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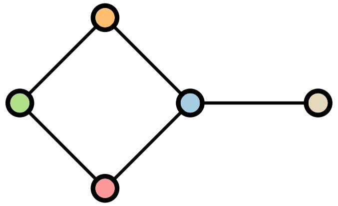

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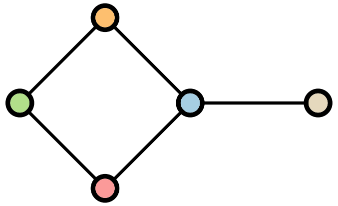

Represent each vertex v by a geometric object $S(v)$

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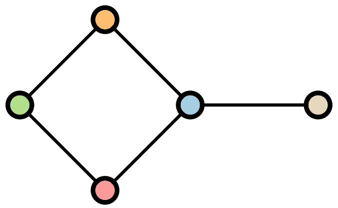

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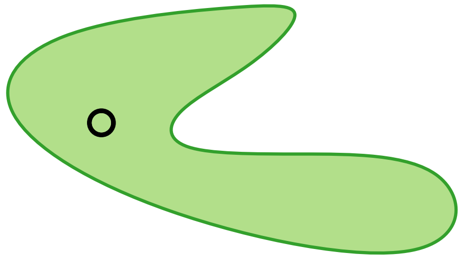

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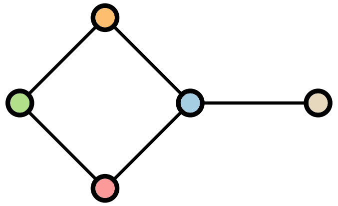

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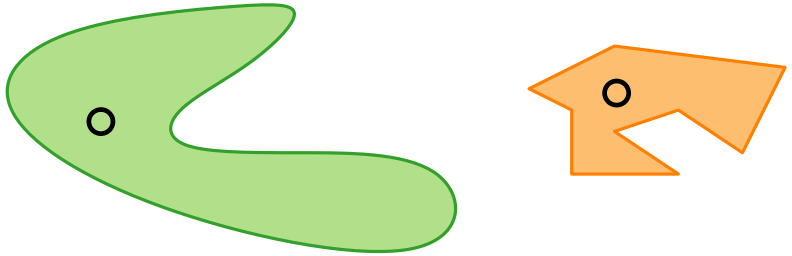

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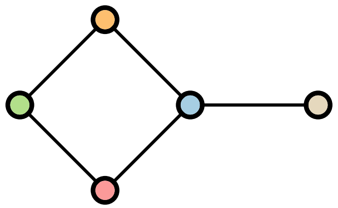

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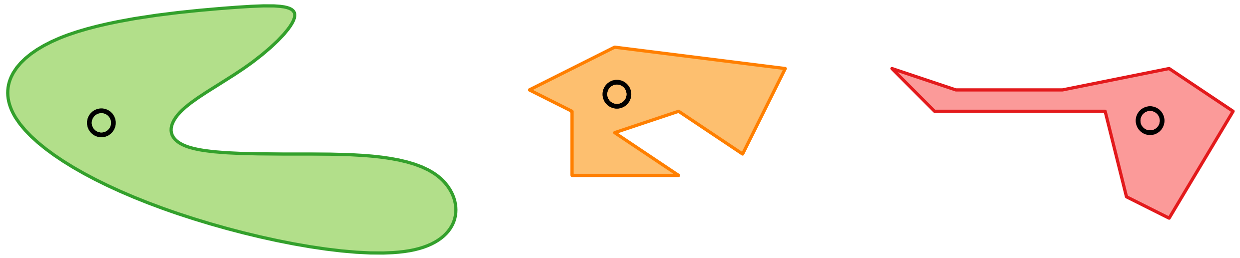

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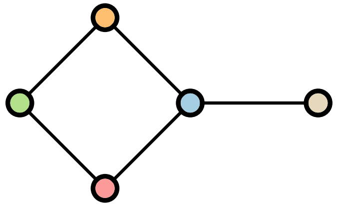

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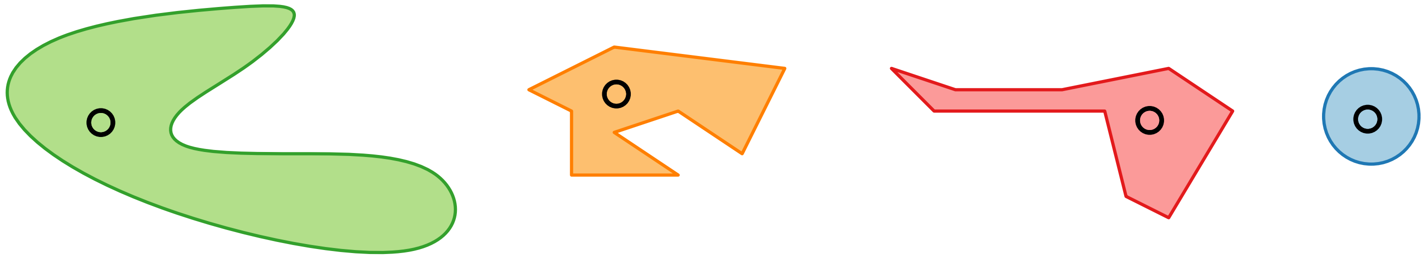

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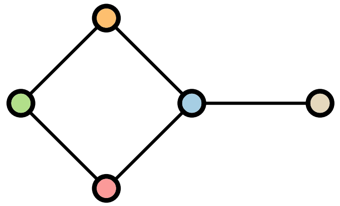

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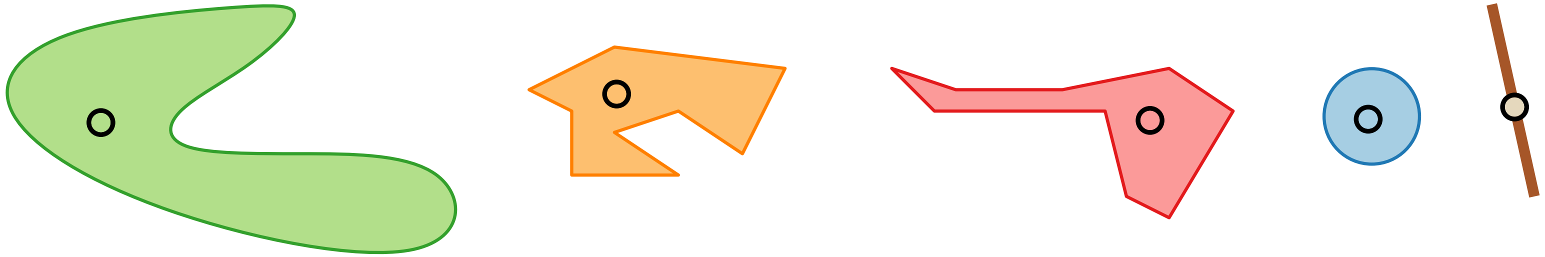

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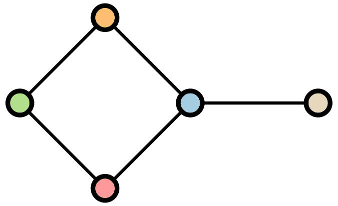

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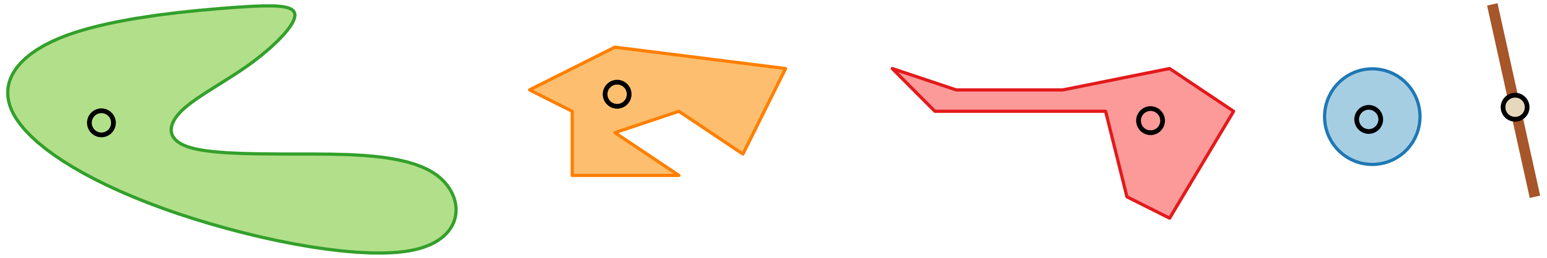

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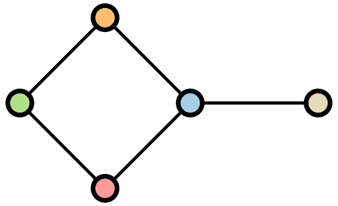

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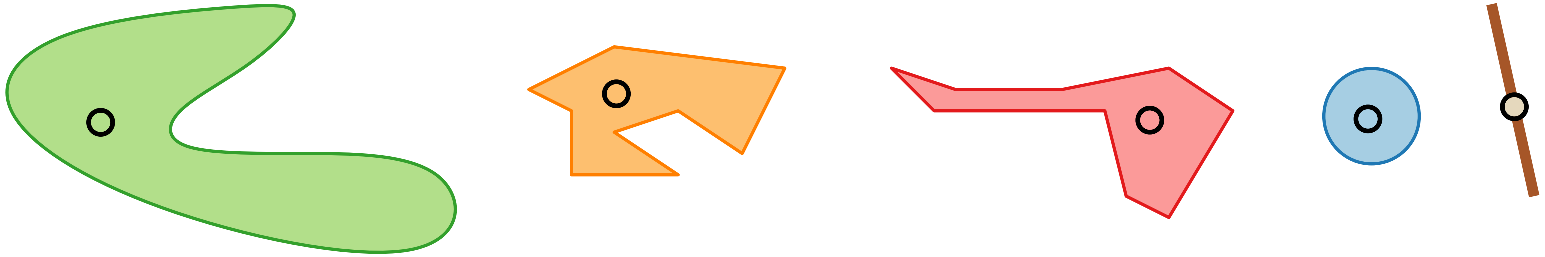

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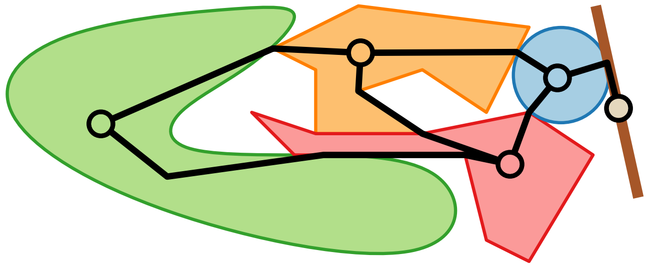

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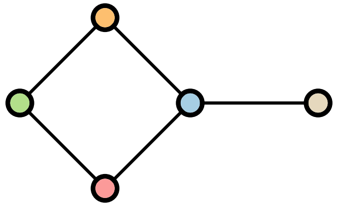

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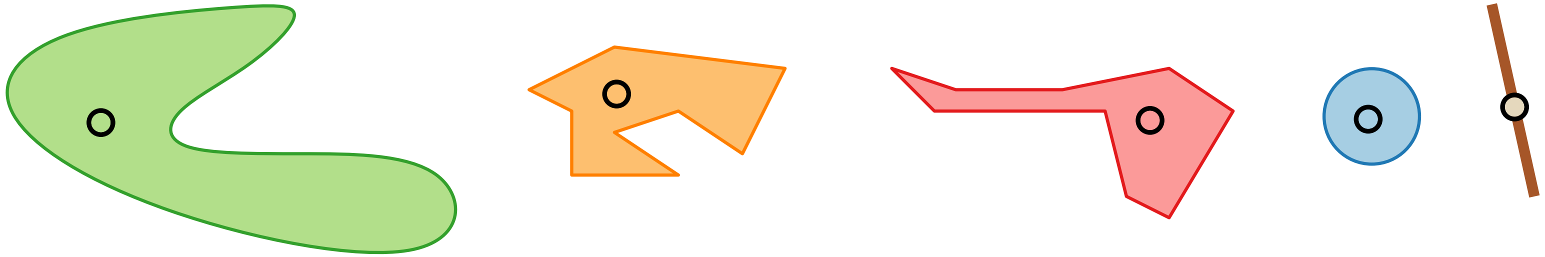

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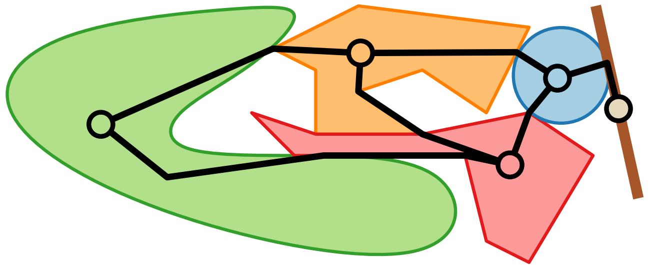

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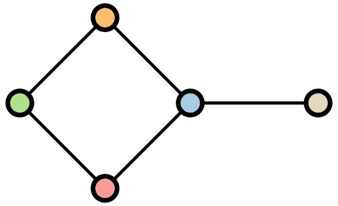

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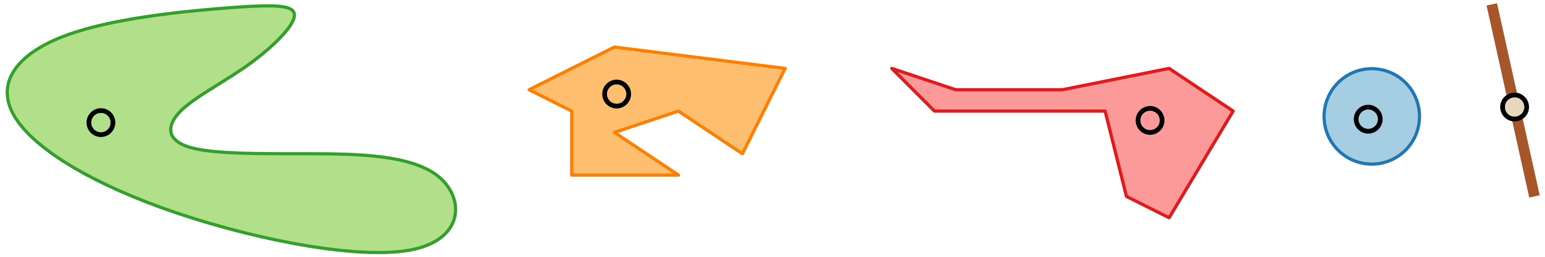

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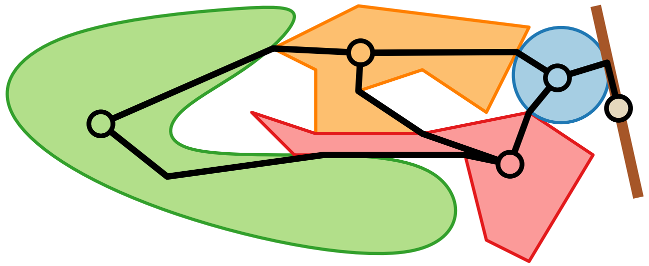

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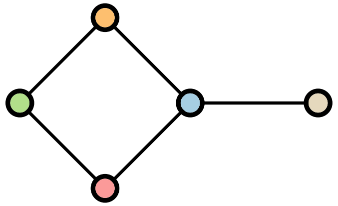

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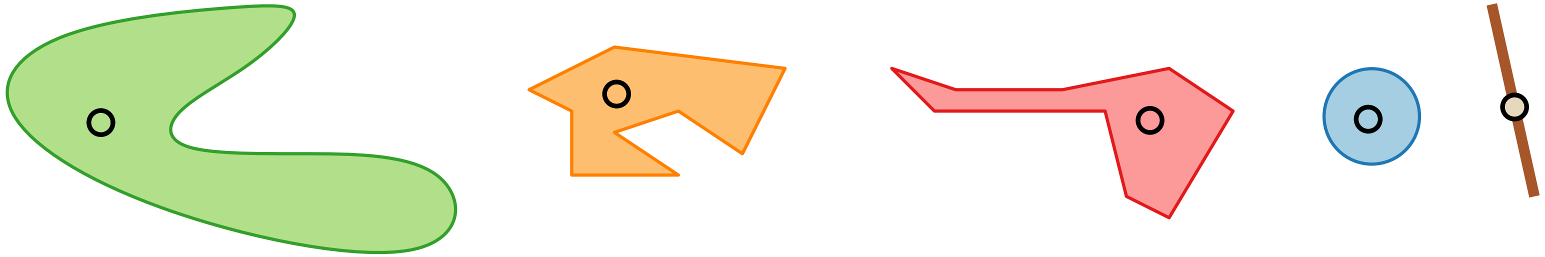

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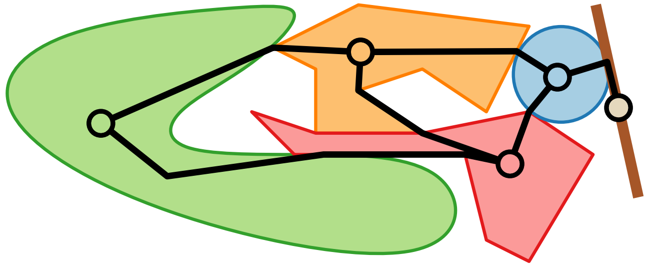

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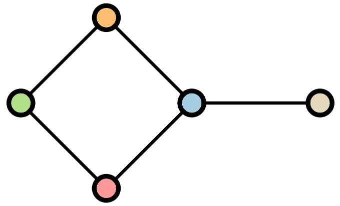

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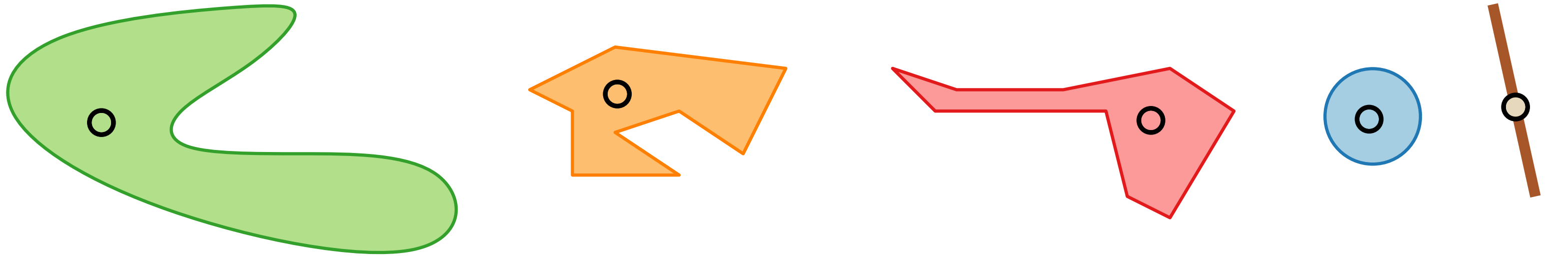

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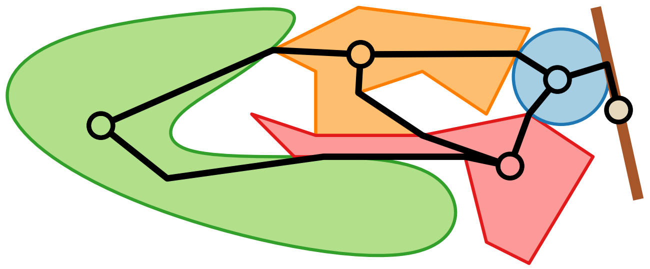

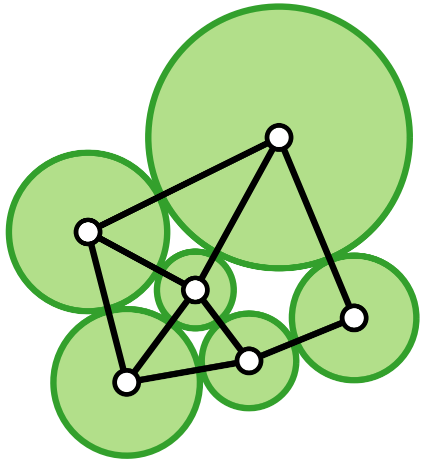

disks

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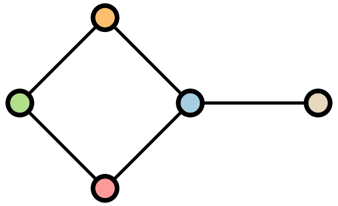

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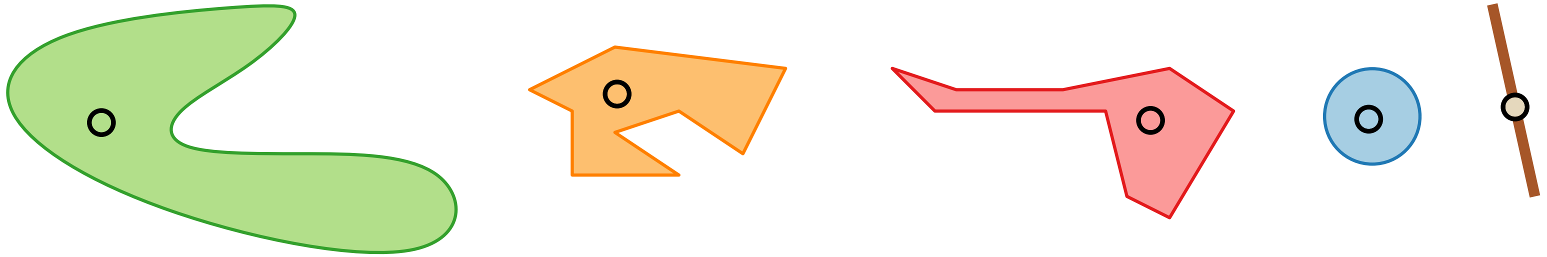

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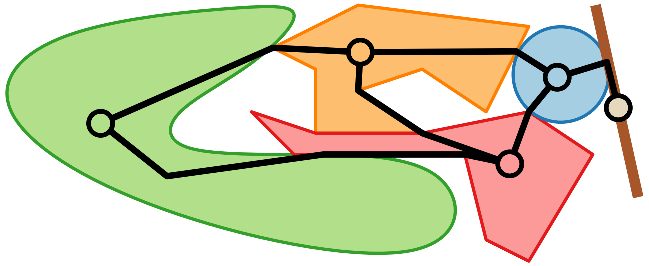

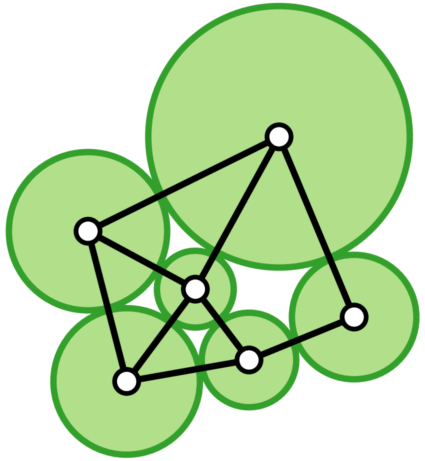

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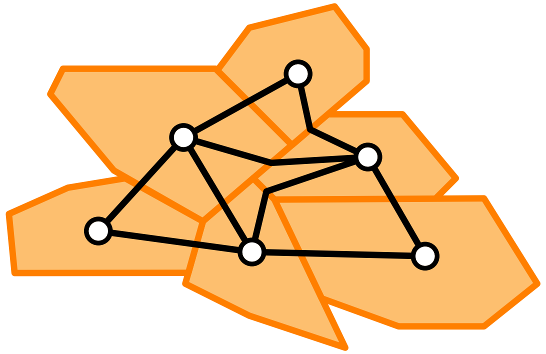

polygons

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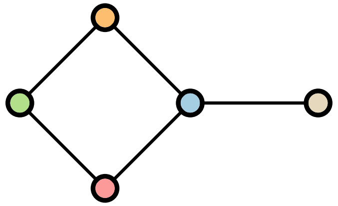
Let G be a graph.  Let $\mathcal{S}$ be a family of geometric objects (e.g., disks).

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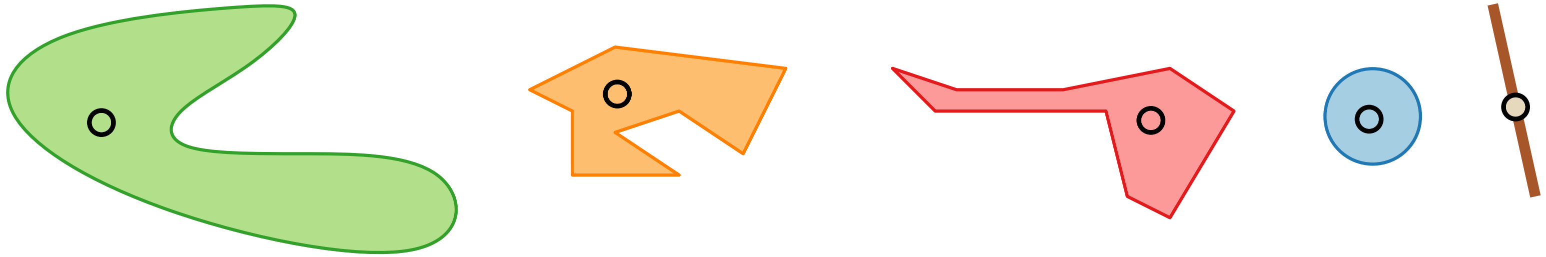
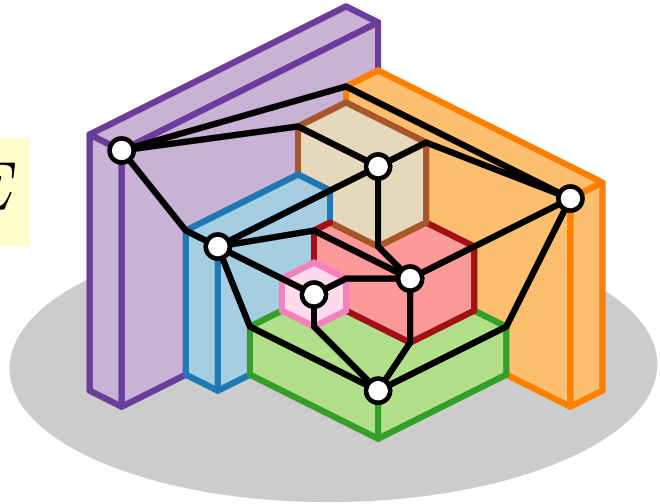


rectangular cuboids



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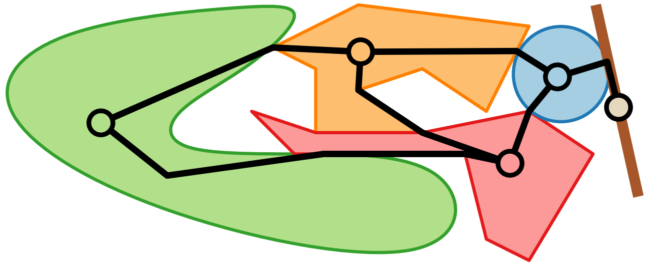

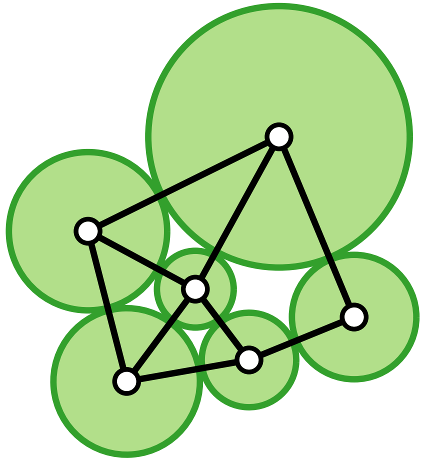

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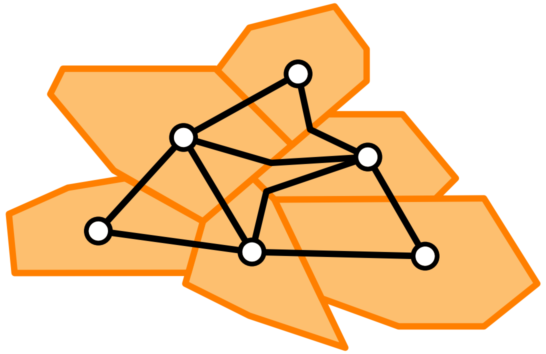

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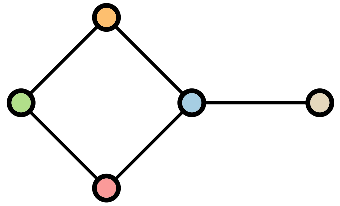

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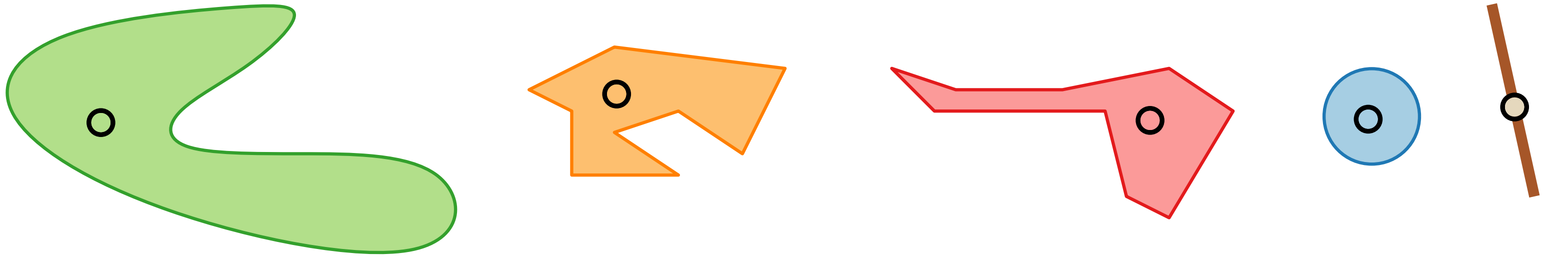

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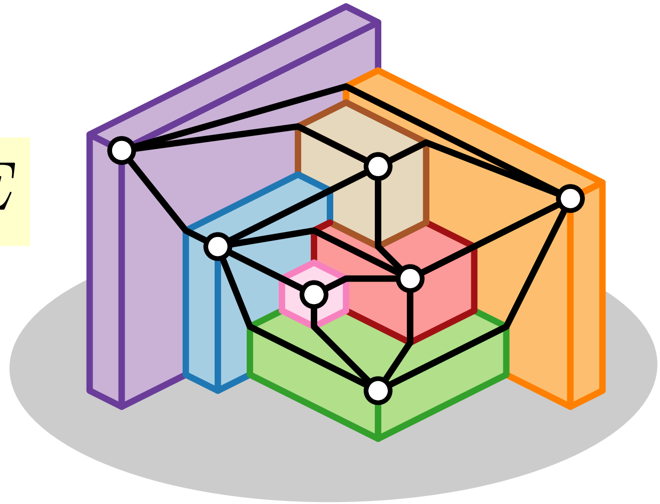

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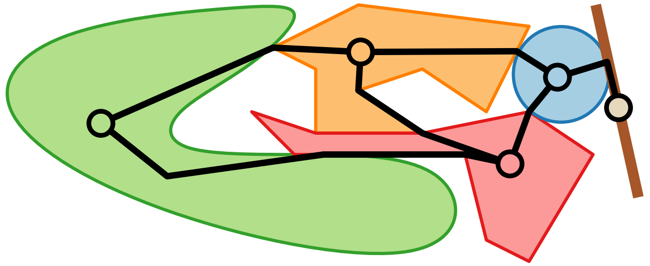
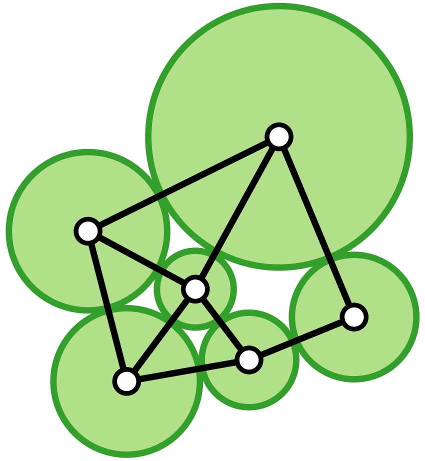


G is planar



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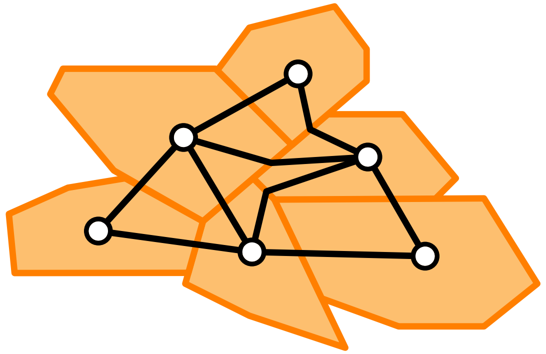

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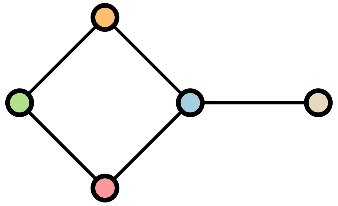
Let G be a graph.  Let $\mathcal{S}$ be a family of geometric objects (e.g., disks).

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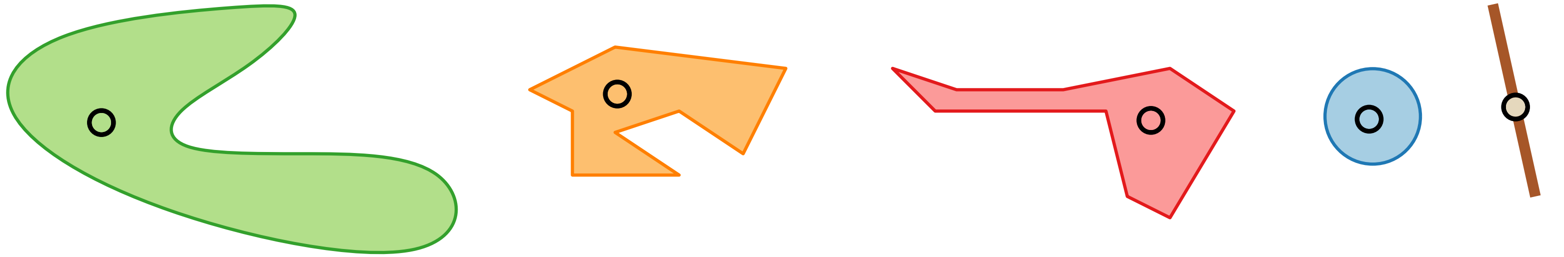
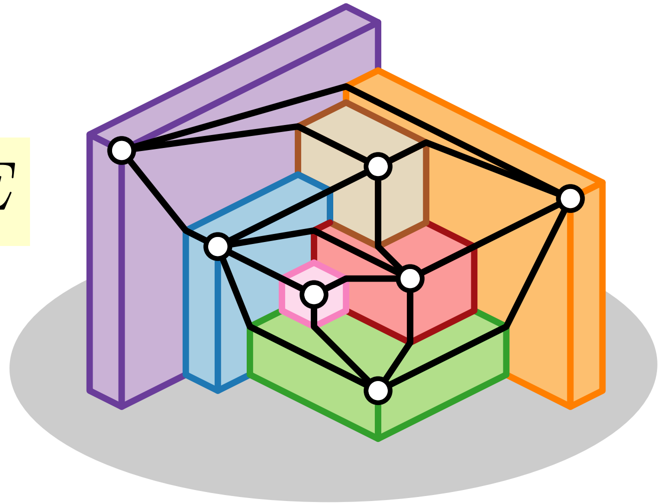


rectangular cuboids



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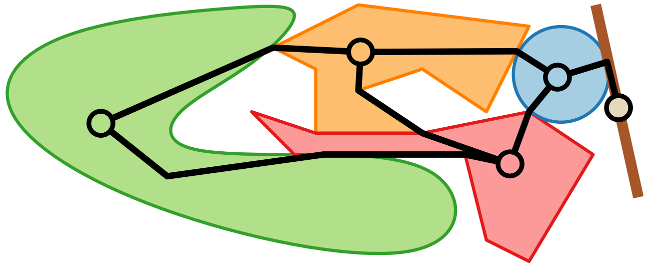

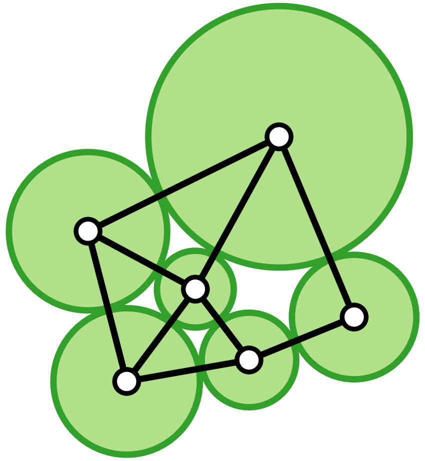

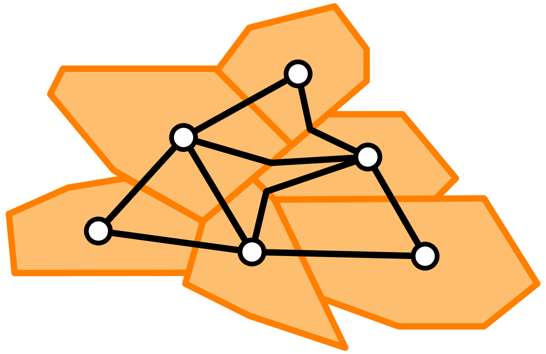

G is planar → disks [Koebe 1936]

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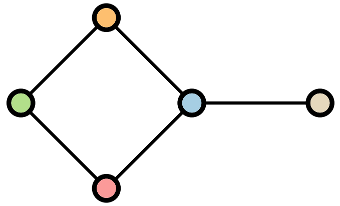

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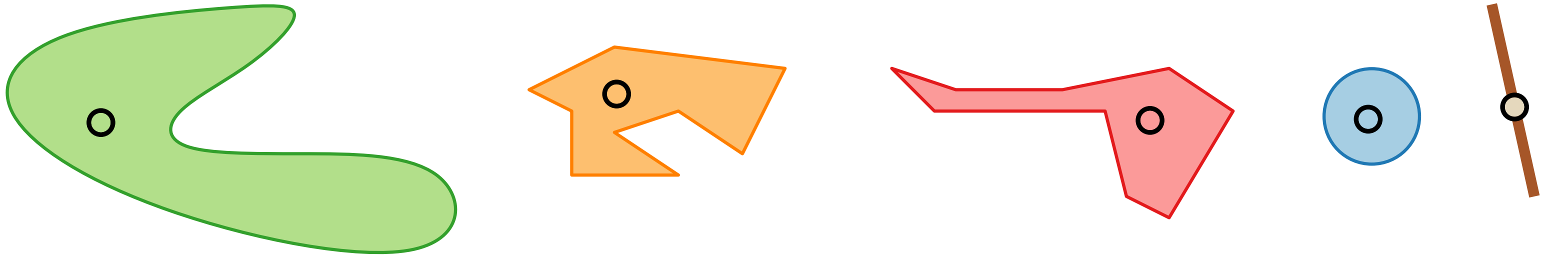
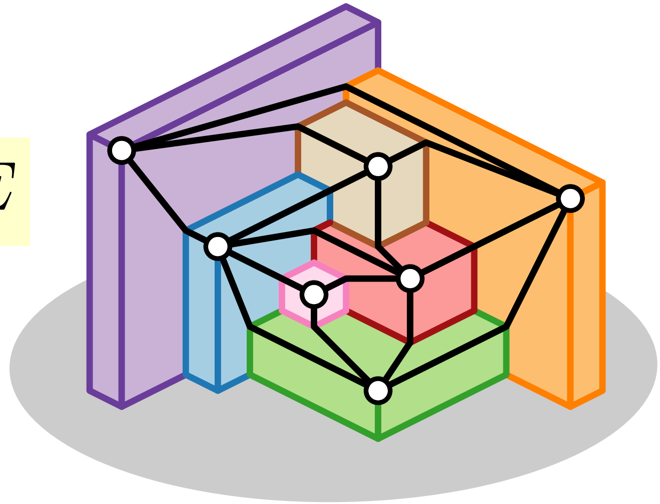


rectangular cuboids



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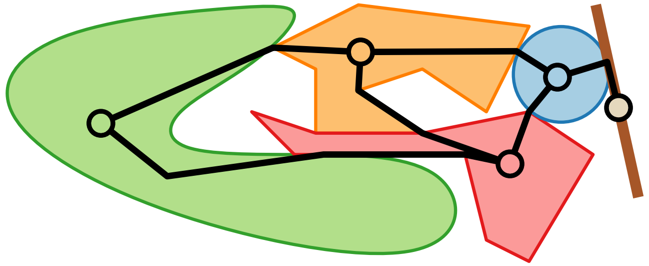
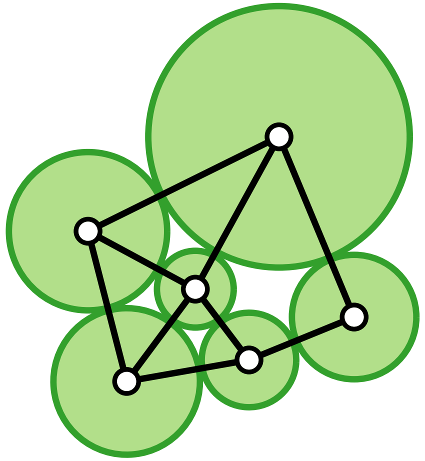
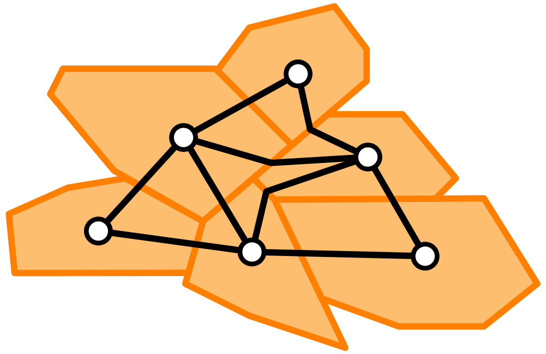




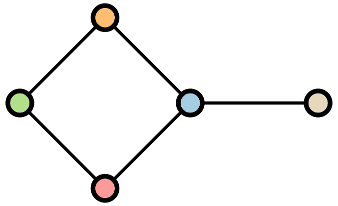


G is planar → disks → polygons

[Koebe 1936]

Contact Representation of Graphs

Let G be a graph.



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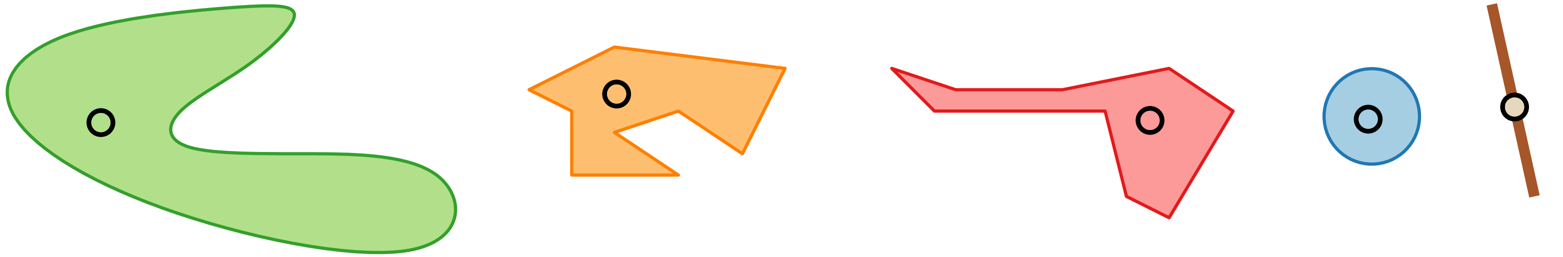

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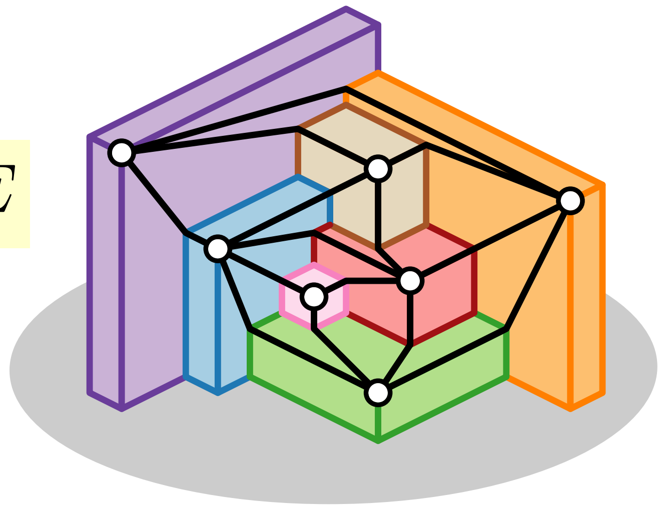

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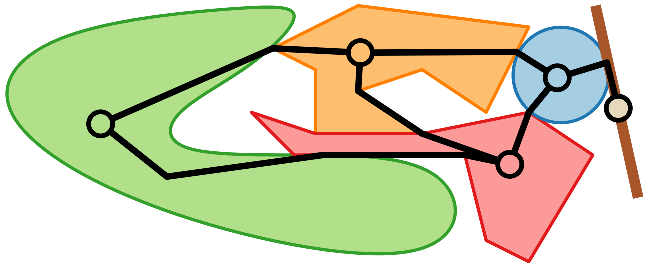

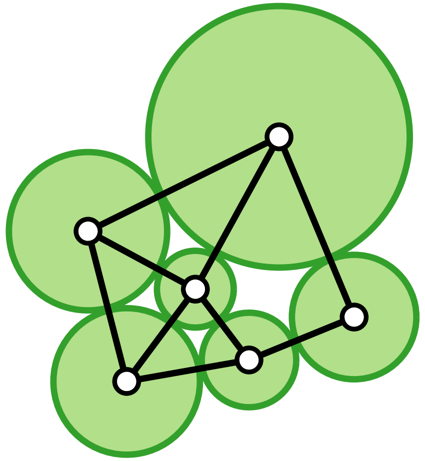

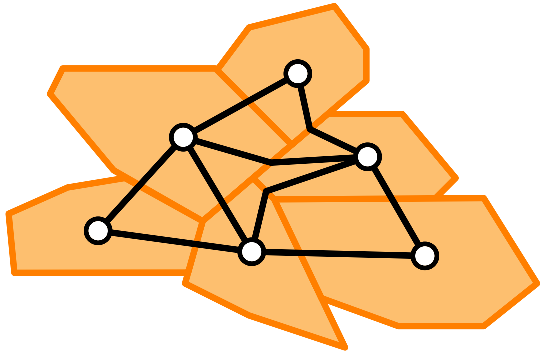

G is planar → [Koebe 1936] disks → polygons

A contact representation is an intersection representation with interior-disjoint sets.

Contact Representation of Planar Graphs

Is the intersection graph of a contact representation always planar?

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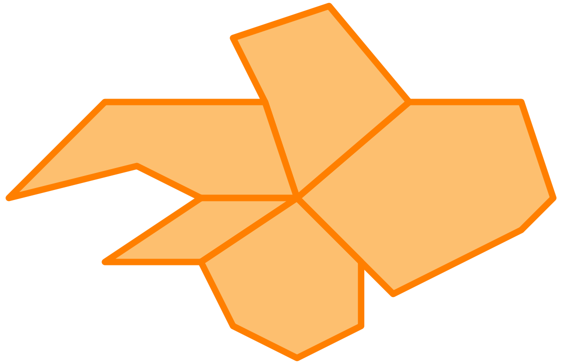

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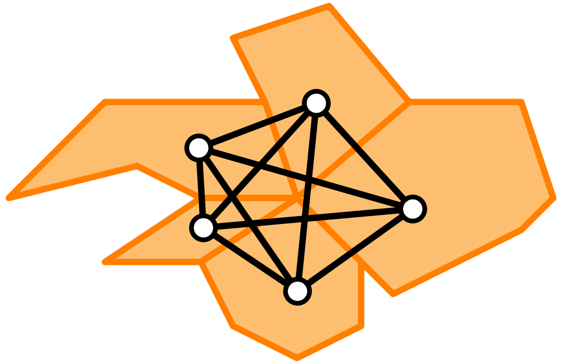

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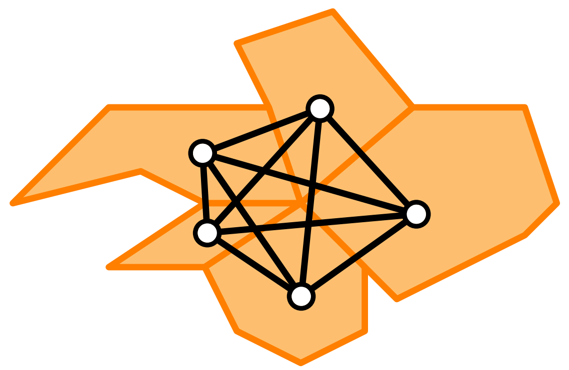

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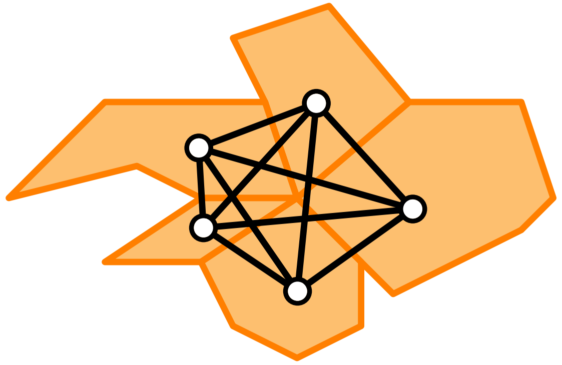

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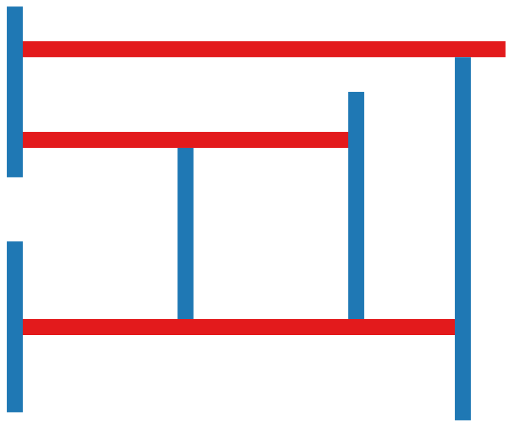

bipartite planar graphs

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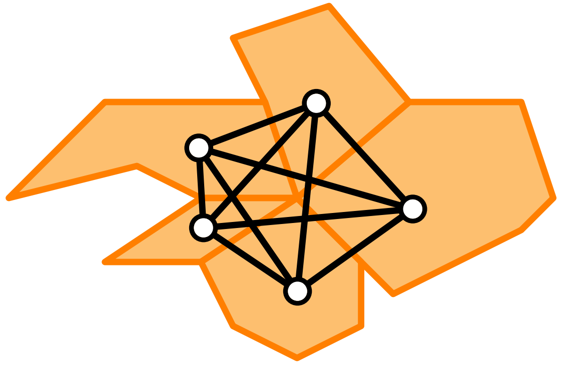

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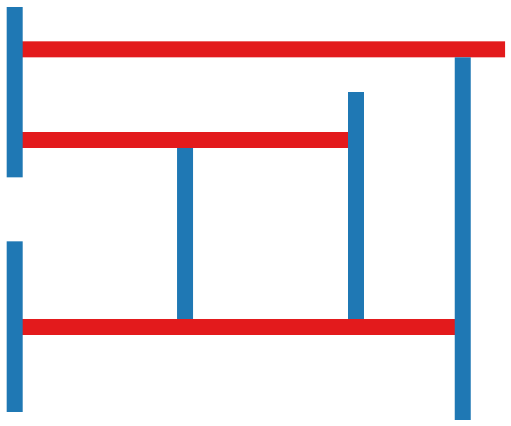

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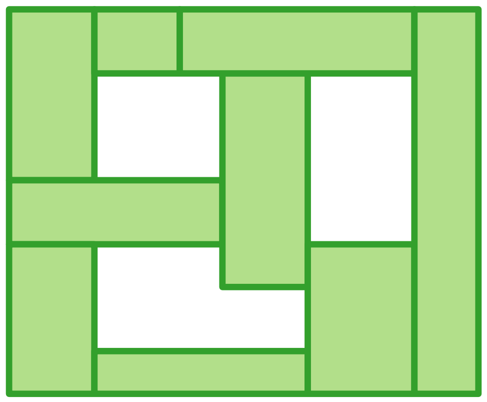

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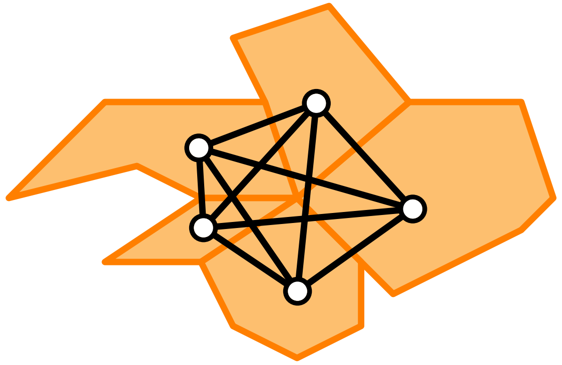

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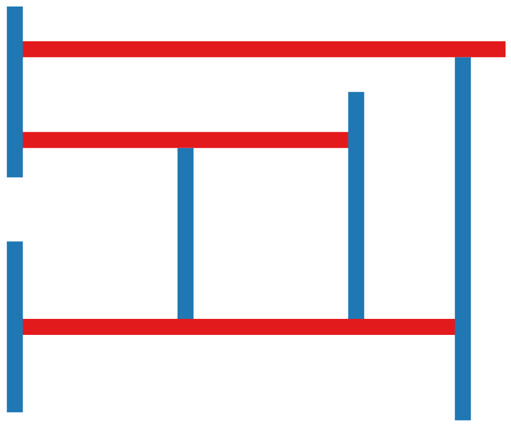

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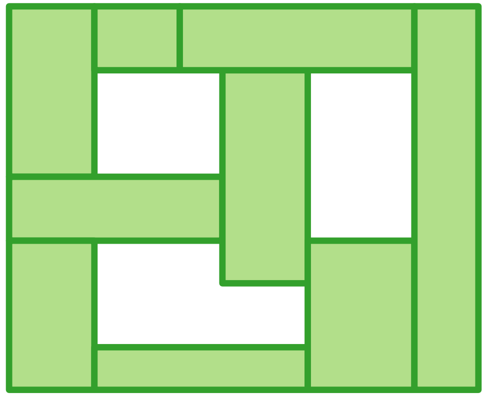

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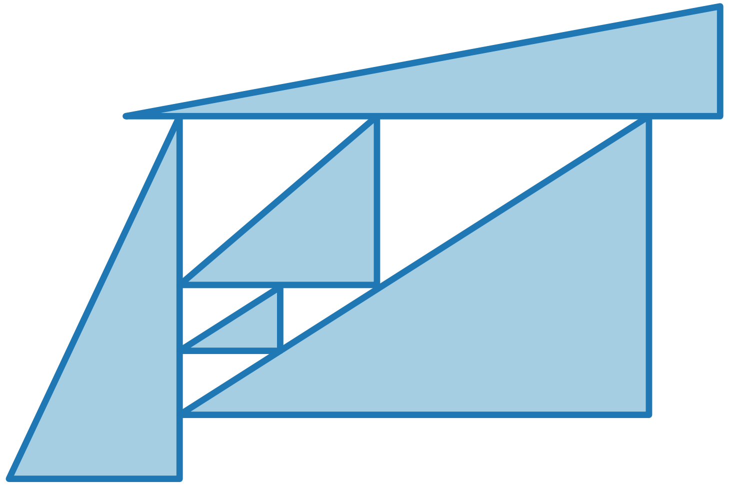

planar triangulations

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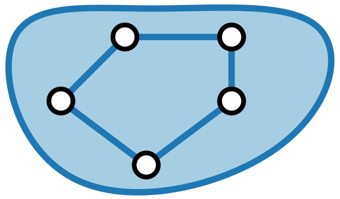

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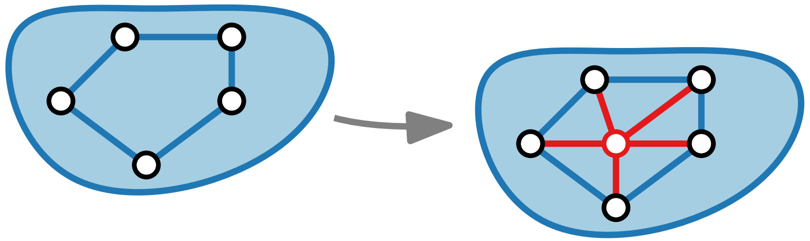

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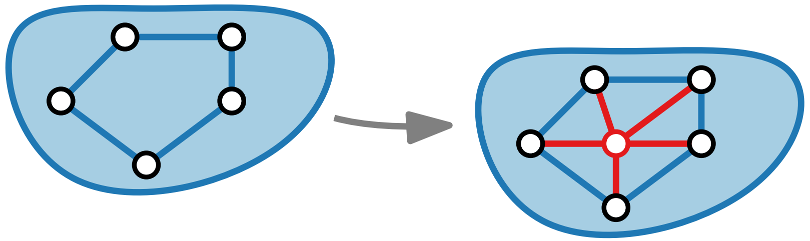

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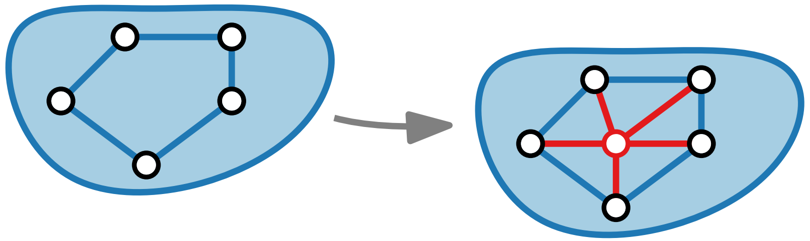

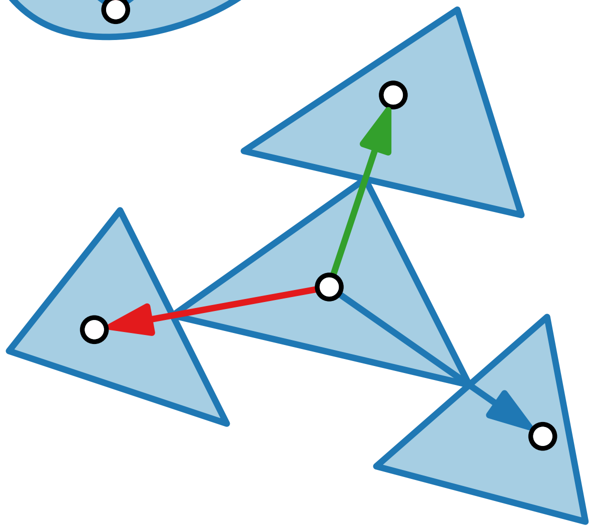

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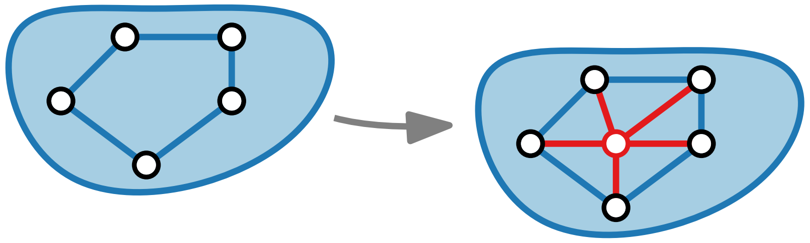

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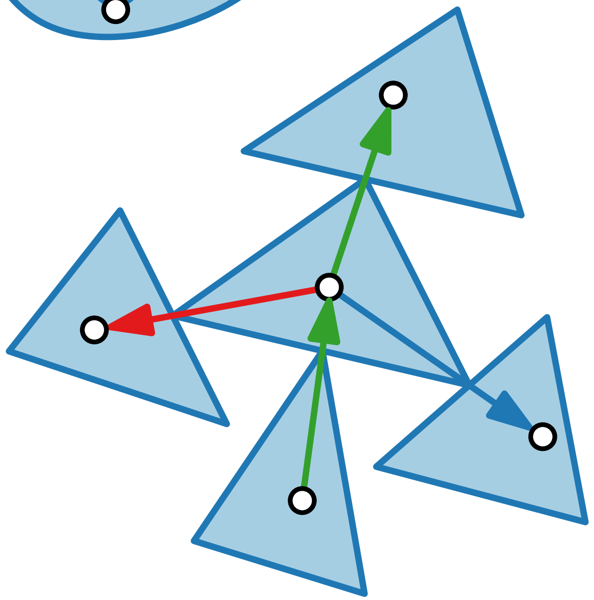

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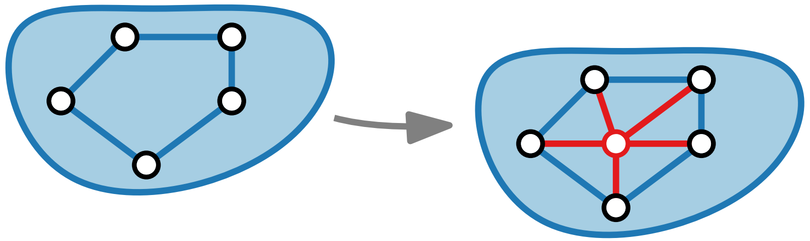

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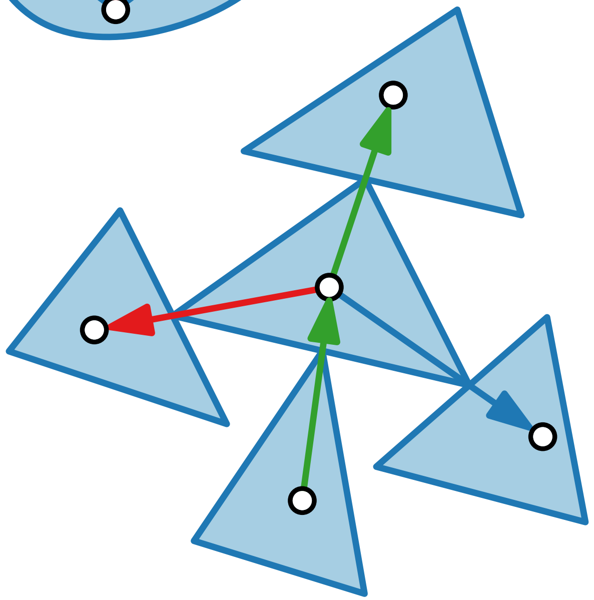

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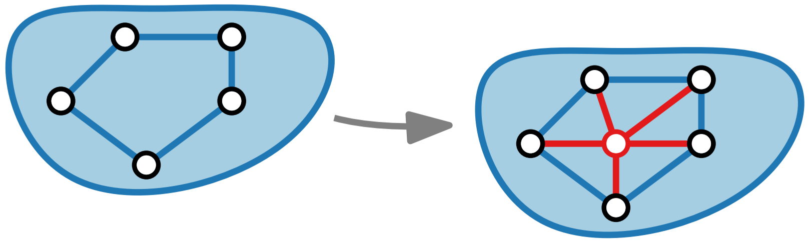

- Describe contact representation combinatorially.
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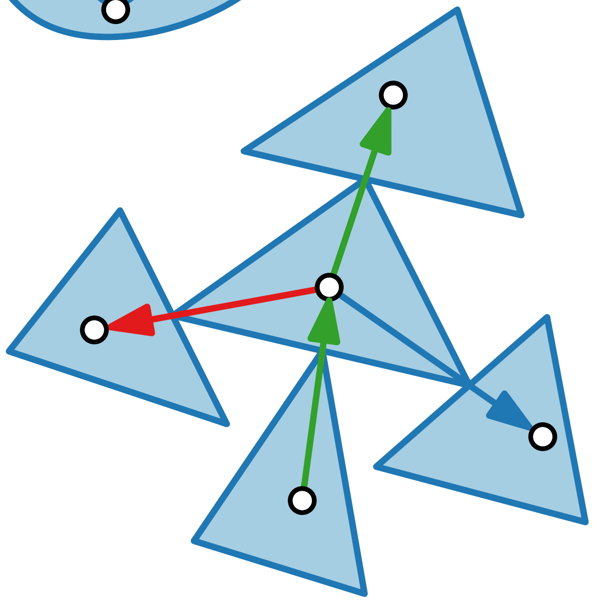
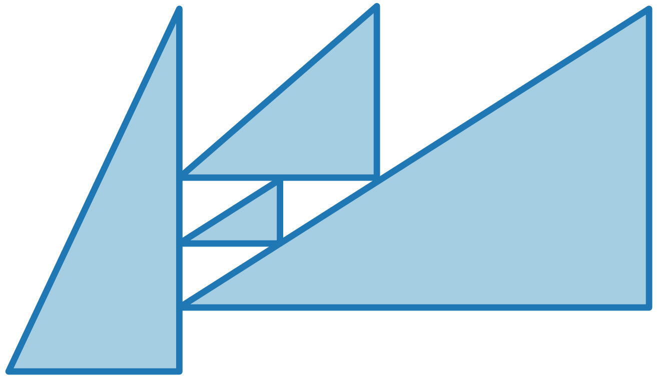
- Compute combinatorial description.
- Show that combinatorial description can be used to construct drawing.



This Lecture

Representation with right-triangles and corner contact:



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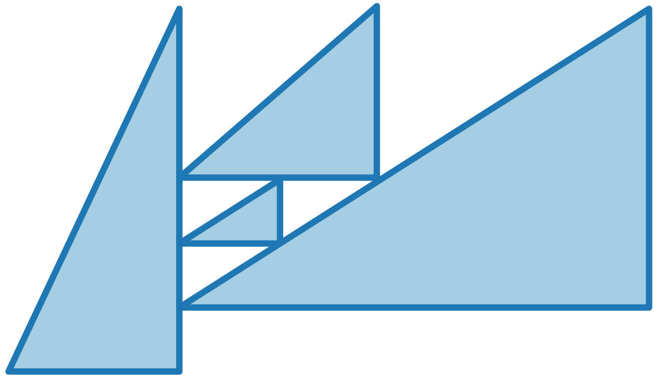

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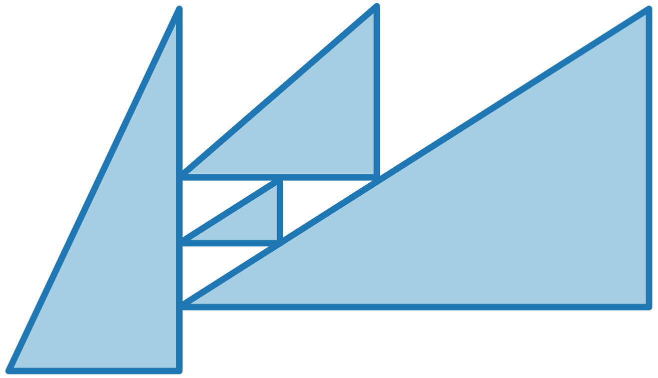

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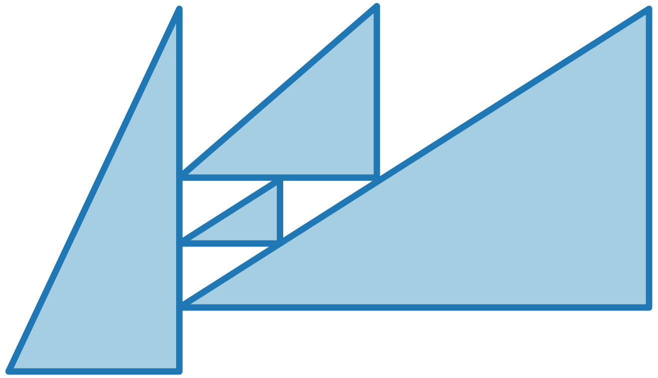

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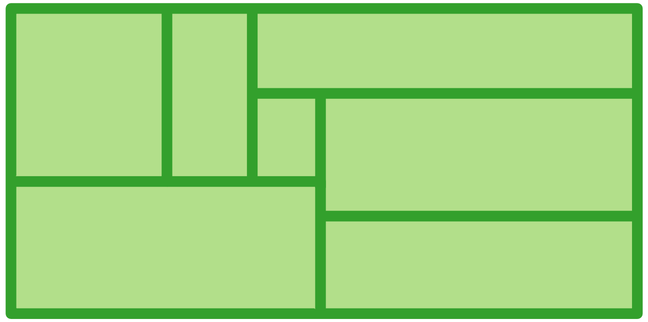

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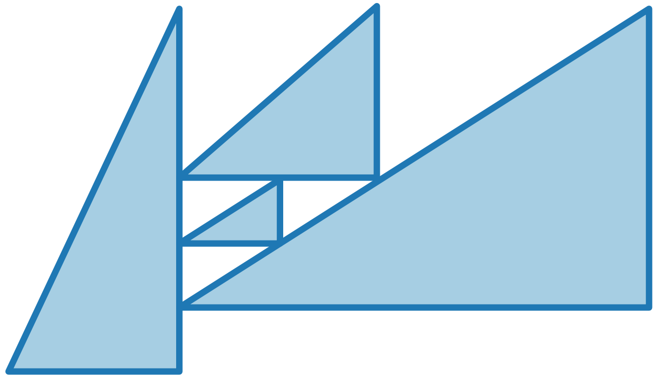

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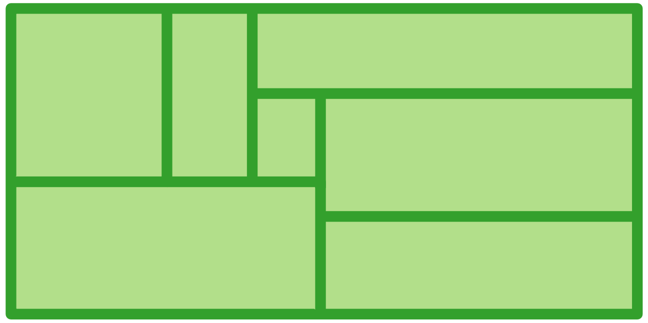

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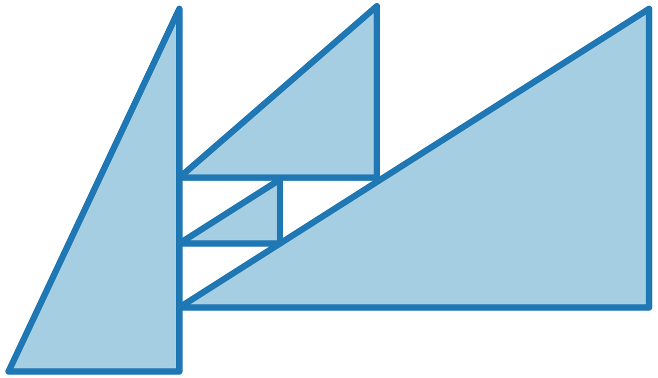

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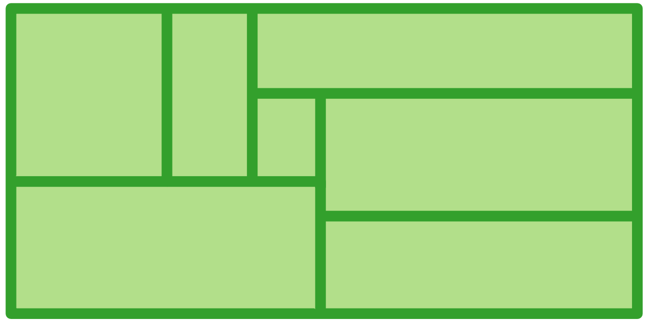

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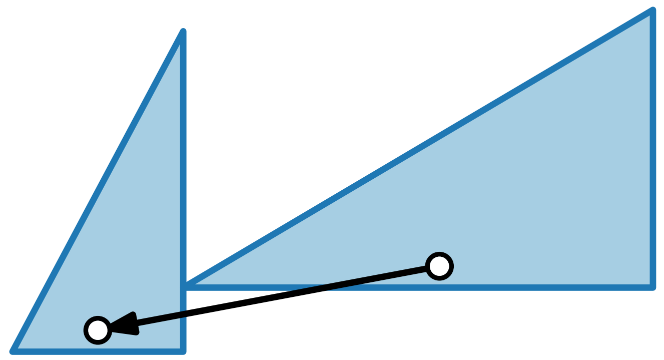

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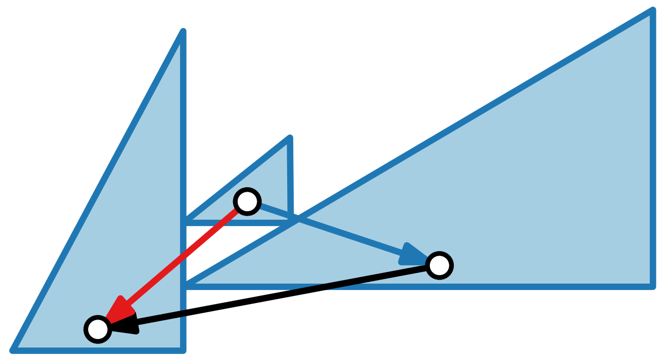

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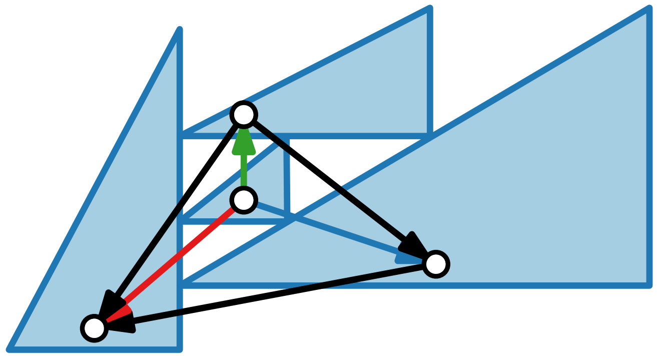

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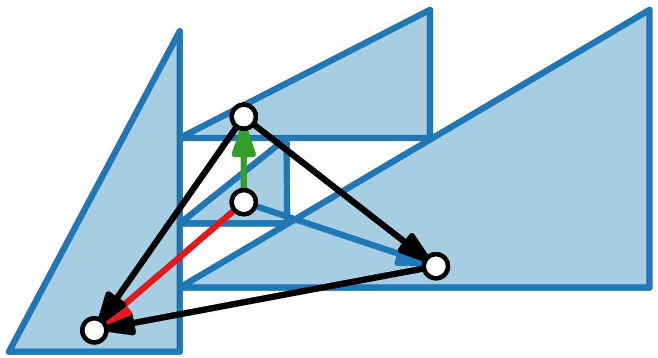

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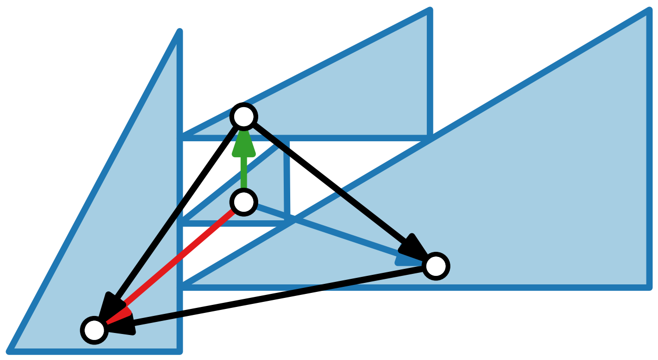

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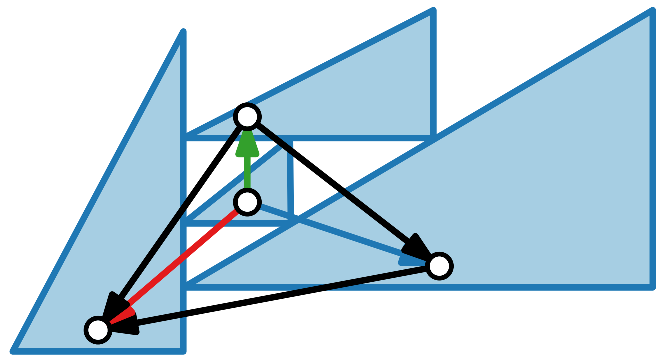

Detailed Idea.

- Place base of triangle at height equal to position in canonical order.
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- Outgoing edges in Schnyder forest indicate corner contacts.

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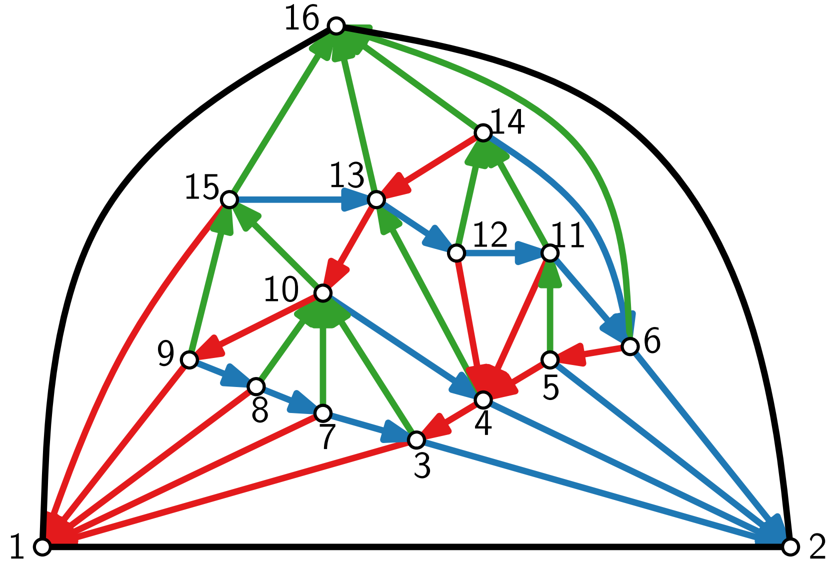

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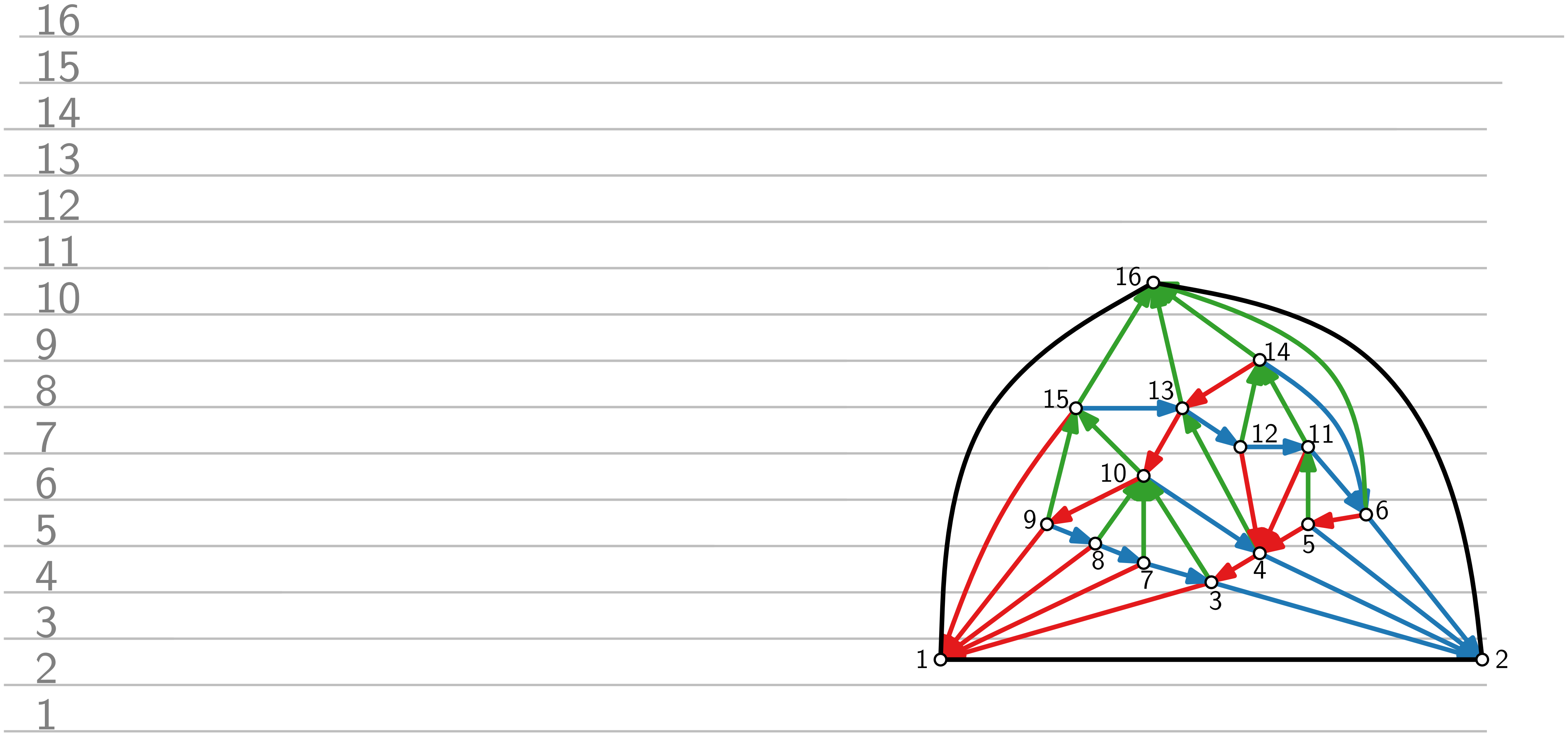

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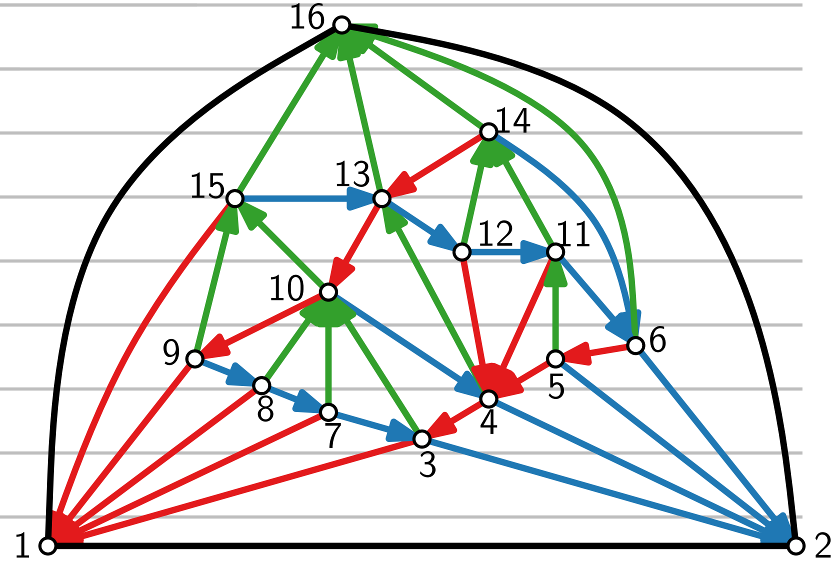

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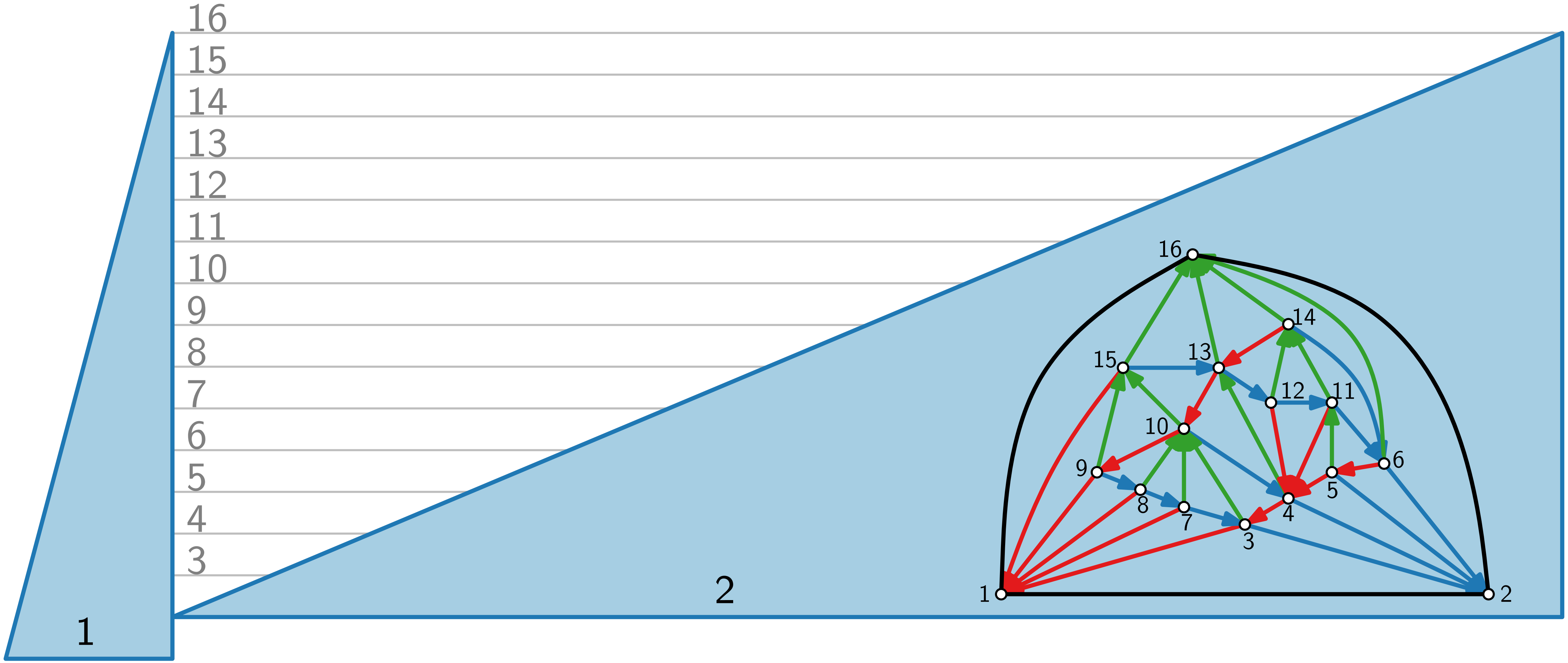

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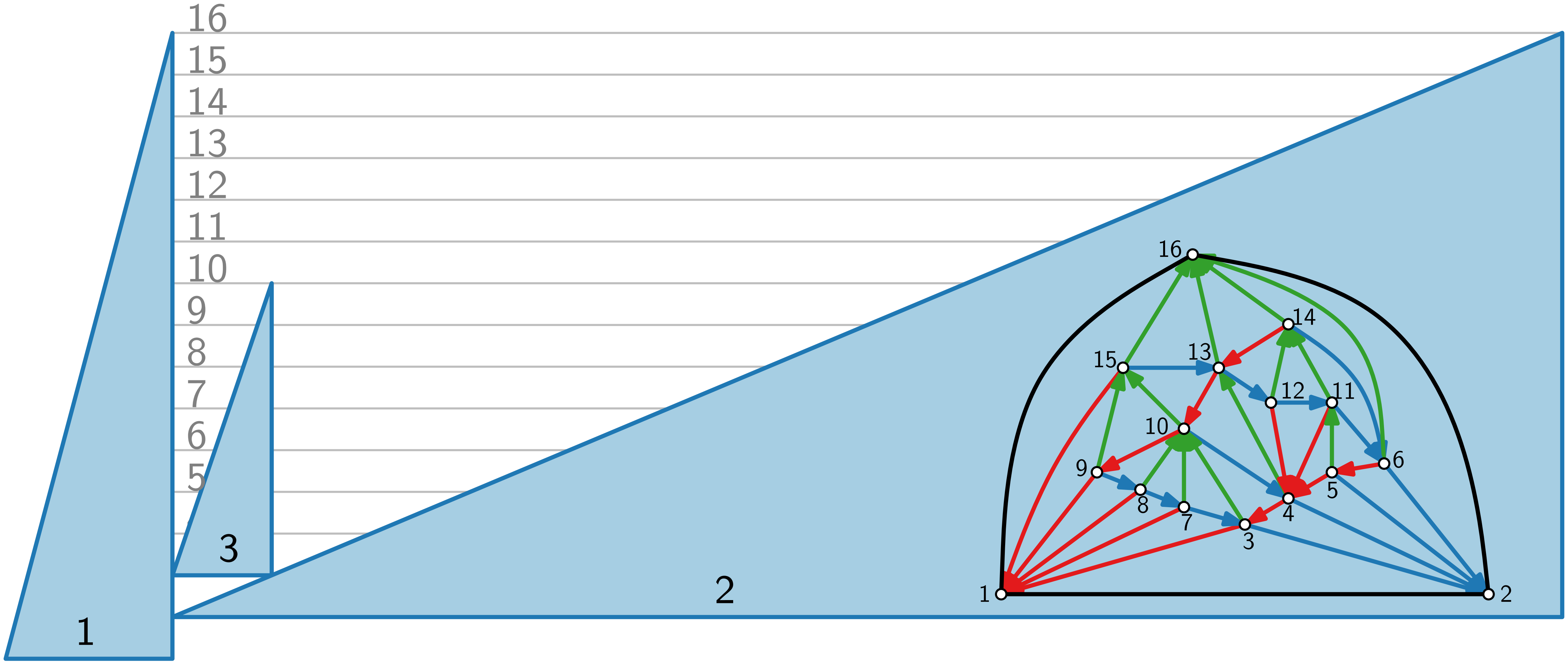

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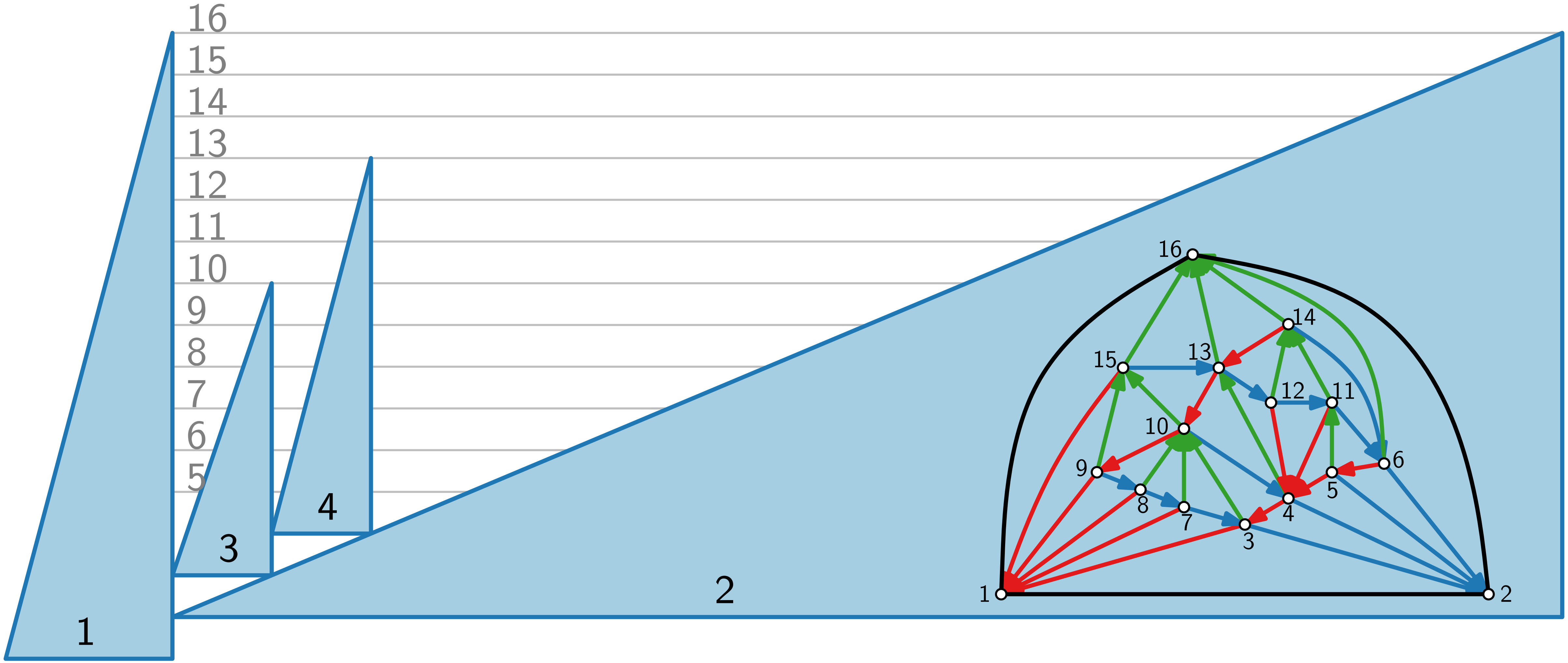

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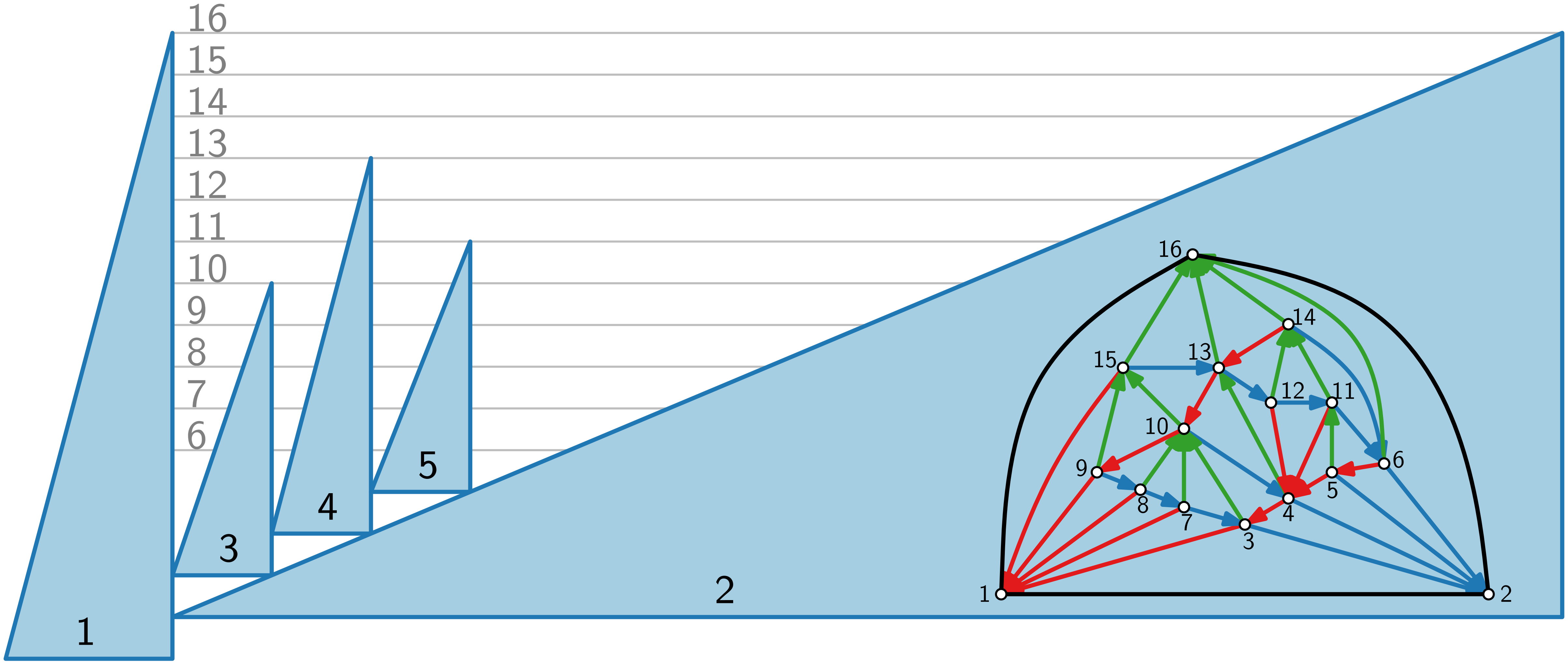

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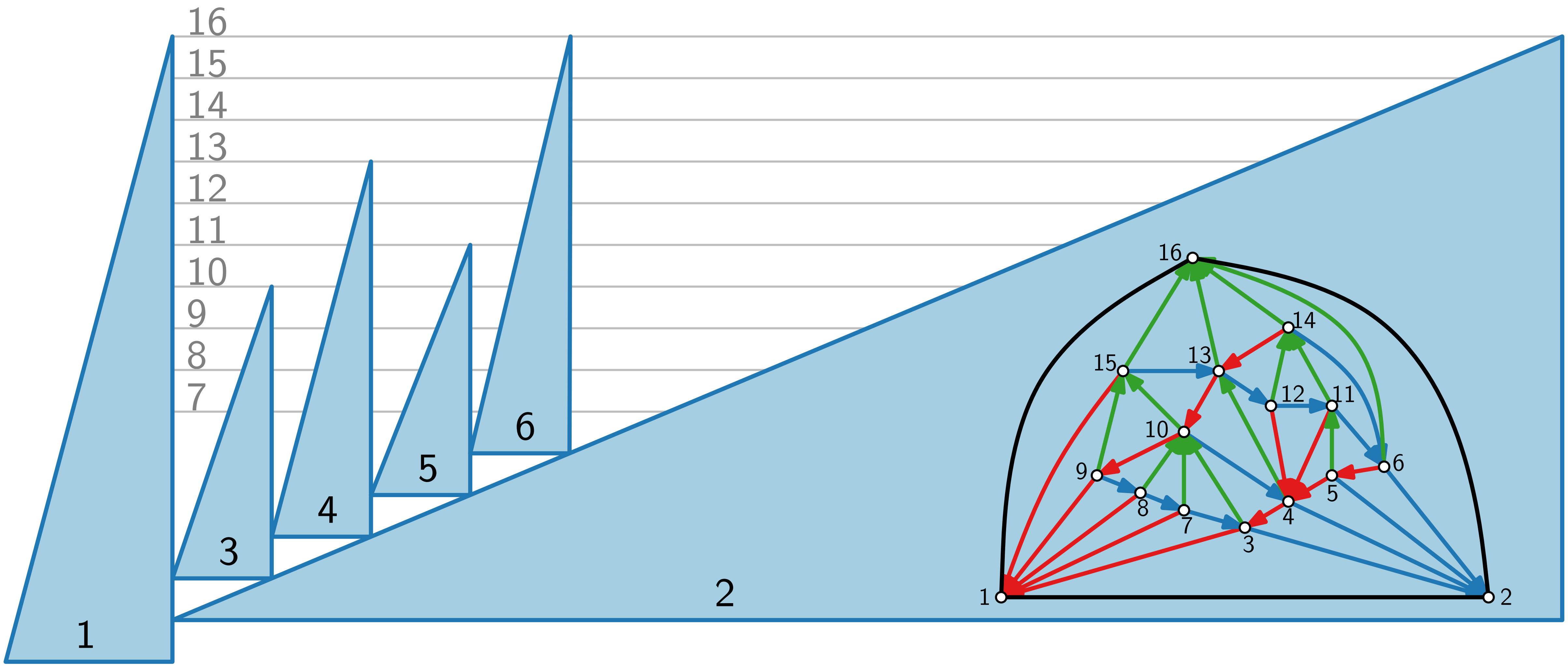

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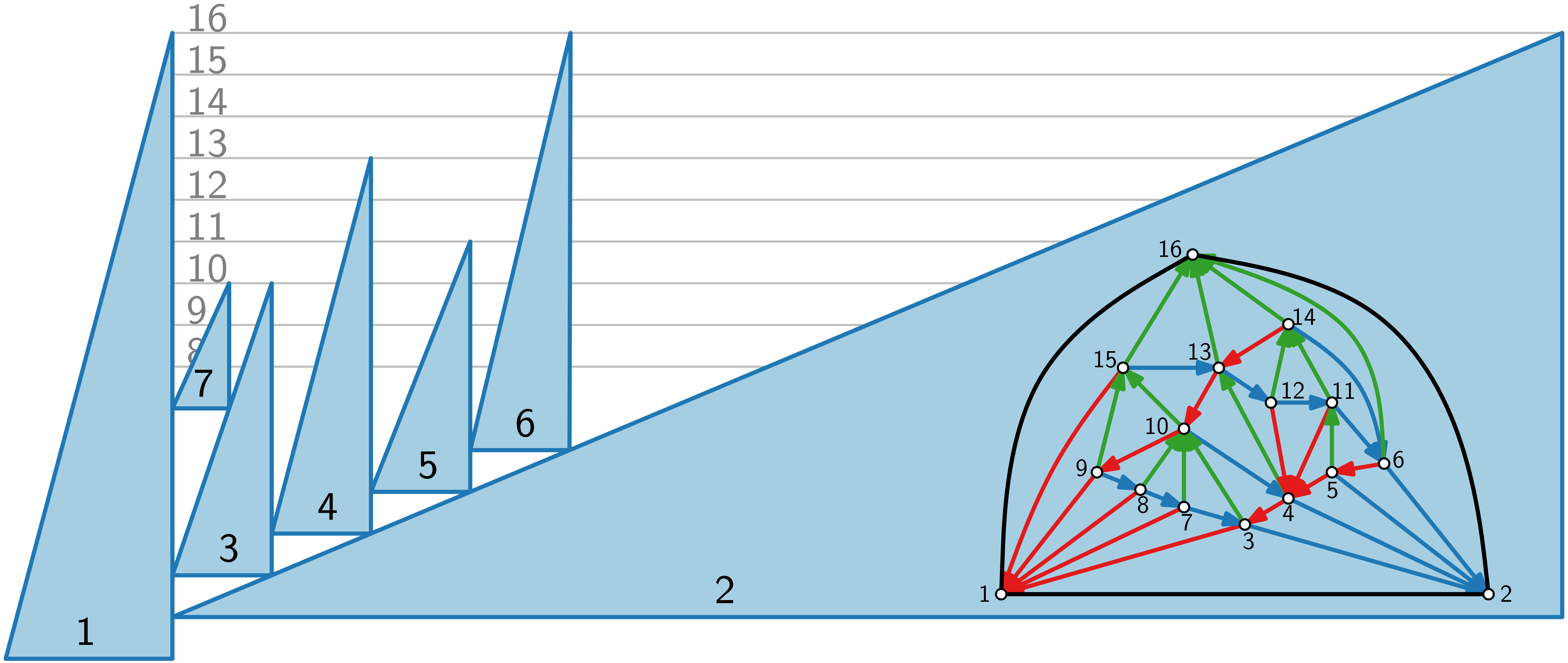

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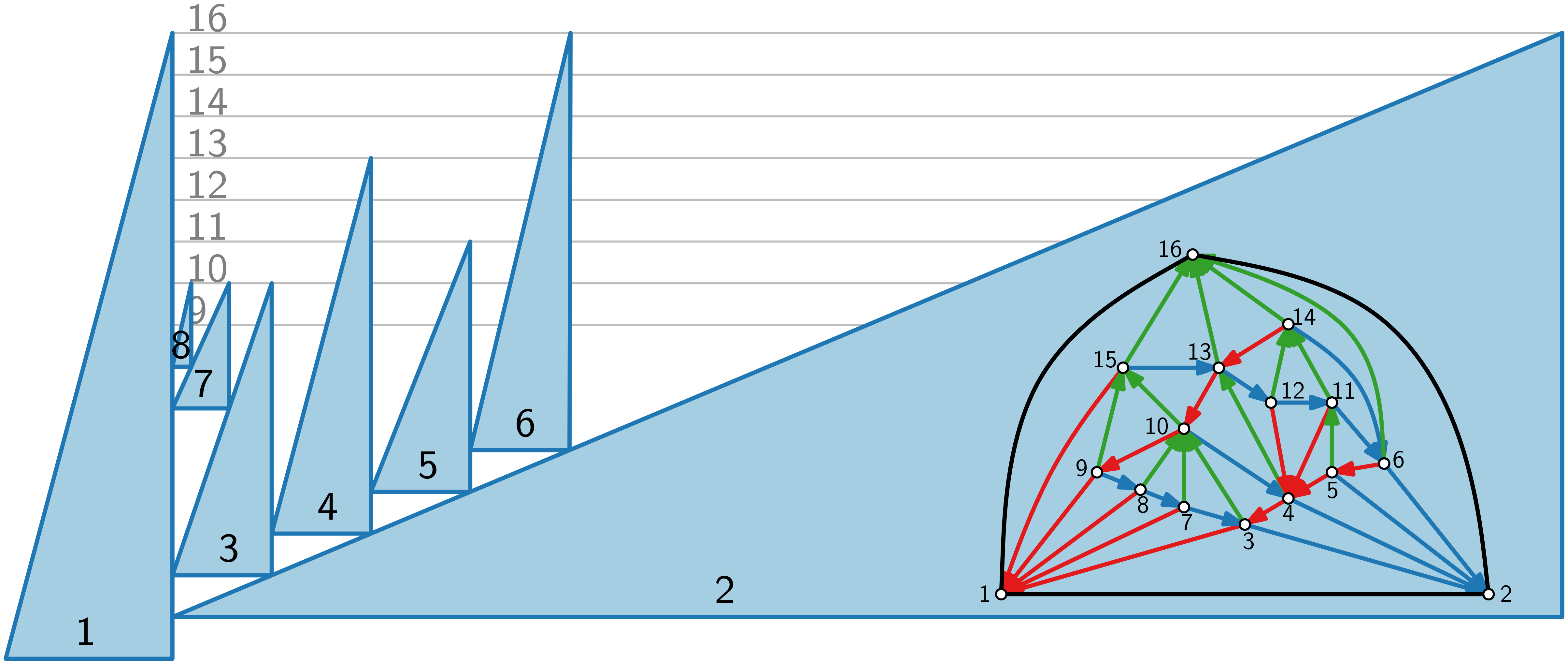

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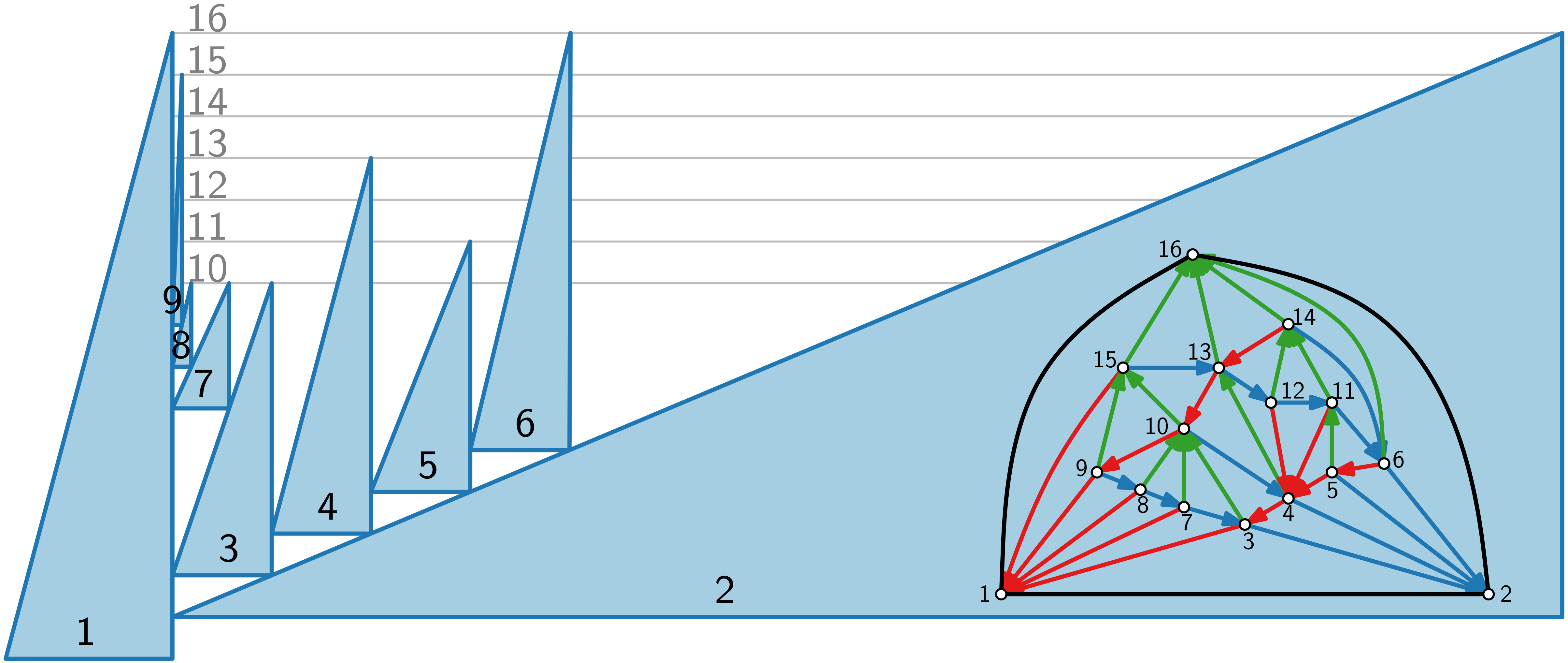
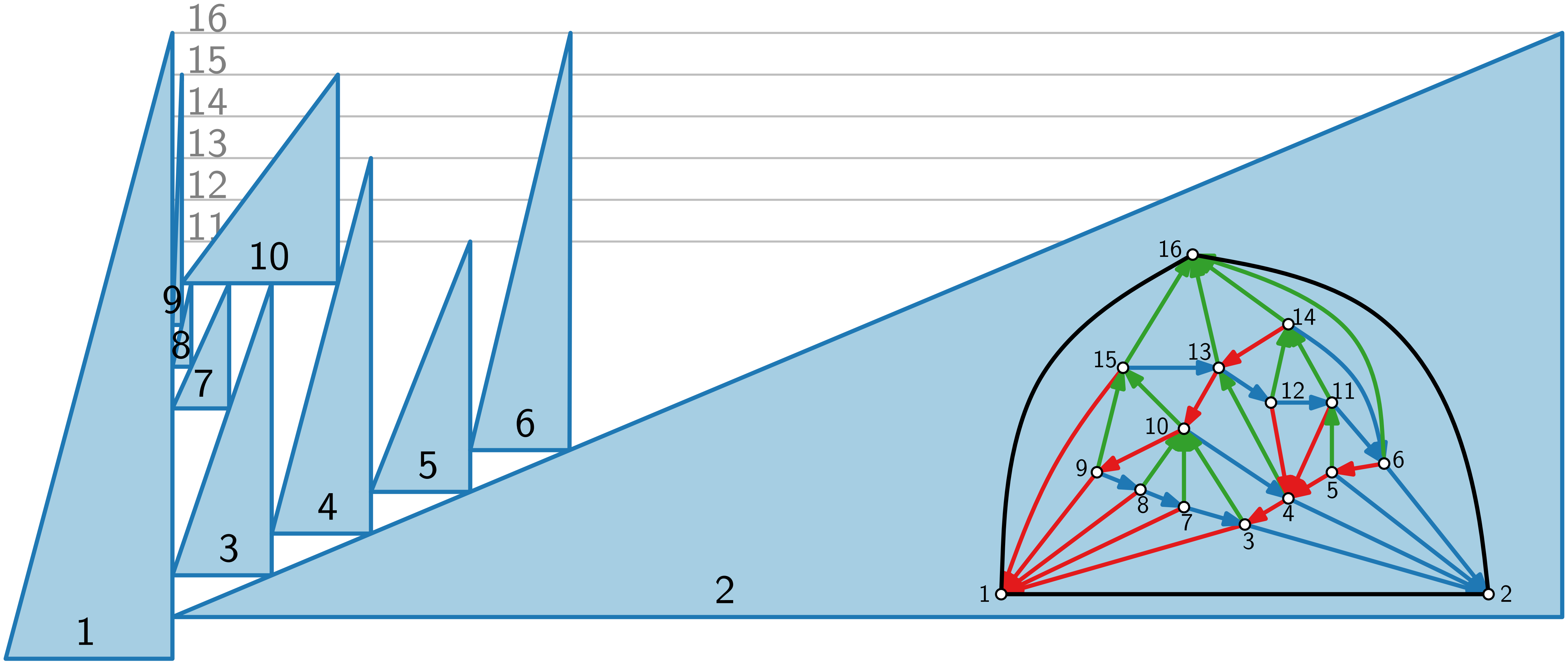


Triangle Contact Representation Example



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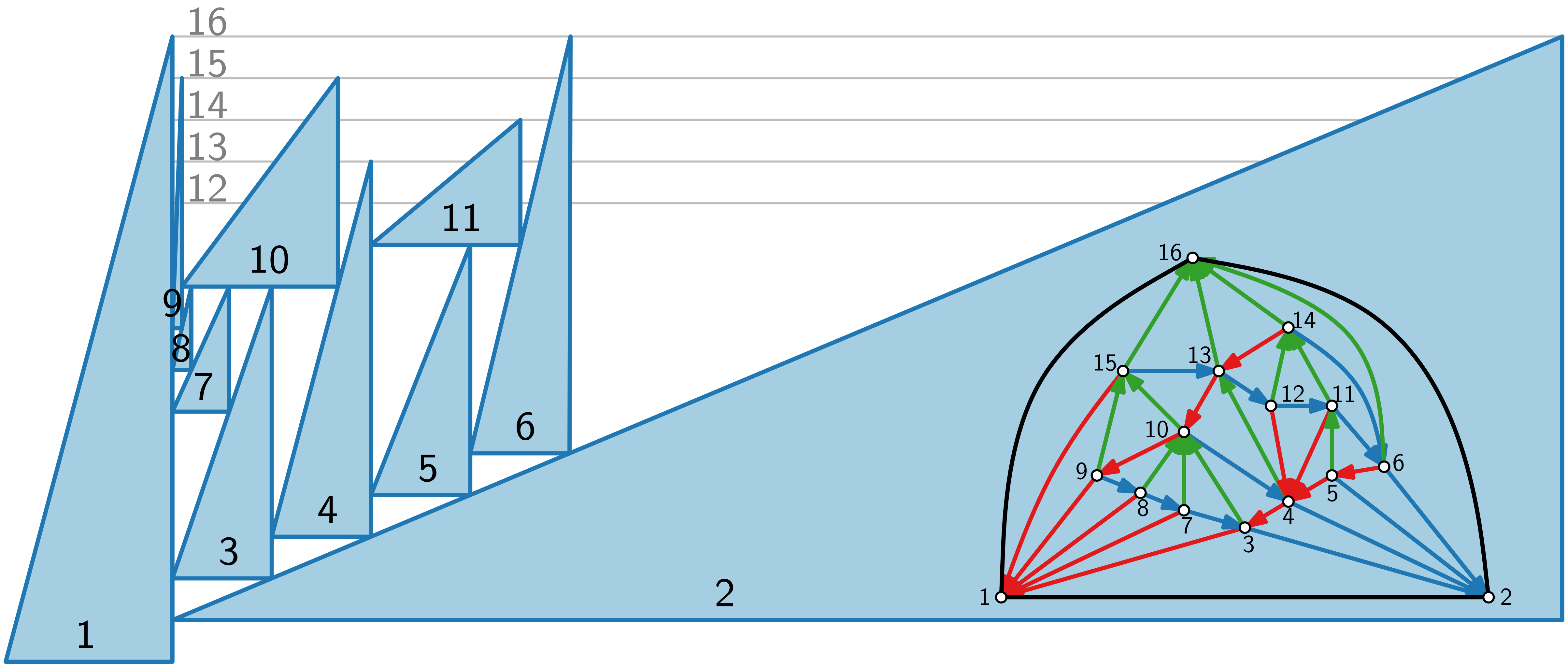

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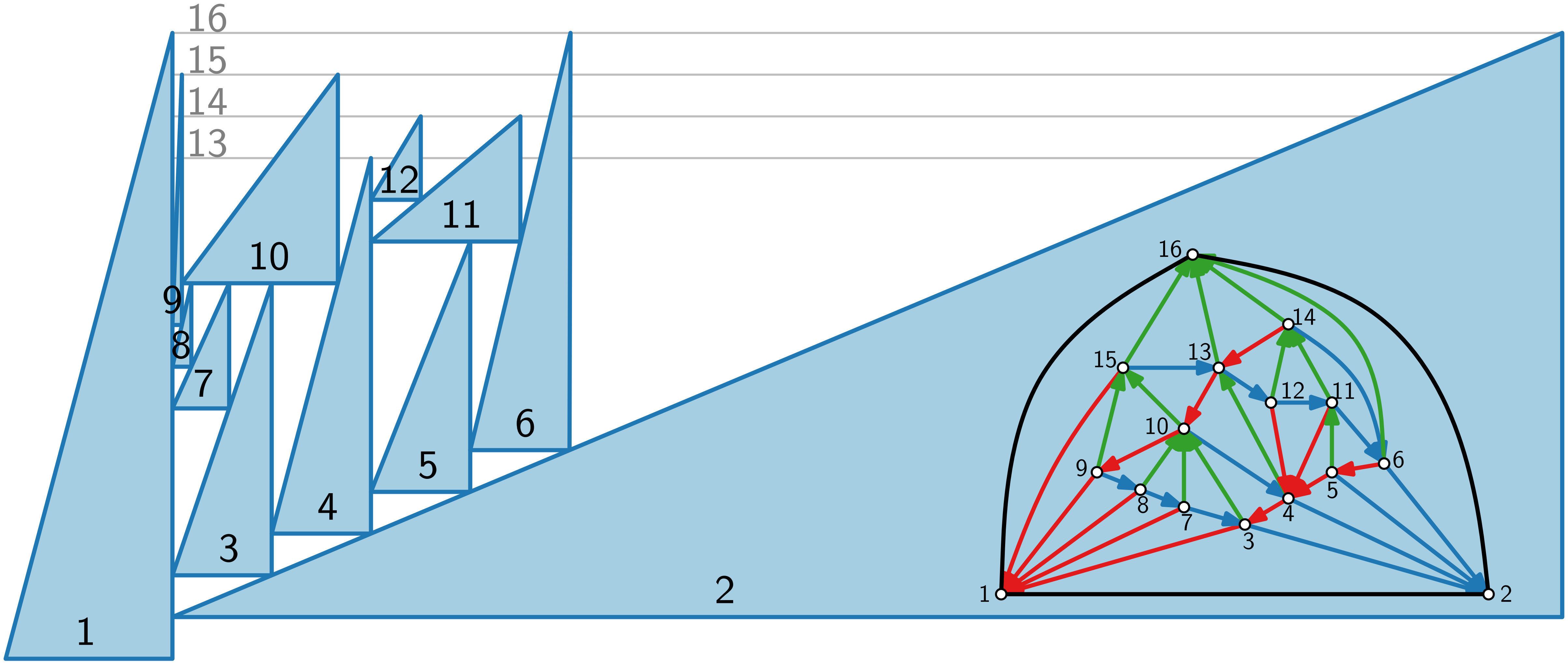

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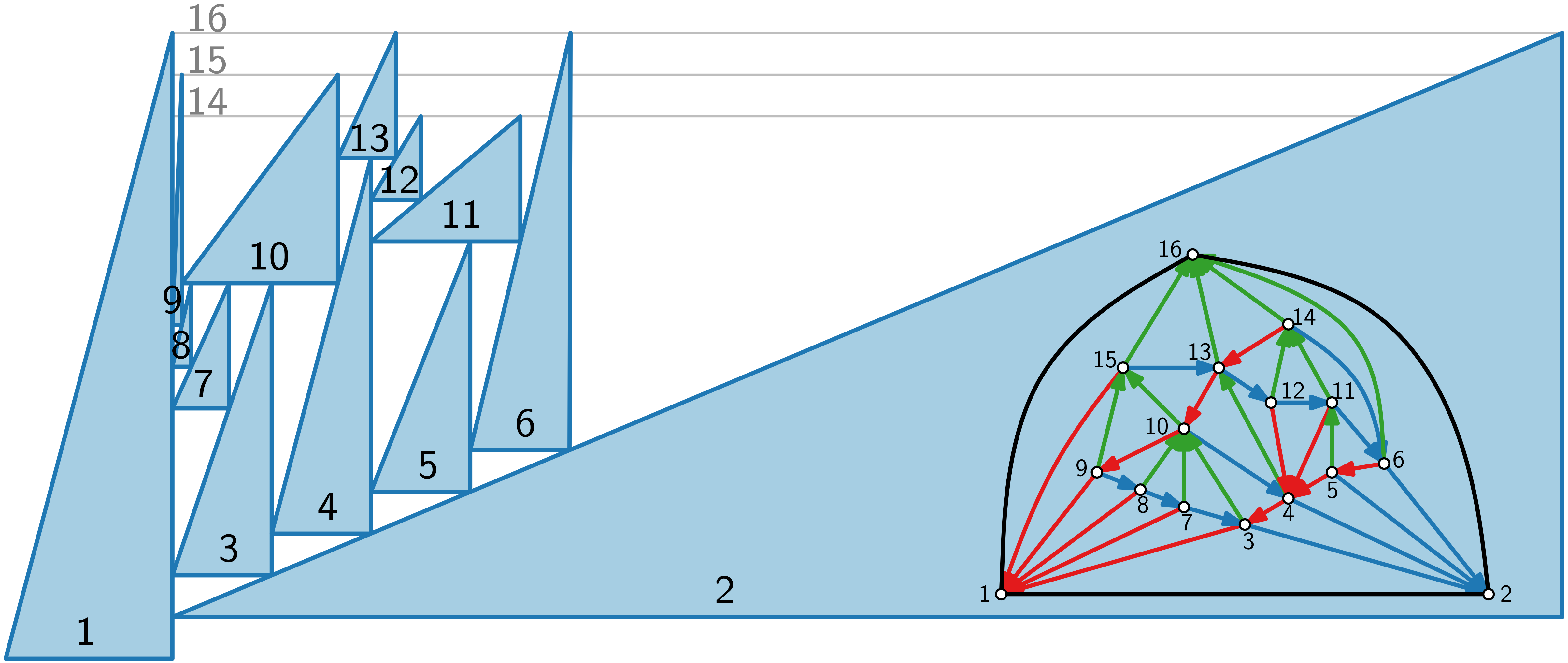

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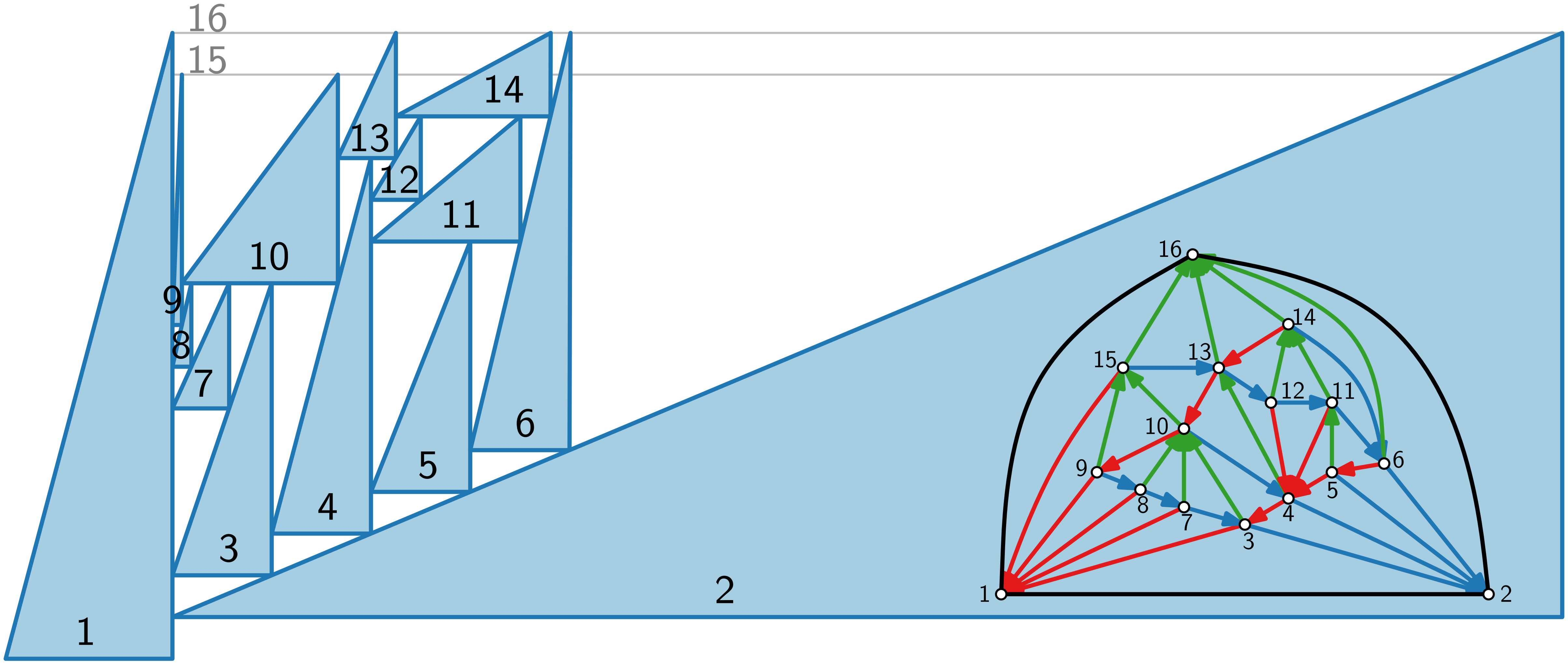

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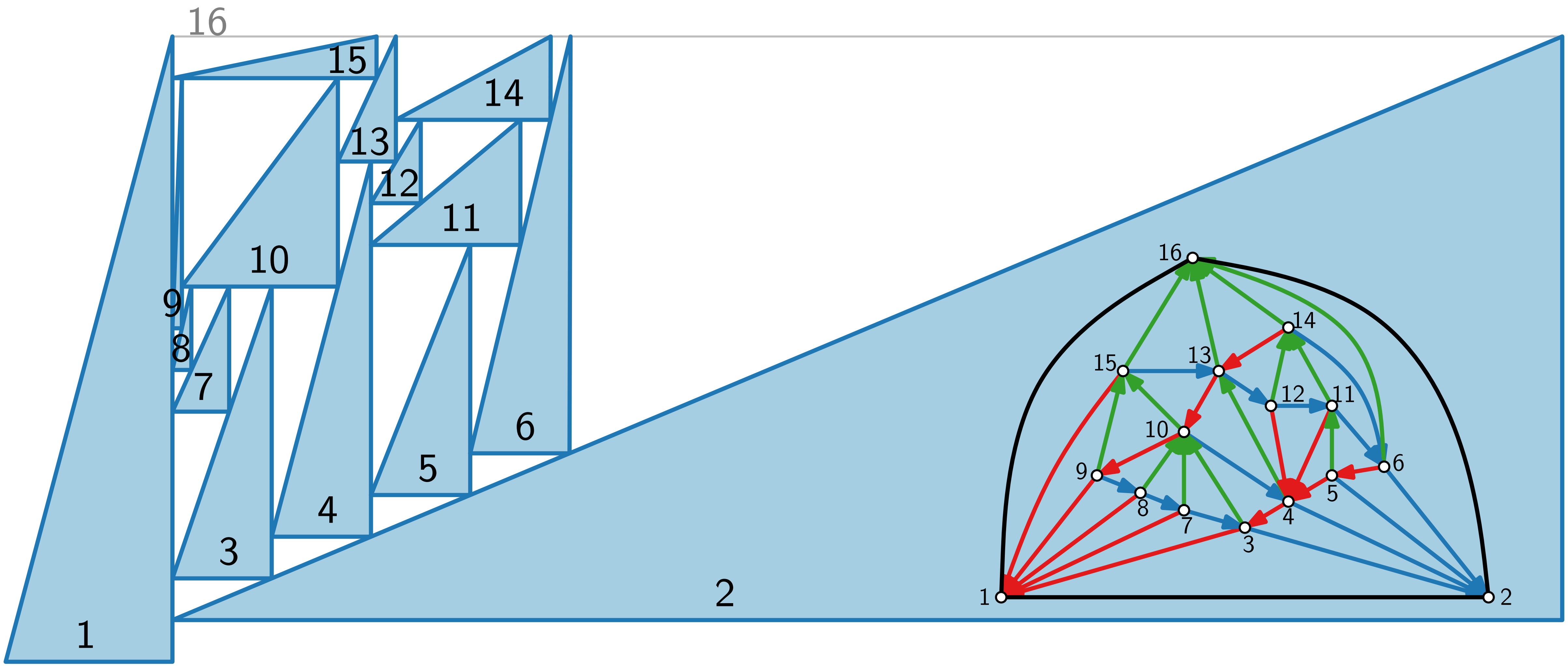

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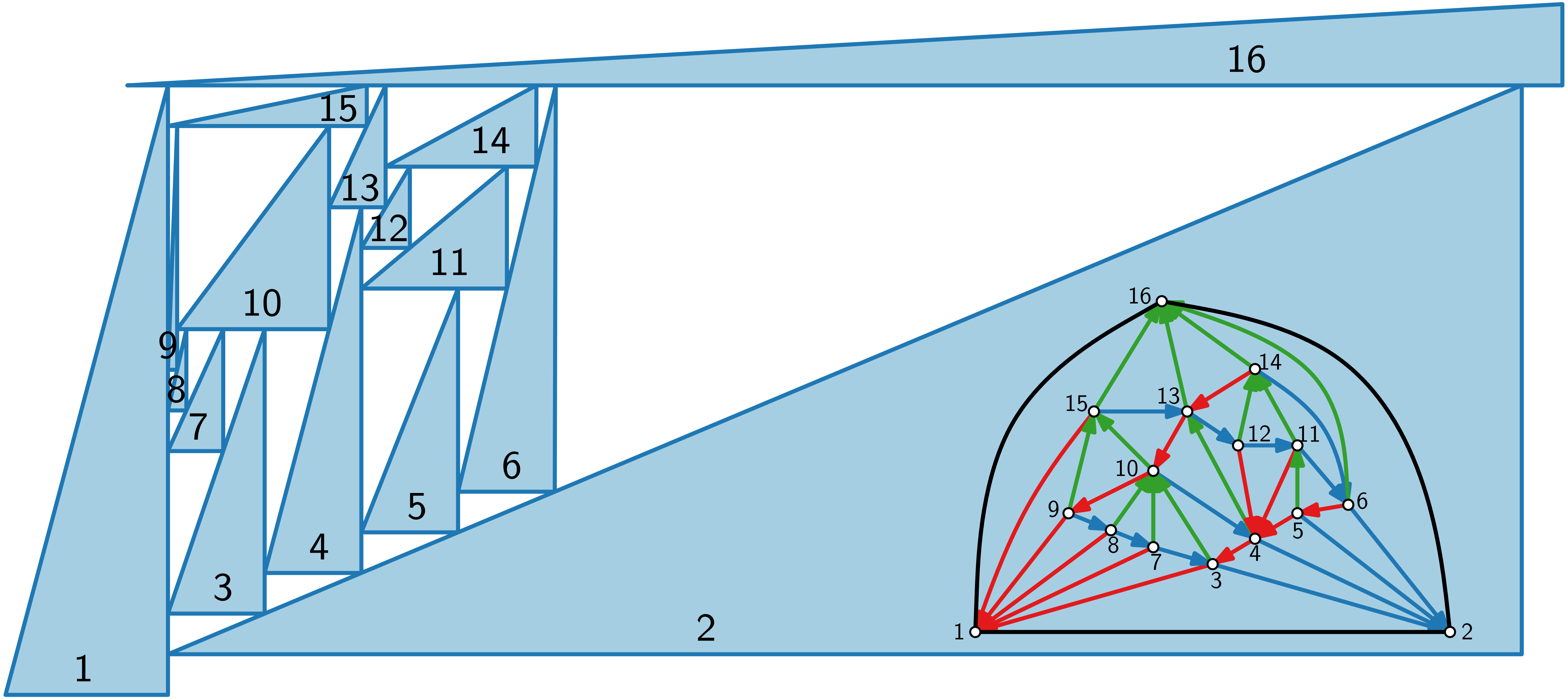
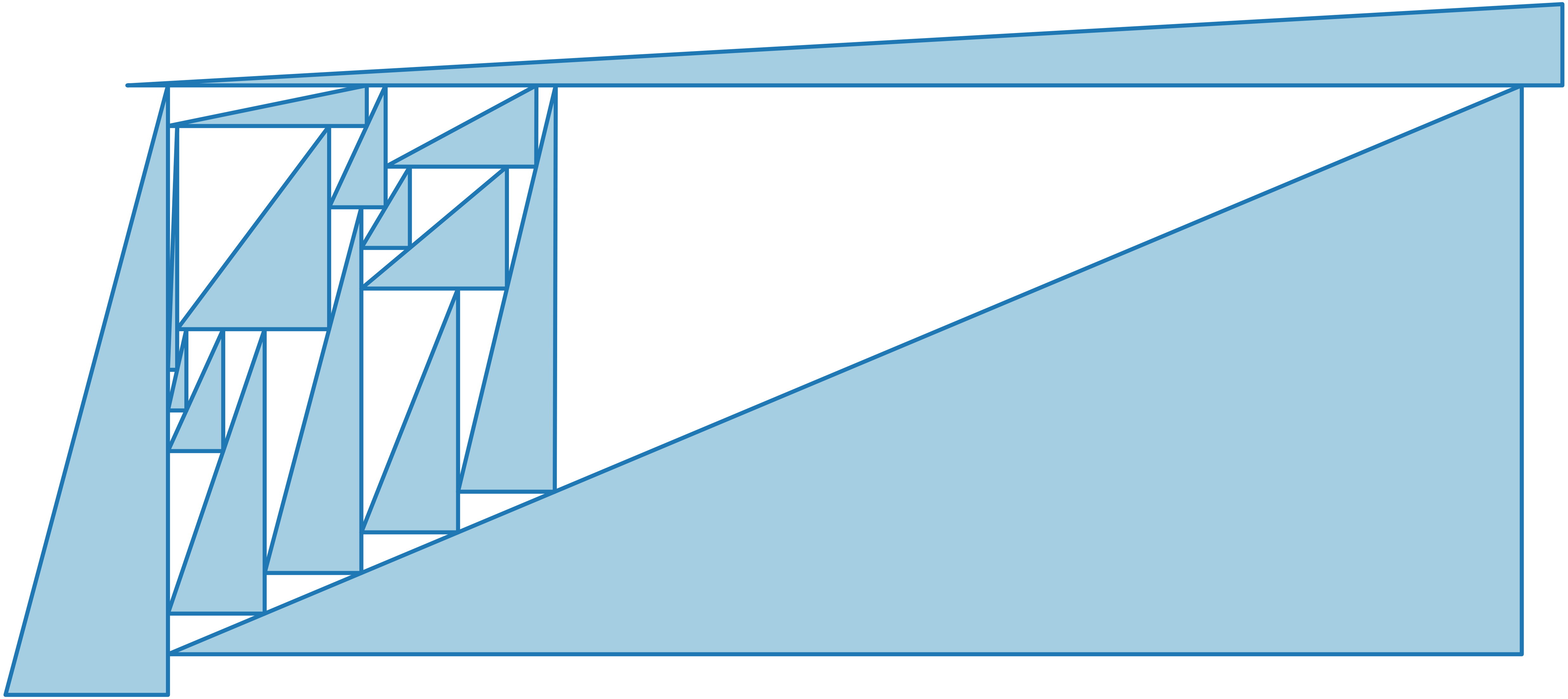


T-shape Contact Representation



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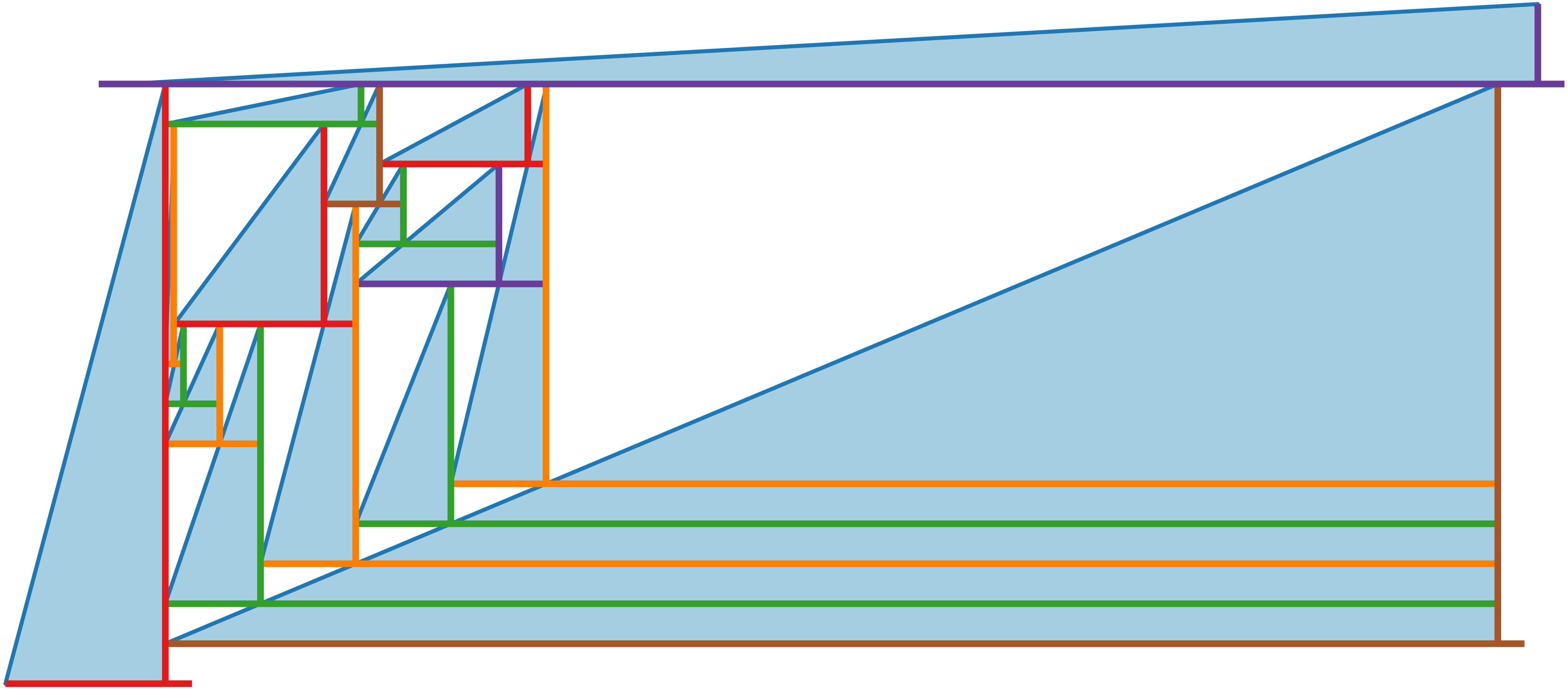

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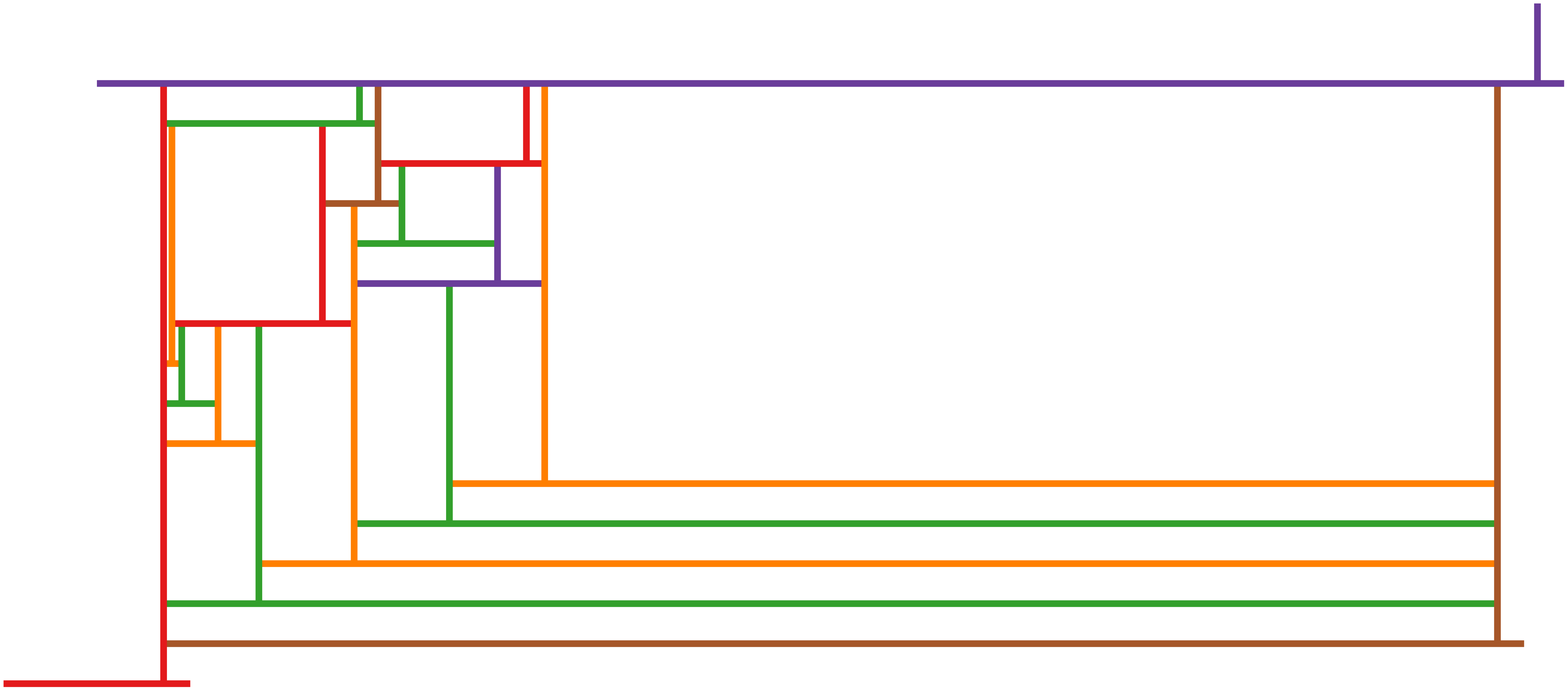

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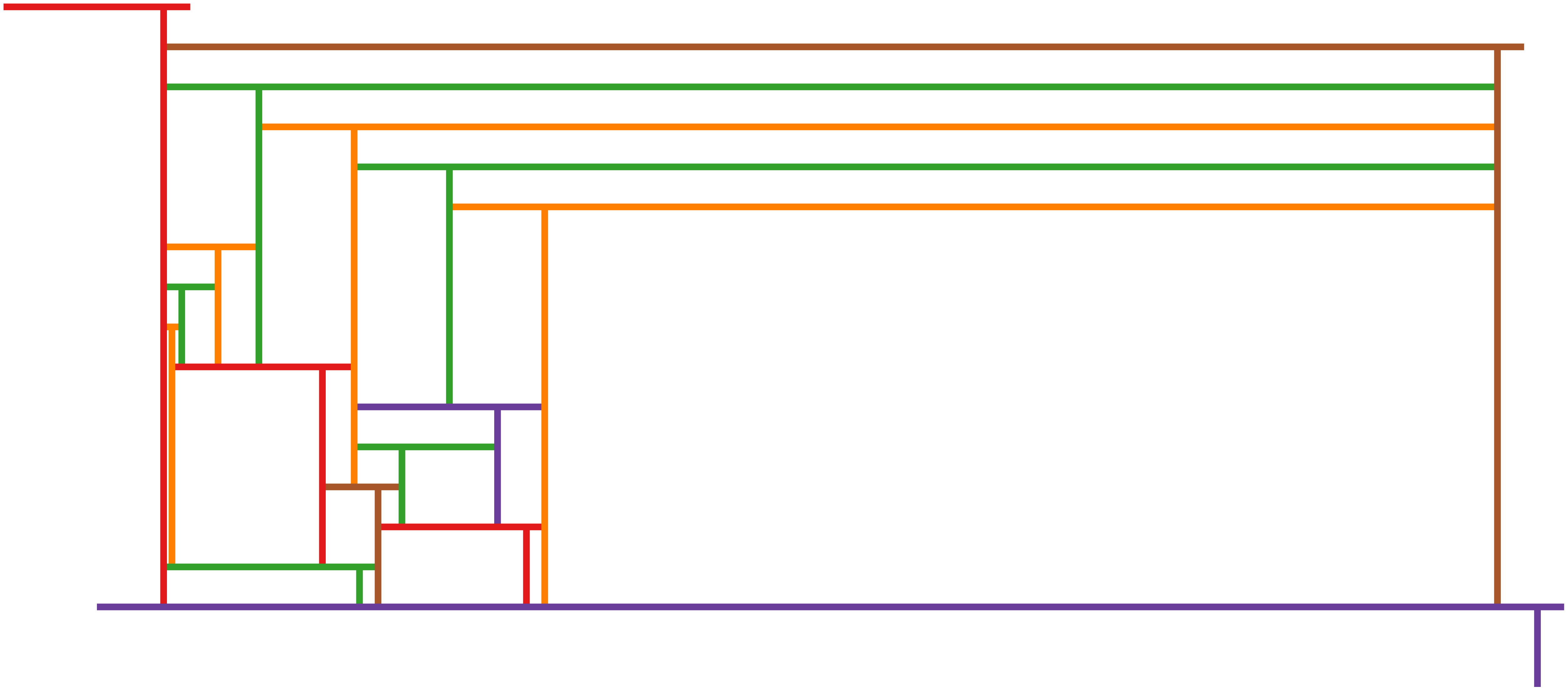
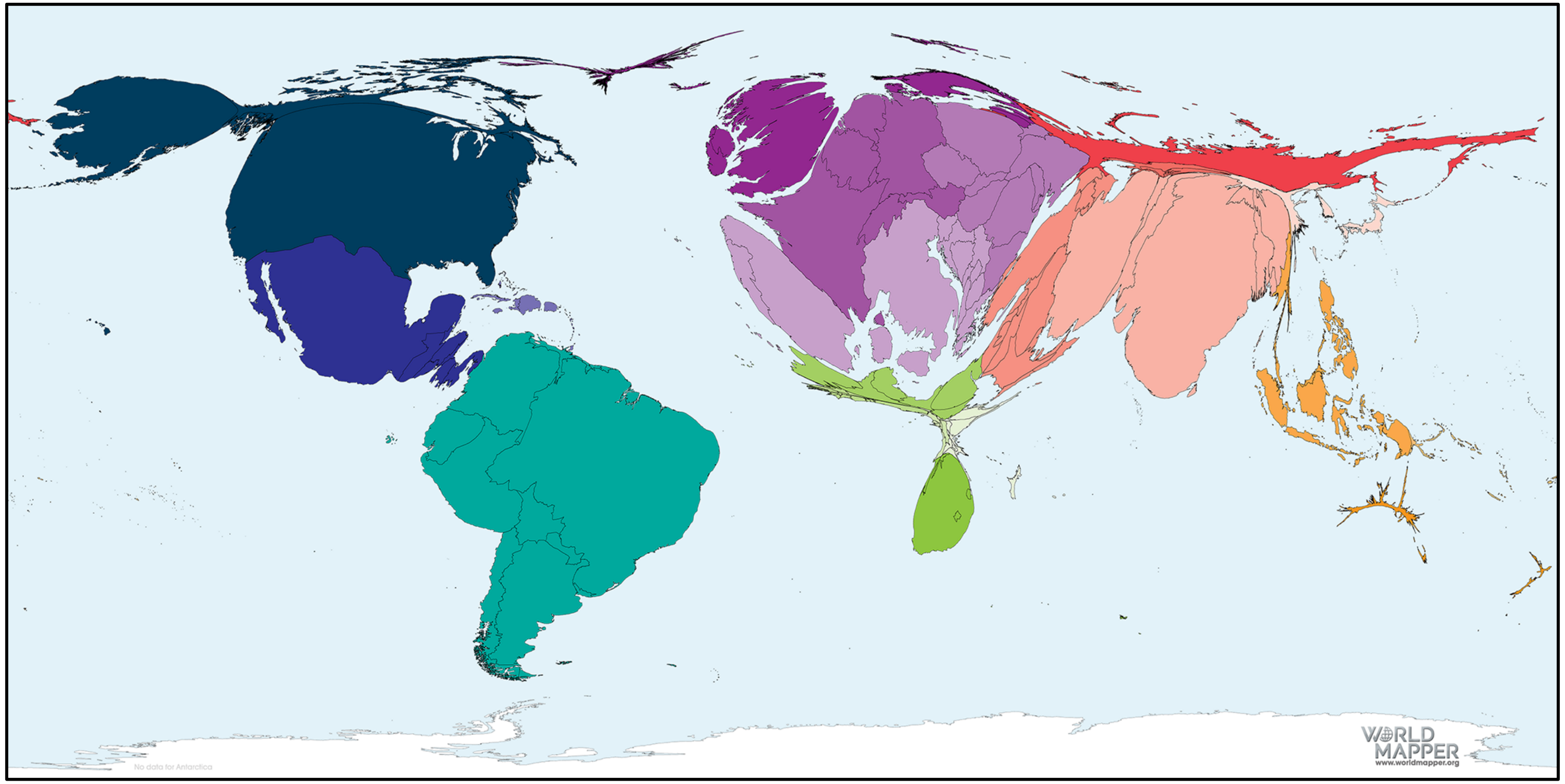


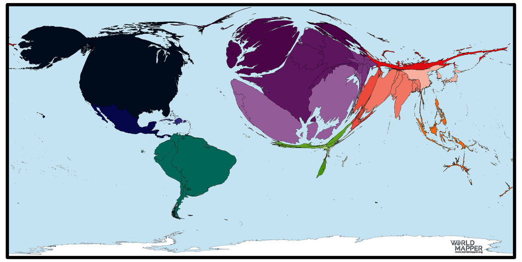
Cartograms

Cartograms



COVID19 reported deaths (January–December 2020)

Cartograms



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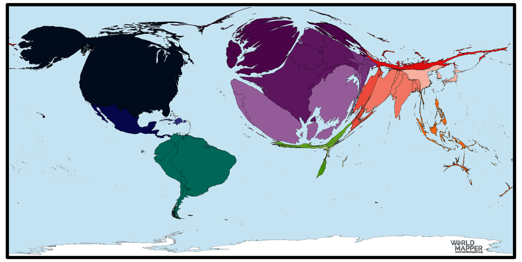

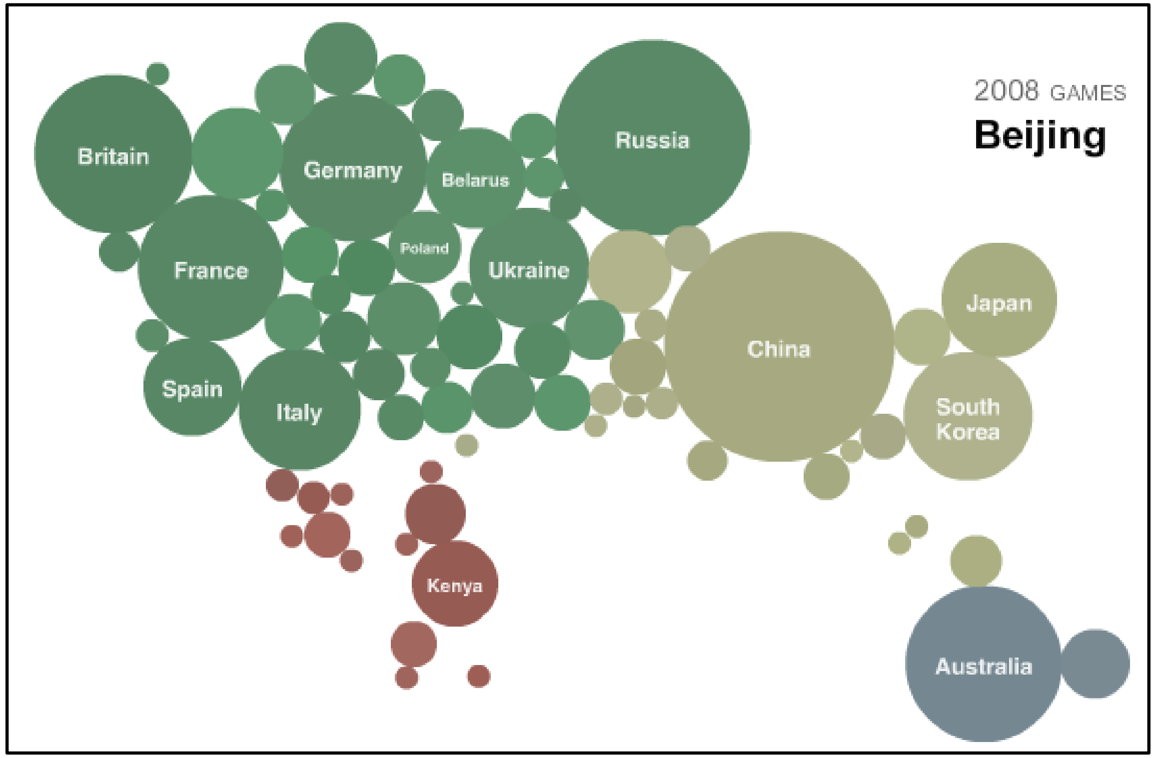
2008 GAMES
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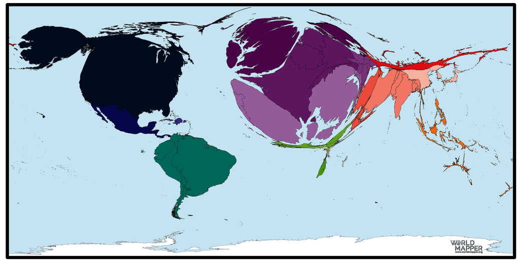

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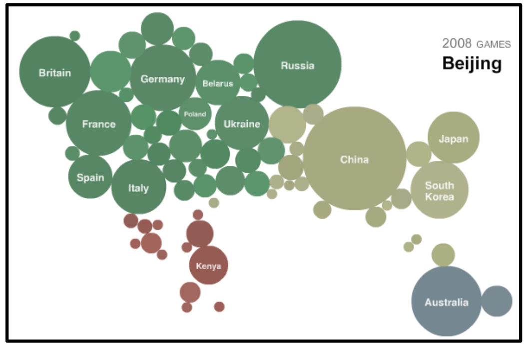

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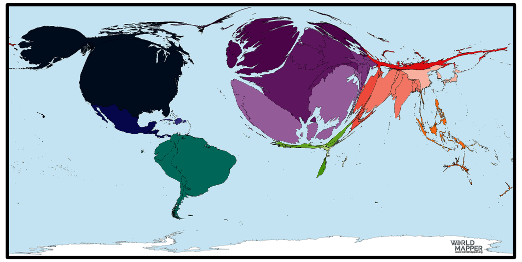

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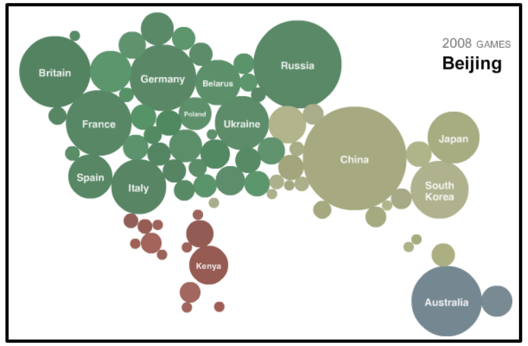

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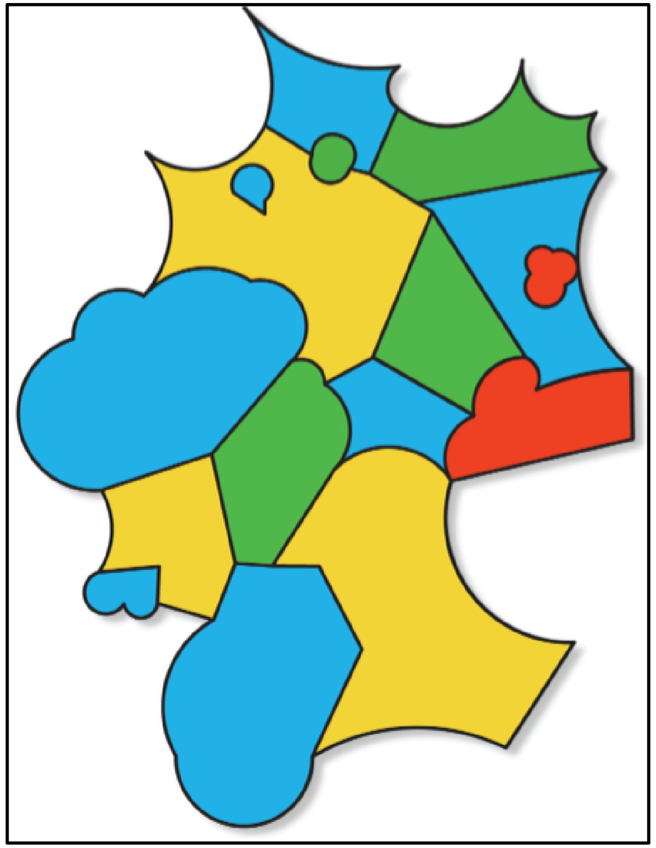

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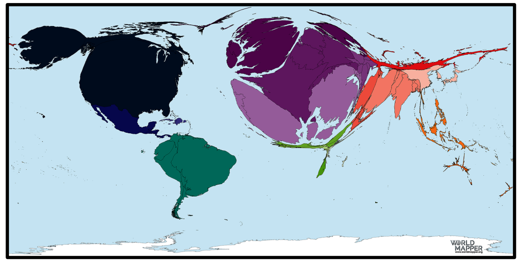
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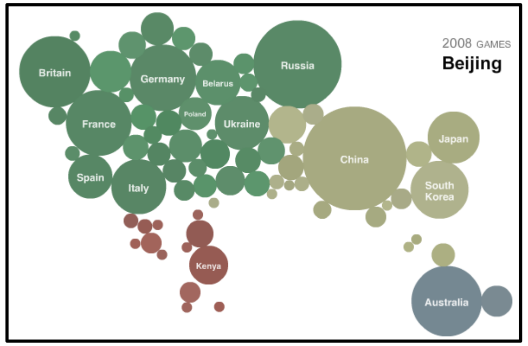
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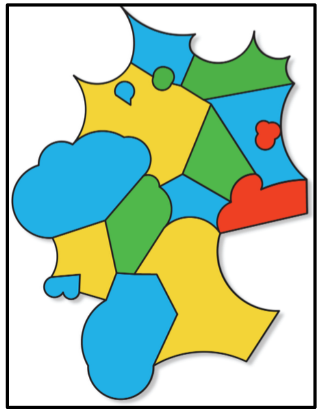

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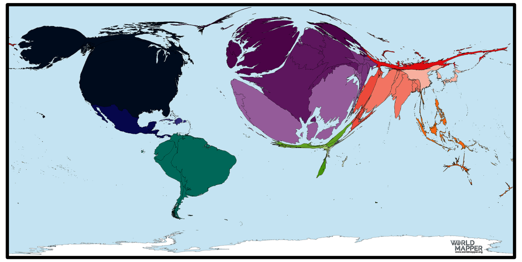

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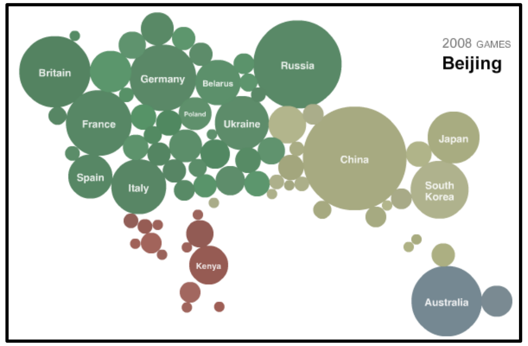

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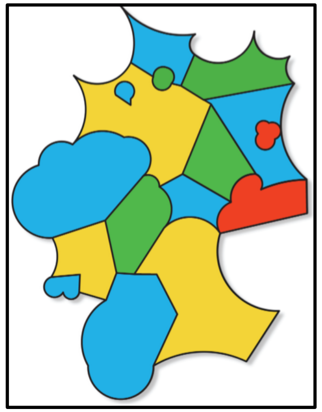

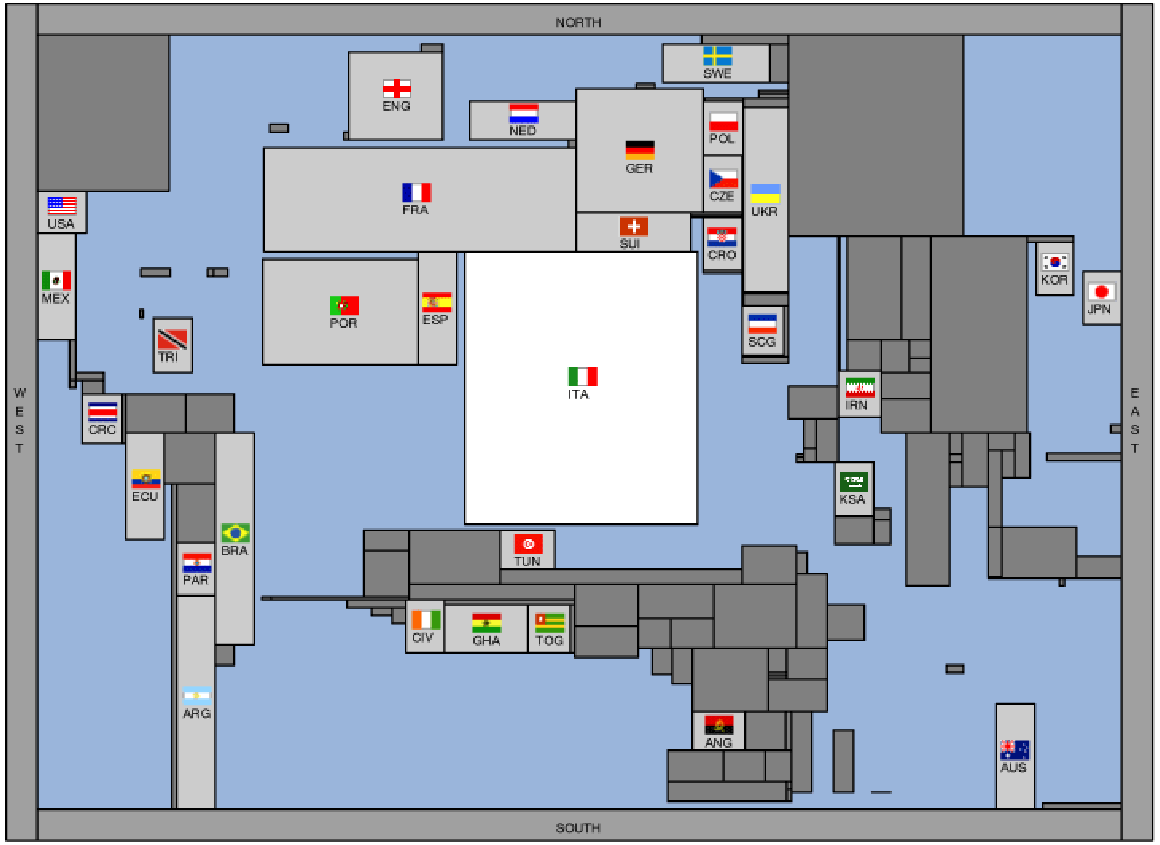

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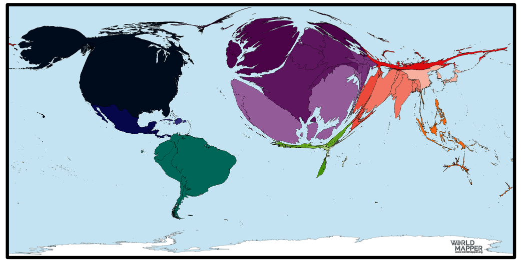

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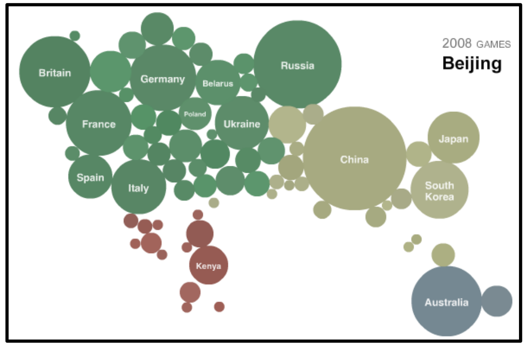

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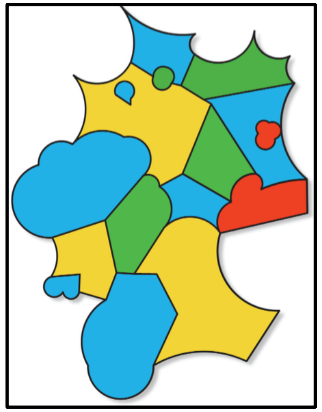

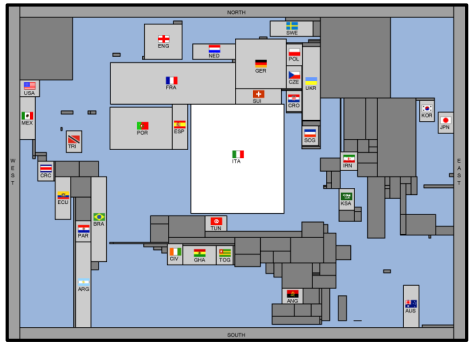

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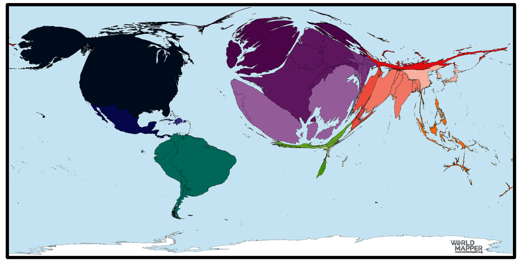

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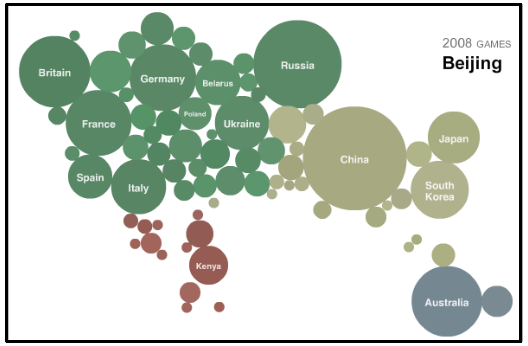

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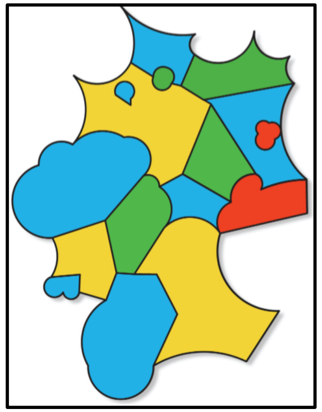

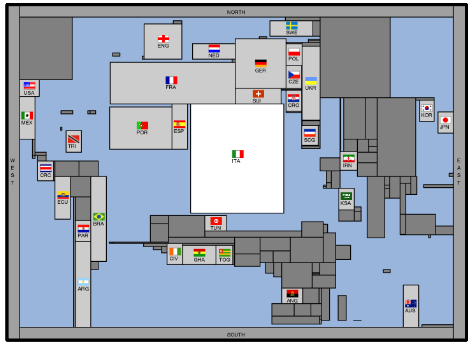

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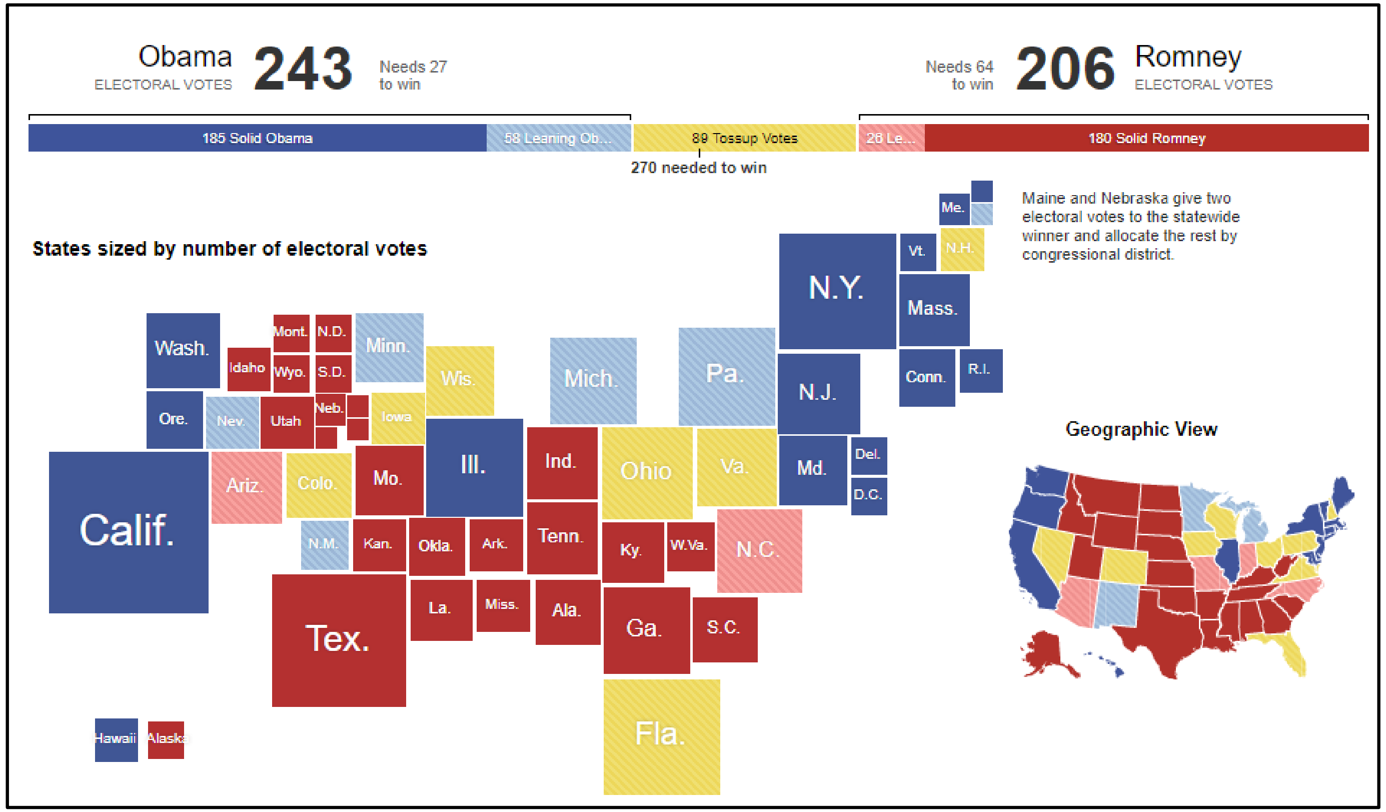

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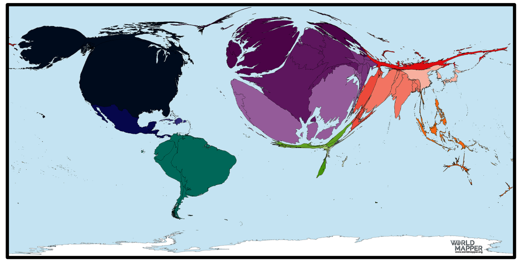

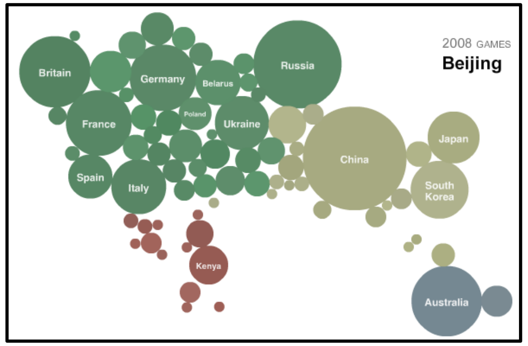
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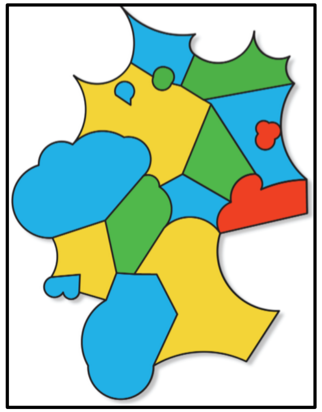

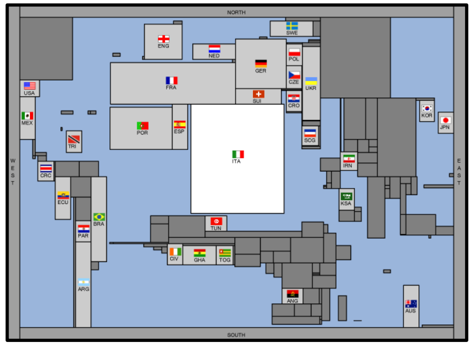

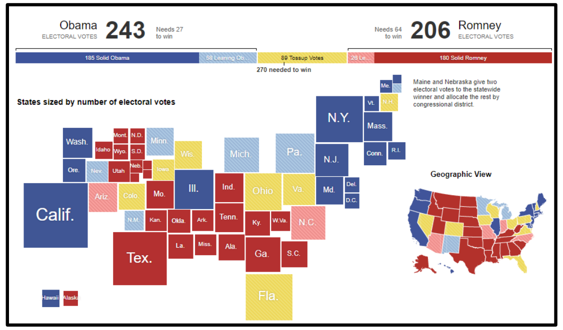
Obama 243
206 Romney
States sized by number of electoral votes
Geographic View
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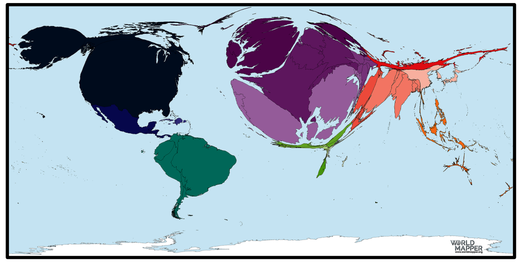
Cartograms



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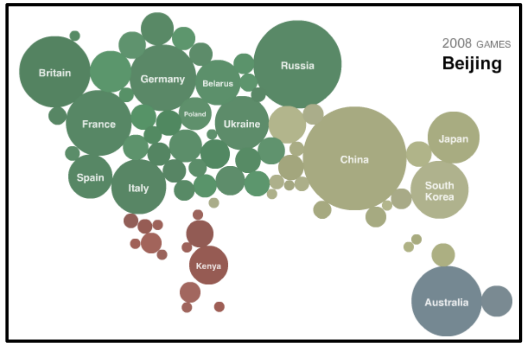

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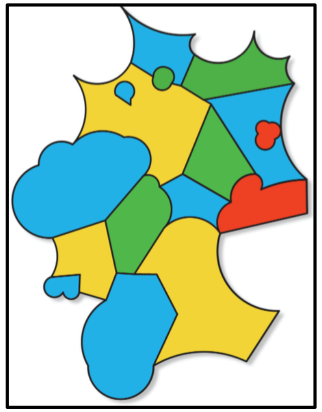

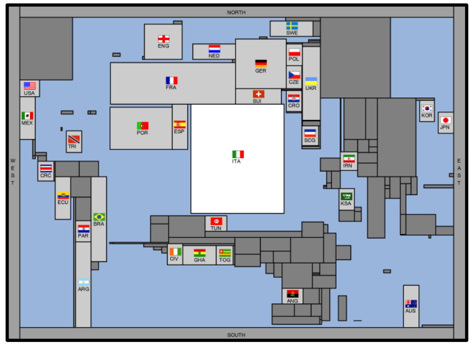

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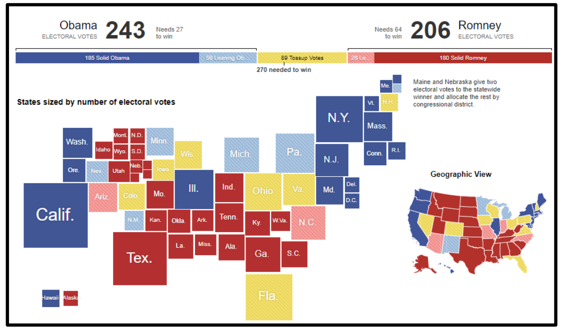

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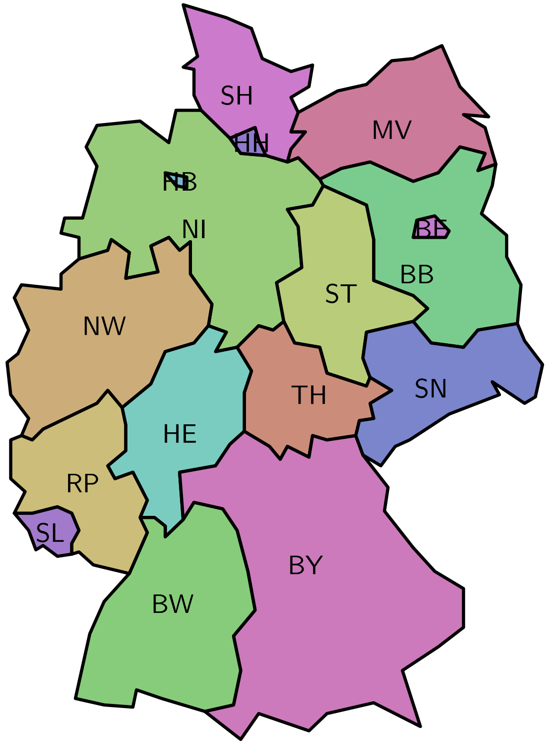

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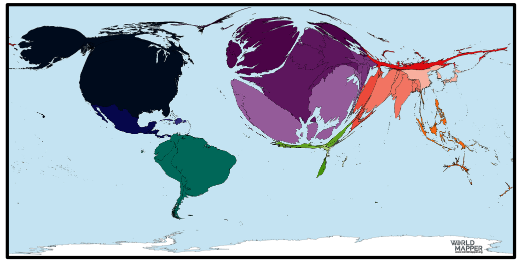

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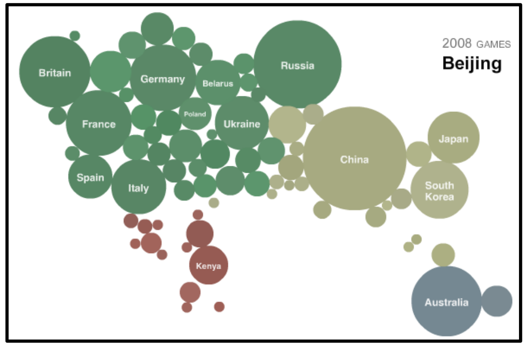

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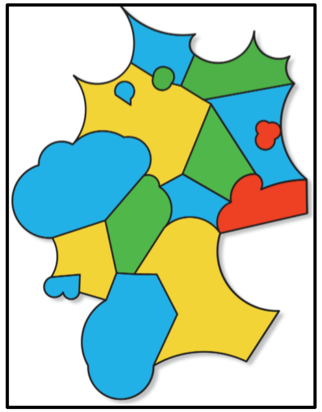

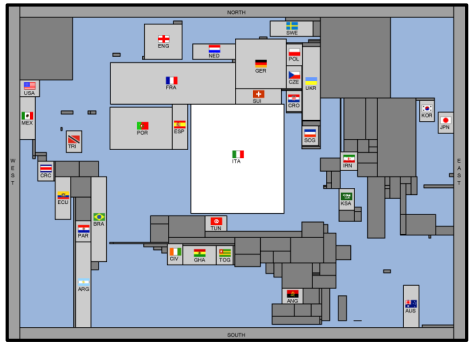

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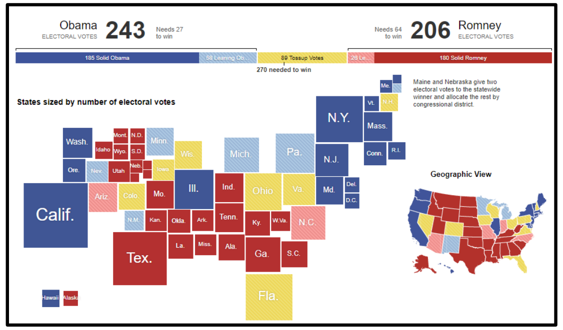

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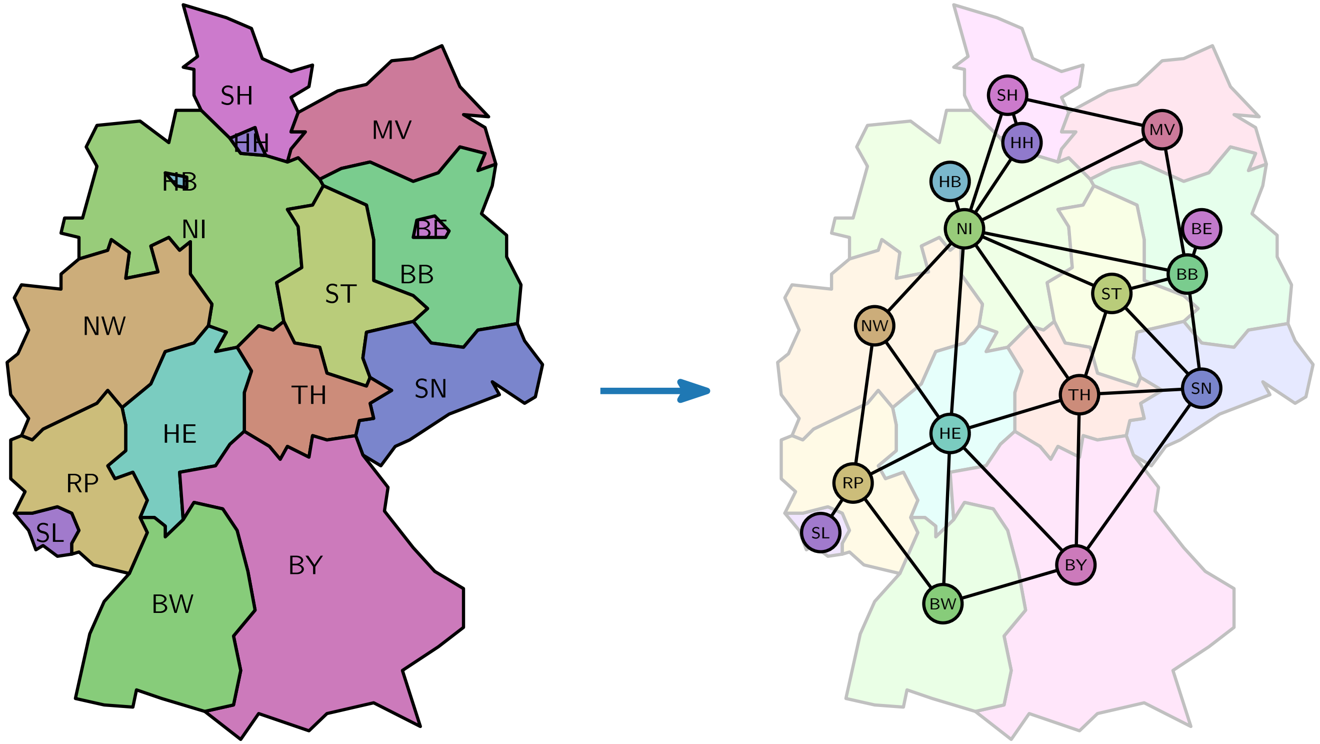

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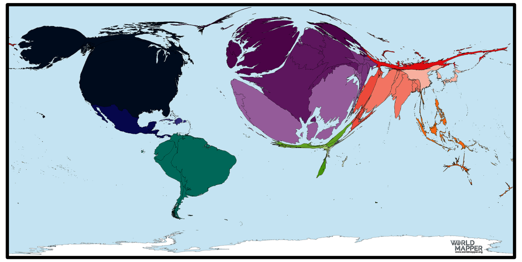

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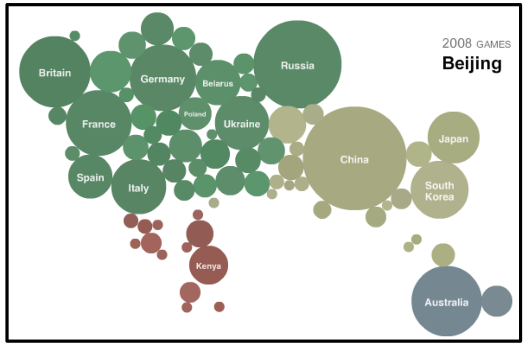

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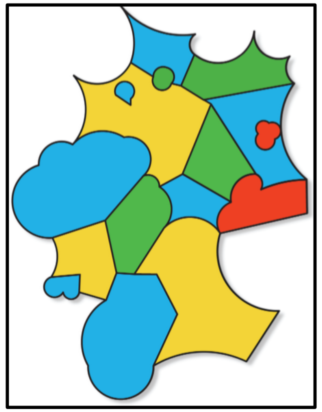

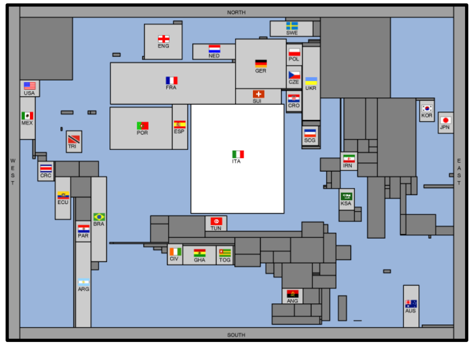

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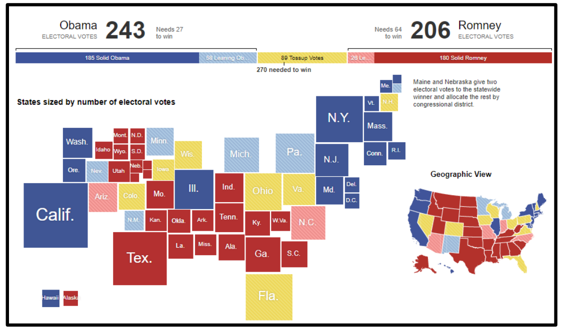

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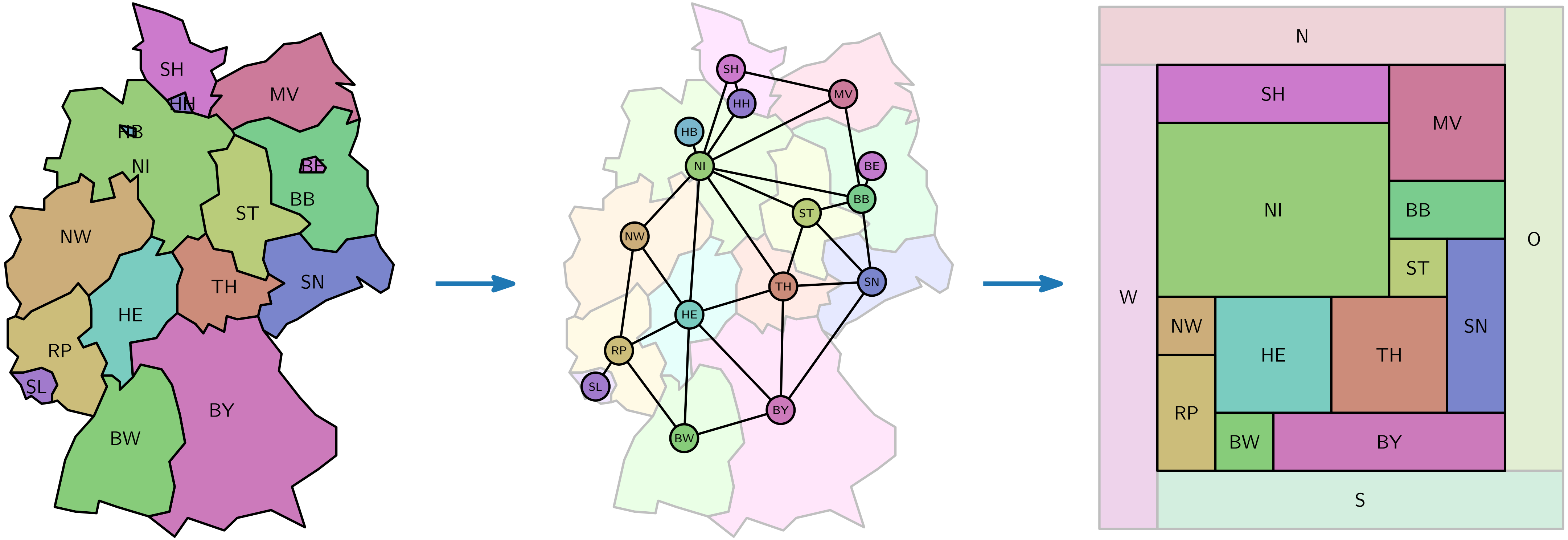

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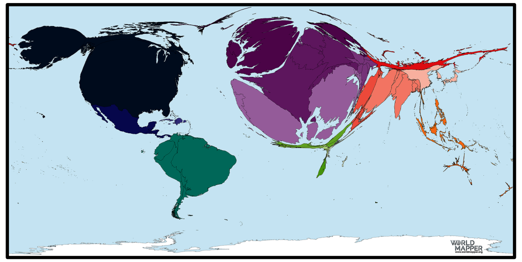

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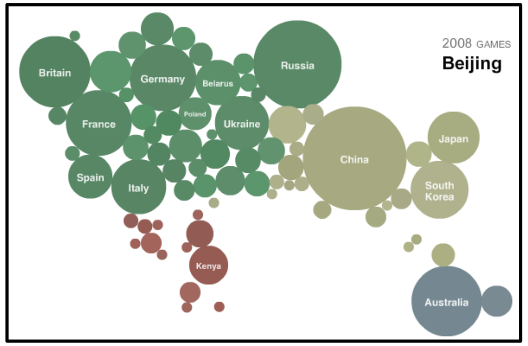

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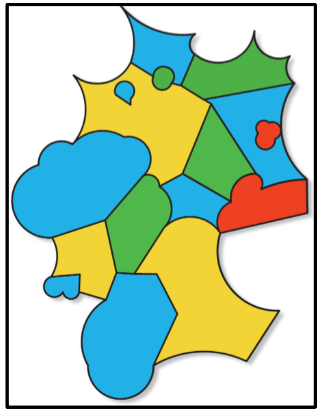

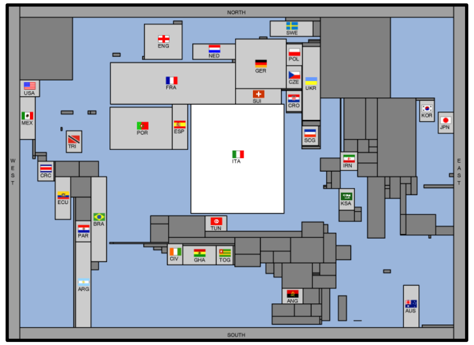

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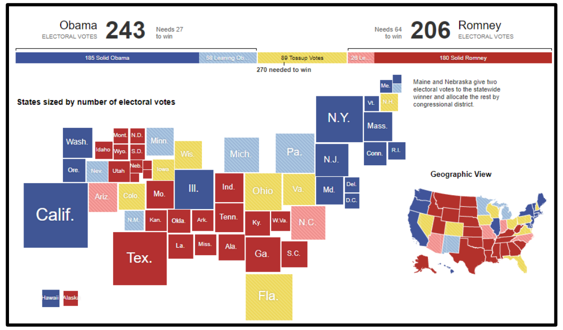

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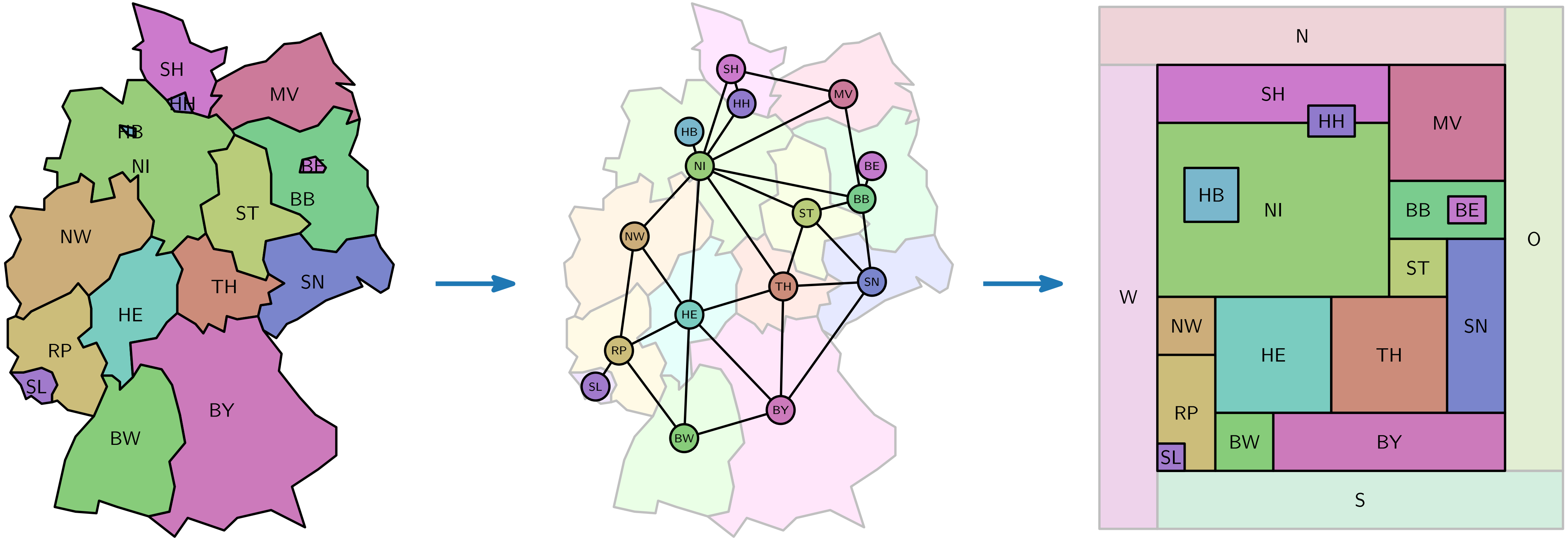
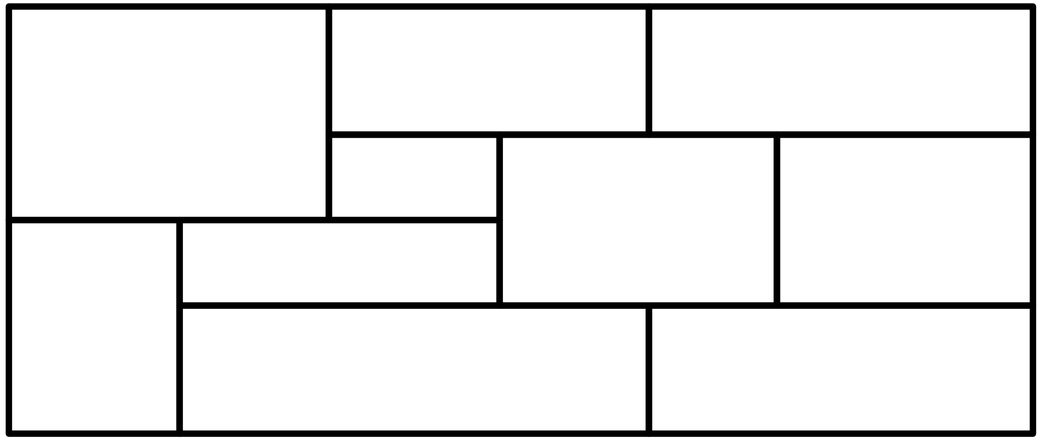
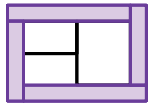


Rectangular Dual

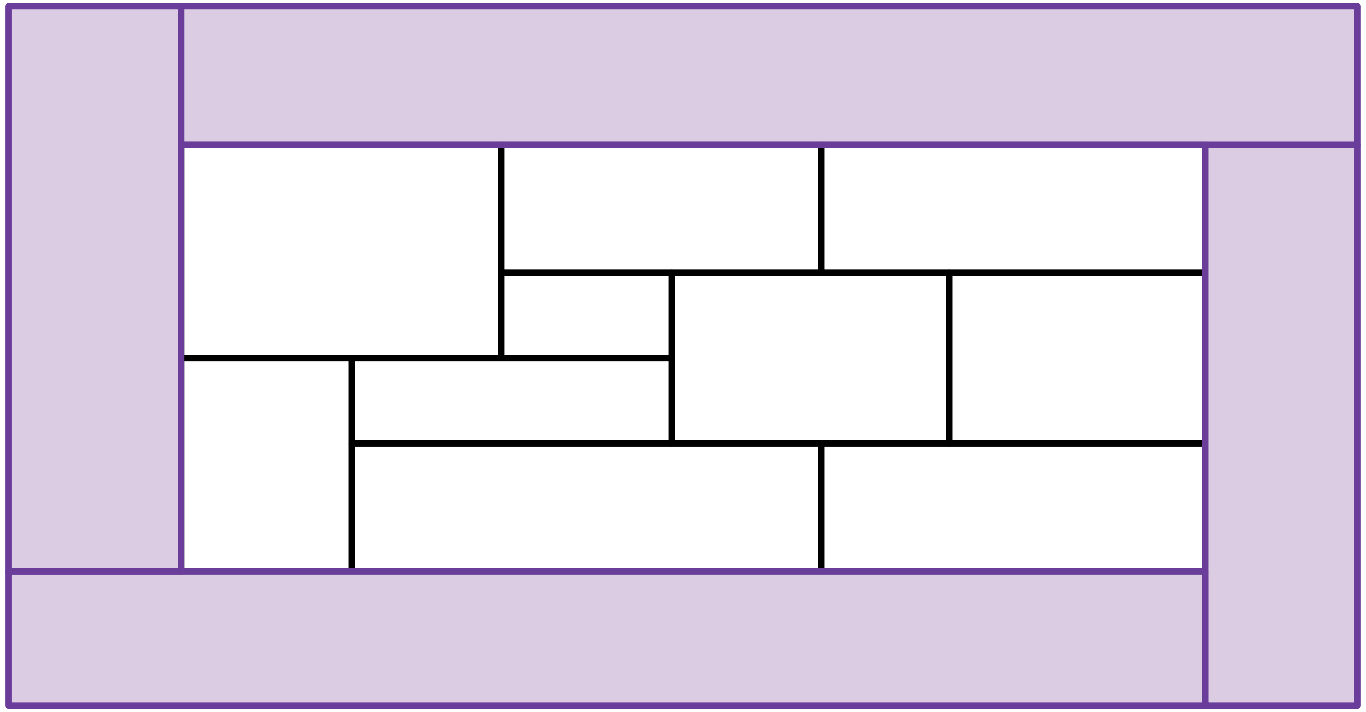
Rectangular Dual



Rectangular Dual



Rectangular Dual $\mathcal{R}$



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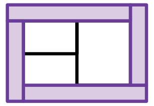
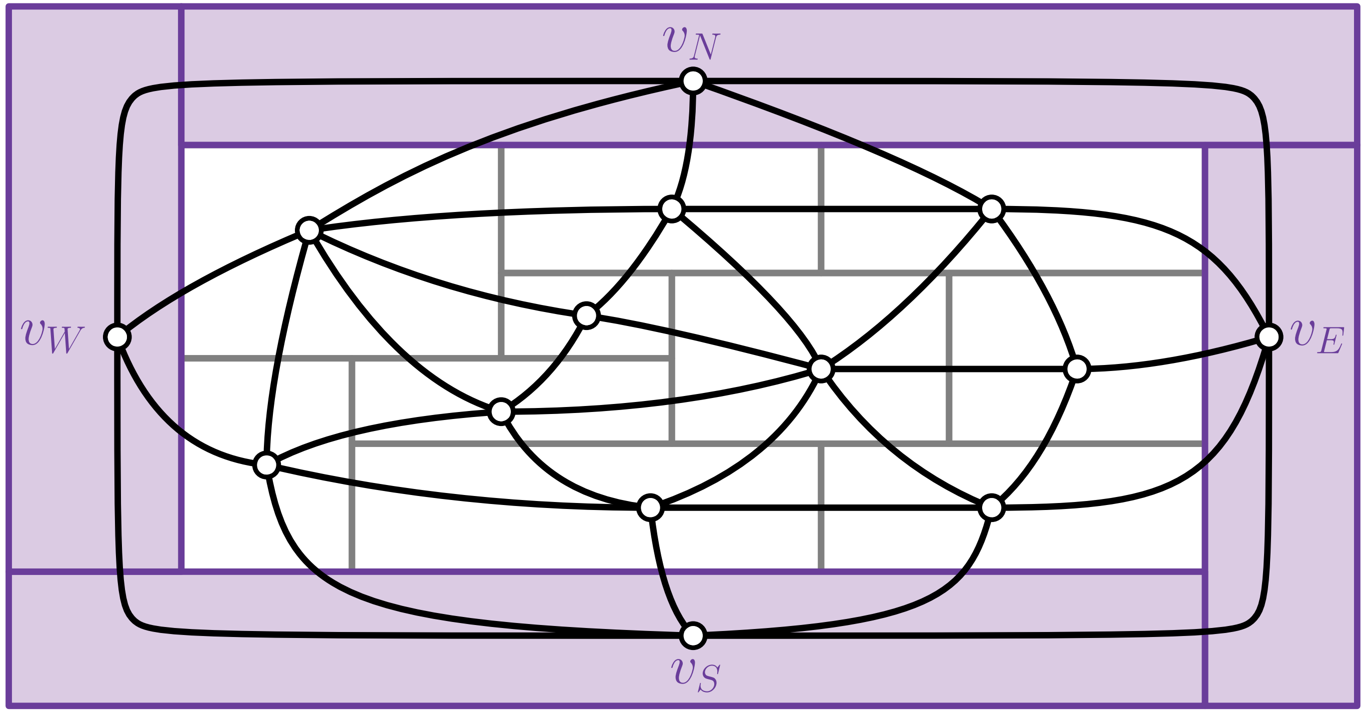
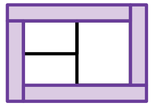


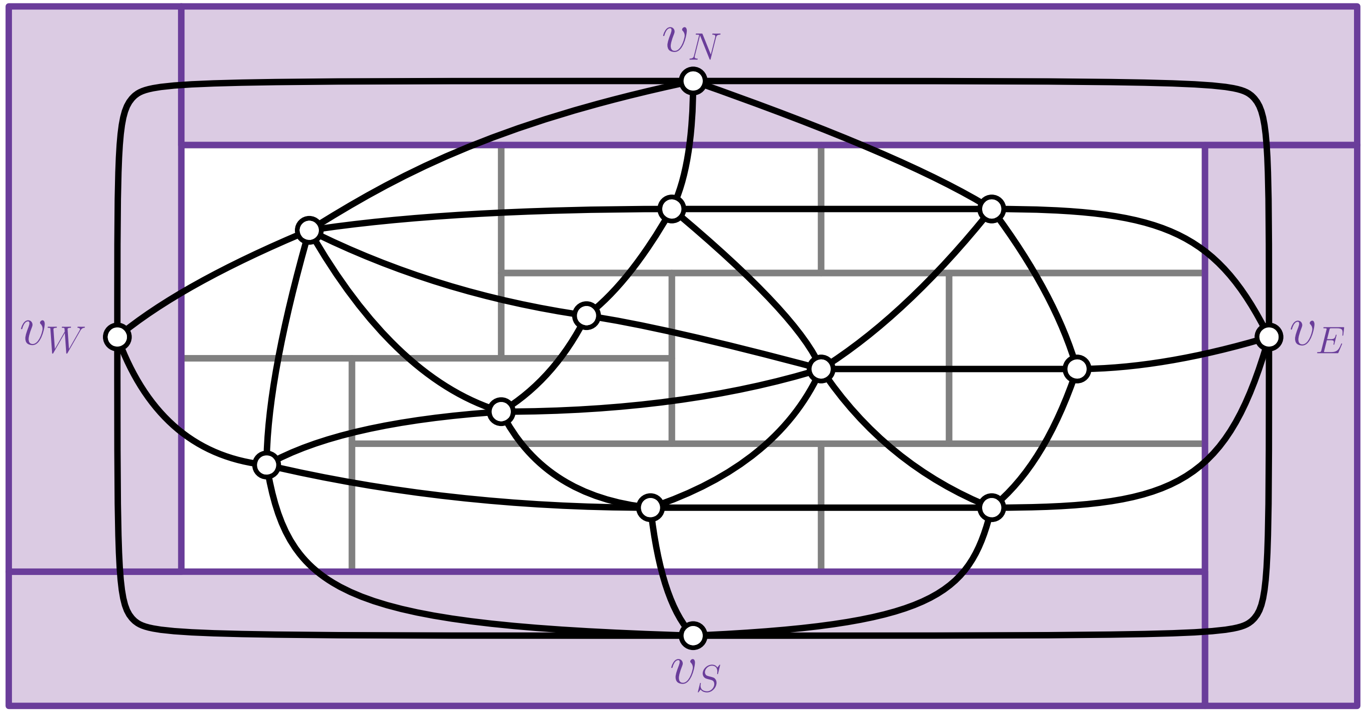
Rectangular Dual $\mathcal{R}$



Rectangular Dual

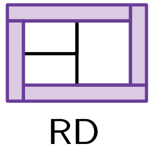


Rectangular Dual $\mathcal{R}$

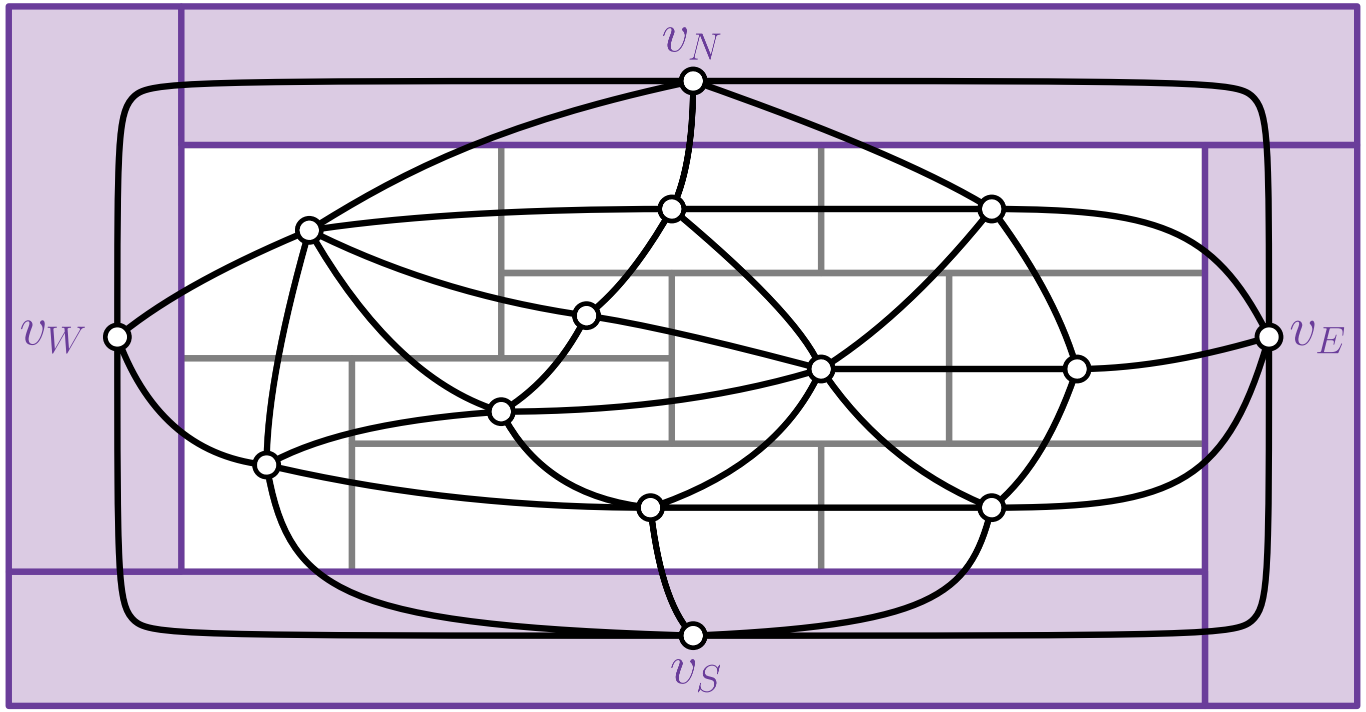


A **rectangular dual** of a graph G is a contact representation with axis-aligned rectangles s.t.

Rectangular Dual



Rectangular Dual $\mathcal{R}$



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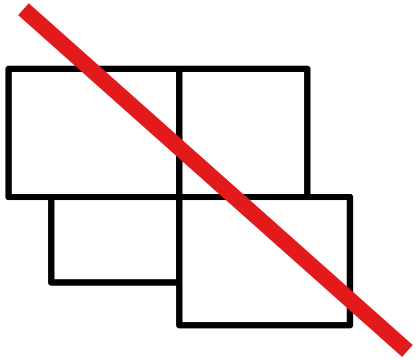

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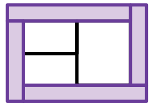

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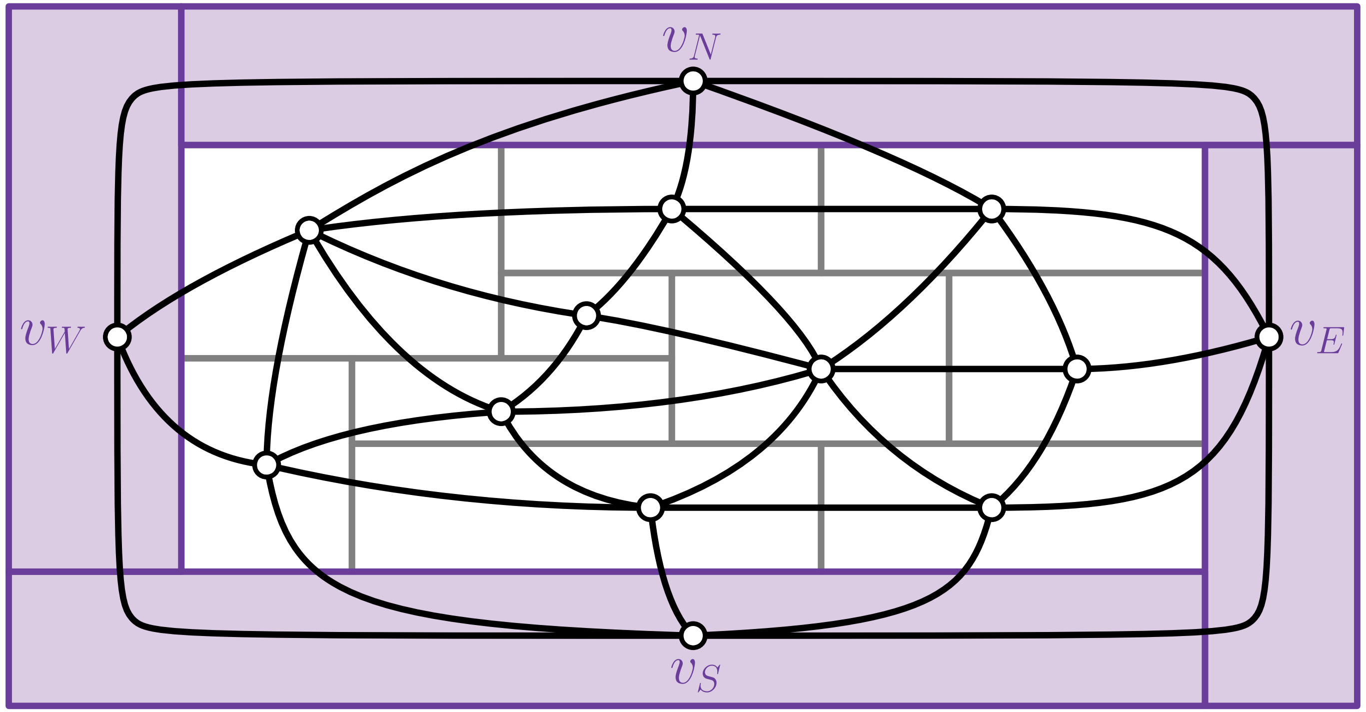

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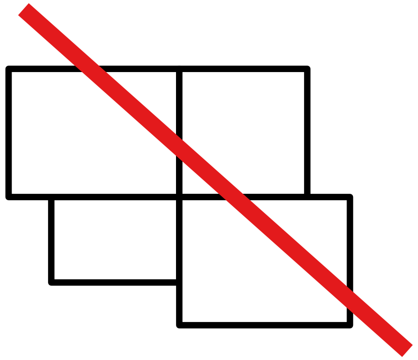

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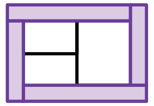
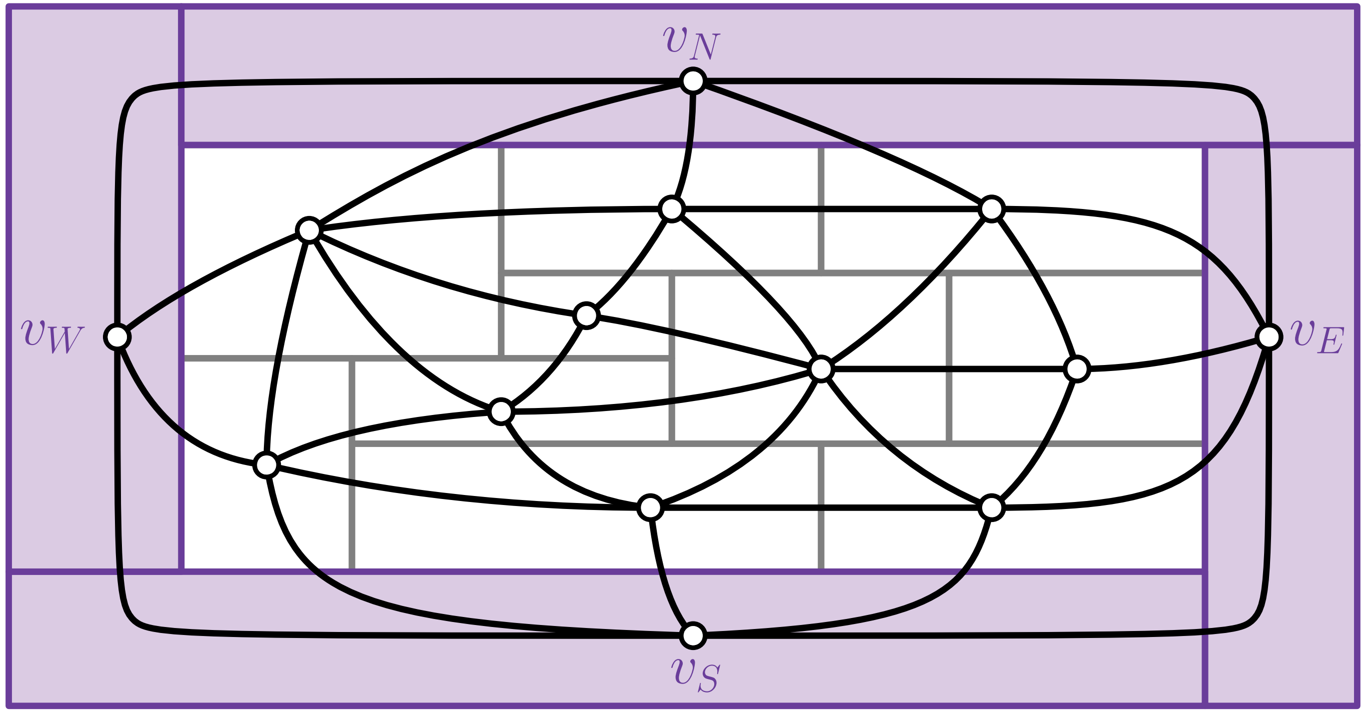


Rectangular Dual $\mathcal{R}$



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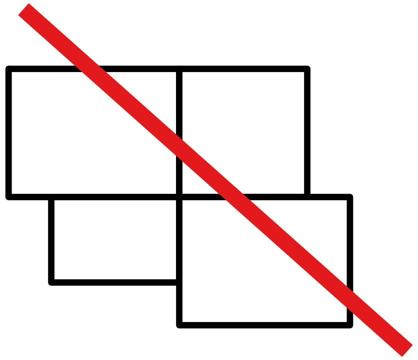

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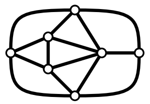
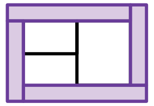
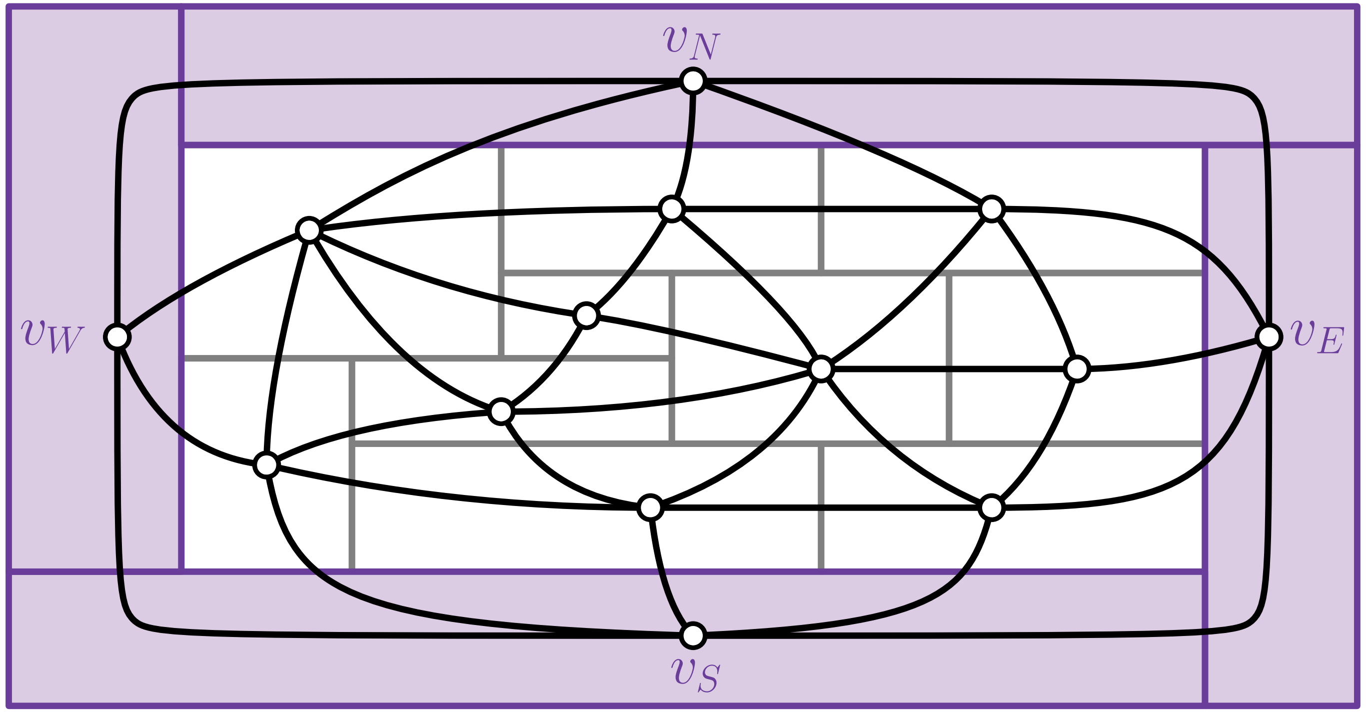
Rectangular Dual



Properly Triangulated Planar Graph G



Rectangular Dual $\mathcal{R}$



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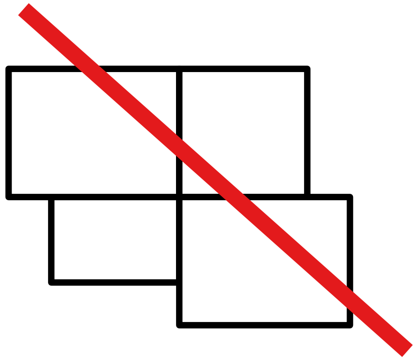

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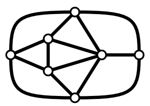

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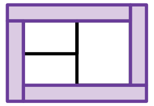
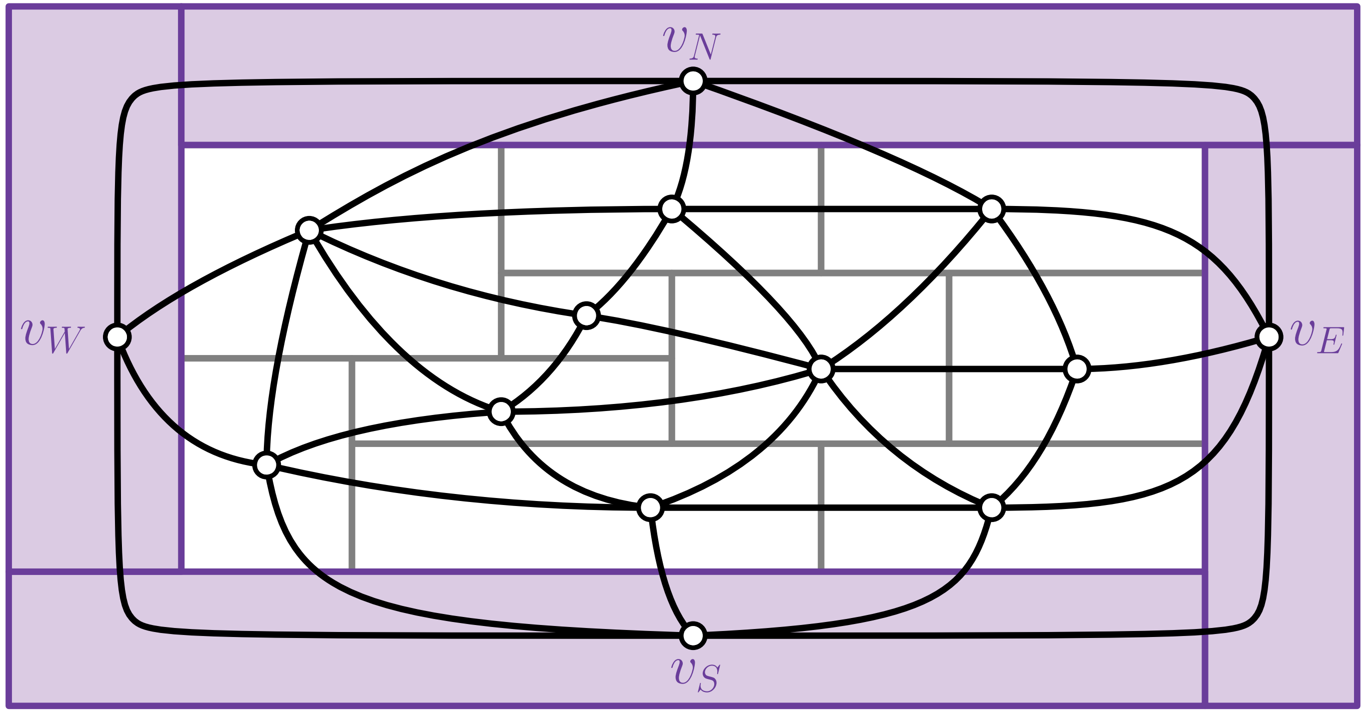


Rectangular Dual $\mathcal{R}$



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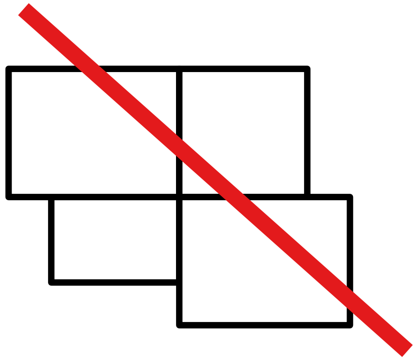

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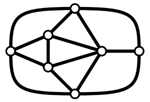
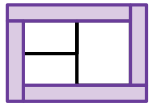


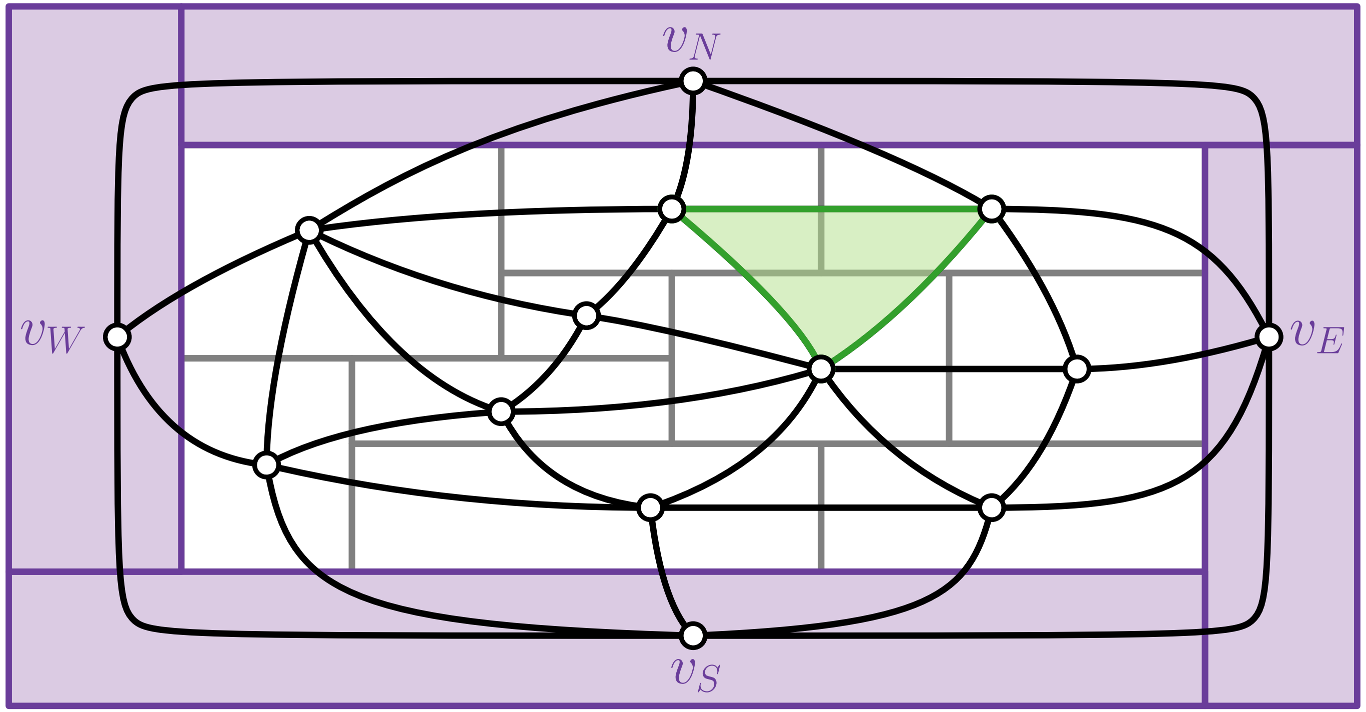
PTP

Properly Triangulated Planar Graph G



RD

Rectangular Dual $\mathcal{R}$



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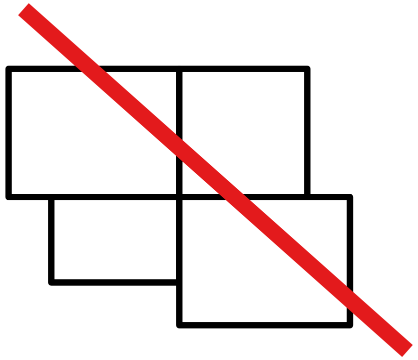

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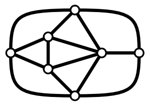
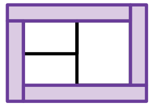


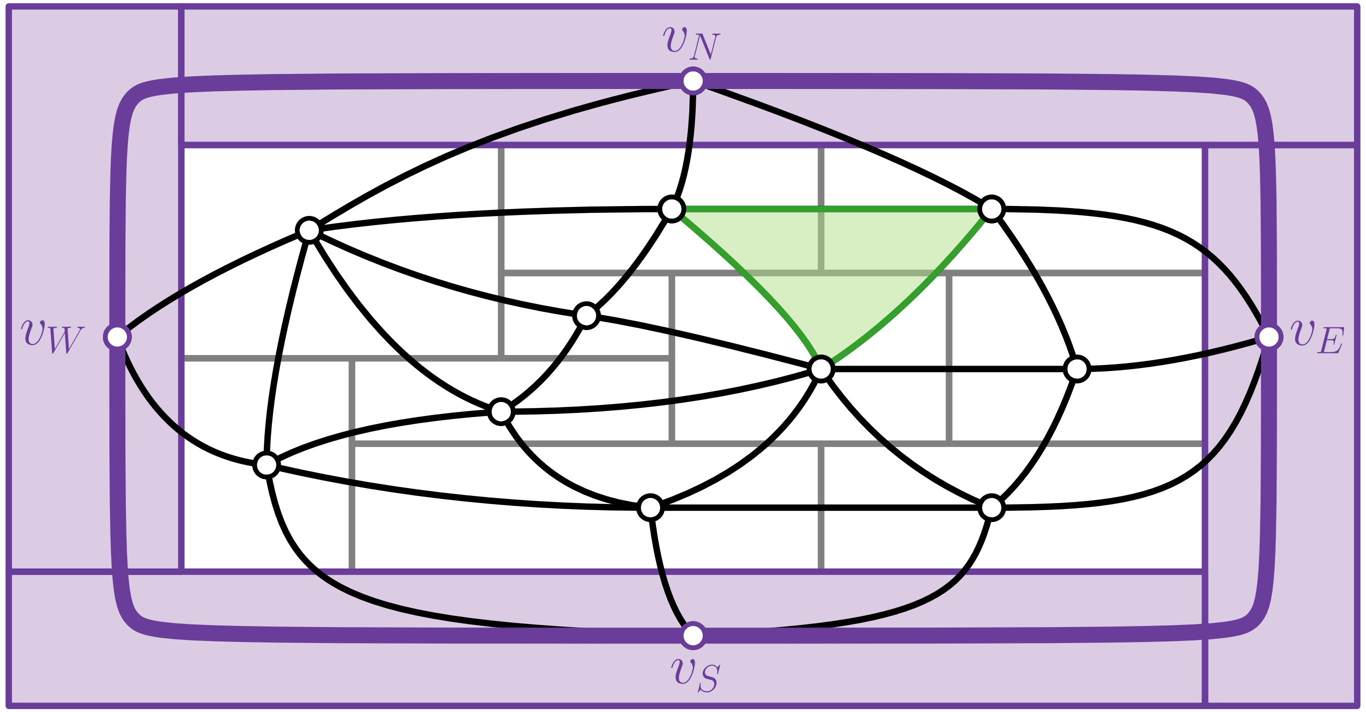
PTP

Properly Triangulated Planar Graph G



RD

Rectangular Dual $\mathcal{R}$



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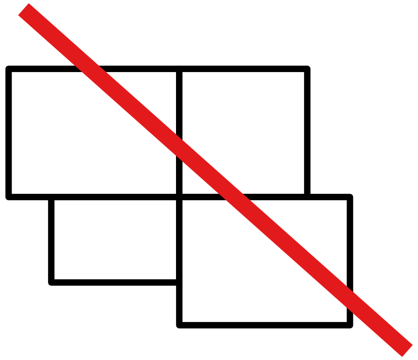

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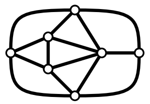
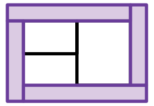


PTP

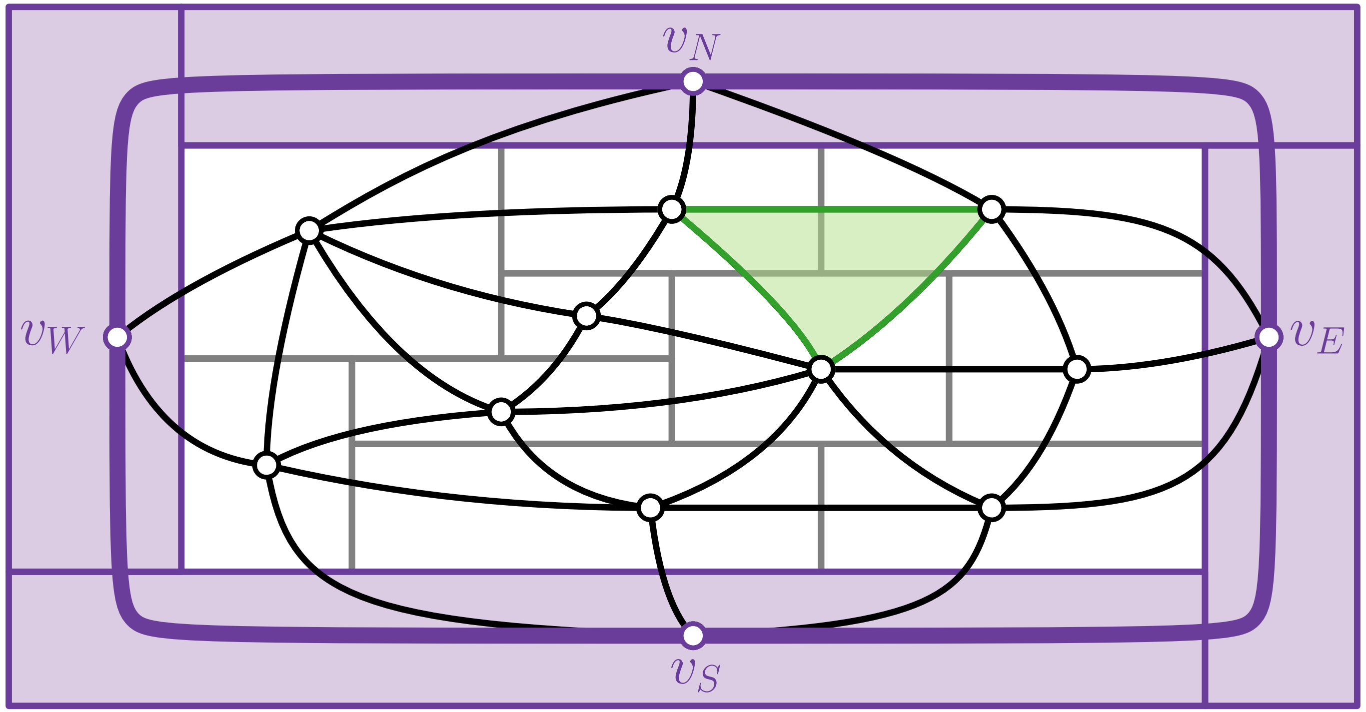
Properly Triangulated Planar Graph G



RD

Rectangular Dual $\mathcal{R}$

Exactly four vertices on the outer face.



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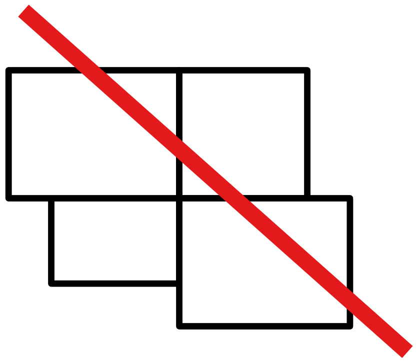

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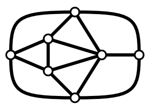
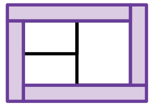
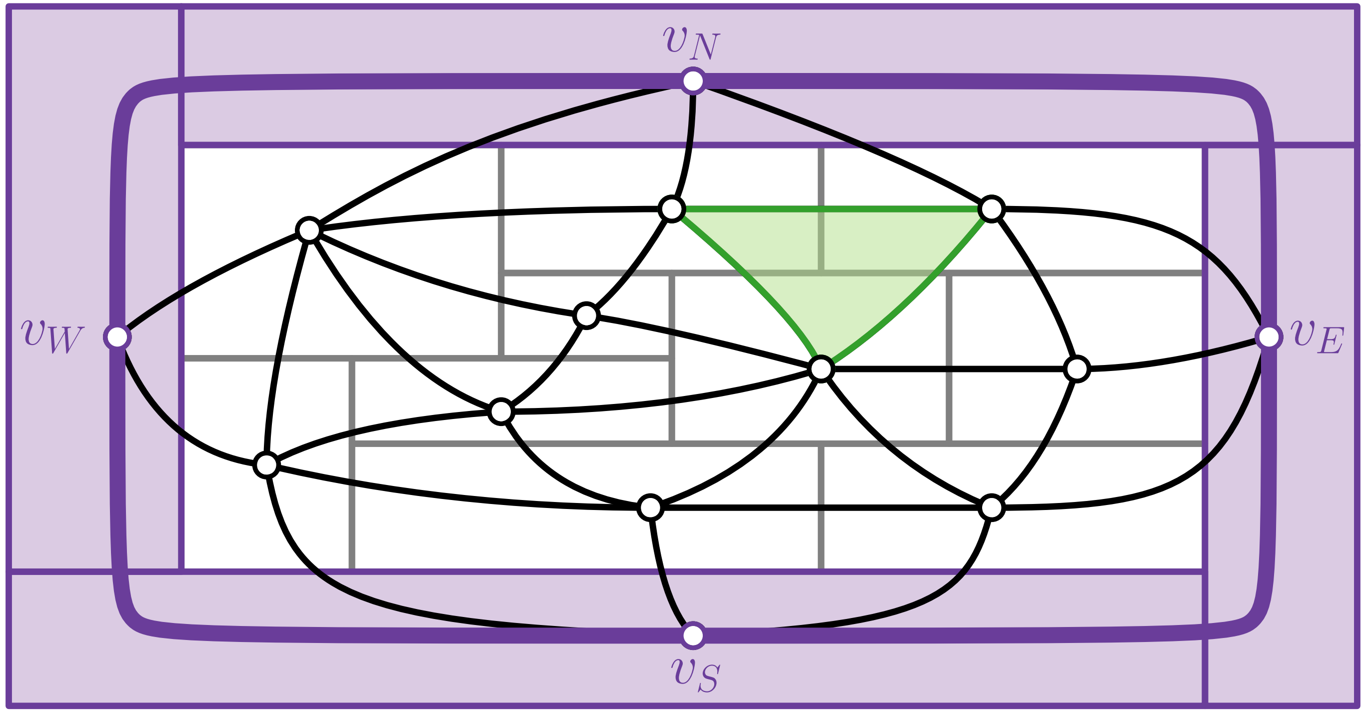


Properly Triangulated Planar Graph G



Rectangular Dual $\mathcal{R}$



No separating triangle!

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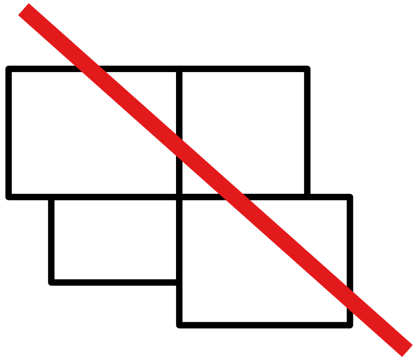

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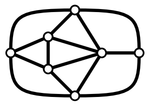
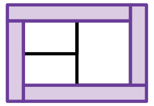


Properly Triangulated Planar Graph G



Rectangular Dual $\mathcal{R}$

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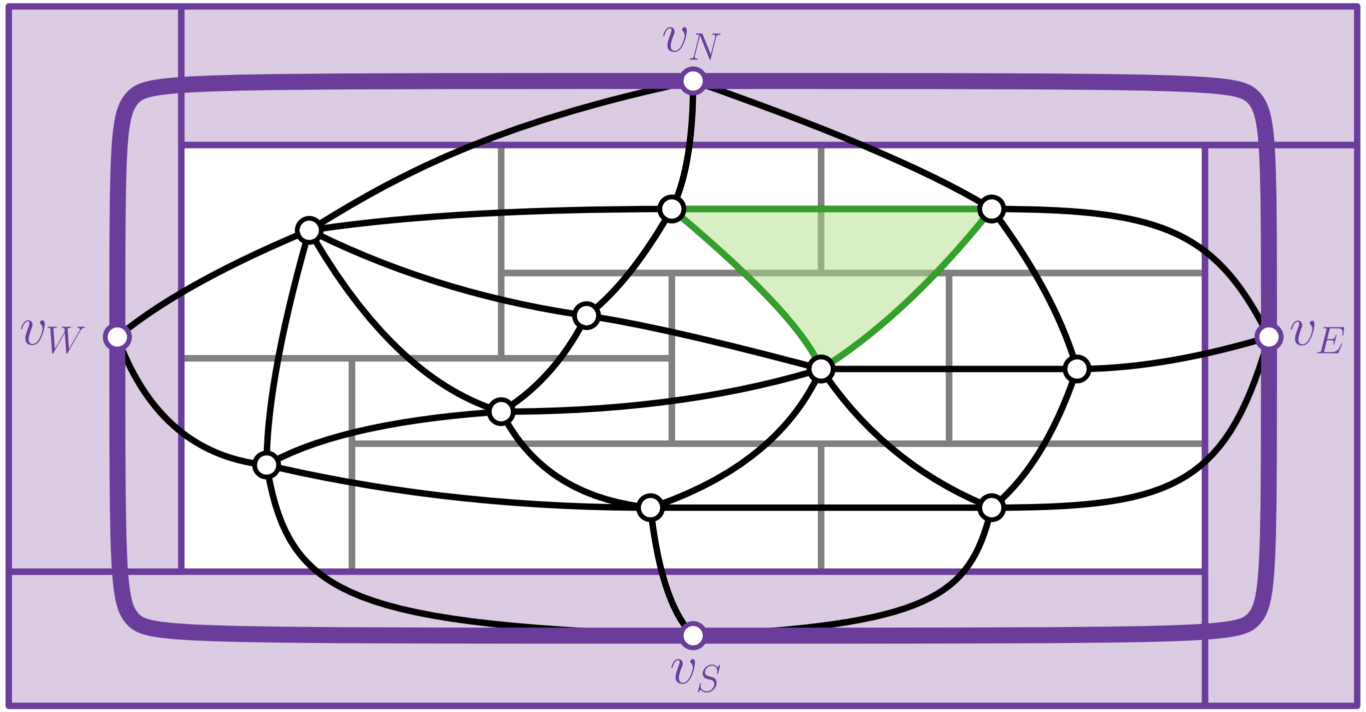

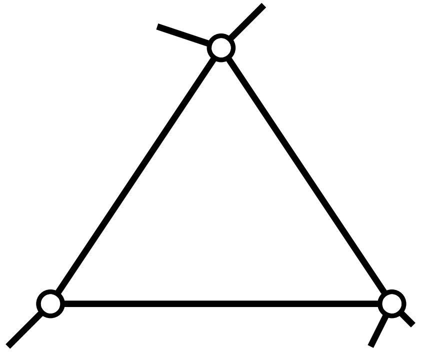

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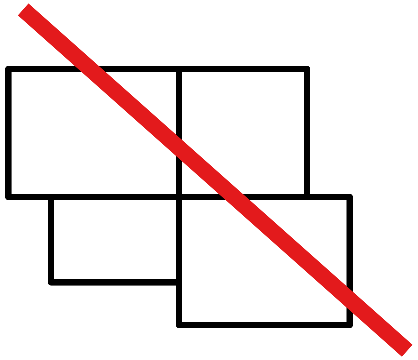

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Rectangular Dual

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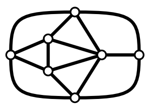
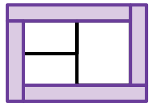


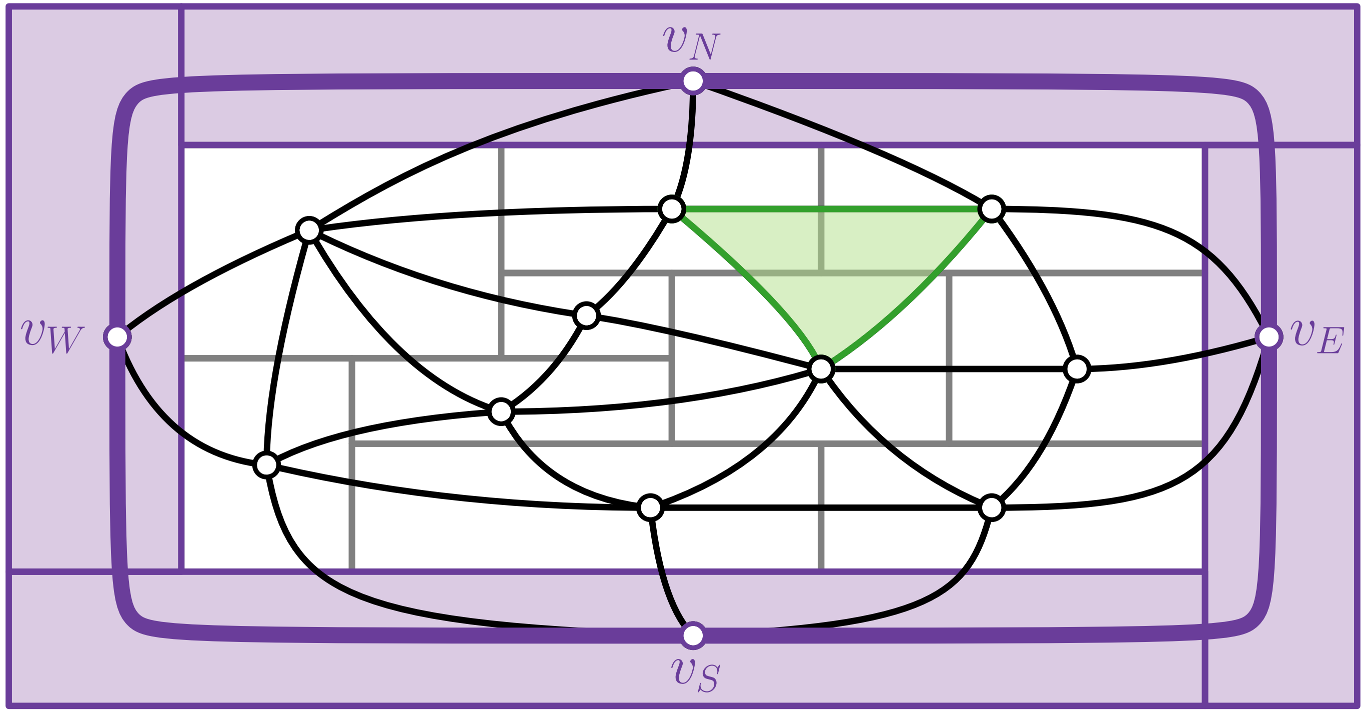
PTP

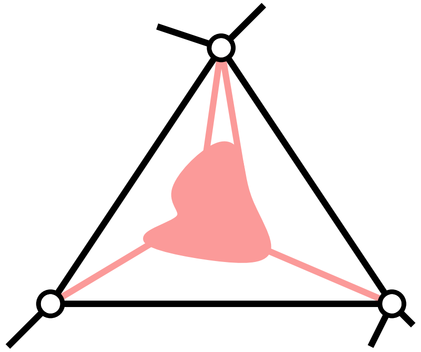
Properly Triangulated Planar Graph G



RD

Rectangular Dual $\mathcal{R}$





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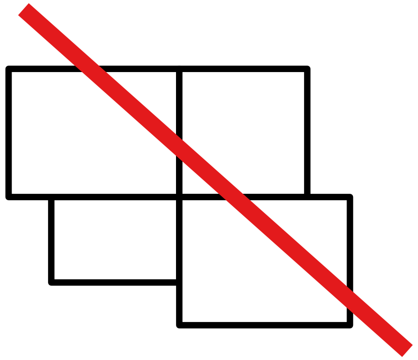

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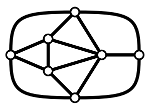
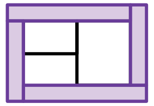
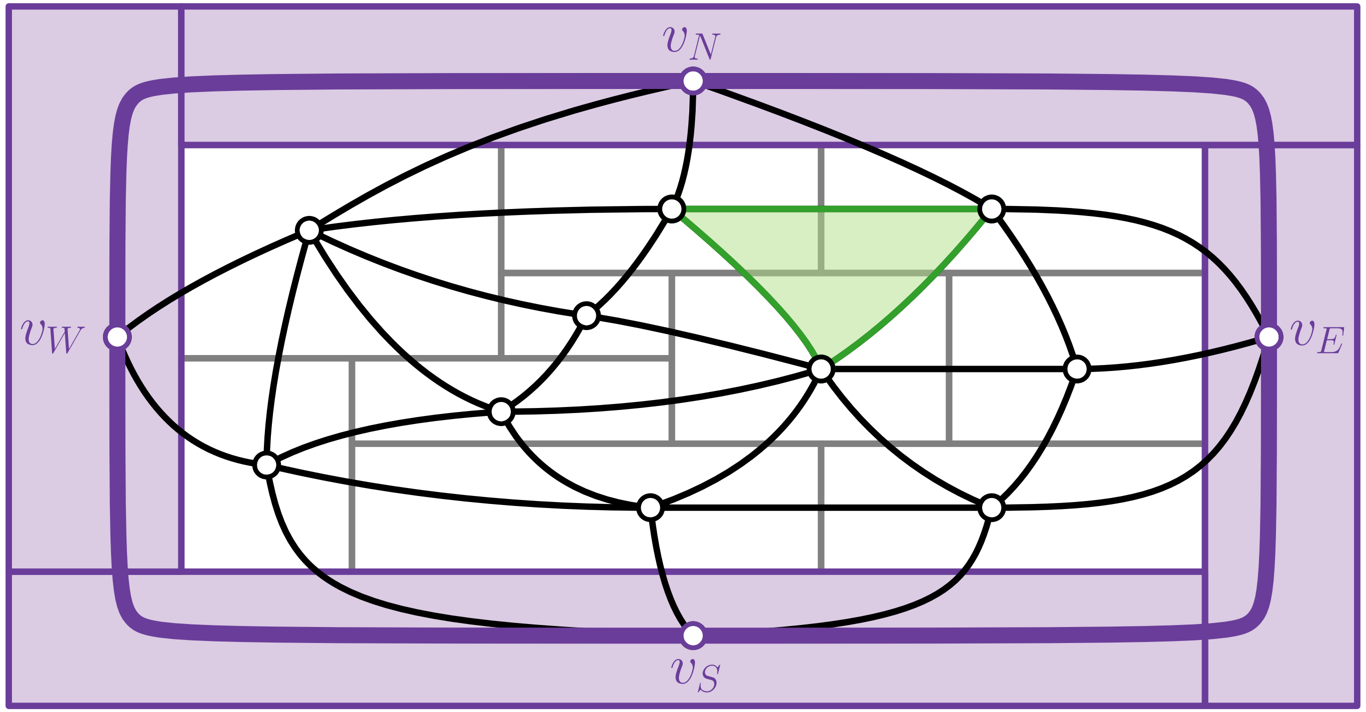
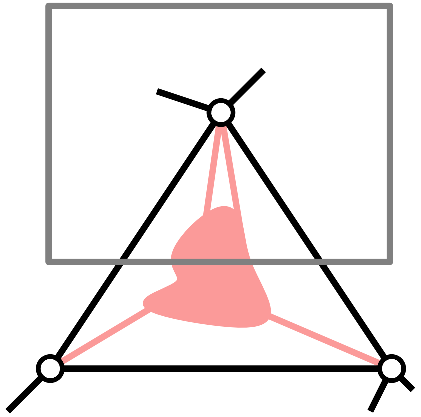

PTP

Properly Triangulated Planar Graph G


RD

Rectangular Dual $\mathcal{R}$





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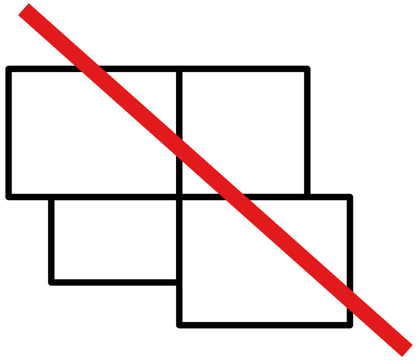

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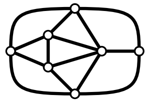
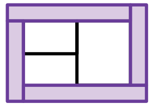


Properly Triangulated Planar Graph G



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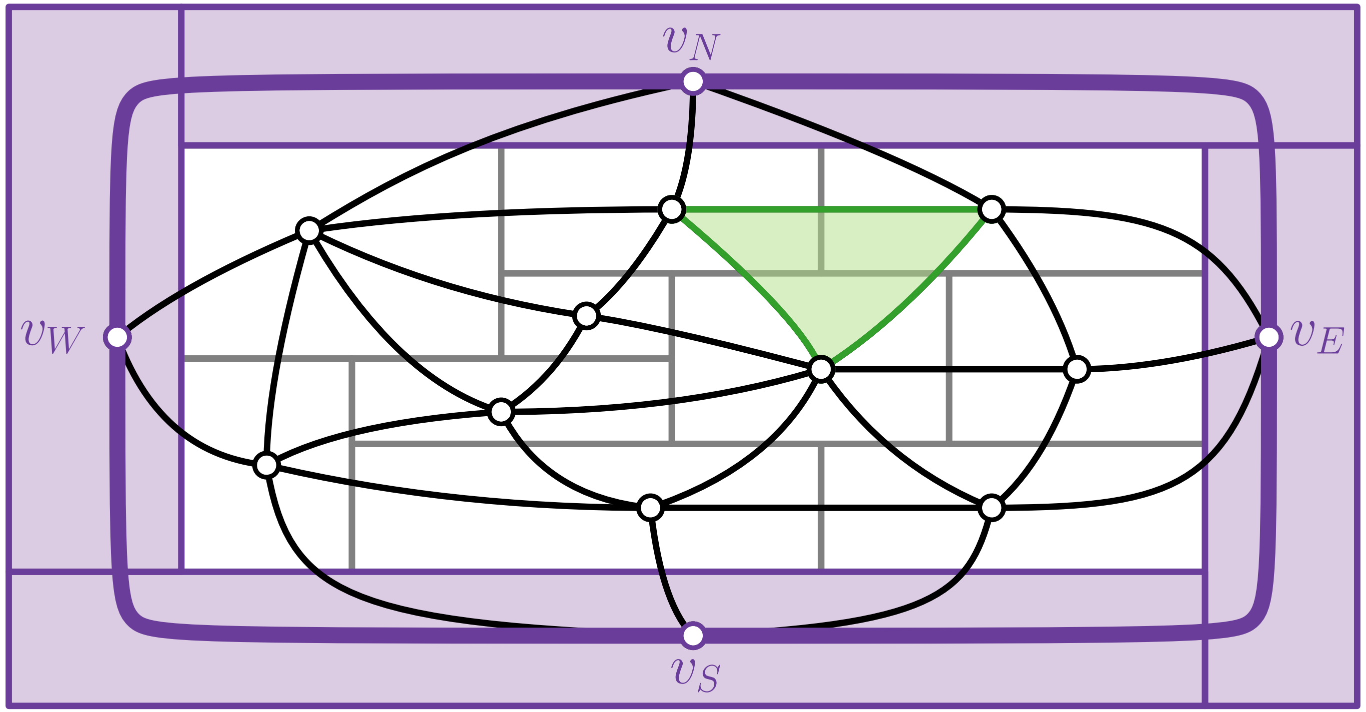

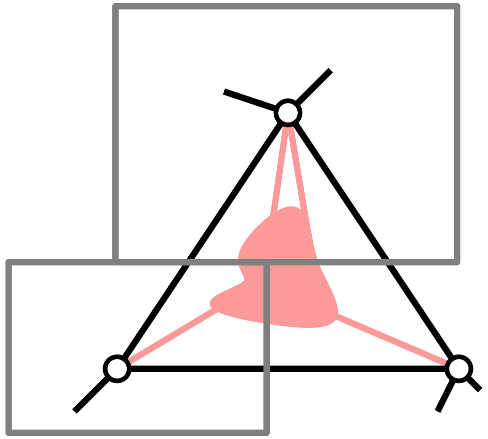

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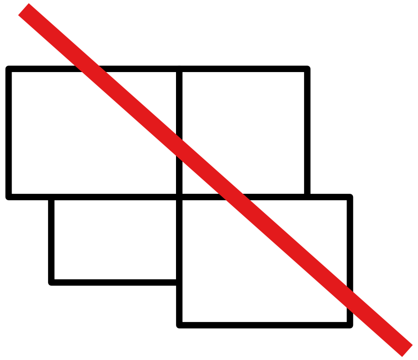

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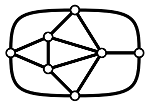
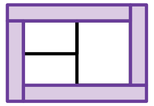
Rectangular Dual



PTP

Properly Triangulated Planar Graph G



RD

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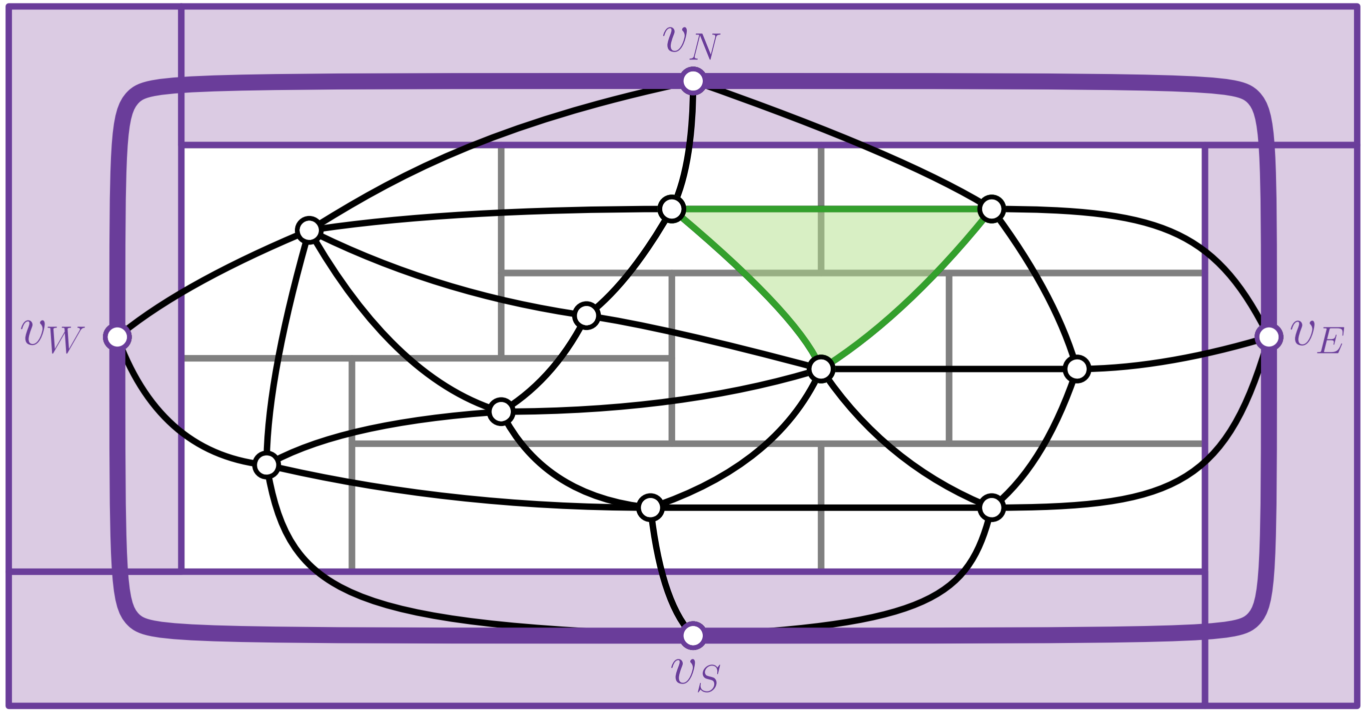

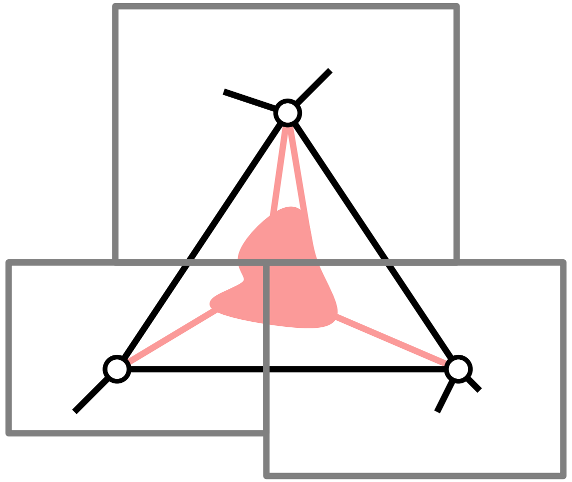

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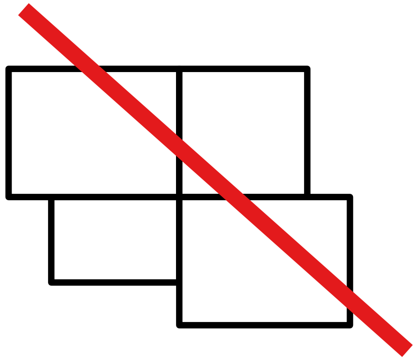

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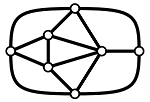
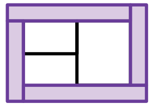
Regular Edge Labeling



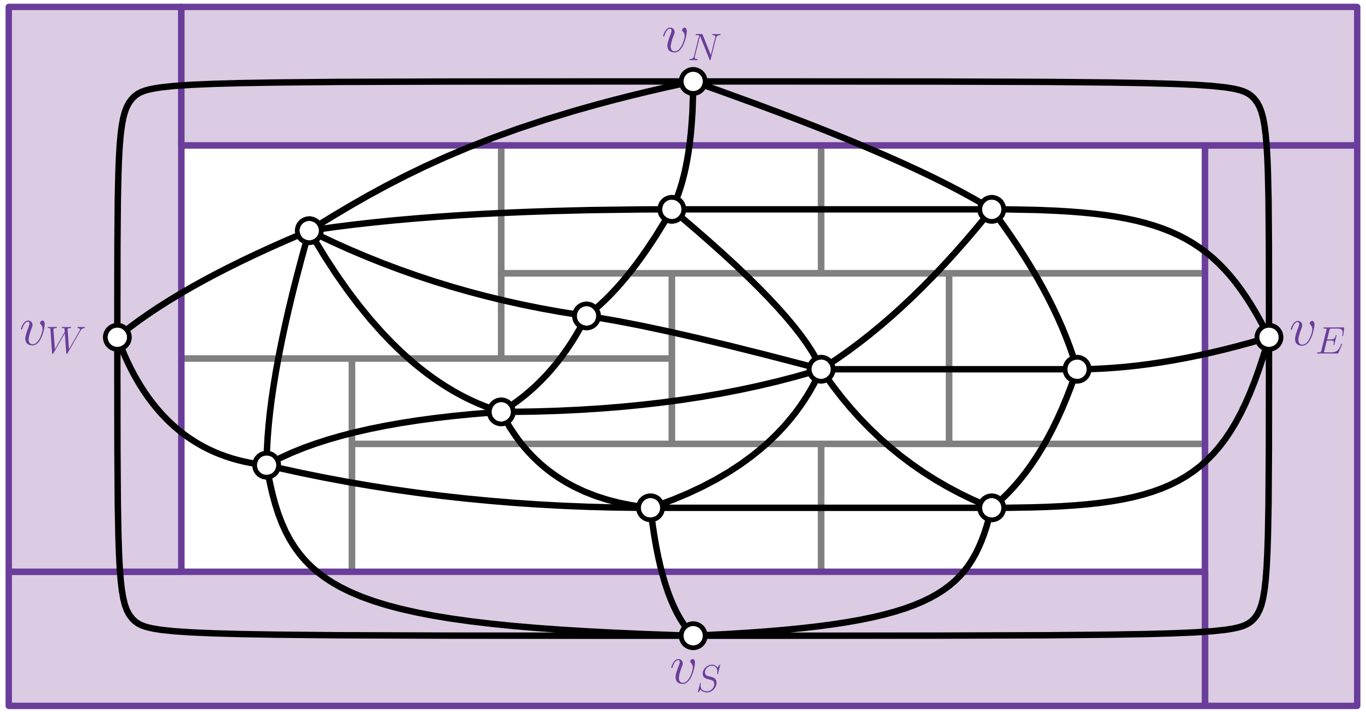
PTP

Properly Triangulated Planar Graph G

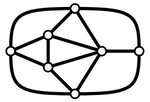


RD

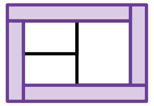
Rectangular Dual $\mathcal{R}$



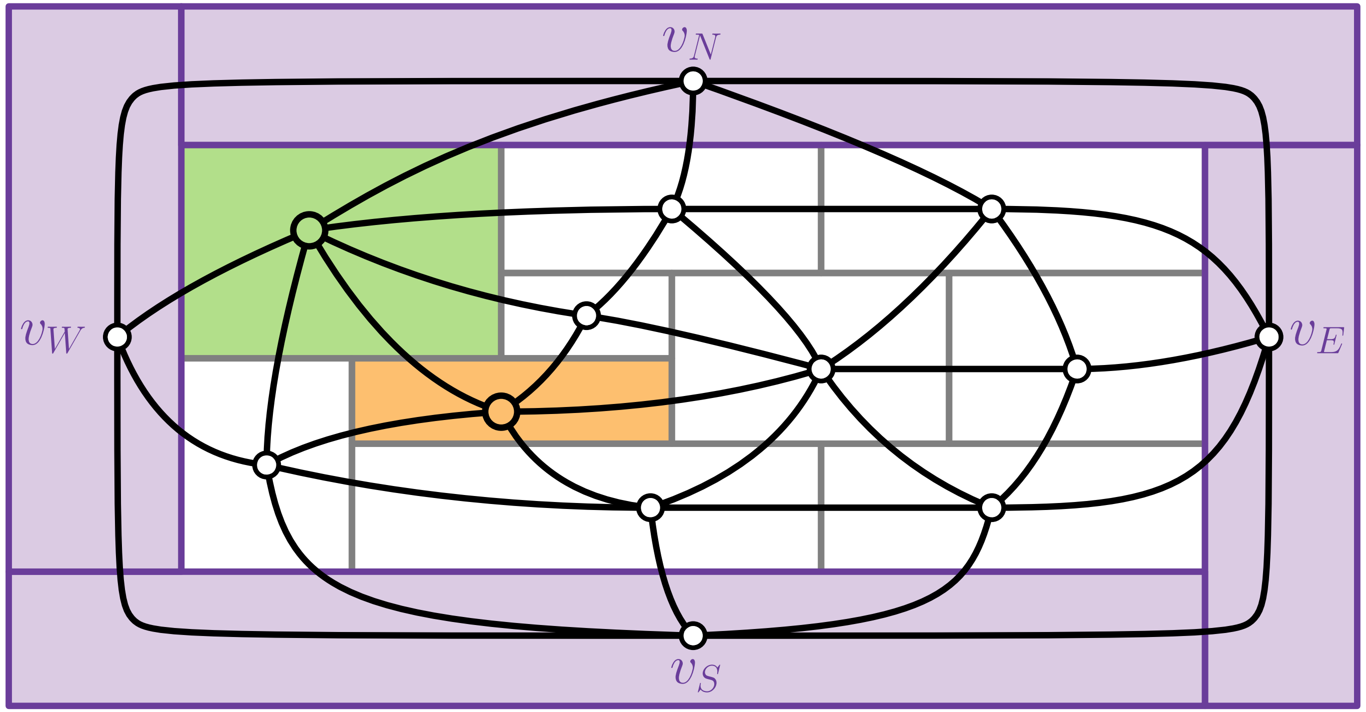
Regular Edge Labeling



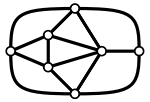
Properly Triangulated Planar Graph G



Rectangular Dual $\mathcal{R}$



Regular Edge Labeling



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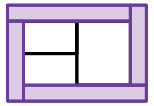
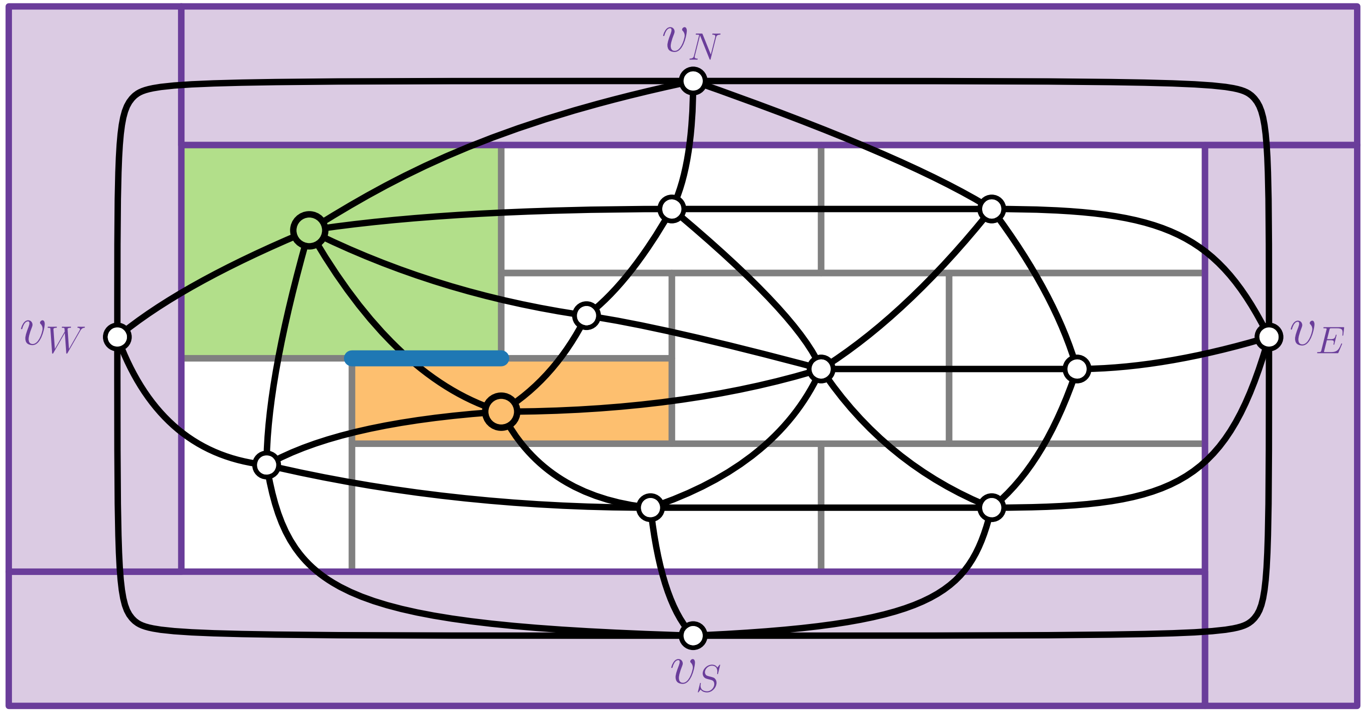
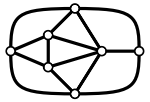


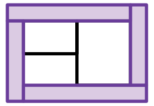
Rectangular Dual $\mathcal{R}$



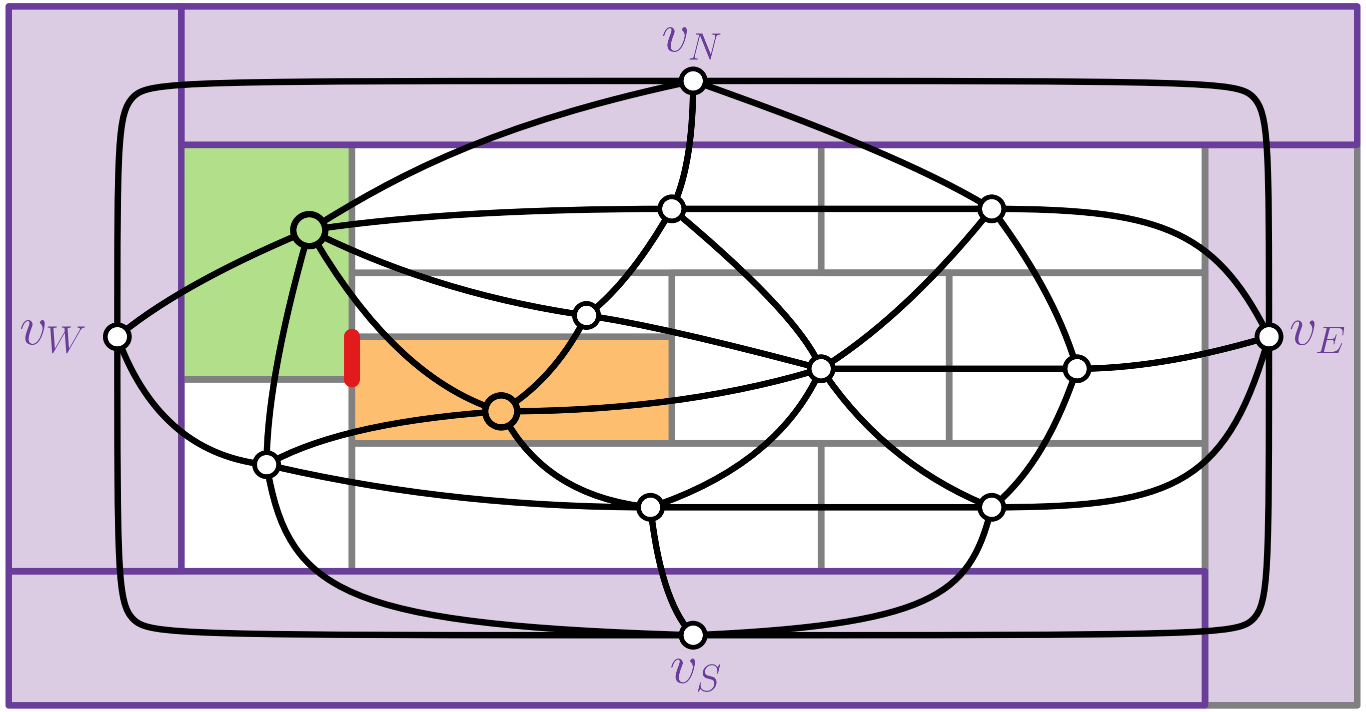
Regular Edge Labeling



Properly Triangulated Planar Graph G



Rectangular Dual $\mathcal{R}$



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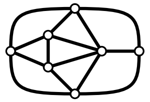
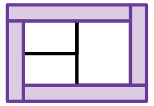
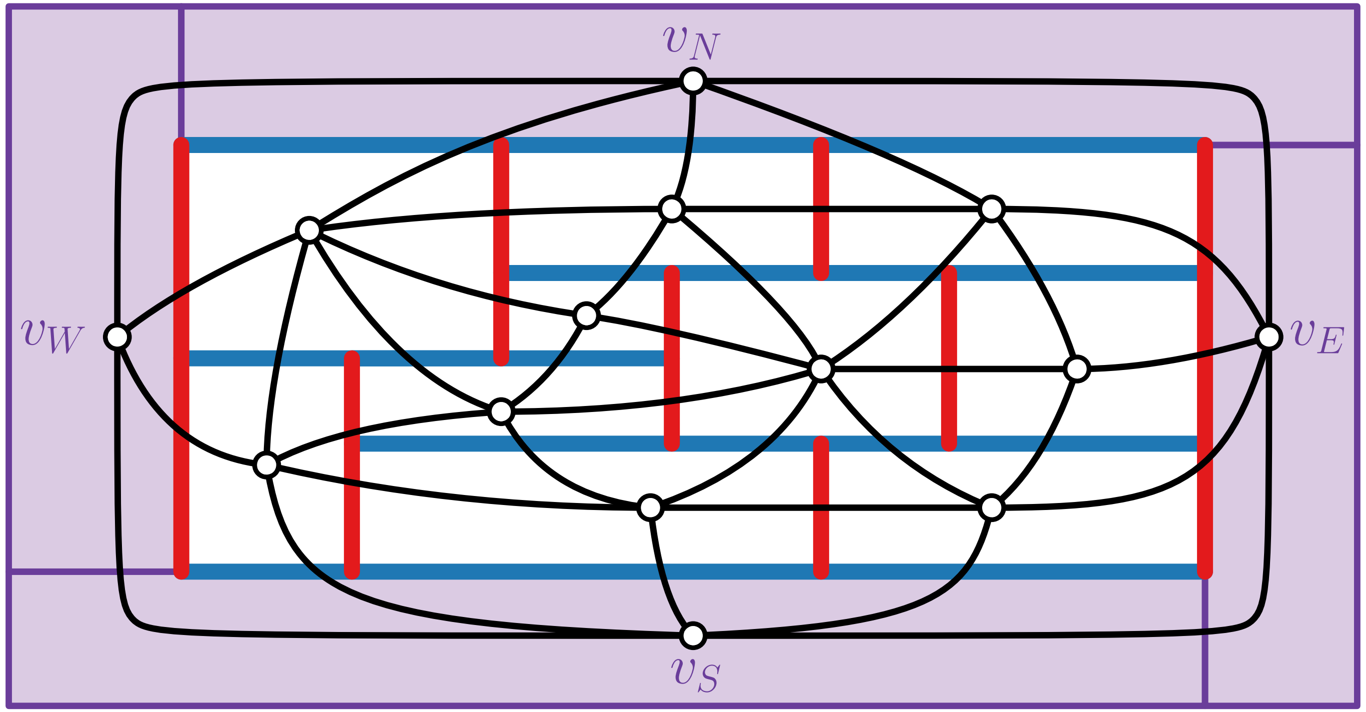


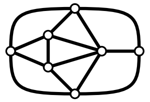
Properly Triangulated Planar Graph G



Rectangular Dual $\mathcal{R}$



Regular Edge Labeling



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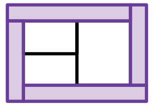
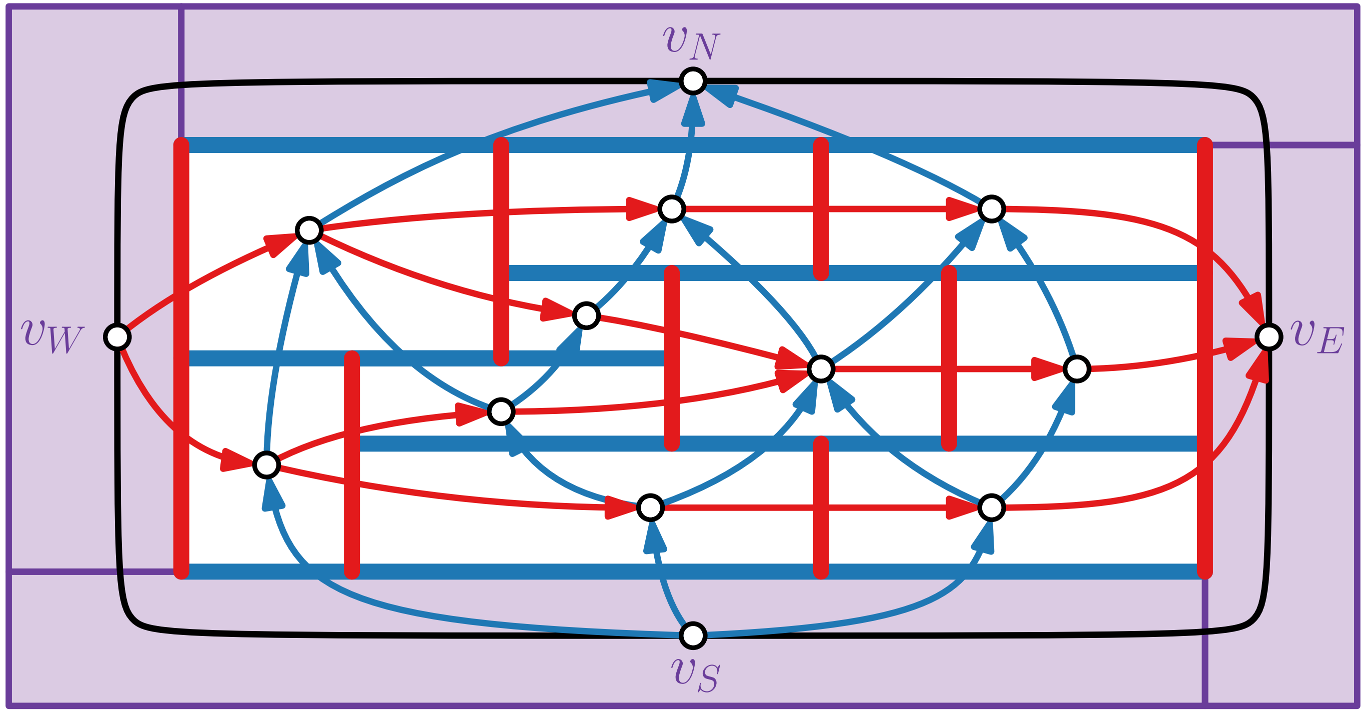
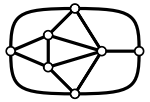


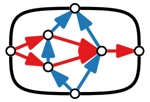
Rectangular Dual $\mathcal{R}$



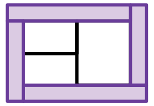
Regular Edge Labeling


PTP

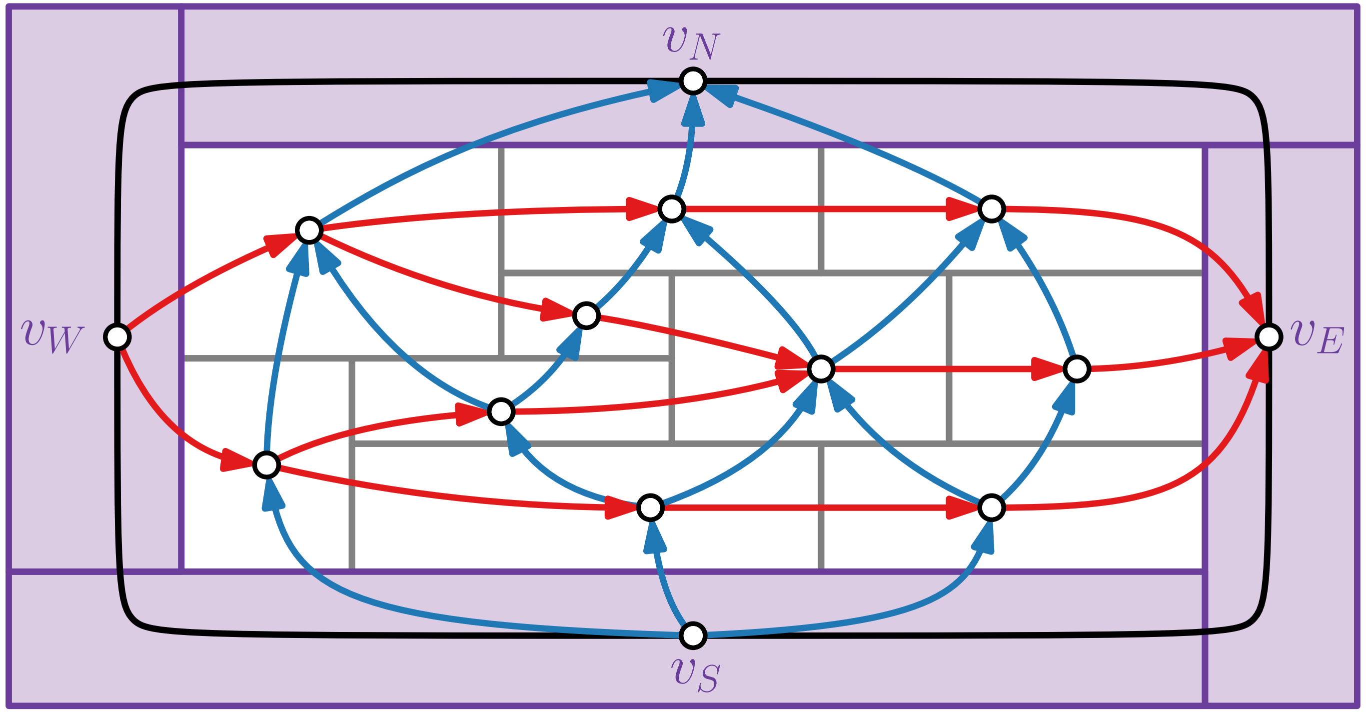
Properly Triangulated Planar Graph G


REL

Regular Edge Labeling


RD

Rectangular Dual $\mathcal{R}$



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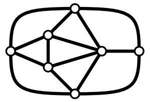
PTP

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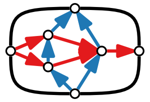
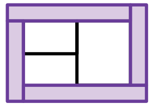
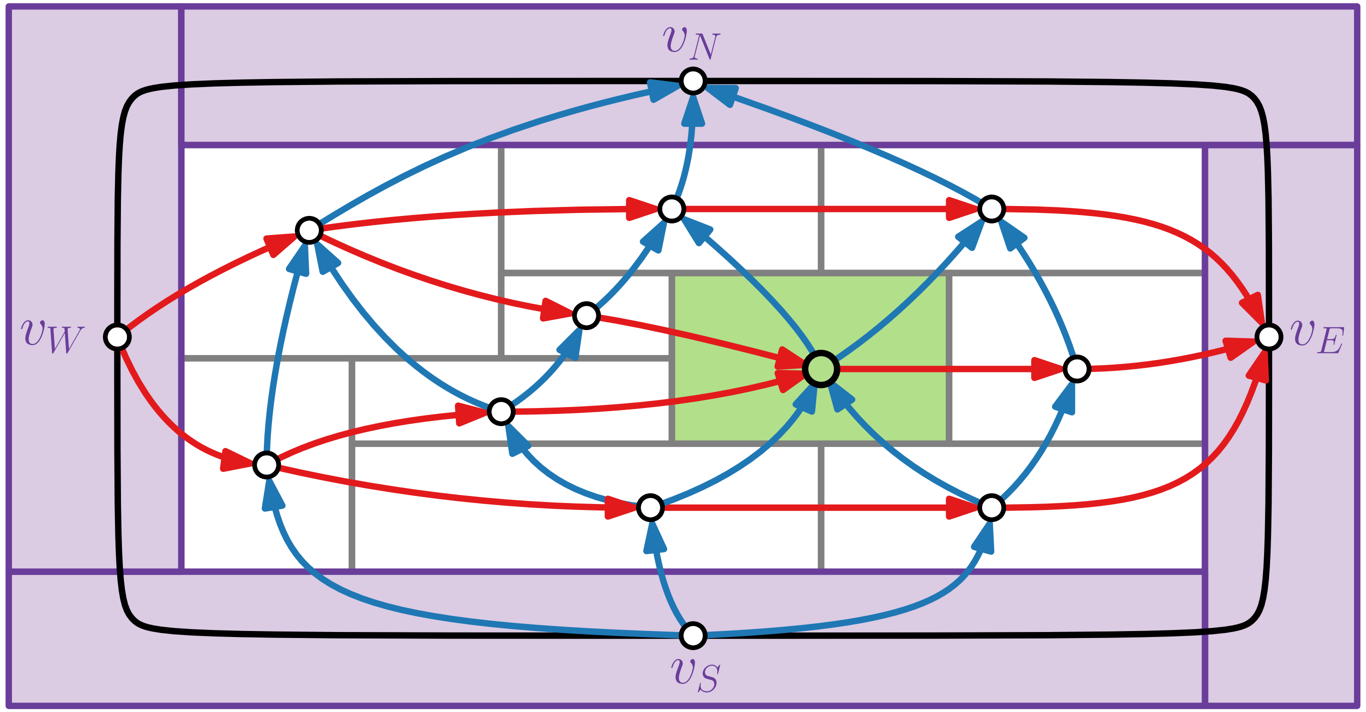

REL

Regular Edge Labeling

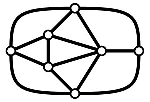

RD

Rectangular Dual $\mathcal{R}$

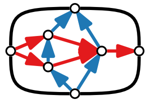


Properties:

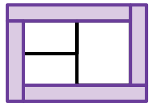
Regular Edge Labeling



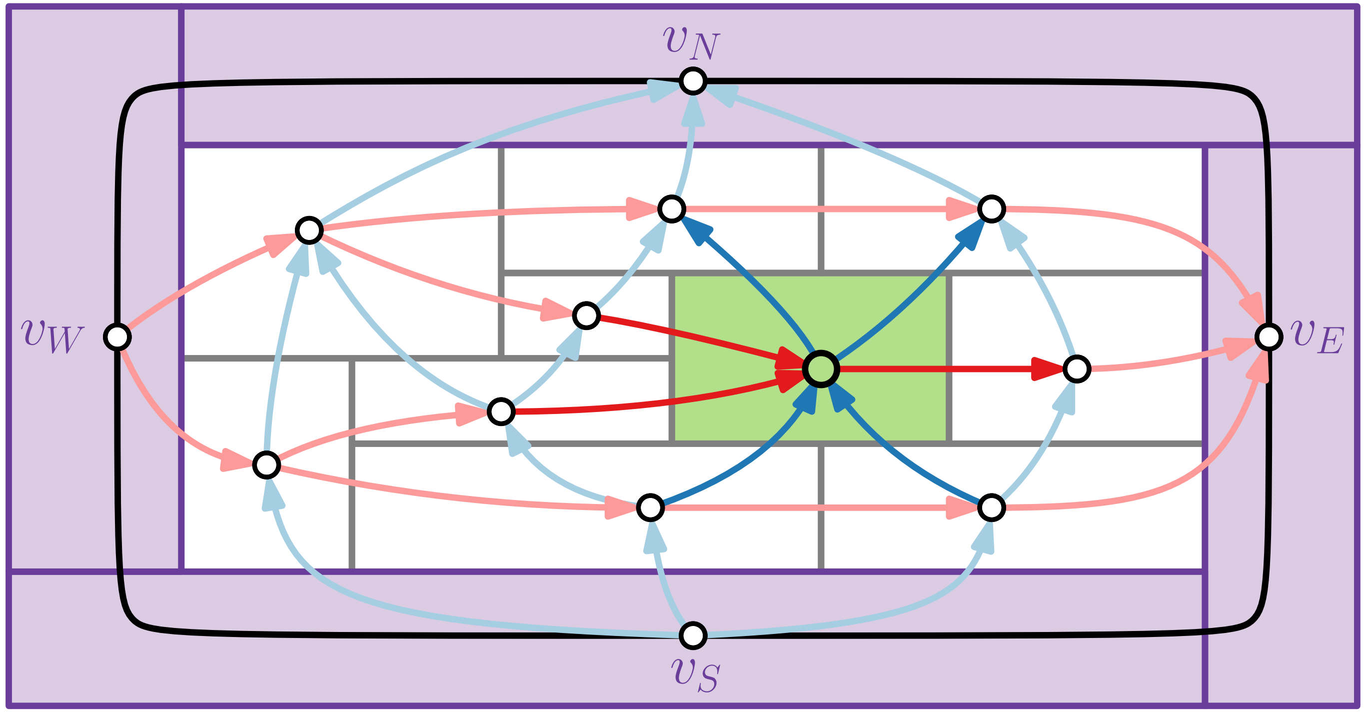
Properly Triangulated Planar Graph G



Regular Edge Labeling

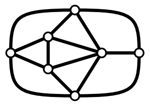


Rectangular Dual $\mathcal{R}$

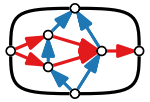


Properties:

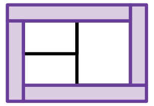
Regular Edge Labeling



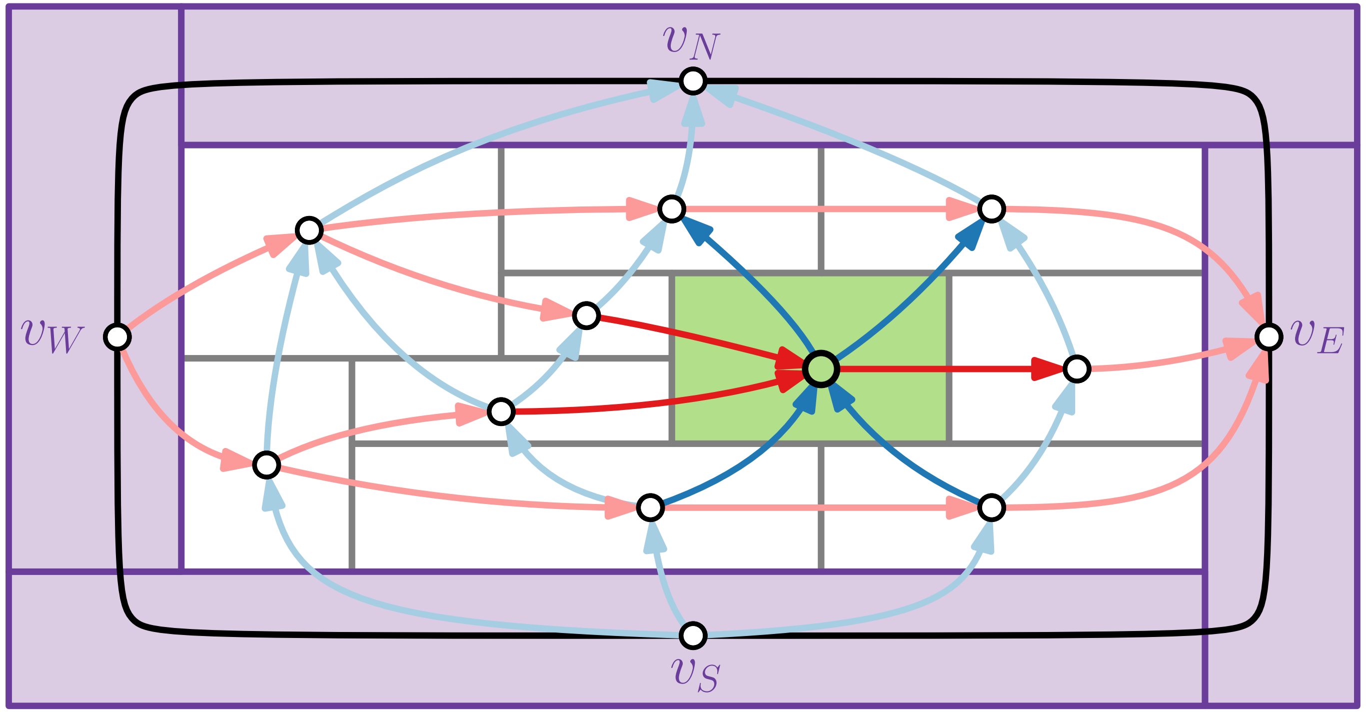
Properly Triangulated Planar Graph G



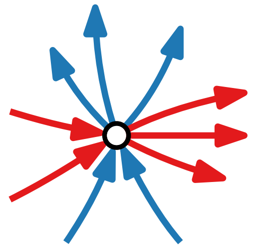
Regular Edge Labeling



Rectangular Dual $\mathcal{R}$

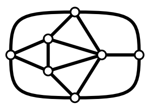


Properties:

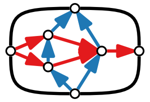


for every inner vertex

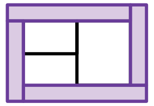
Regular Edge Labeling



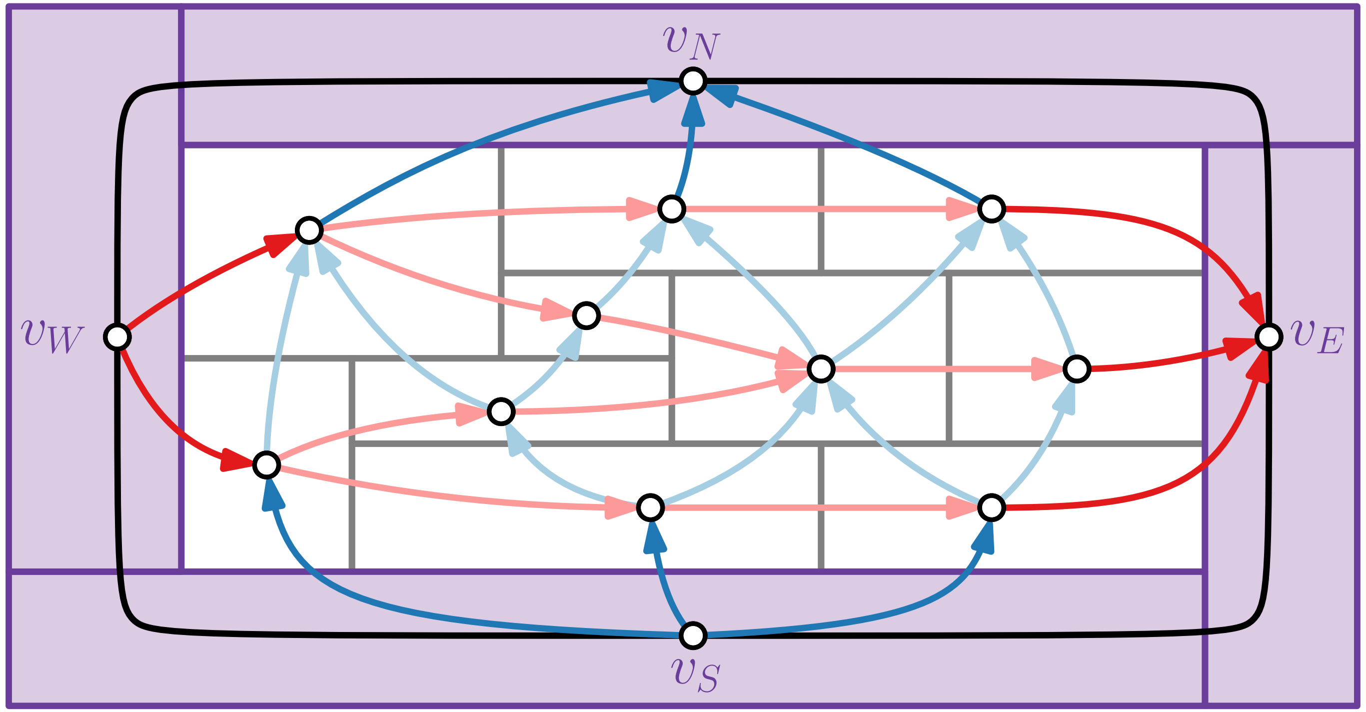
Properly Triangulated Planar Graph G



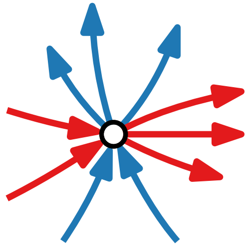
Regular Edge Labeling



Rectangular Dual $\mathcal{R}$

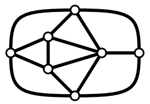


Properties:

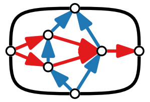


for every inner vertex

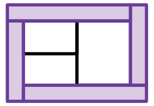
Regular Edge Labeling



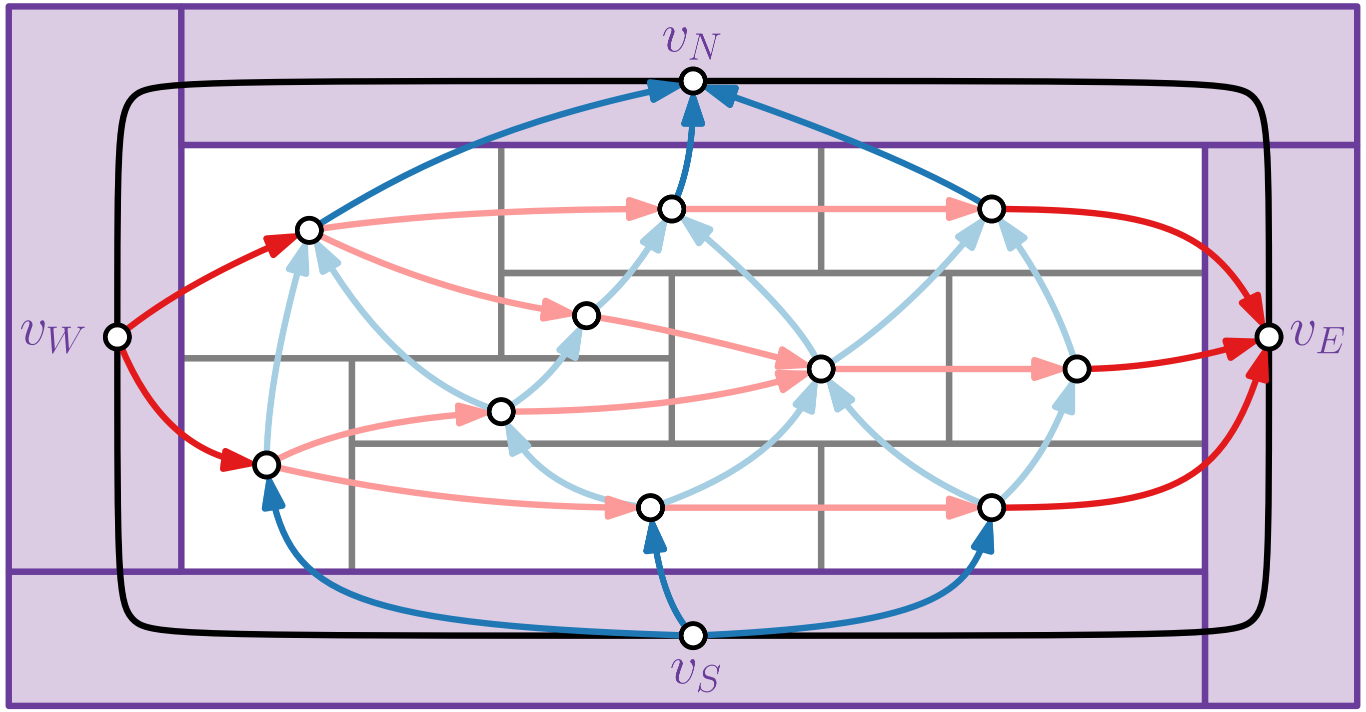
Properly Triangulated Planar Graph G



Regular Edge Labeling



Rectangular Dual $\mathcal{R}$



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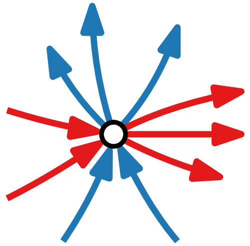

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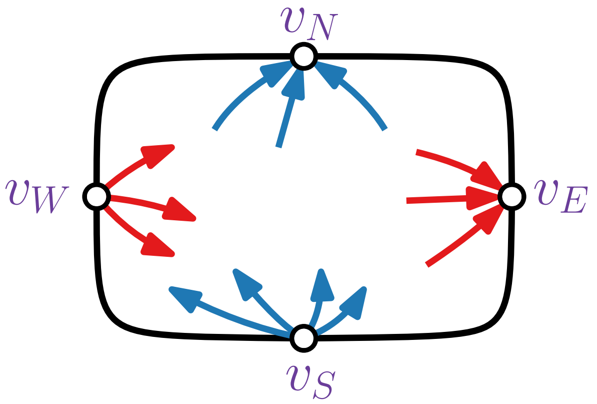
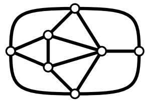


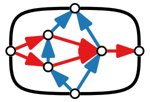
for four outer vertices

Regular Edge Labeling



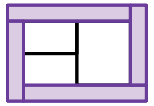
PTP

Properly Triangulated Planar Graph G



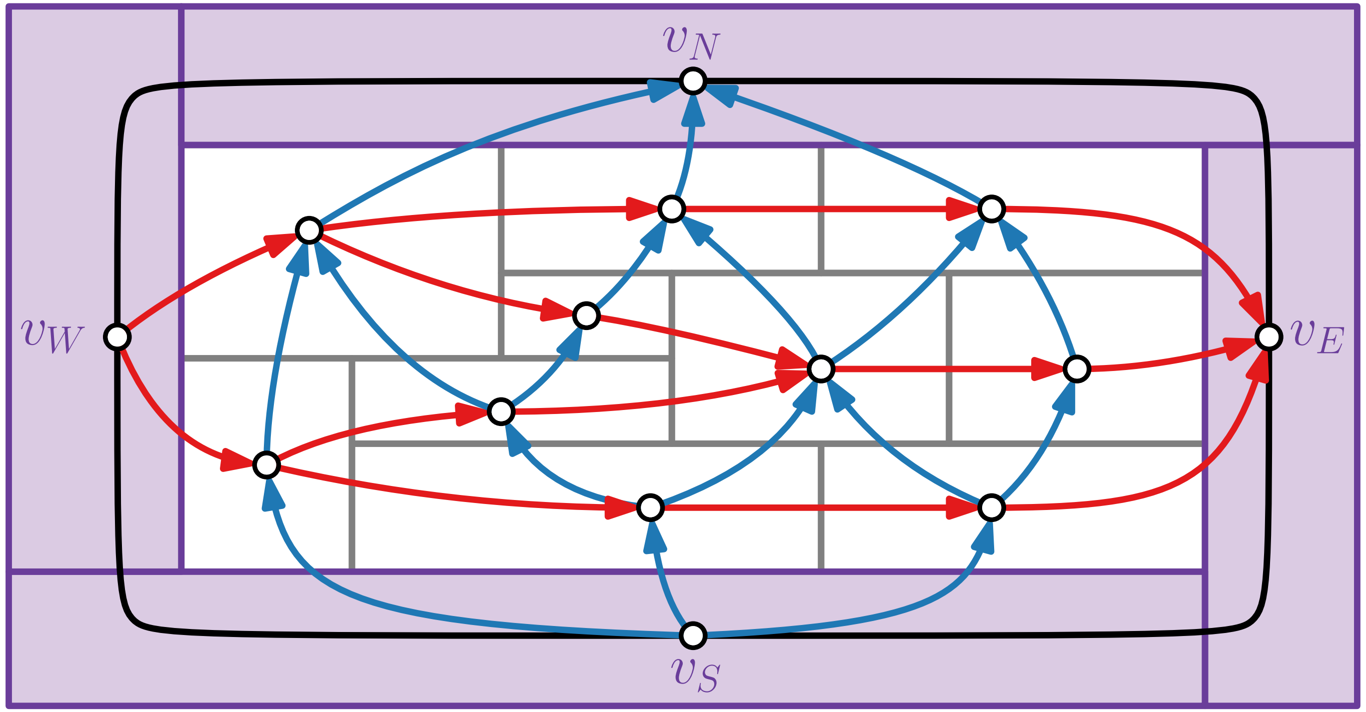
REL

Regular Edge Labeling

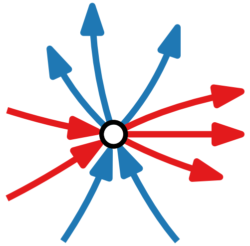


RD

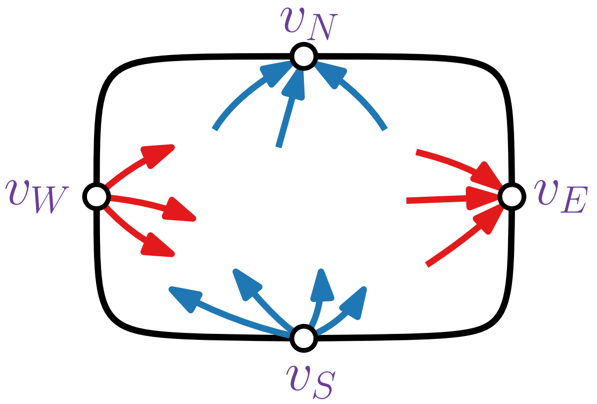
Rectangular Dual $\mathcal{R}$



Properties:

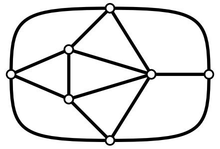


for every inner vertex



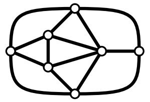
for four outer vertices

[Kant, He '94]:

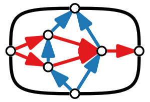


PTP

Regular Edge Labeling


PTP

Properly Triangulated Planar Graph G


REL

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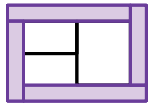
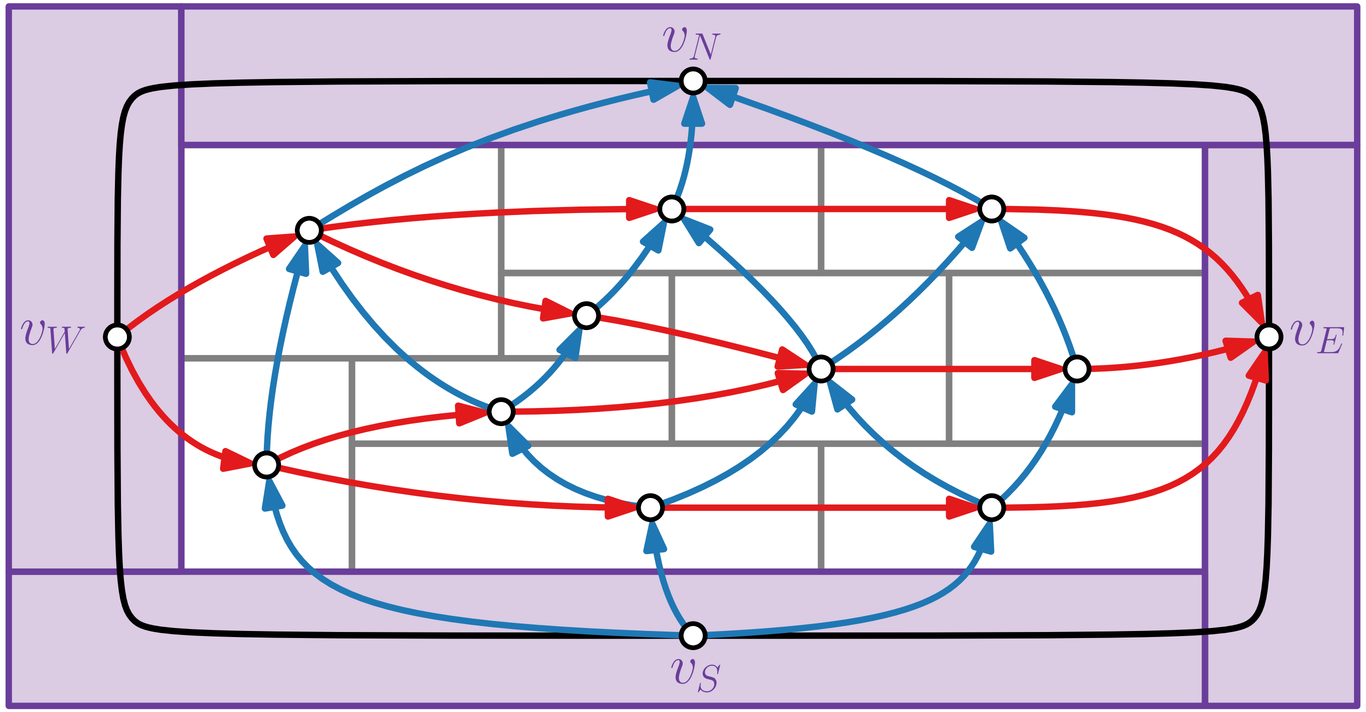
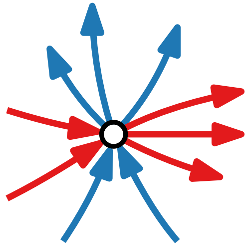

RD

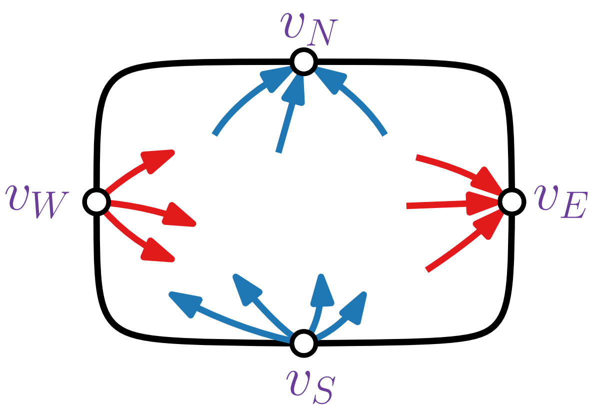
Rectangular Dual $\mathcal{R}$



Properties:



for every inner vertex



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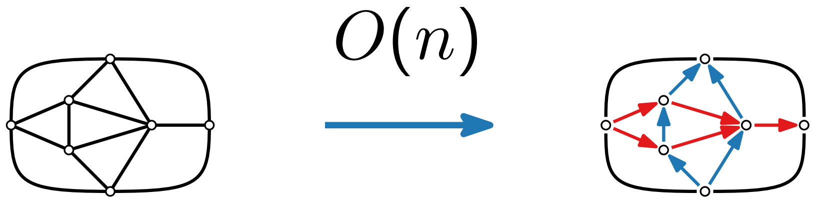
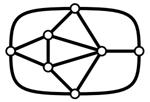


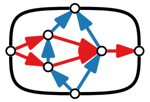
PTP REL

Regular Edge Labeling



PTP

Properly Triangulated Planar Graph G



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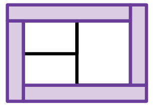
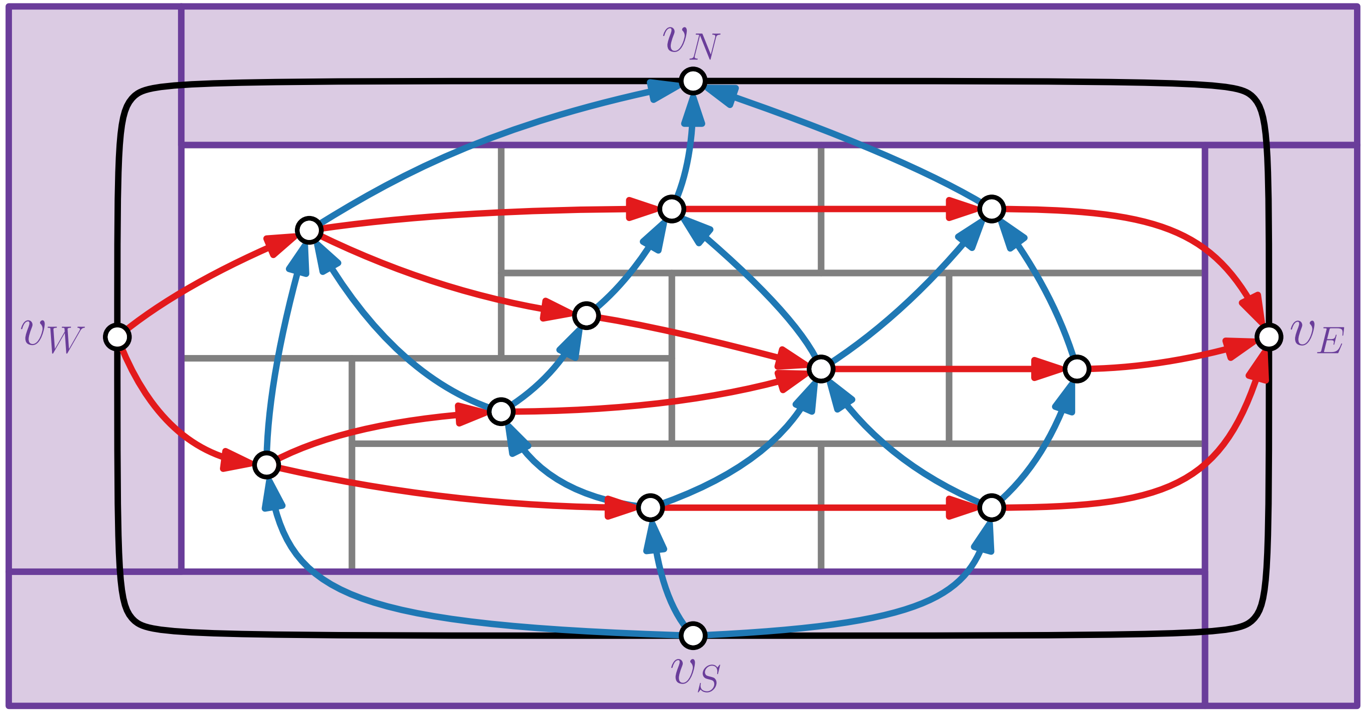


RD

Rectangular Dual $\mathcal{R}$



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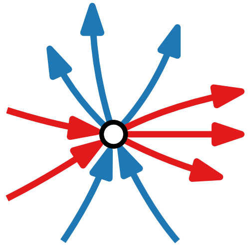

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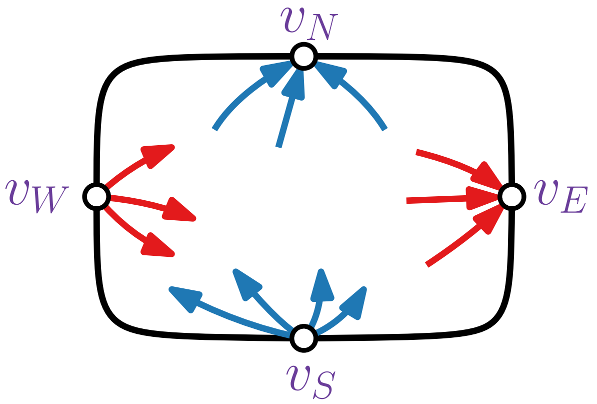

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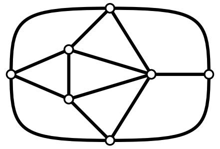
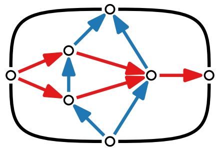


PTP

$O(n)$ →



REL

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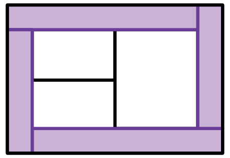

RD

Refined Canonical Order

Theorem.
Let G be a PTP graph that is embedded in its unique planar embedding with counter-clockwise outer face $\langle v_W, v_S, v_E, v_N \rangle$.

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- The subgraph G_{k-1} induced by $v_1, \ldots, v_{k-1}$ is biconnected

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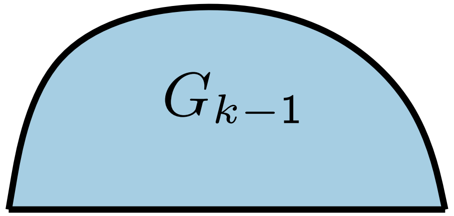

Refined Canonical Order

Theorem.
Let G be a PTP graph that is embedded in its unique planar embedding with counter-clockwise outer face $\langle v_W, v_S, v_E, v_N \rangle$.
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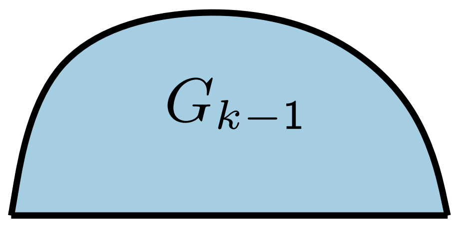

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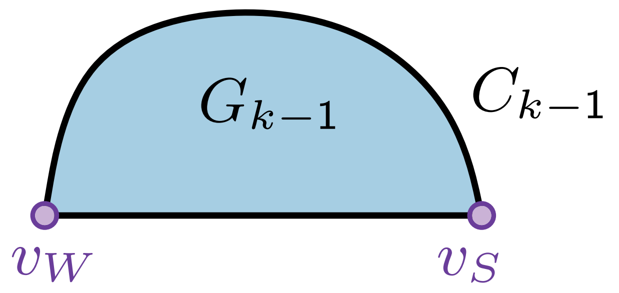

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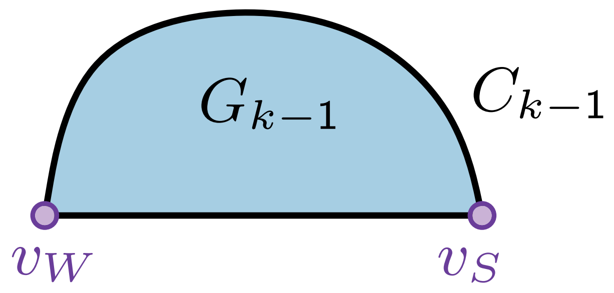

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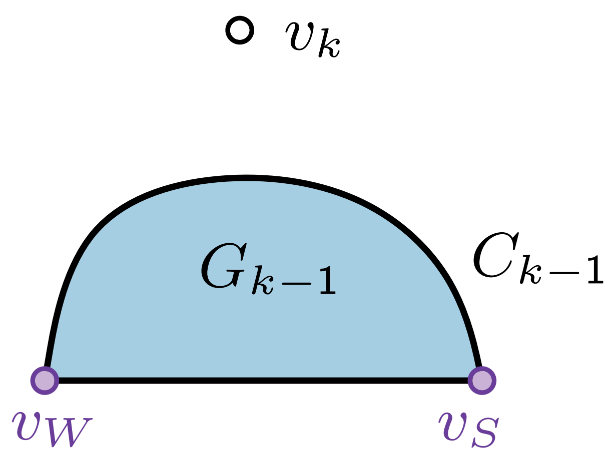

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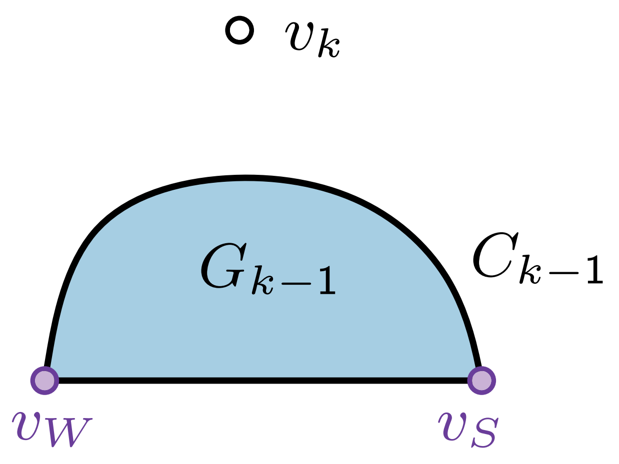

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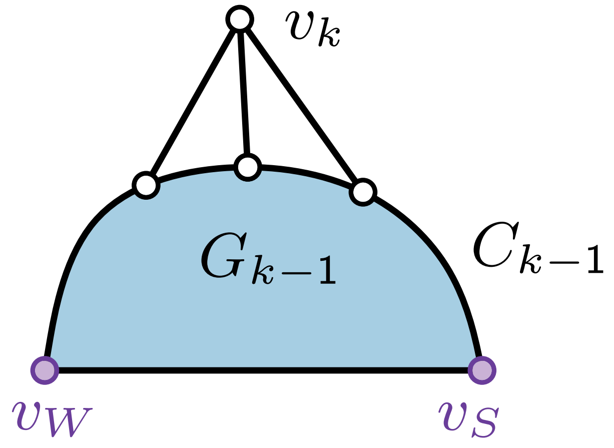

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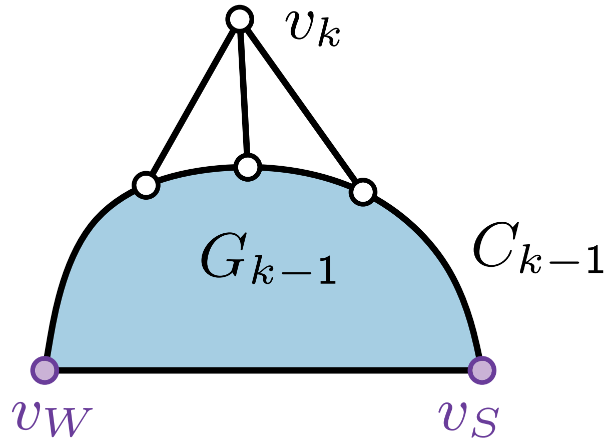

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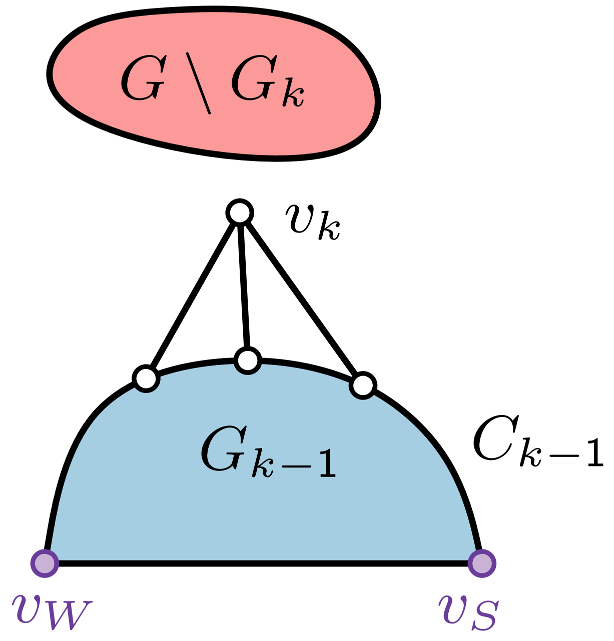

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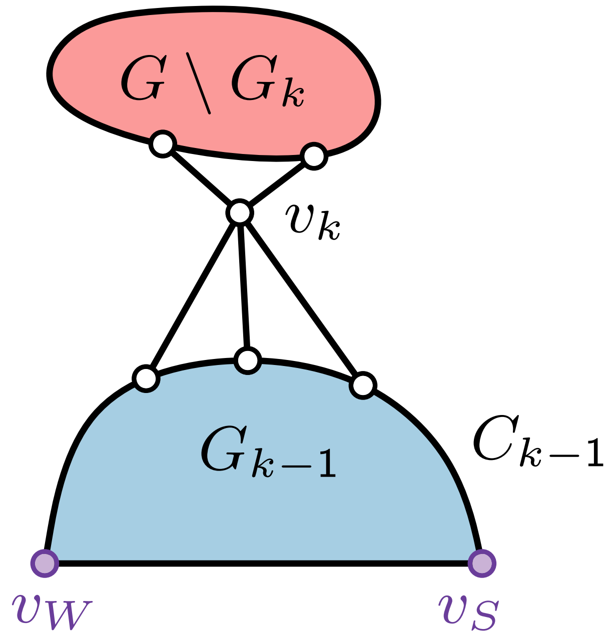
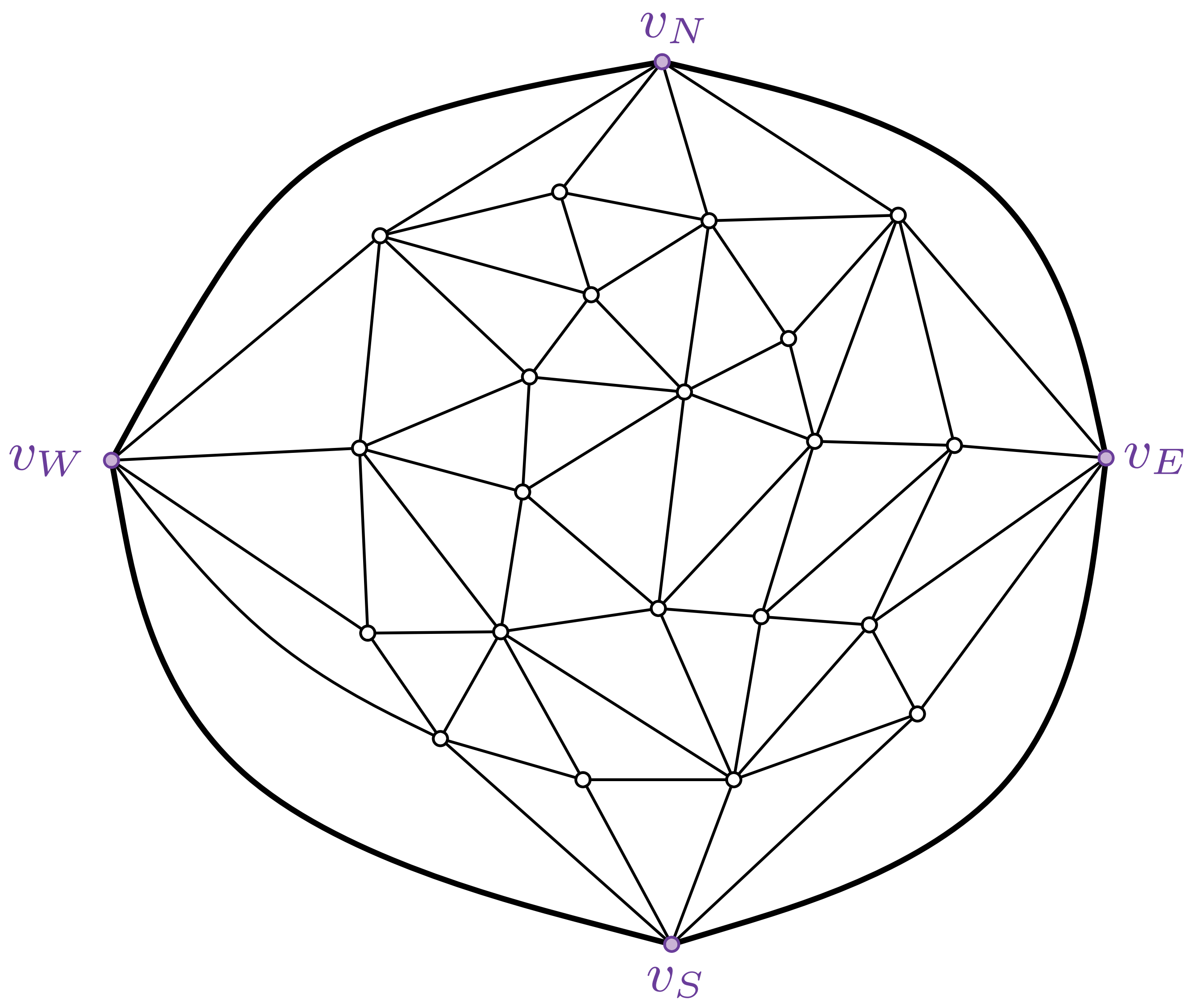


Refined Canonical Order Example



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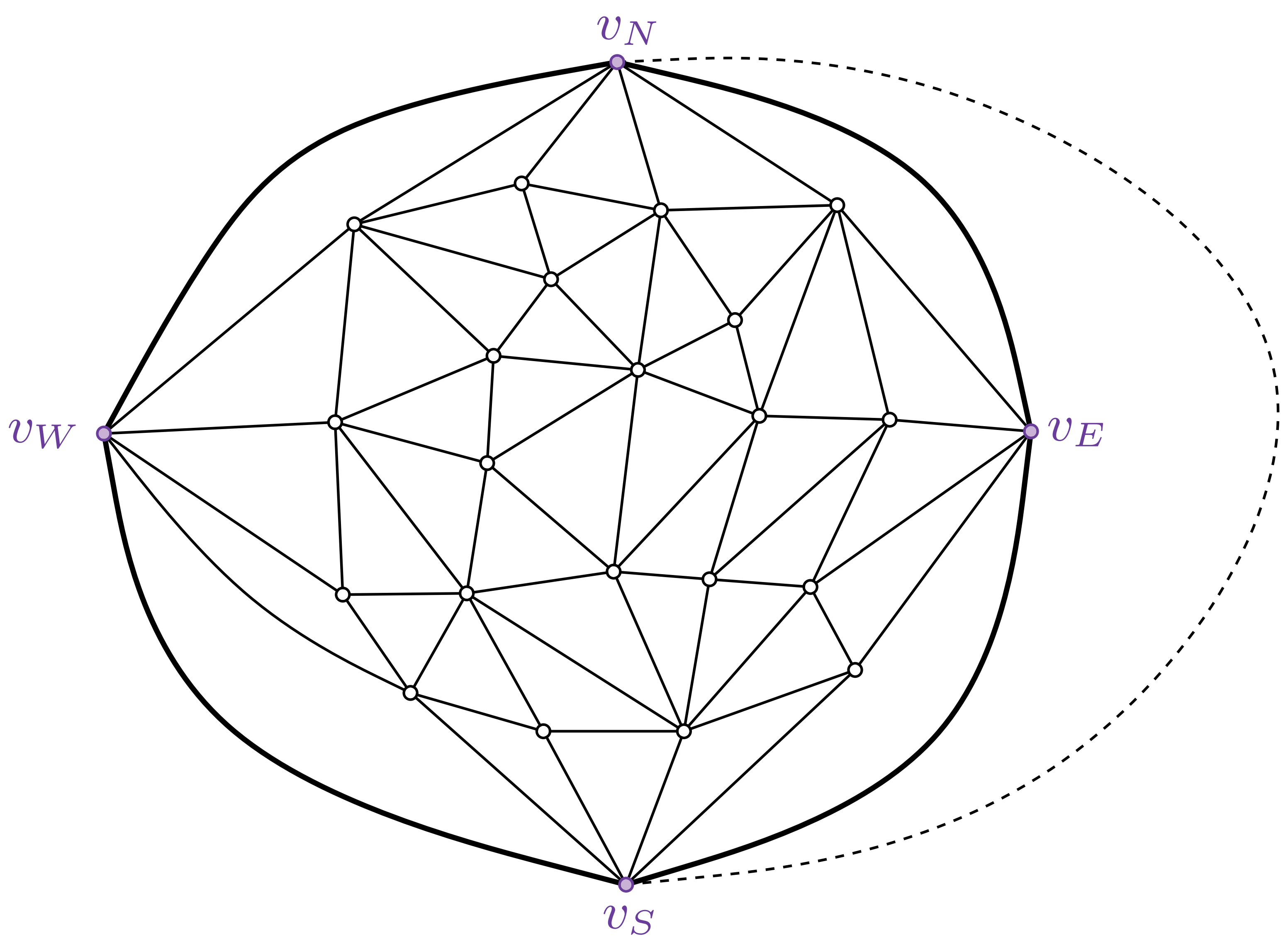

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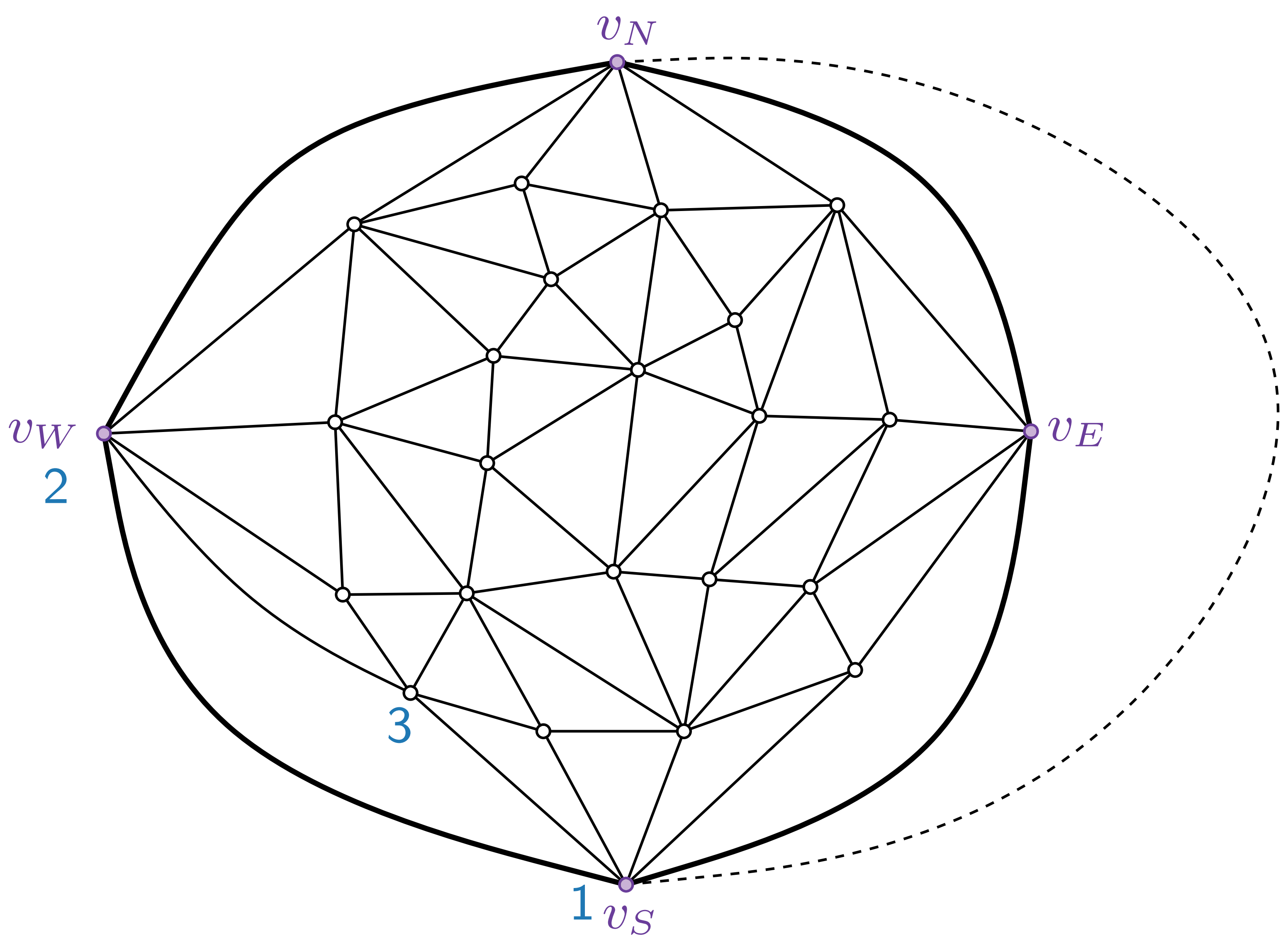

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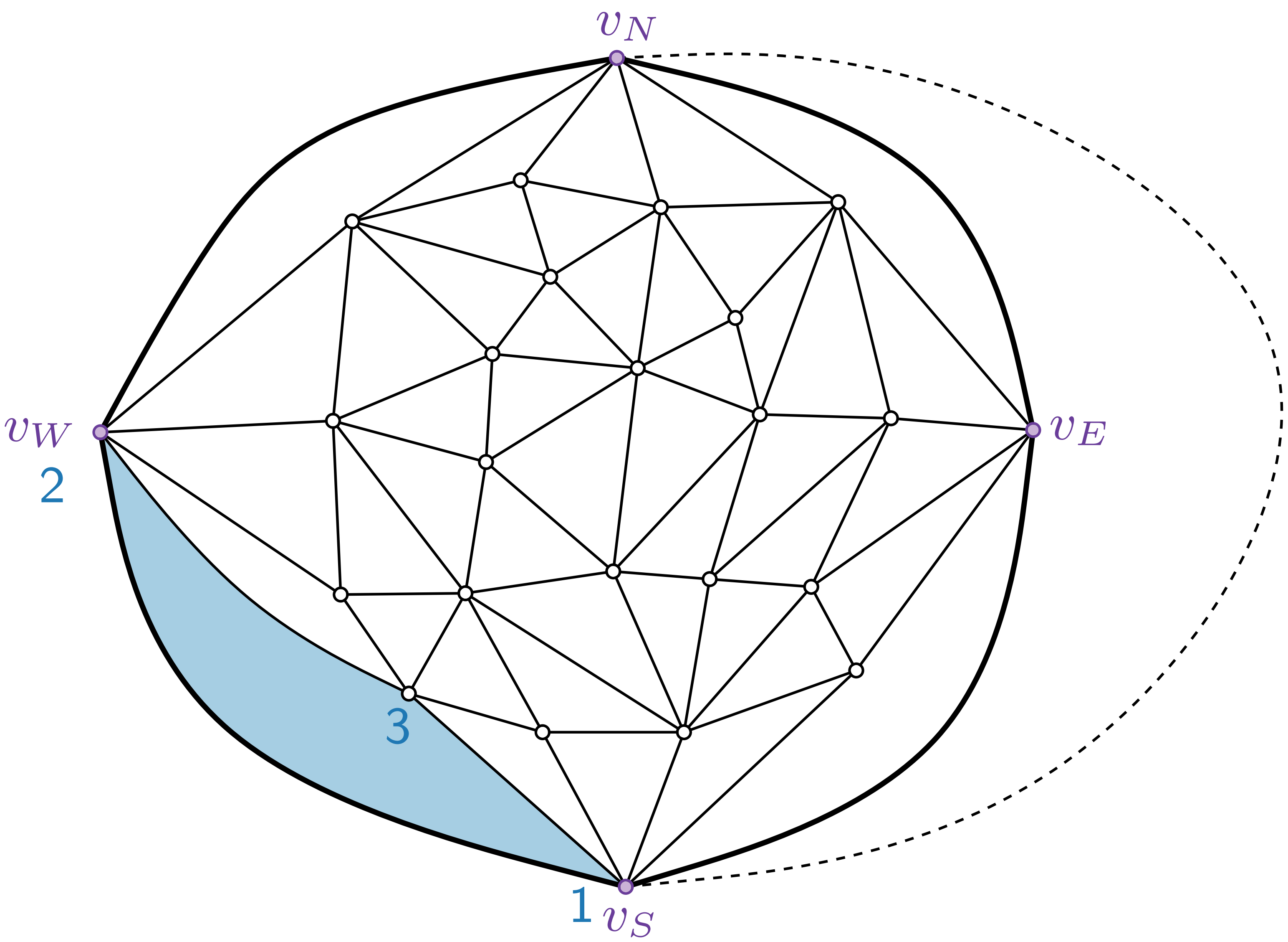

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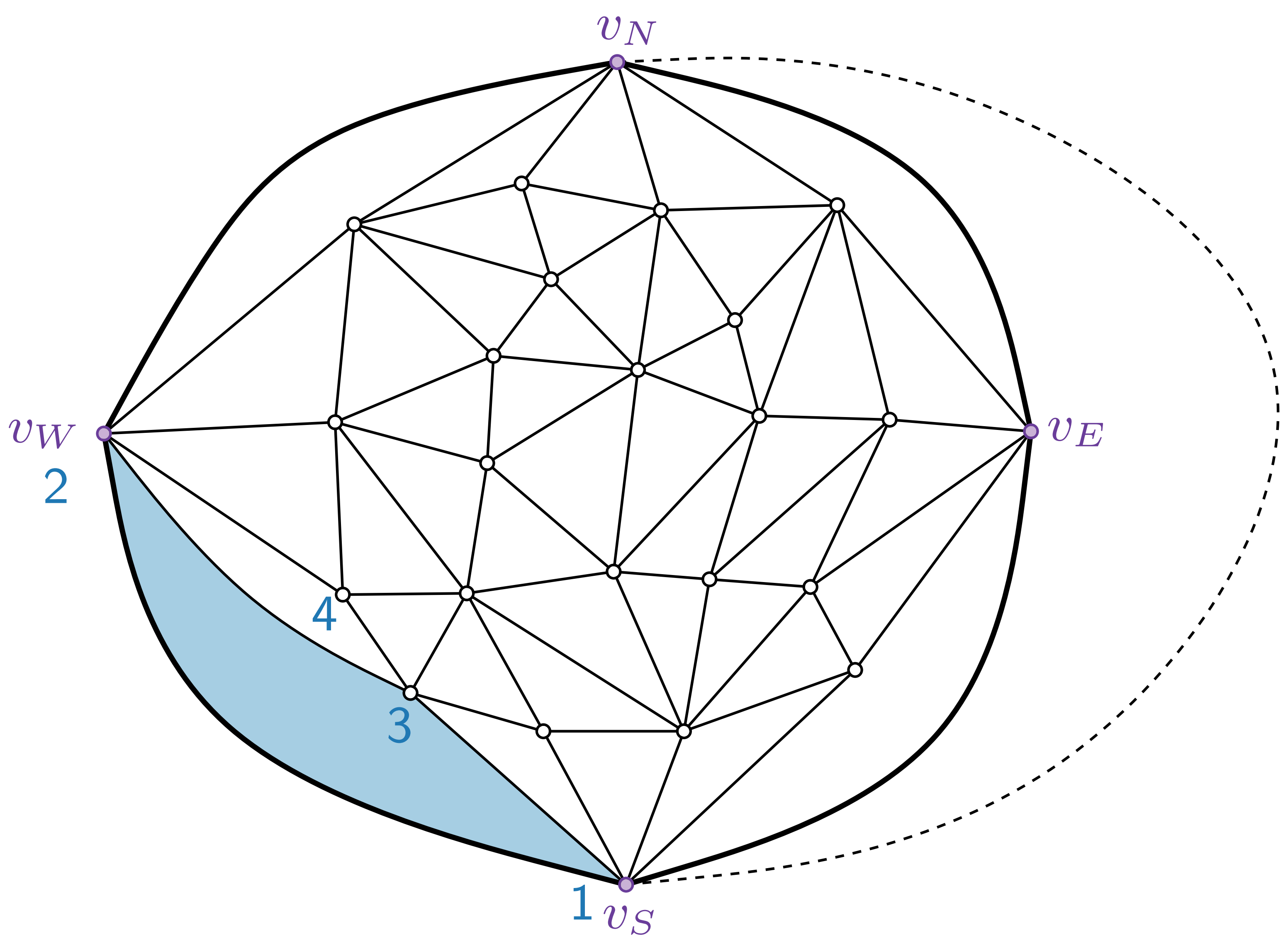

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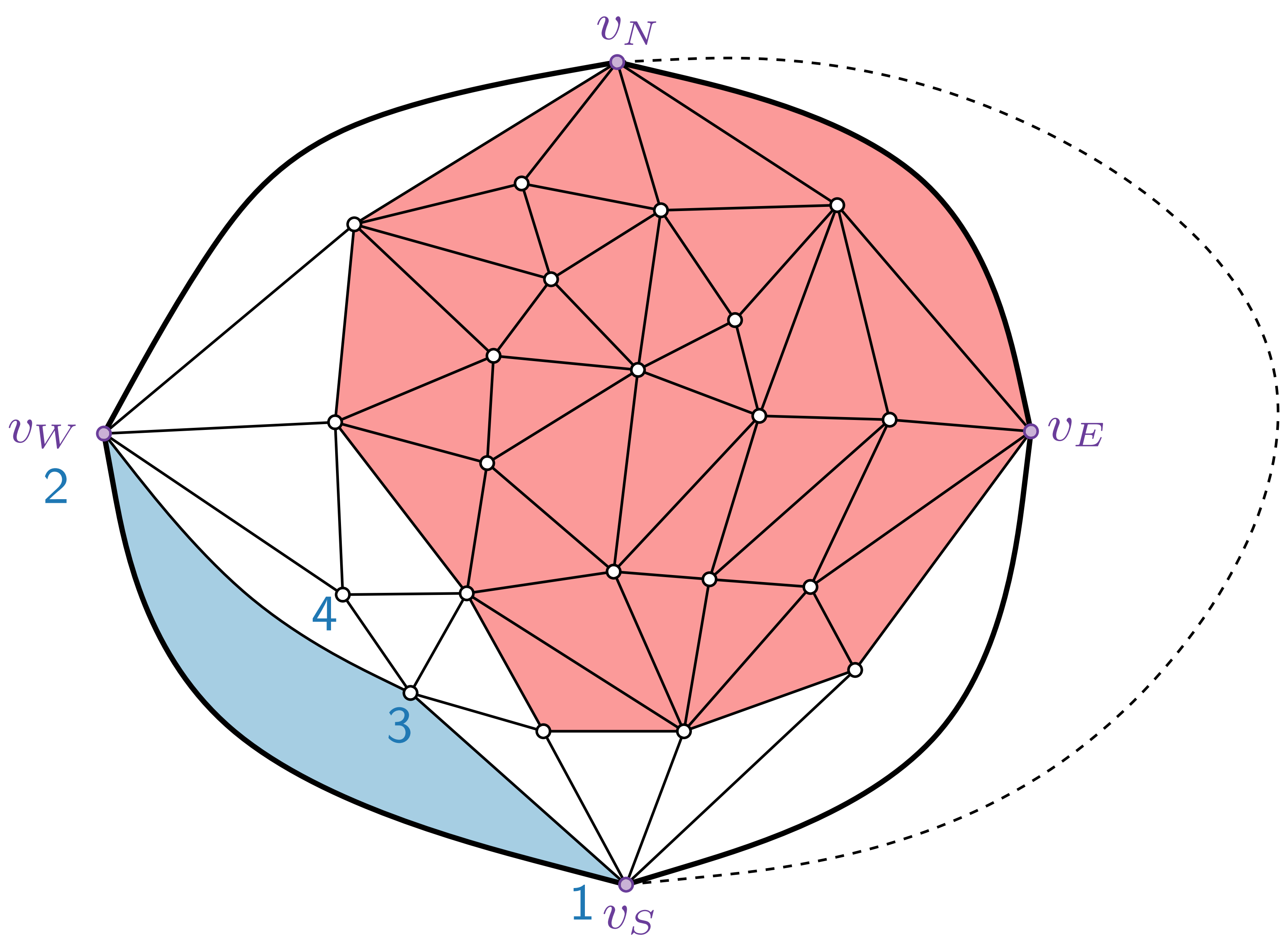

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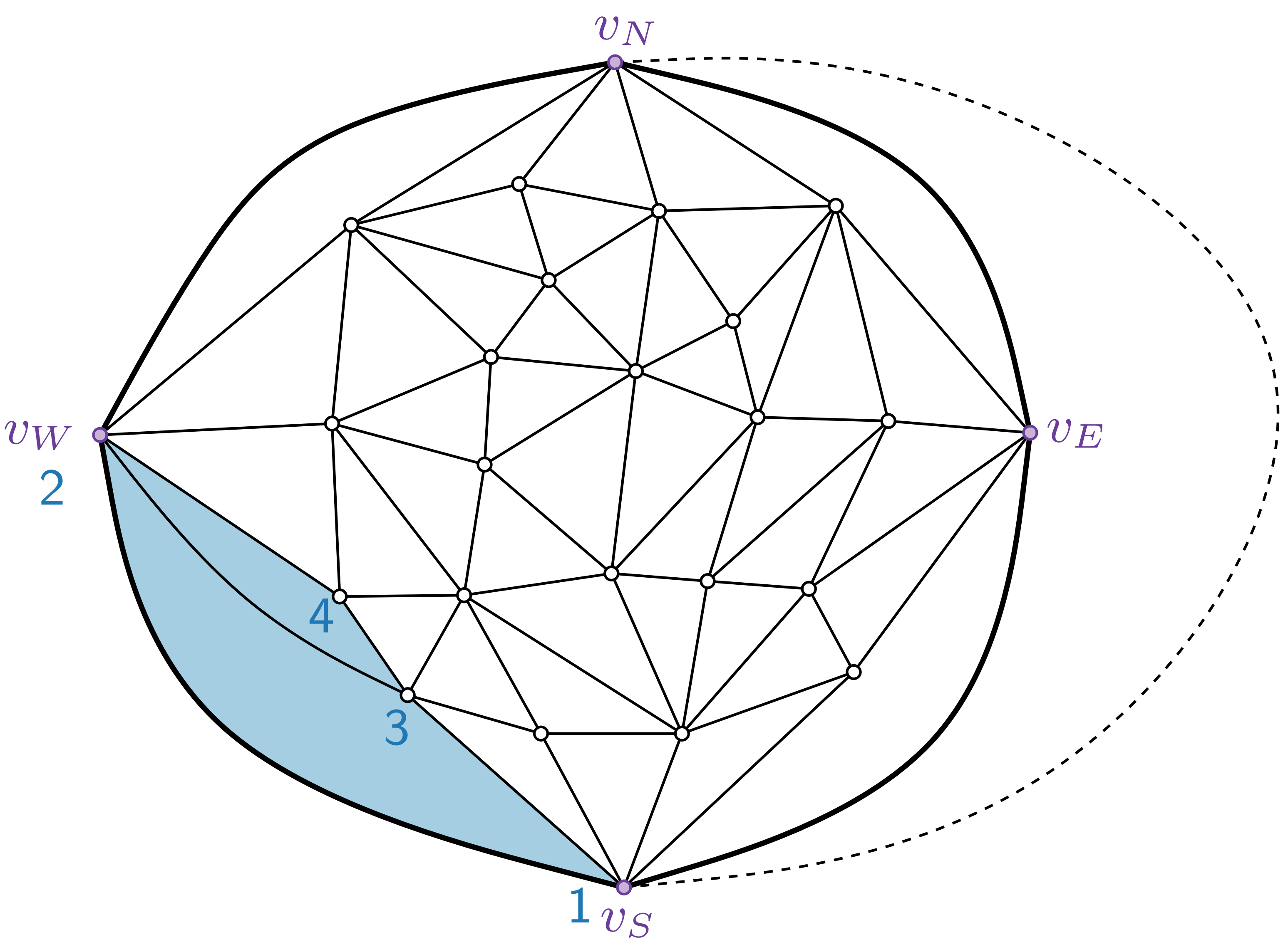

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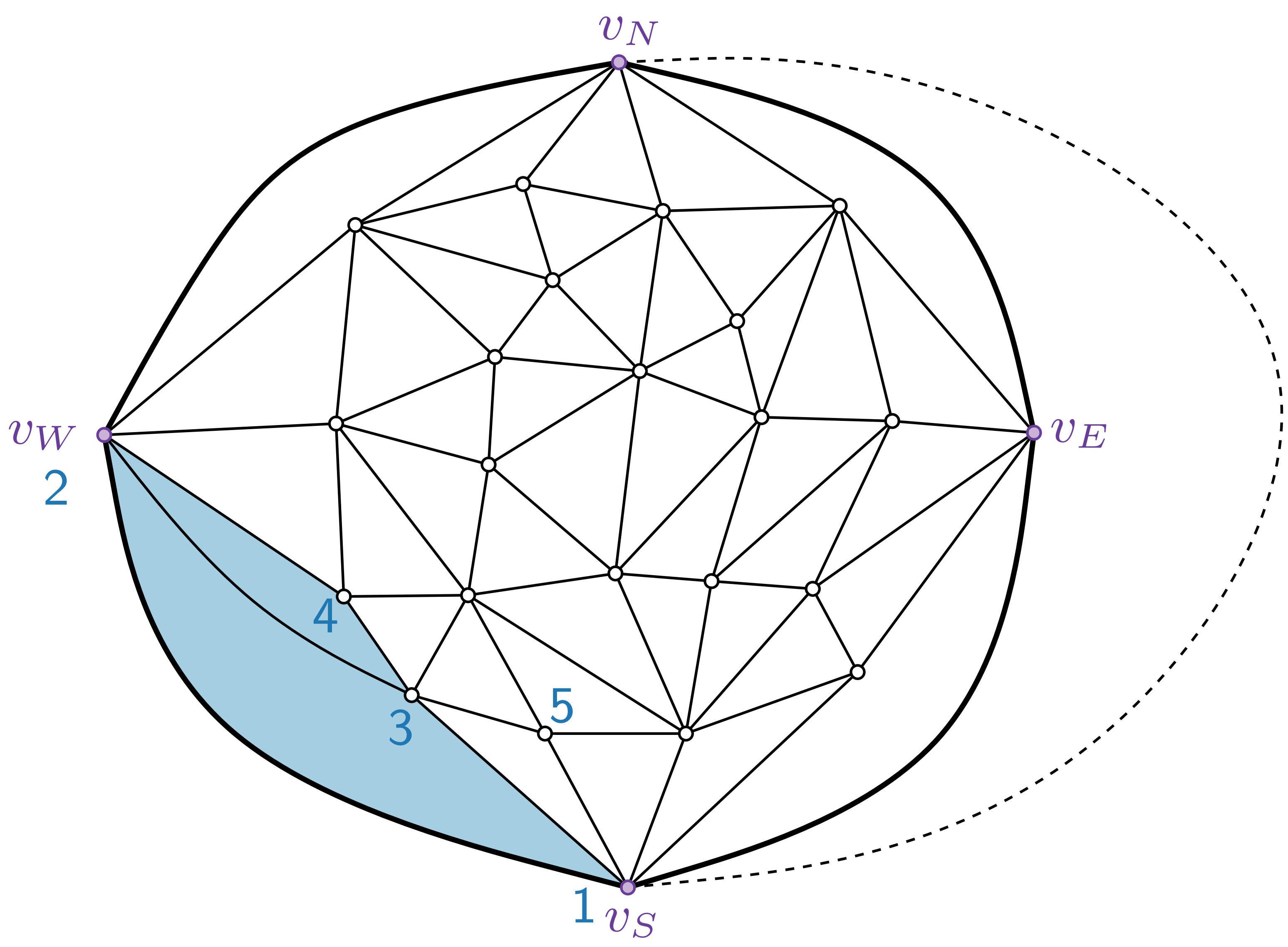

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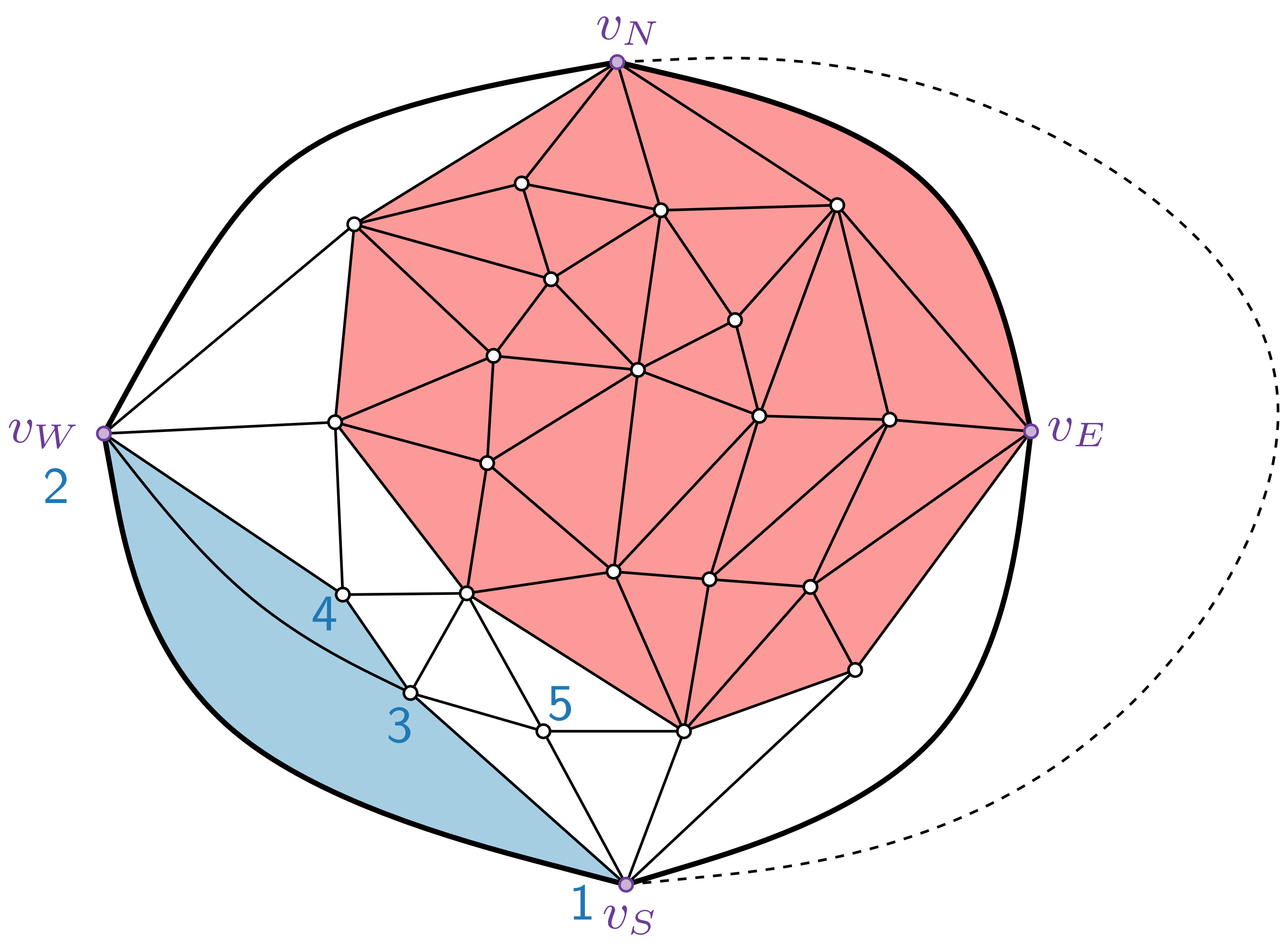

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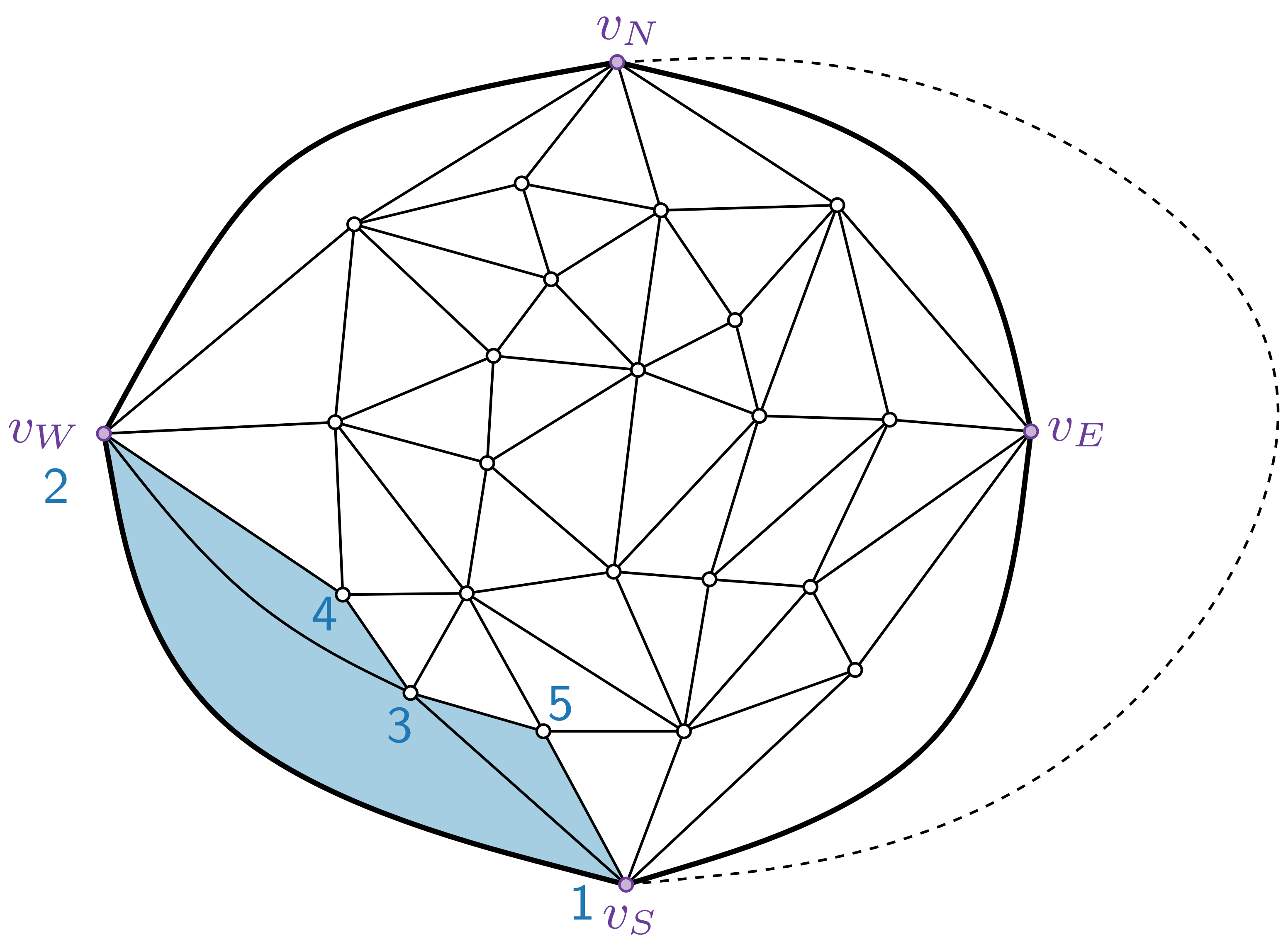

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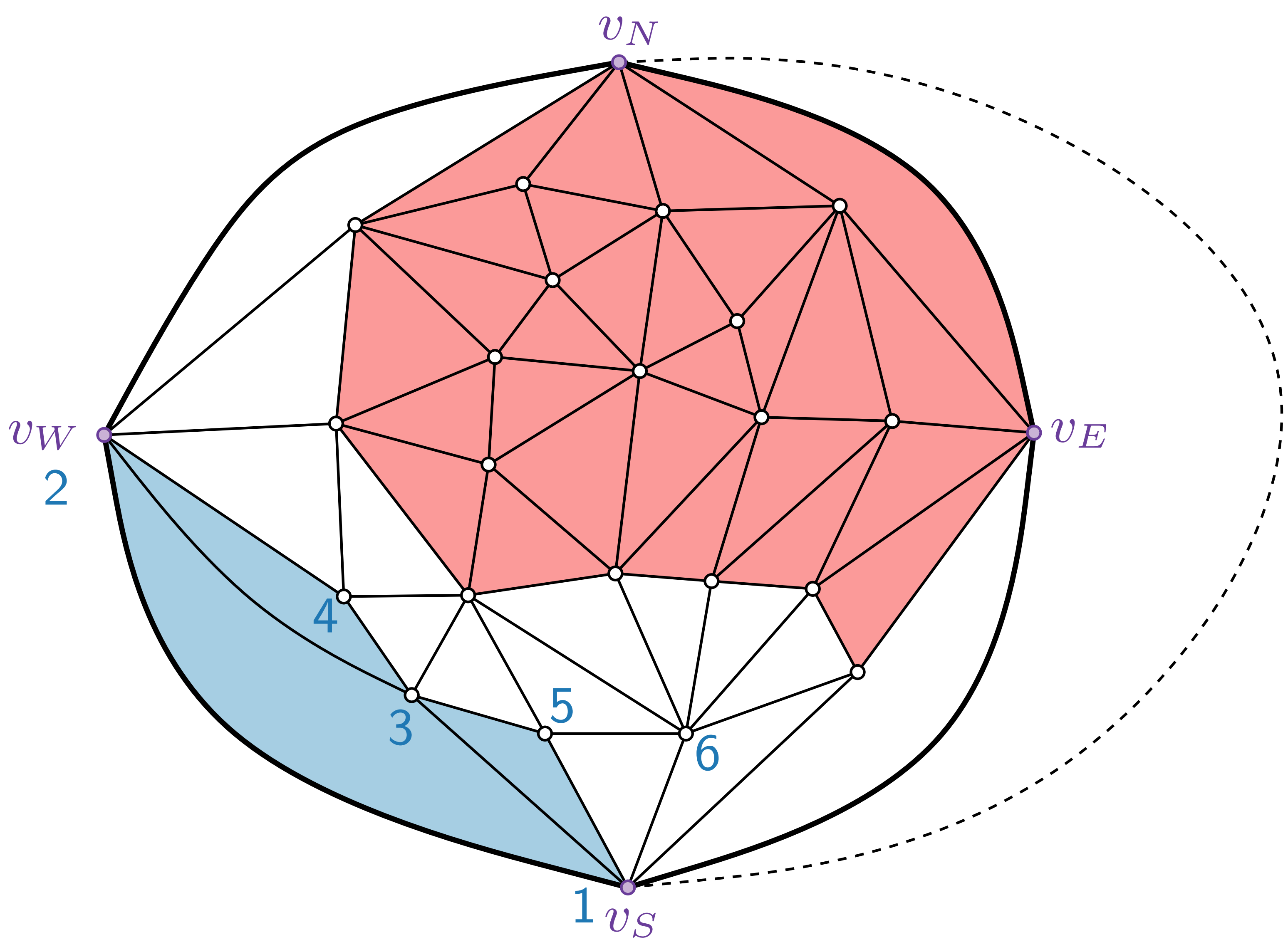

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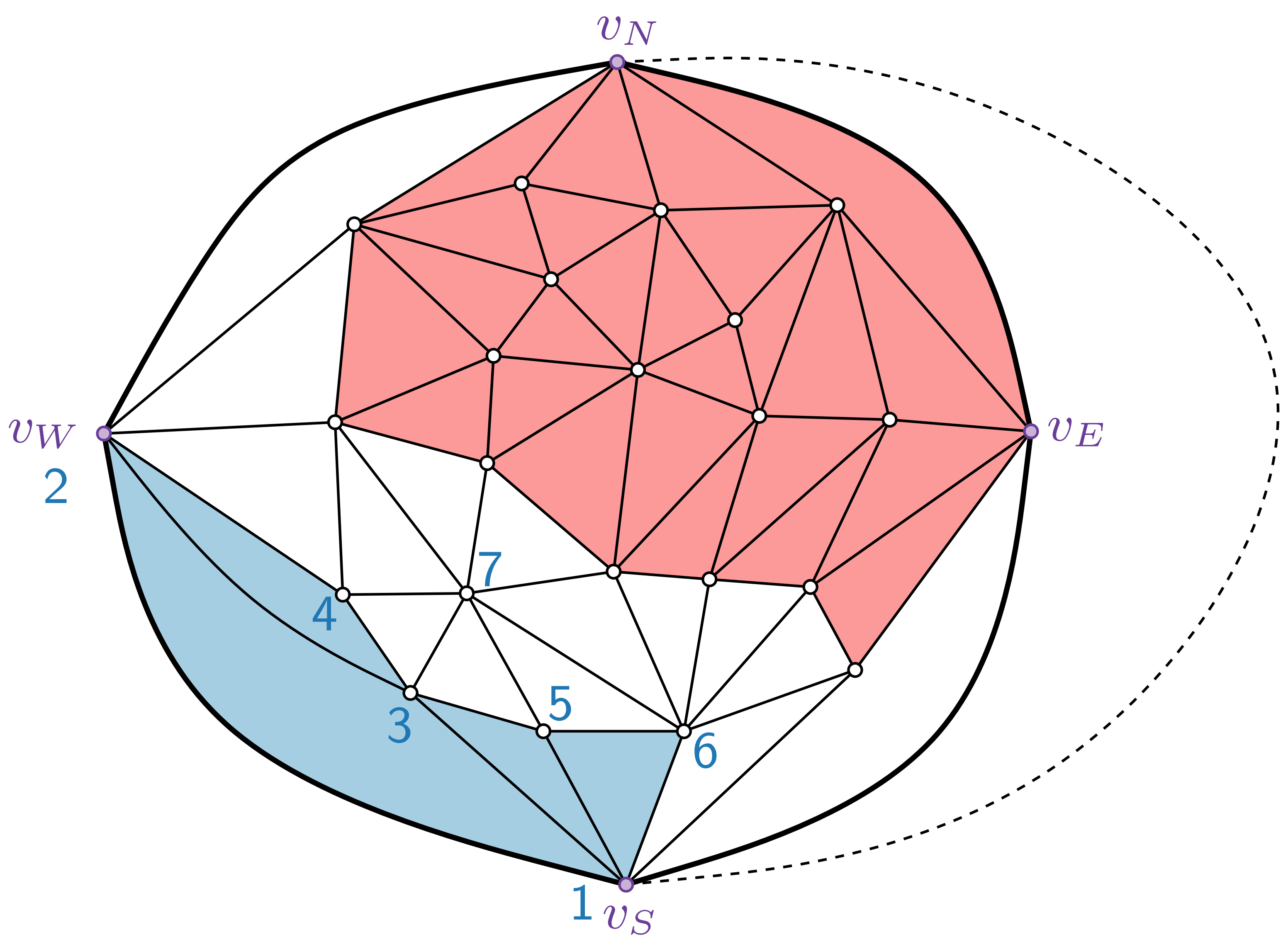

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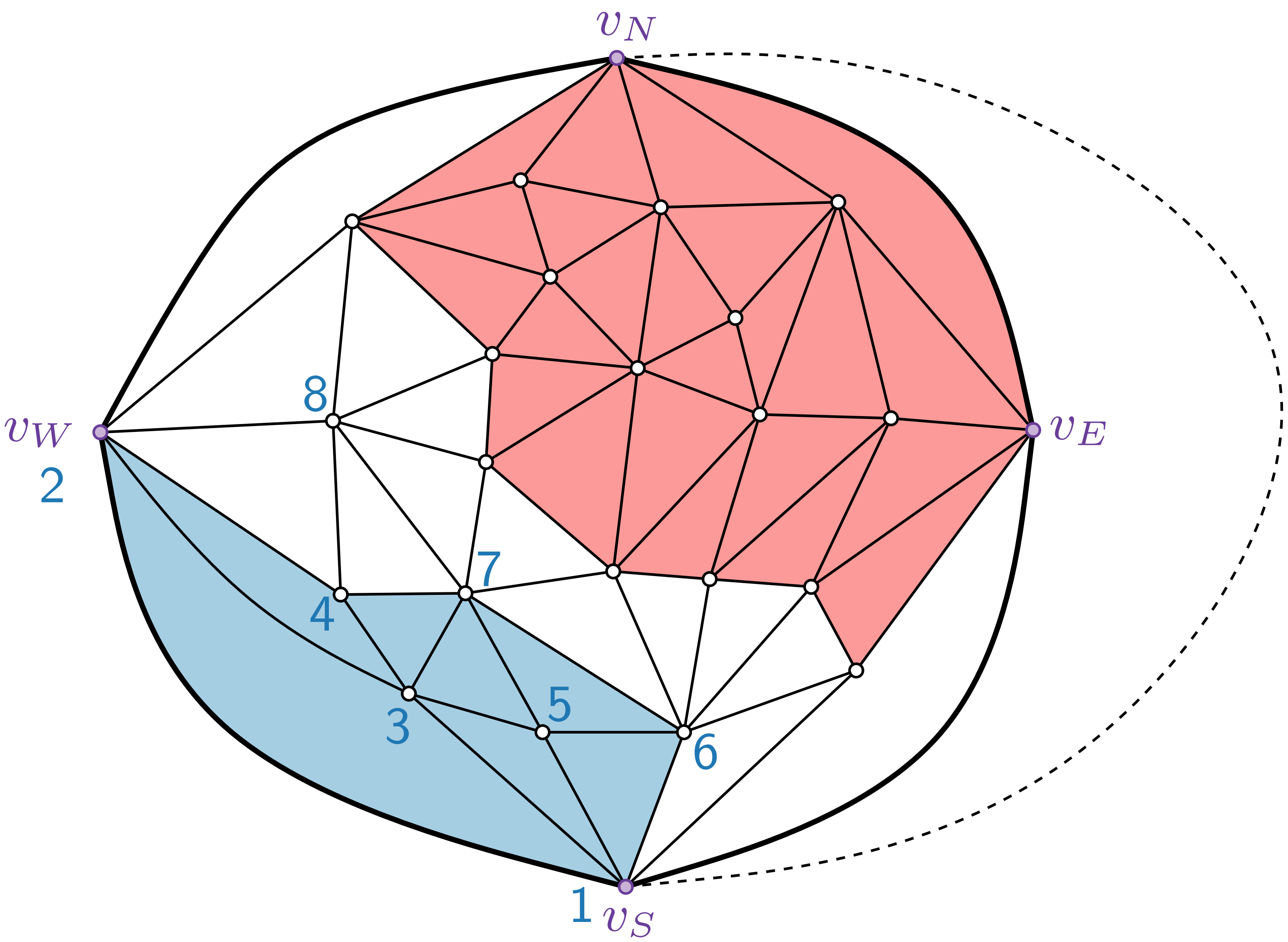

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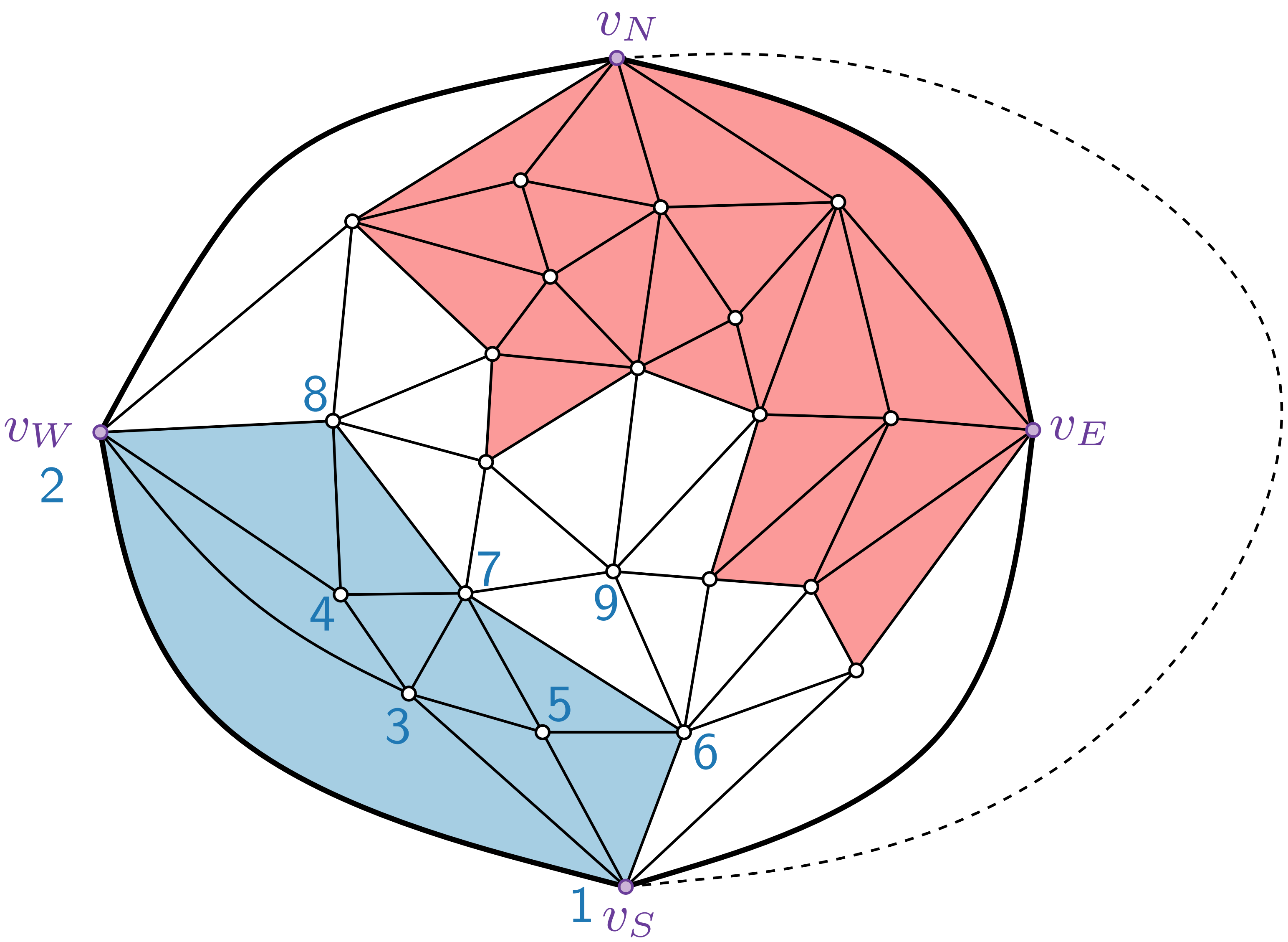

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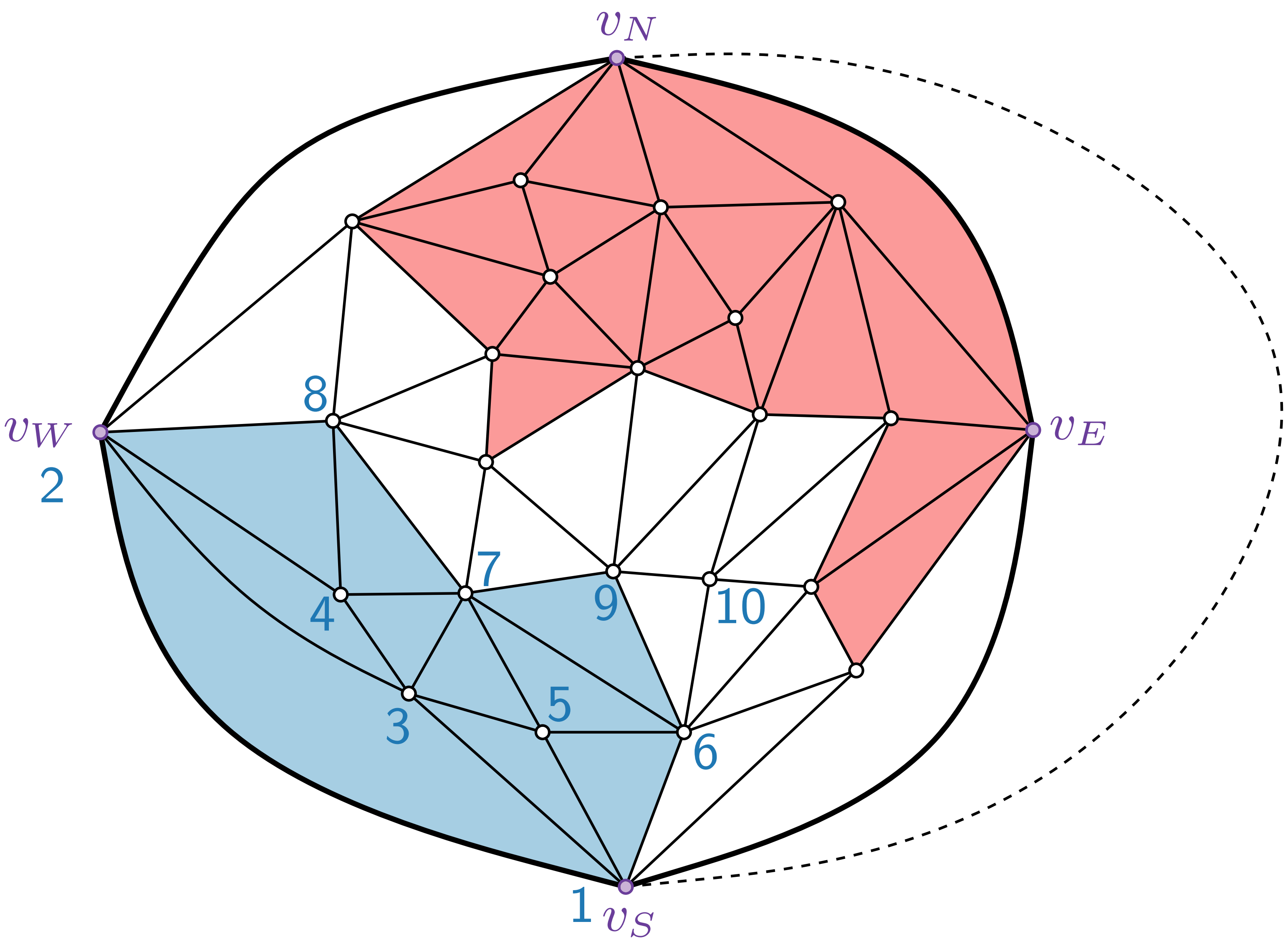

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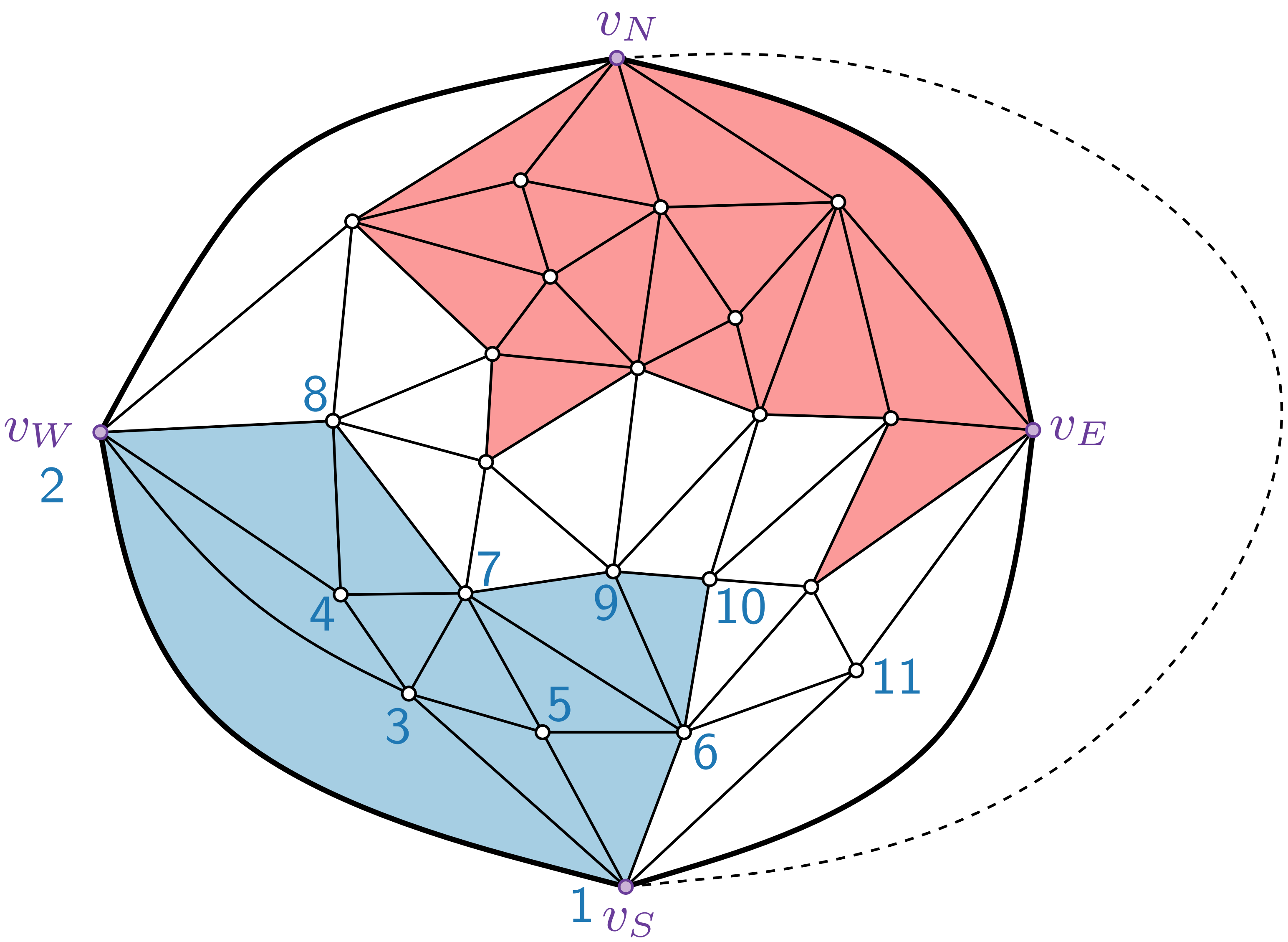

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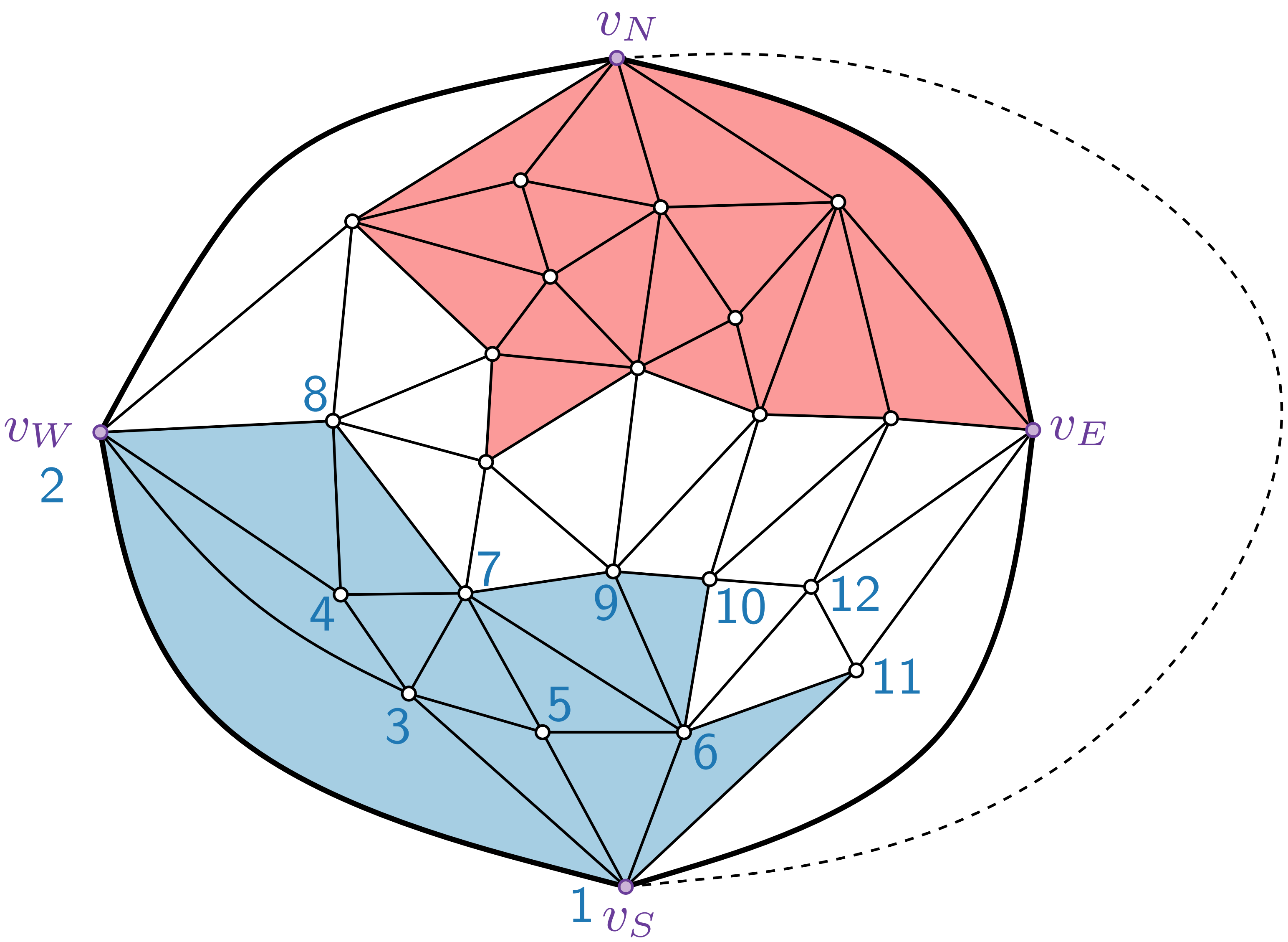

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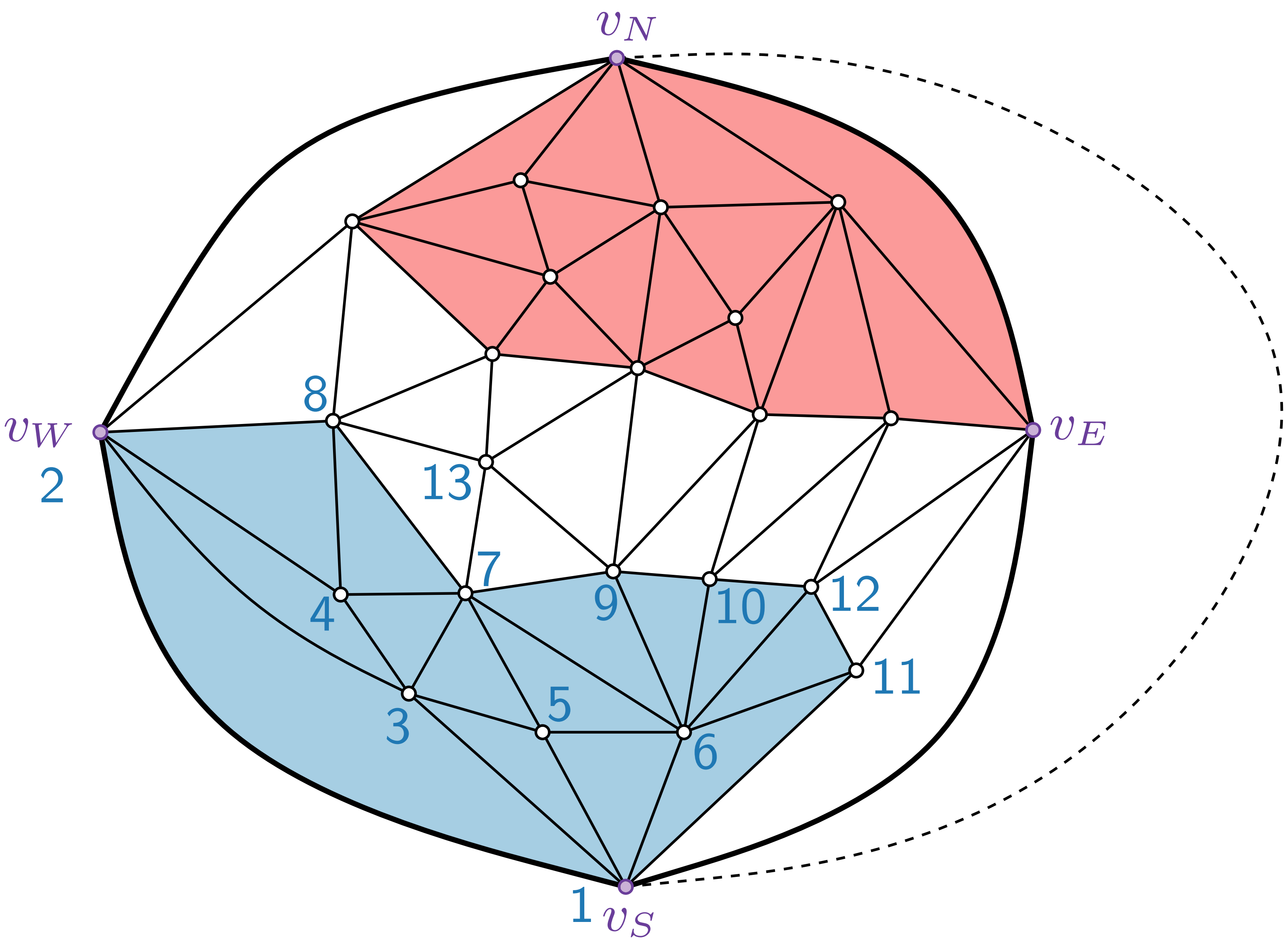

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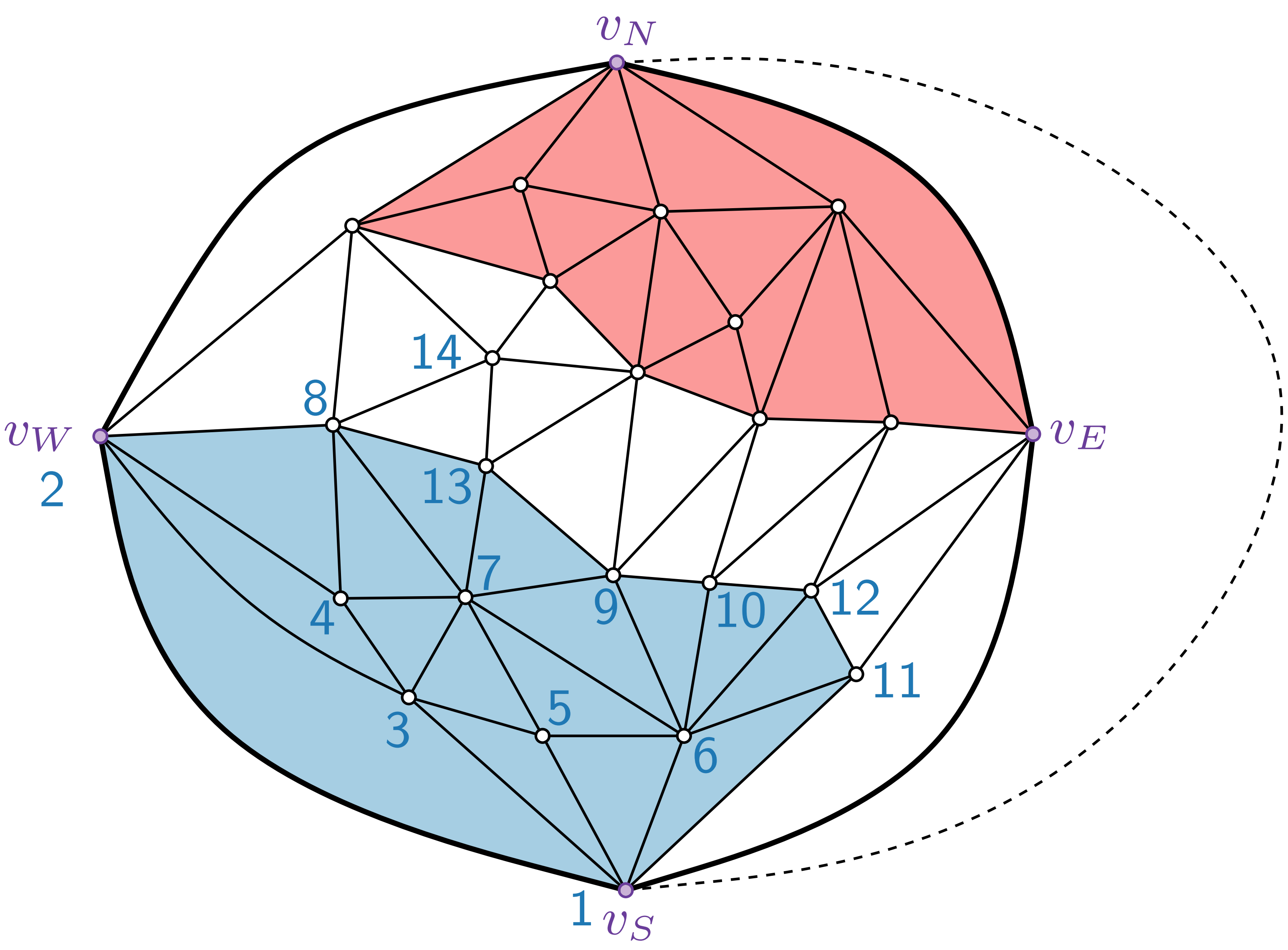

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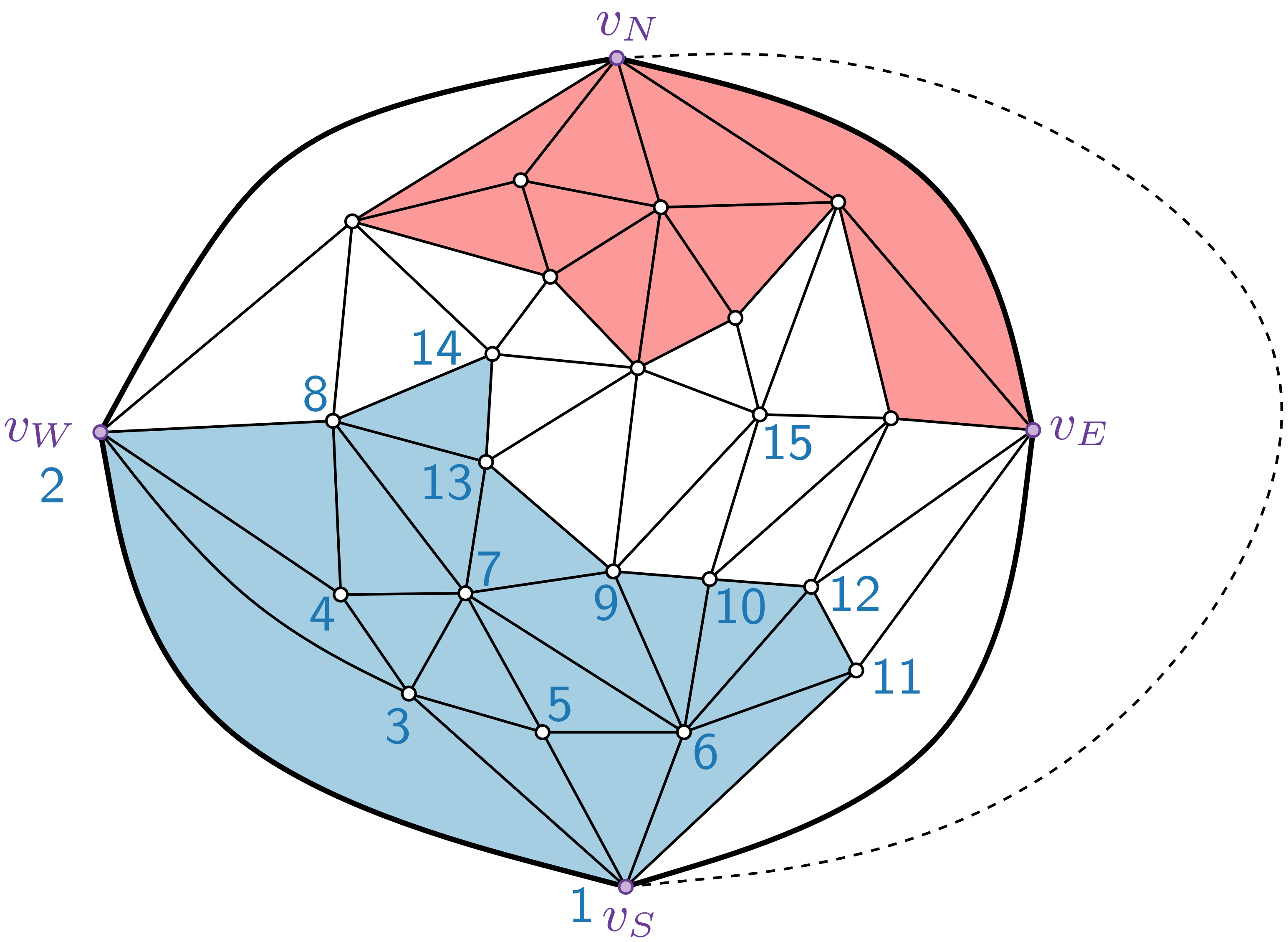

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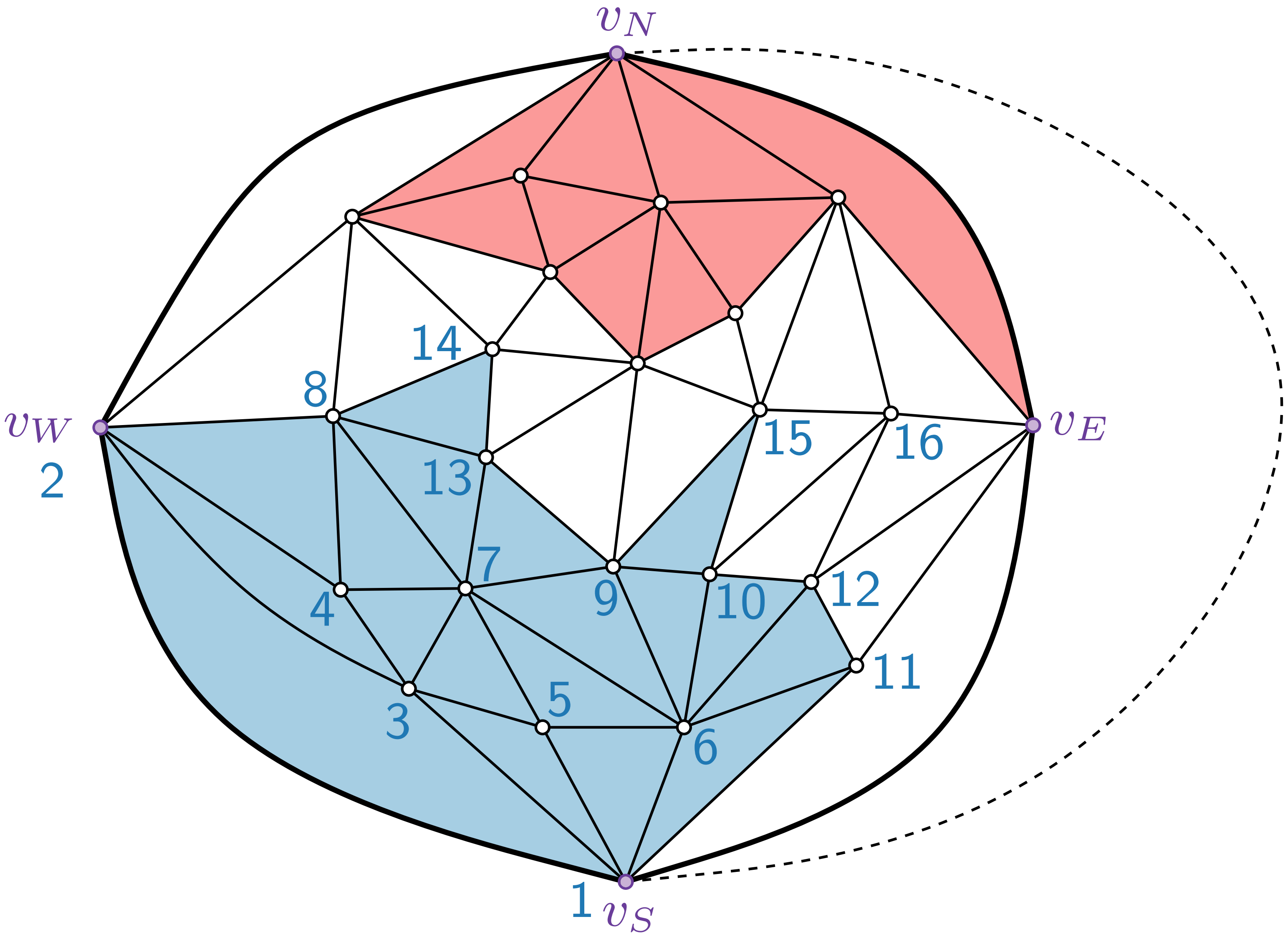

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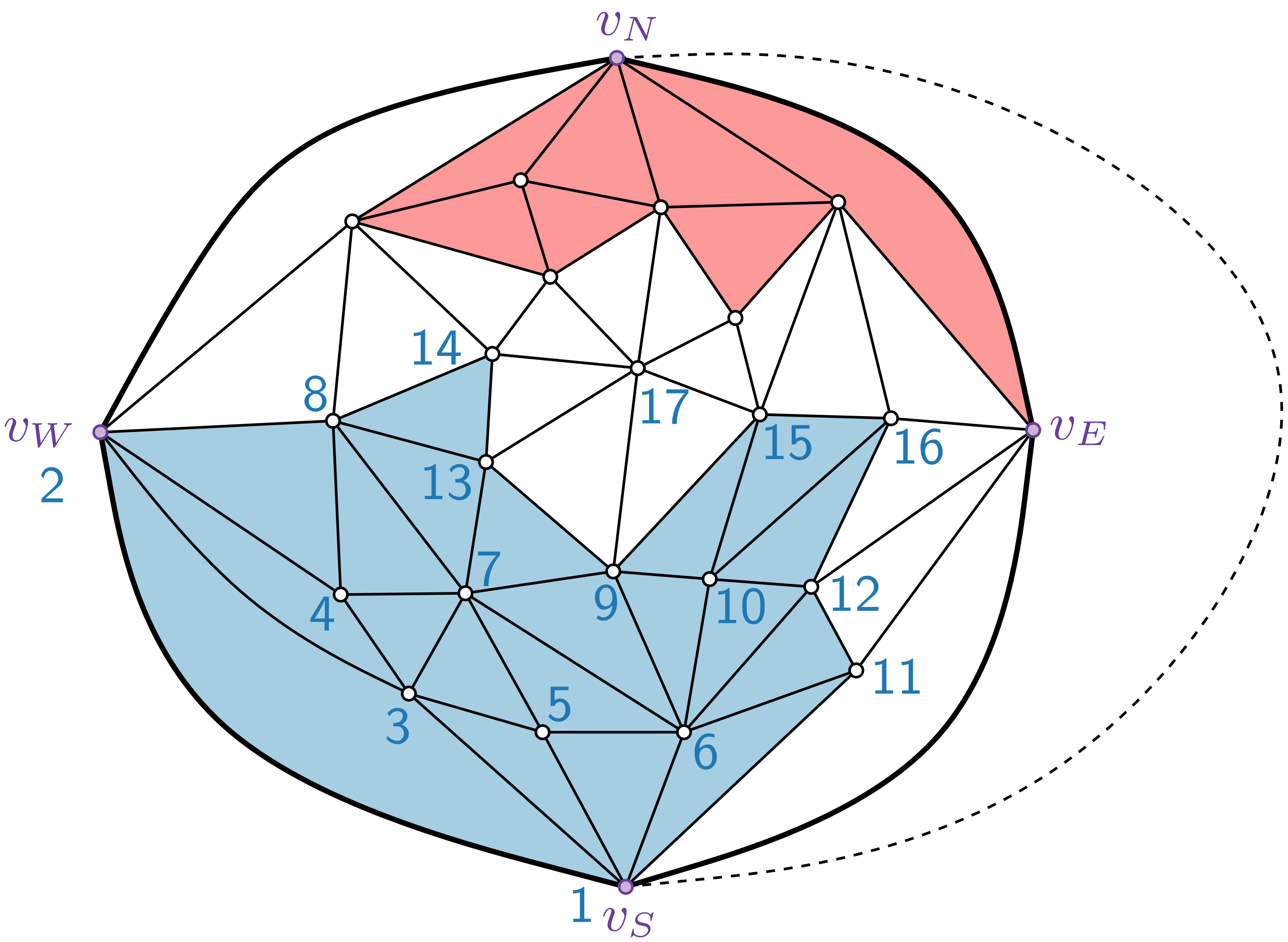

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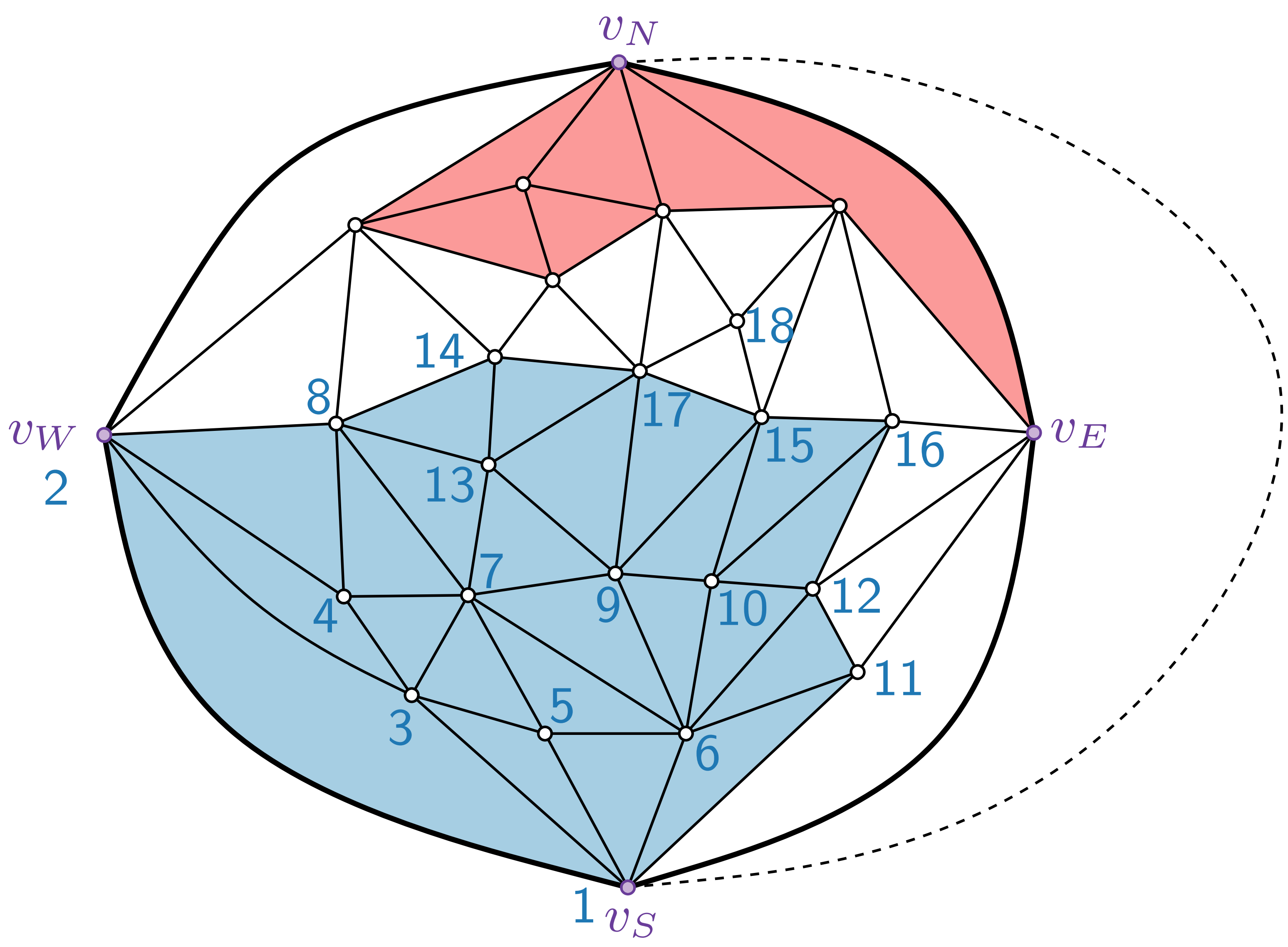

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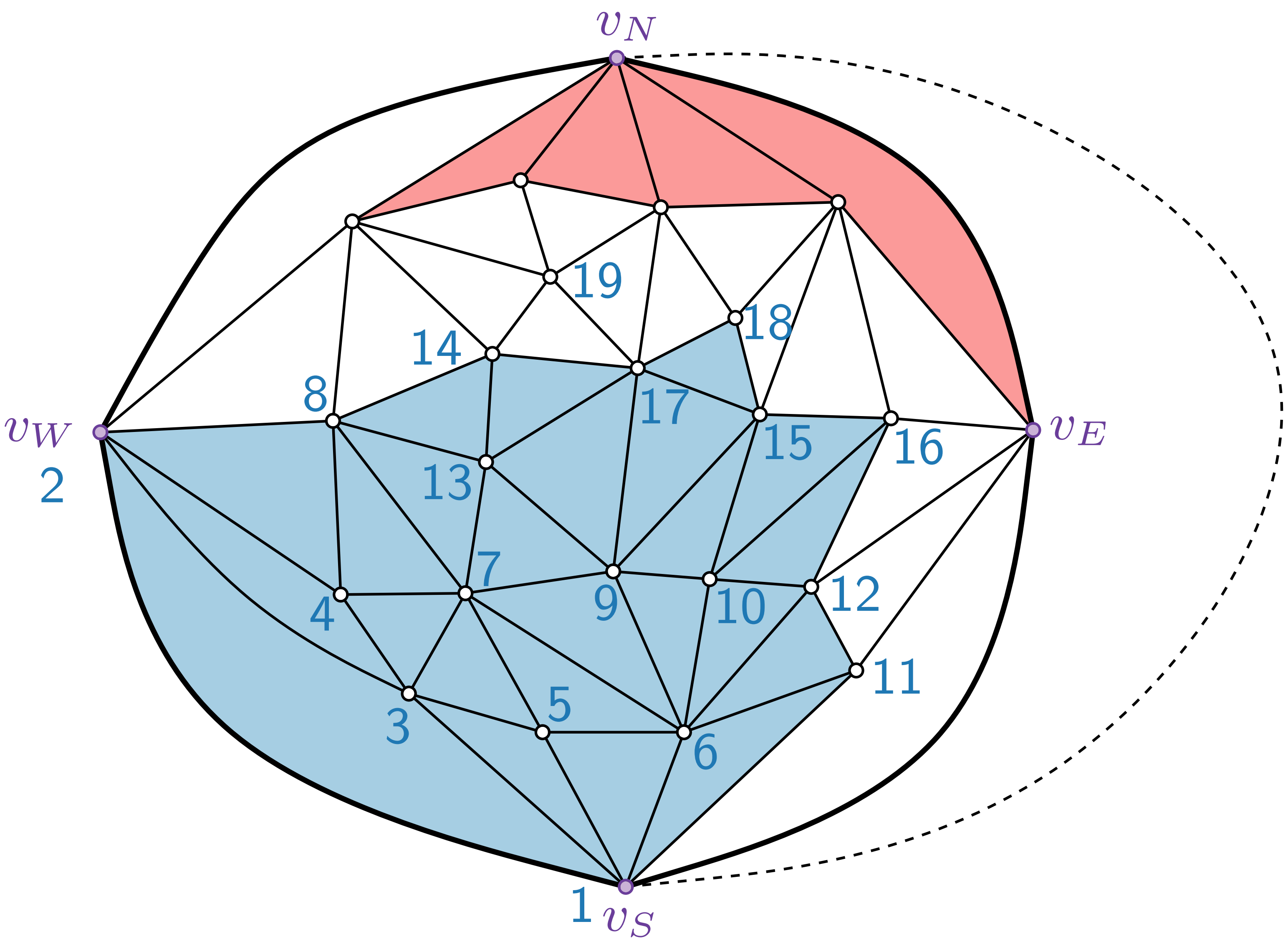

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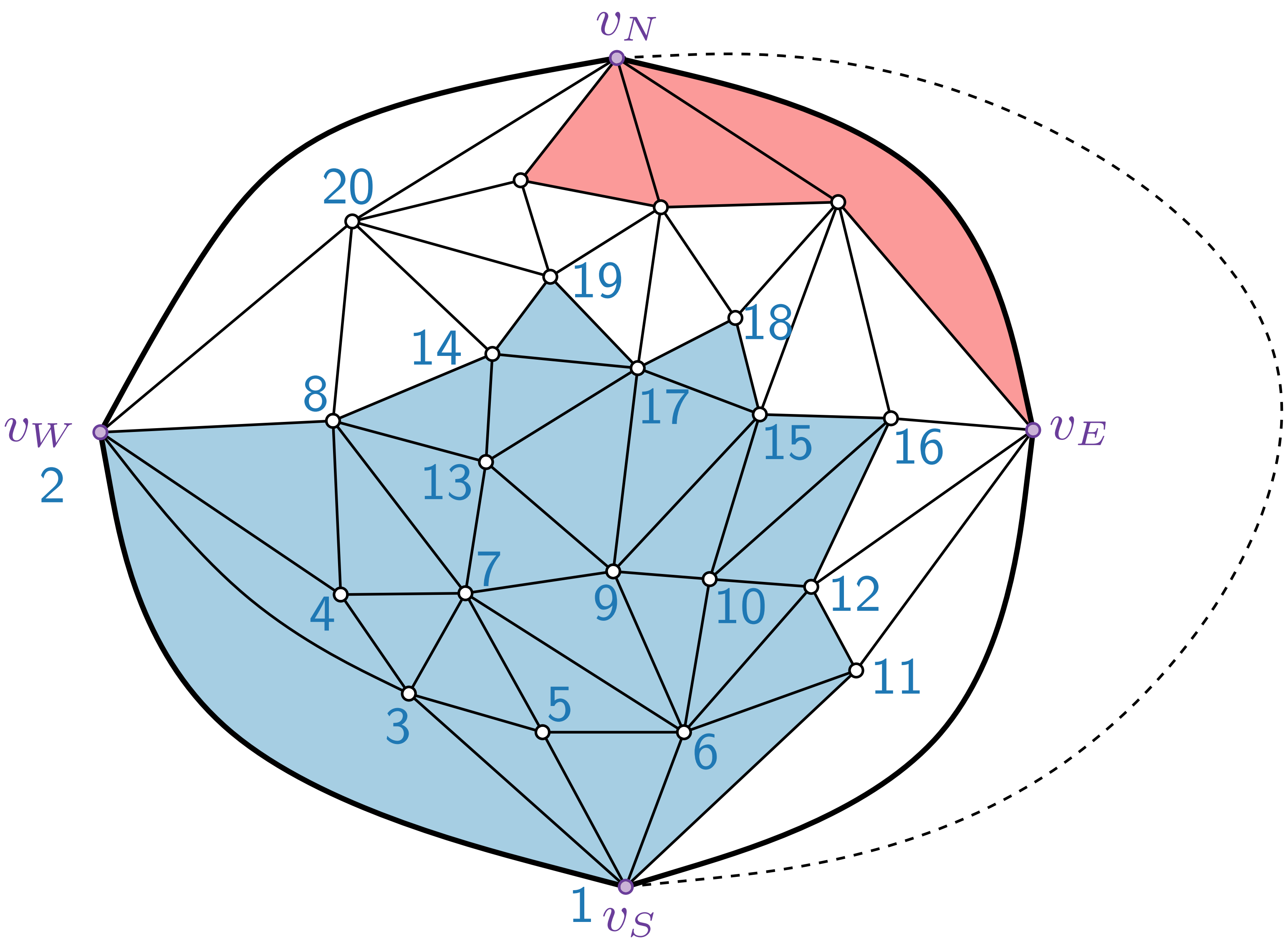

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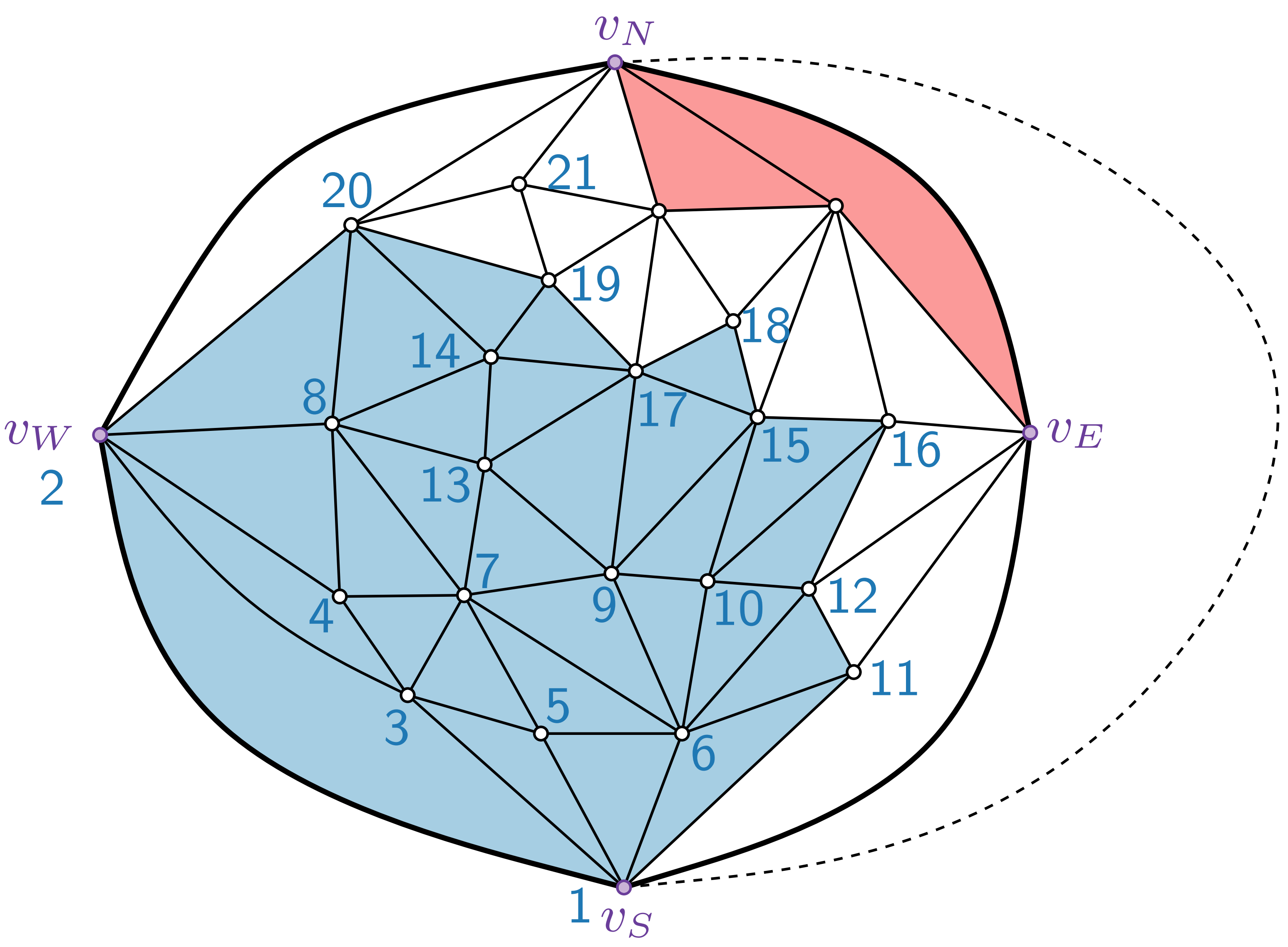

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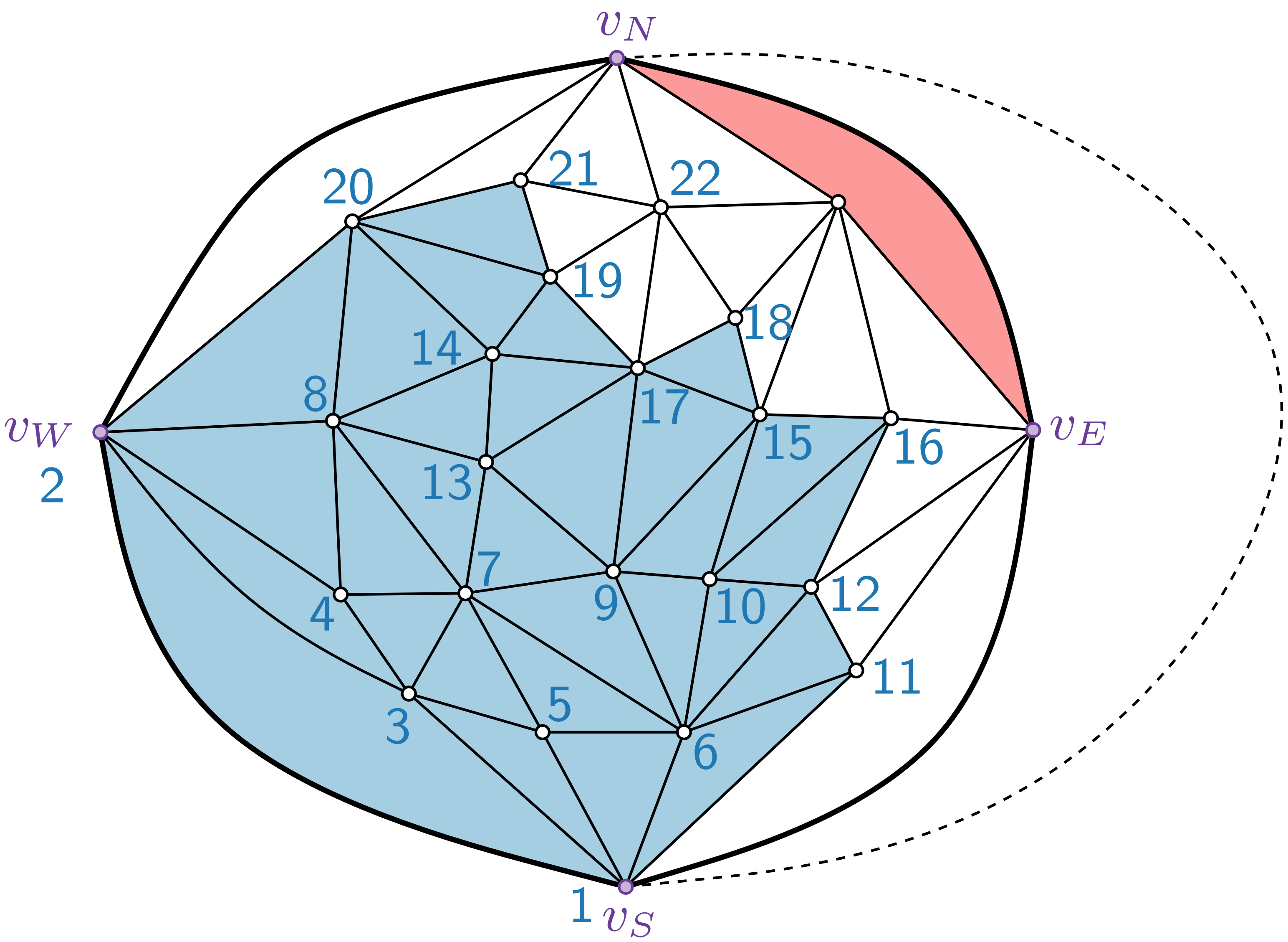

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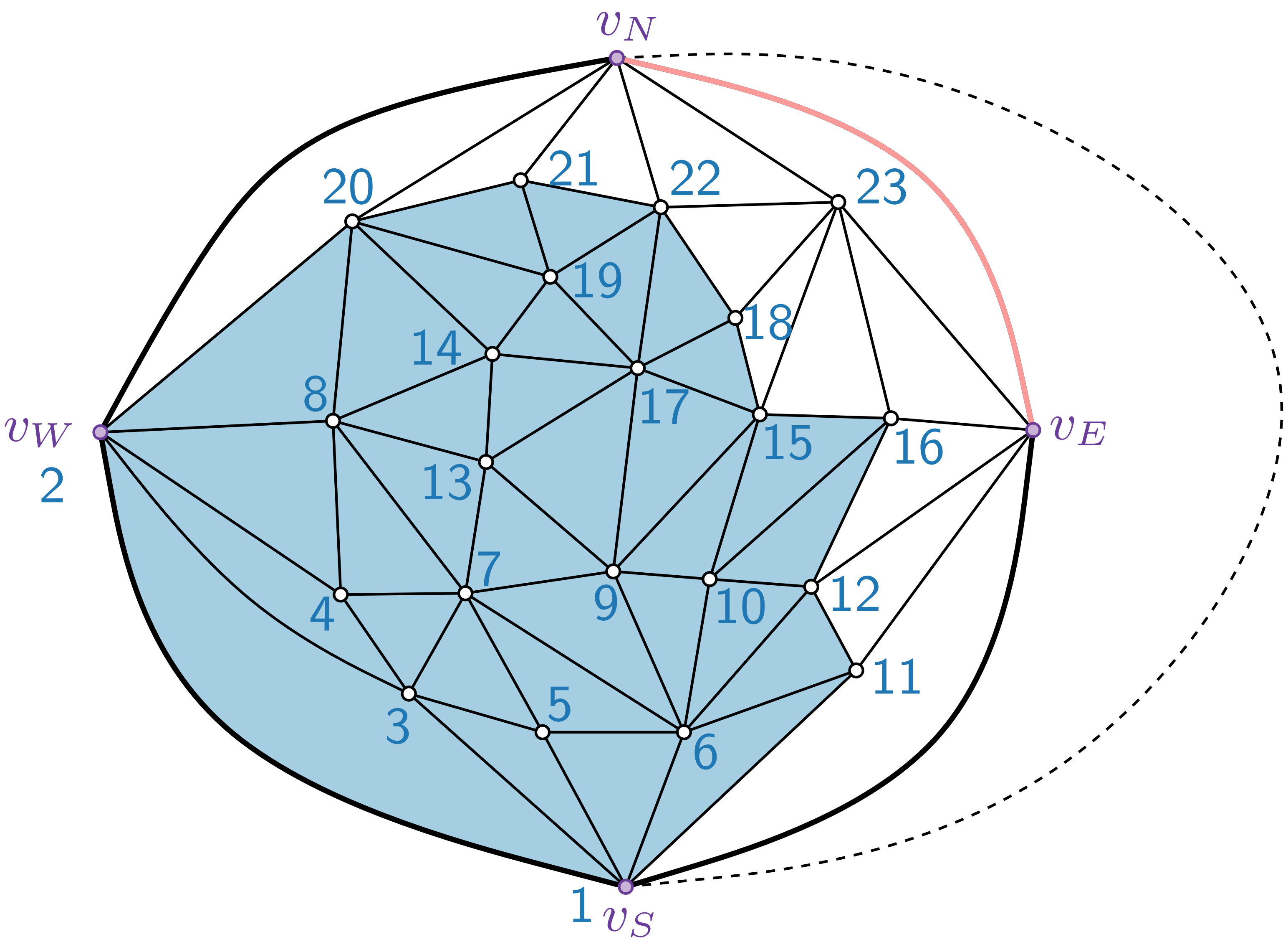

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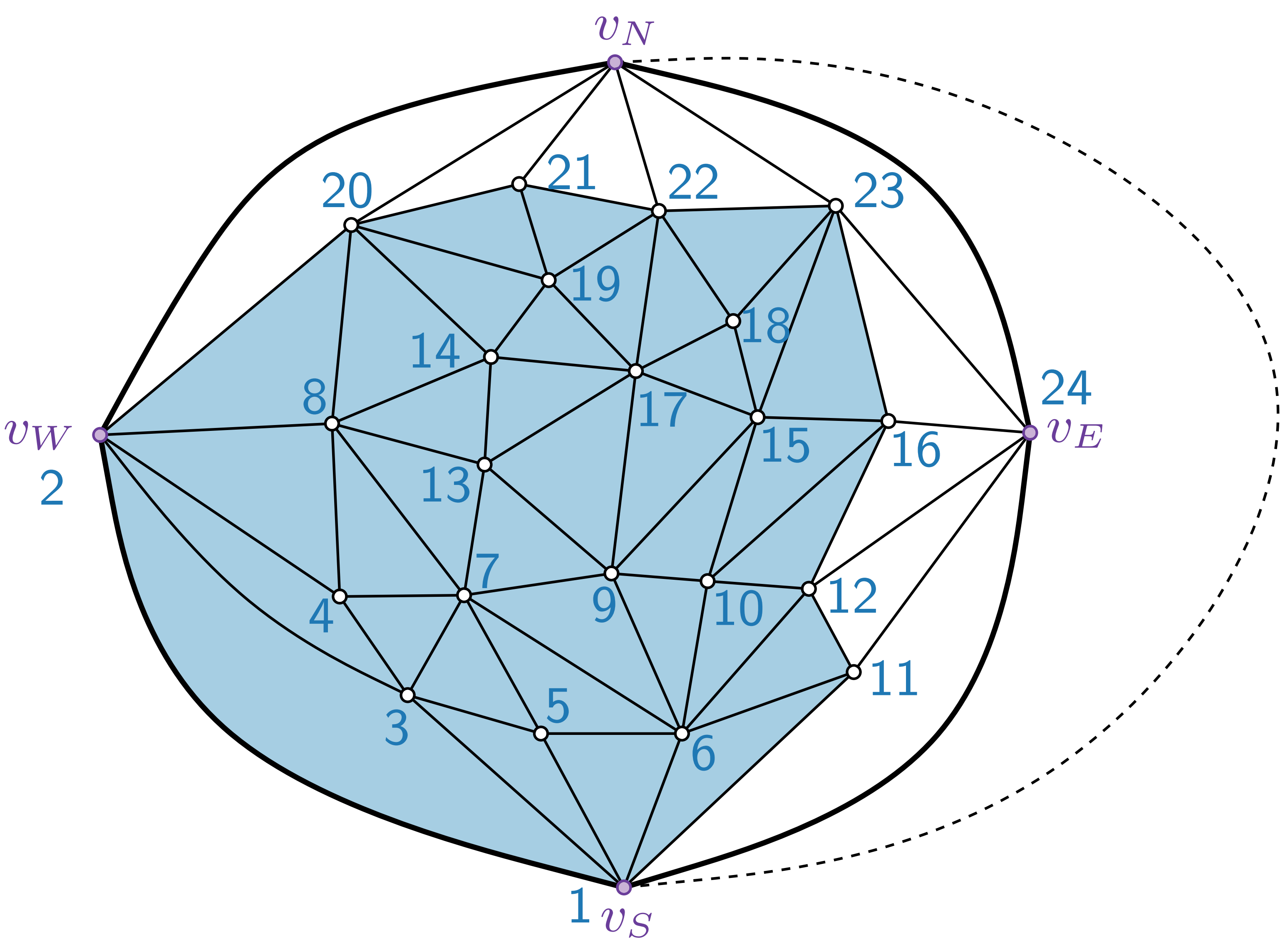

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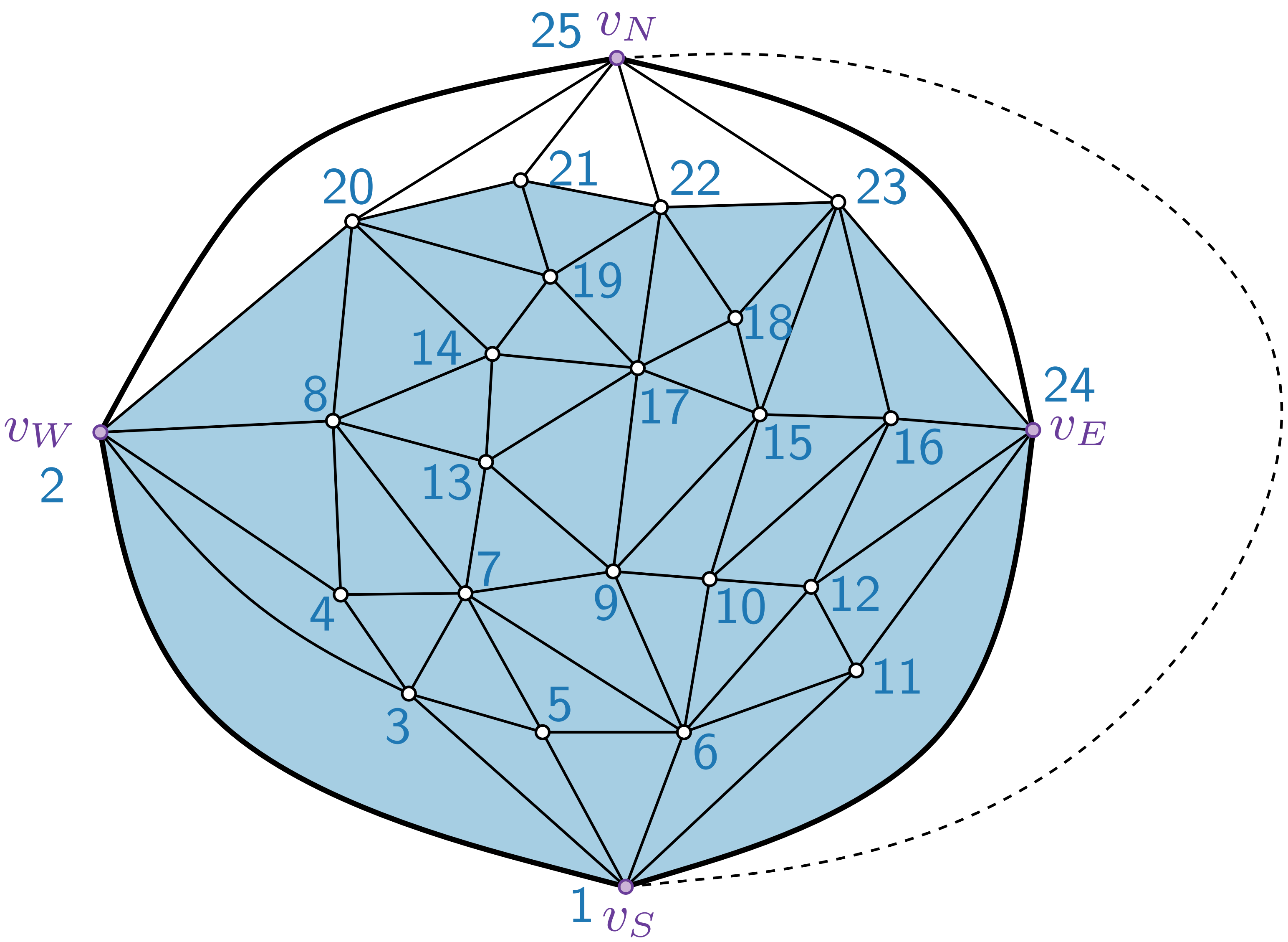

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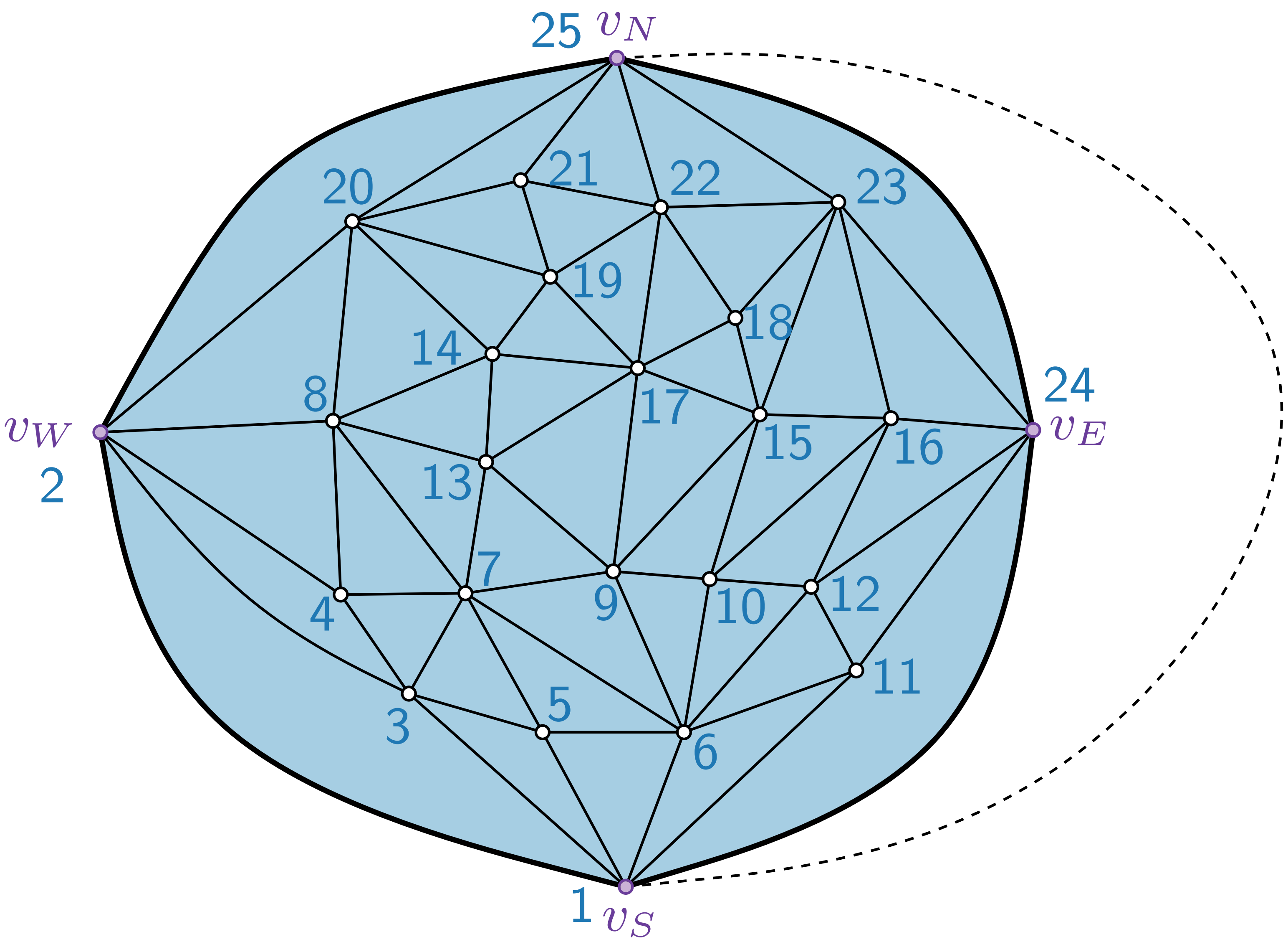

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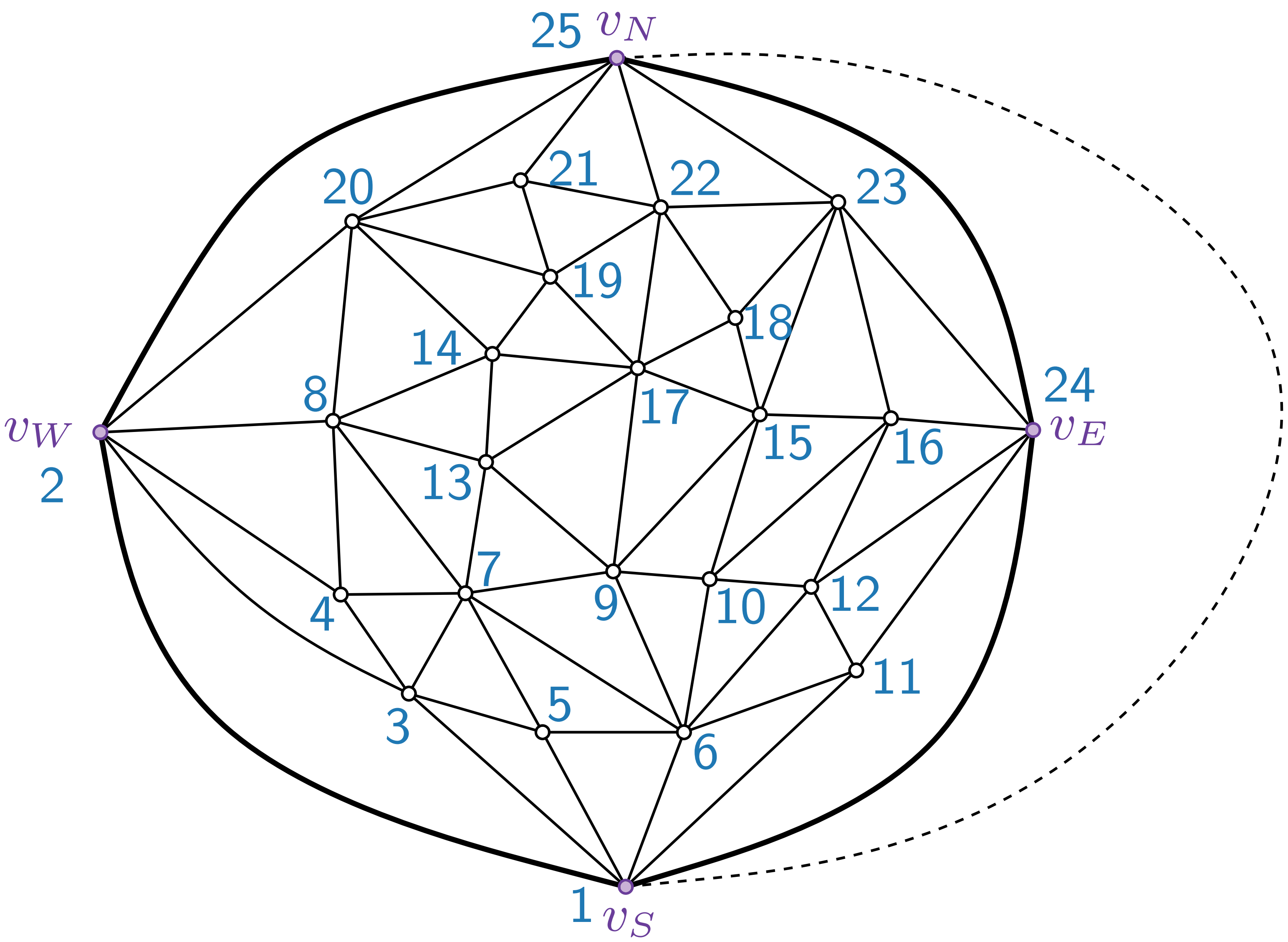

Refined Canonical Order → REL

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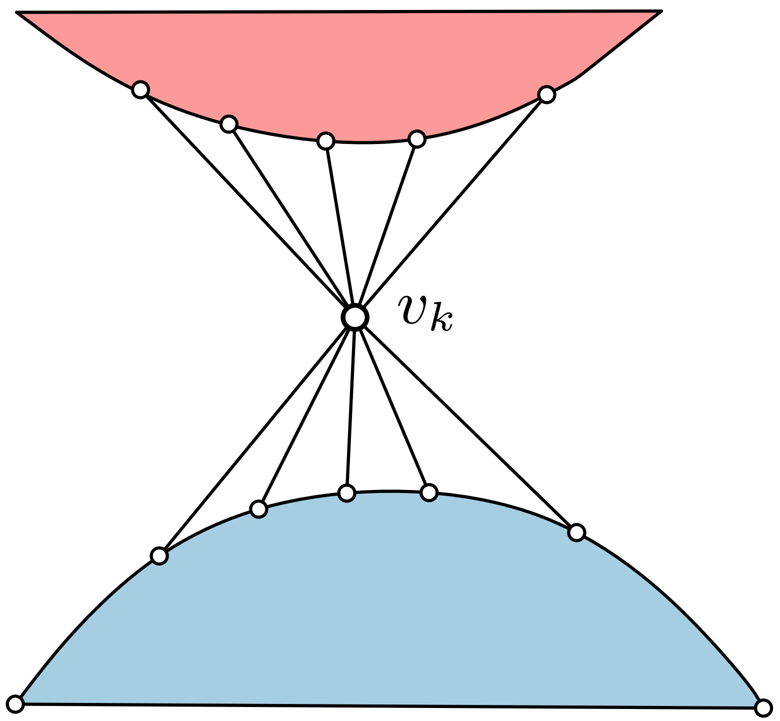

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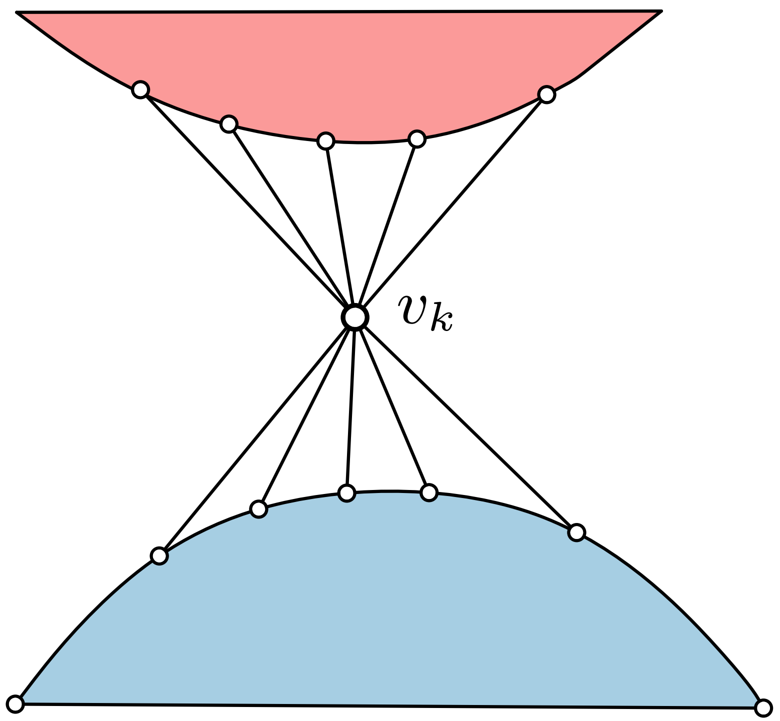

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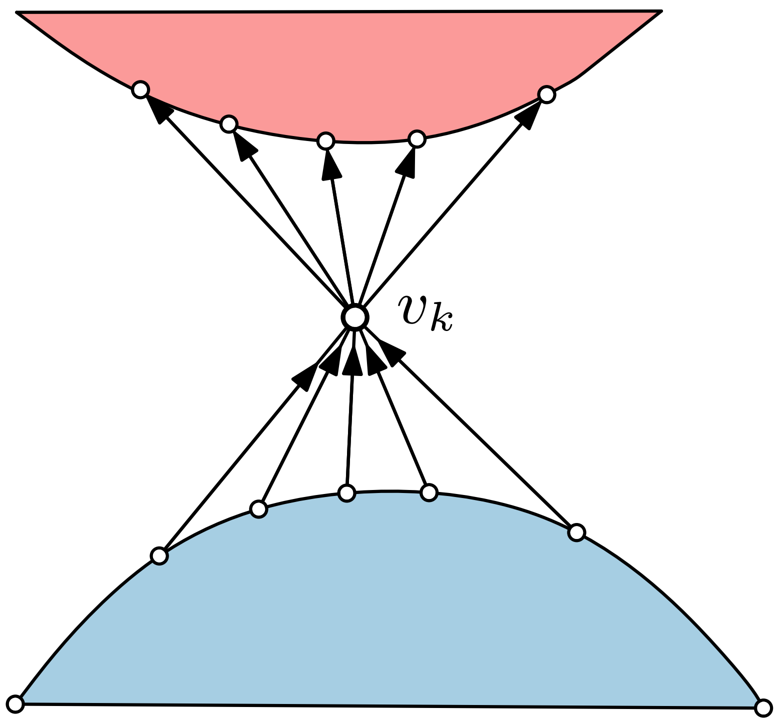

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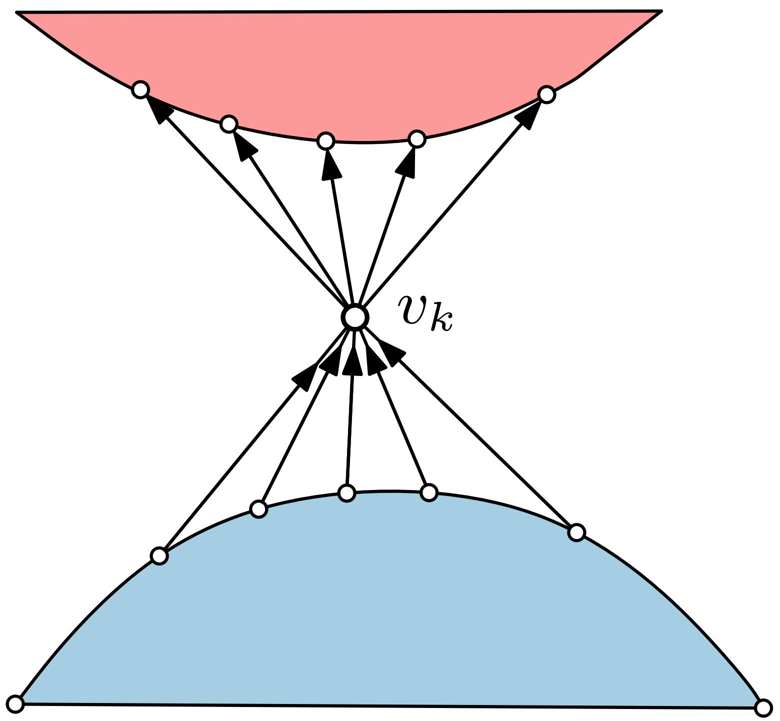

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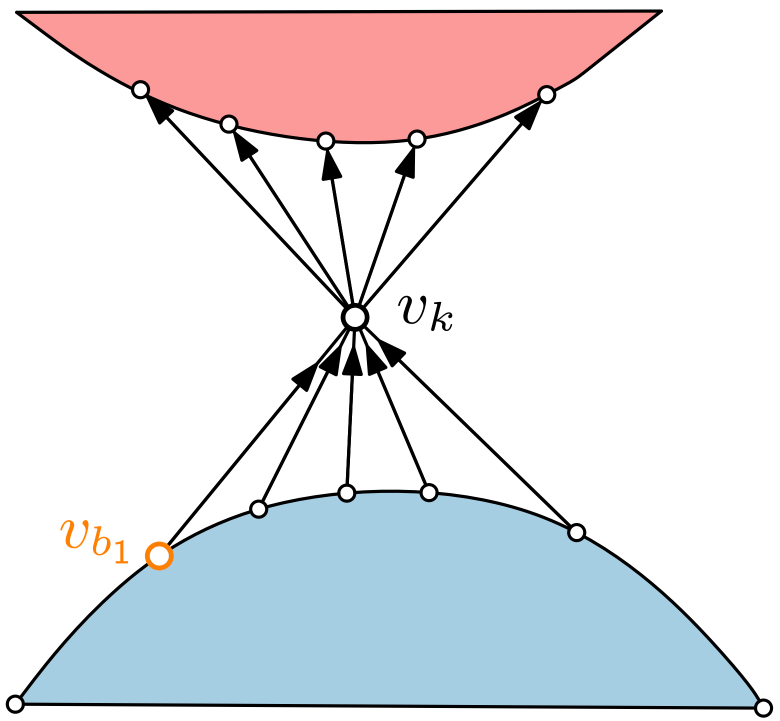

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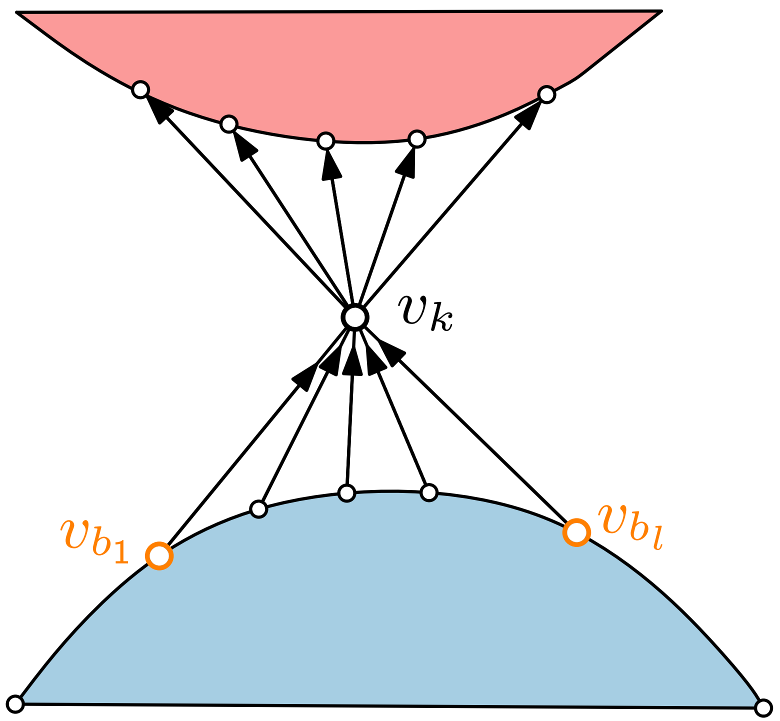

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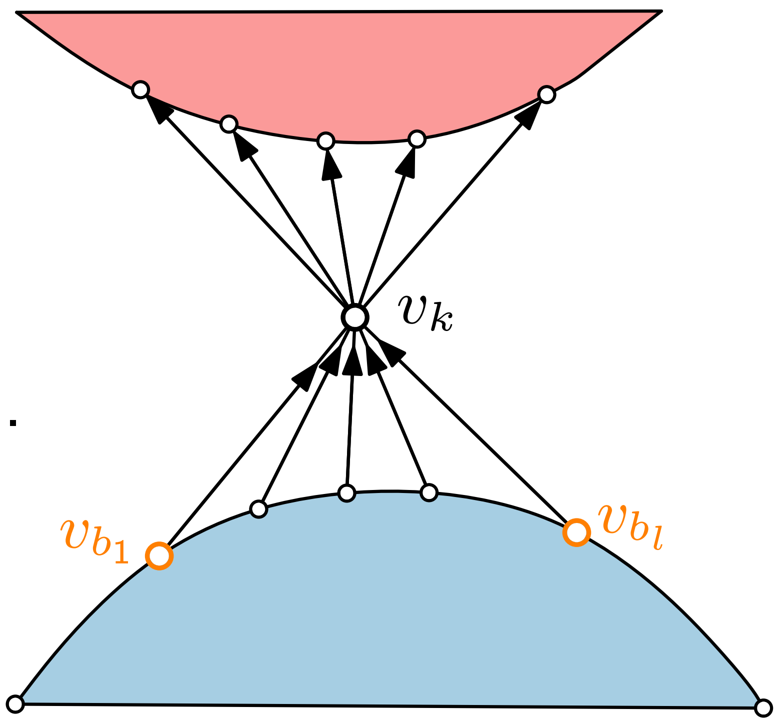

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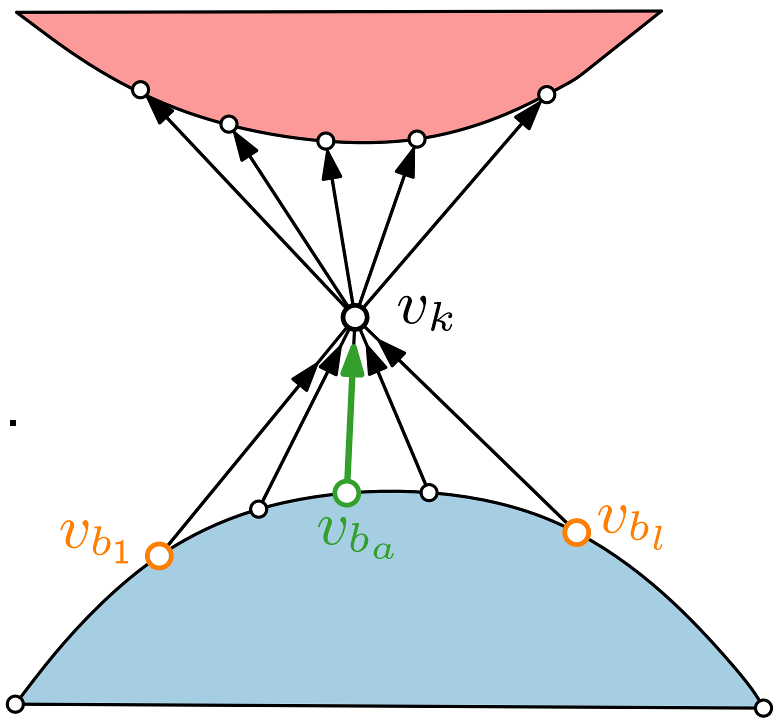

Refined Canonical Order → REL

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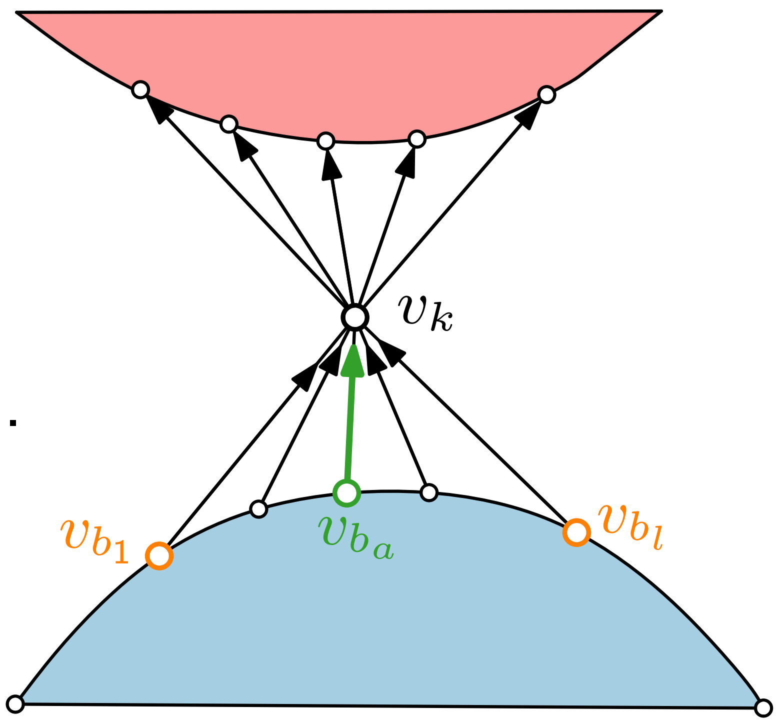

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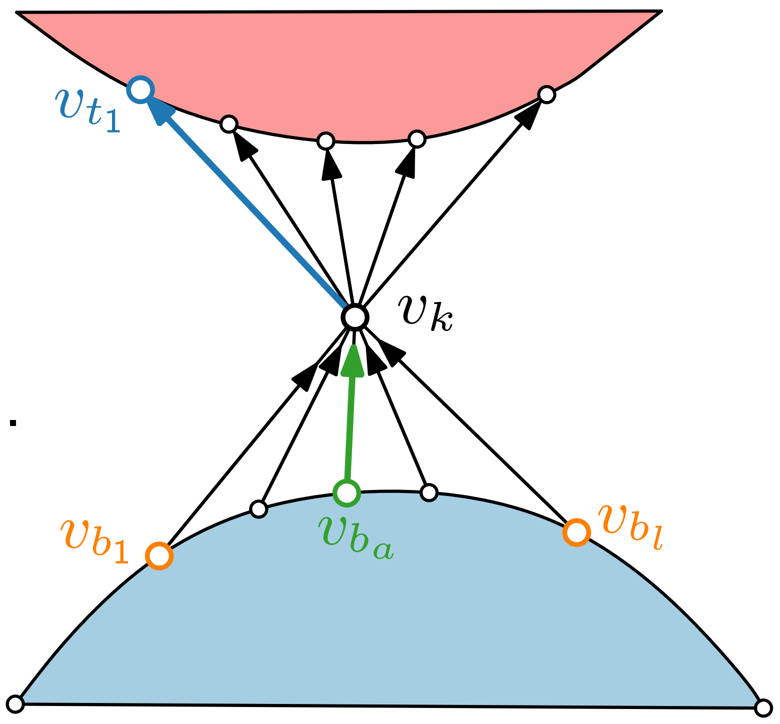

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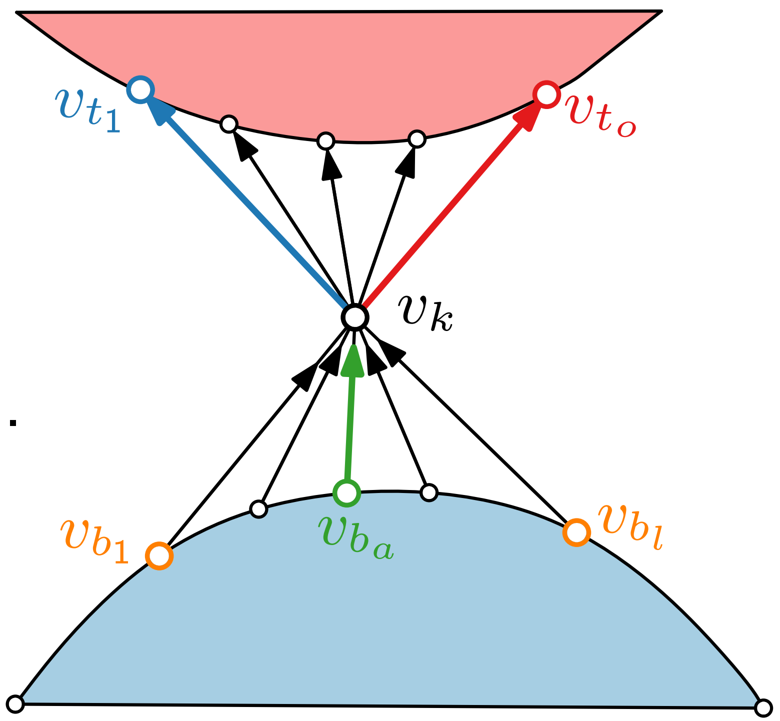

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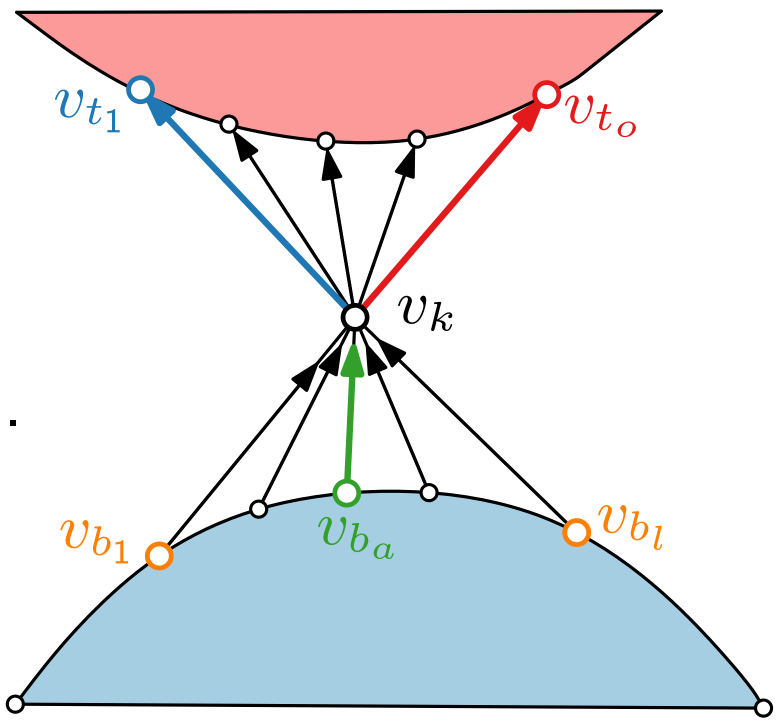

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A left edge or right edge cannot be a base edge.

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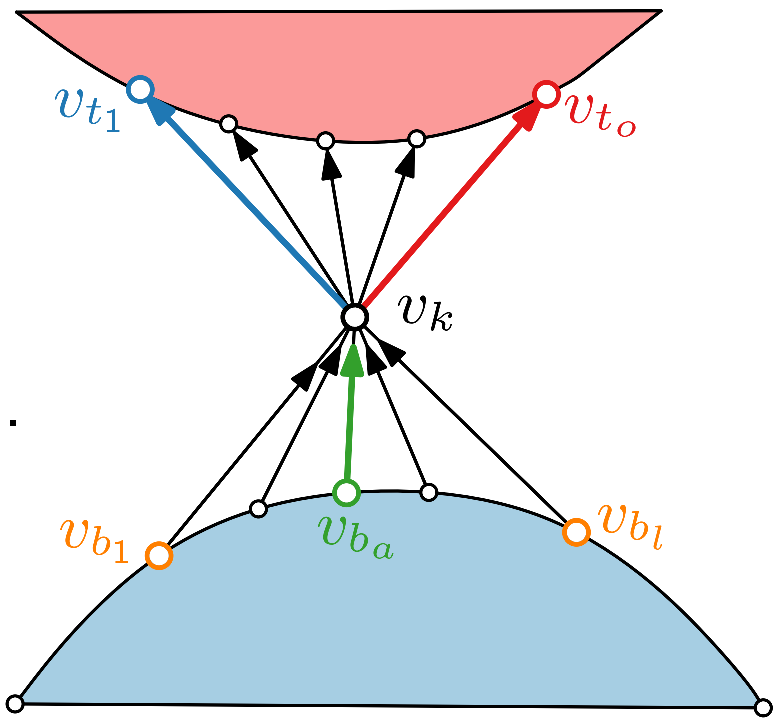

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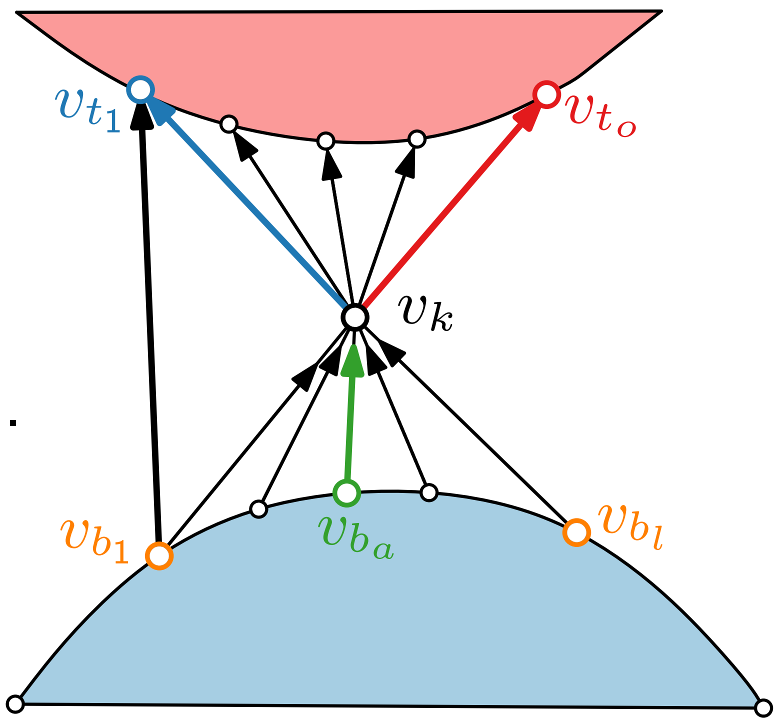

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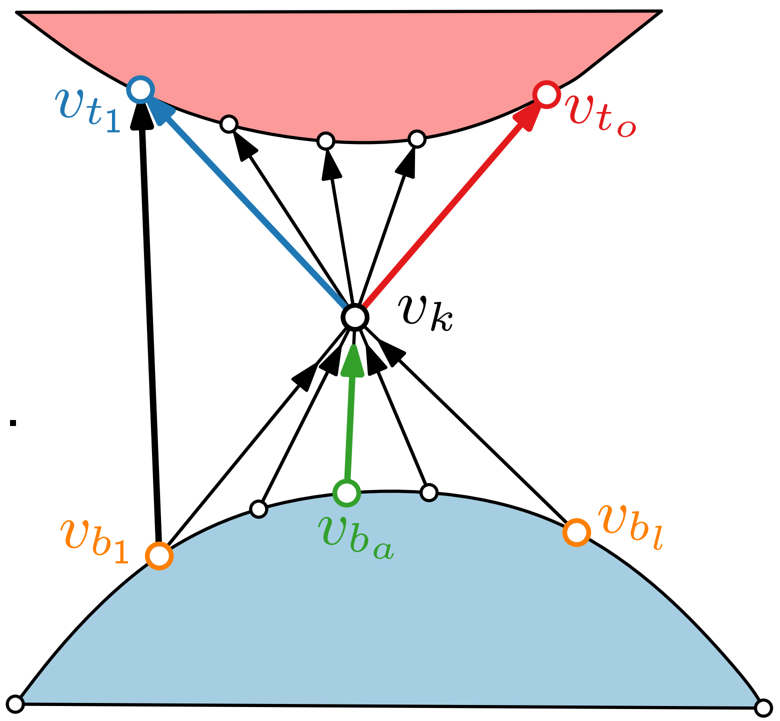

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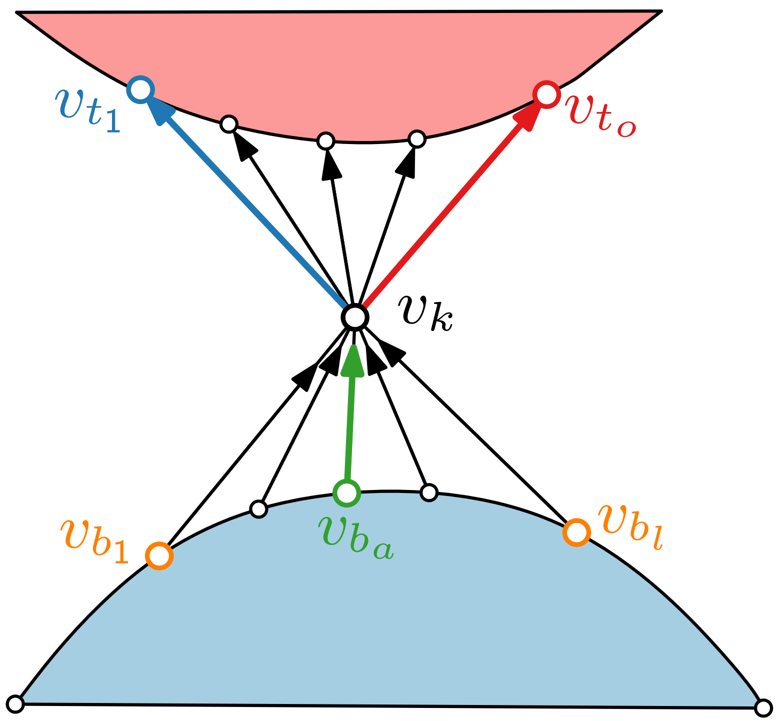
Contradiction since $k > b_1$.

Refined Canonical Order → REL

Lemma 2.
Every edge is either a left edge, a right edge or a base edge.



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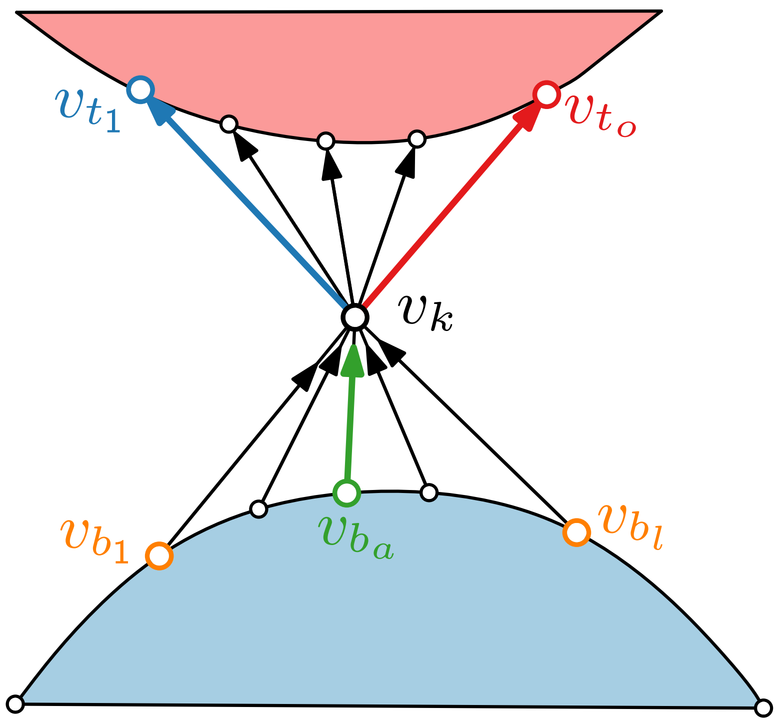

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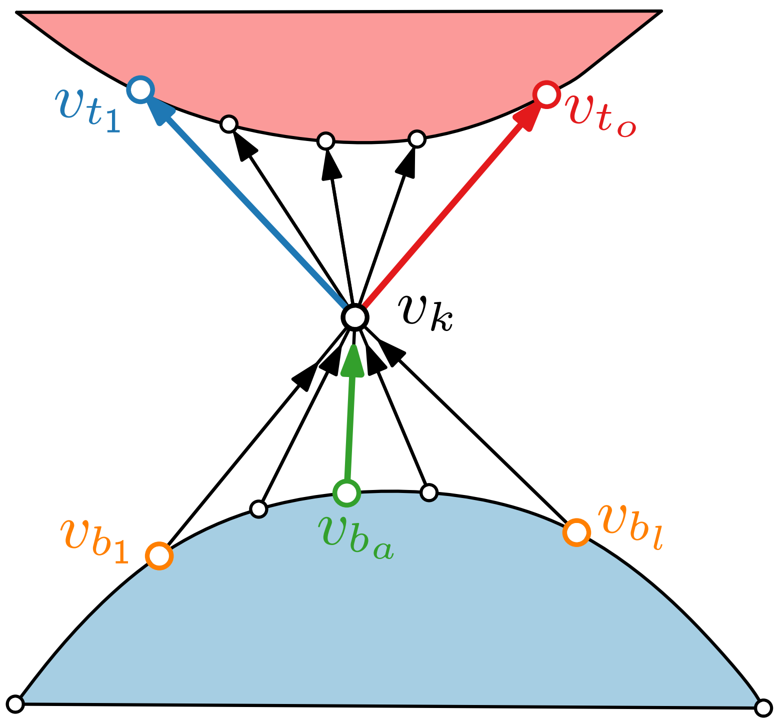

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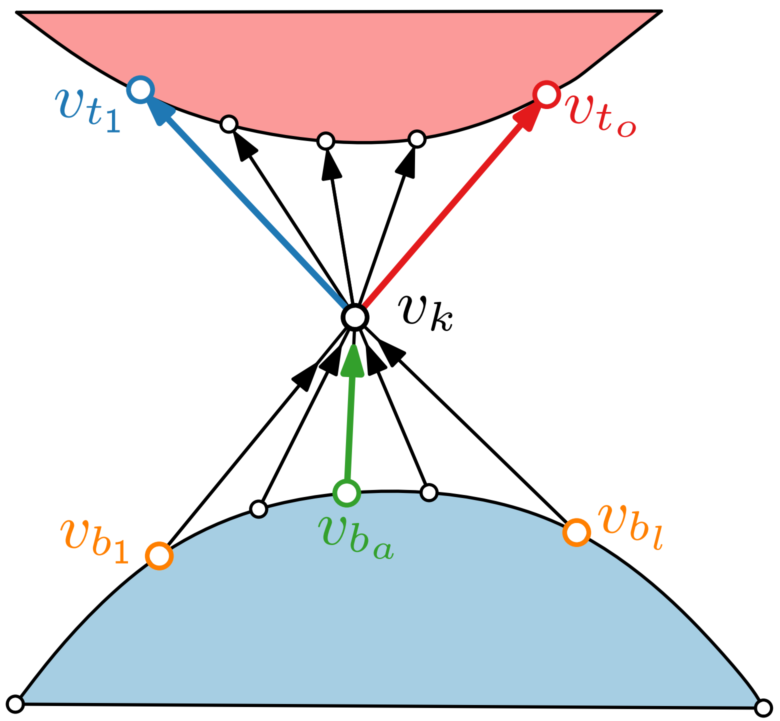

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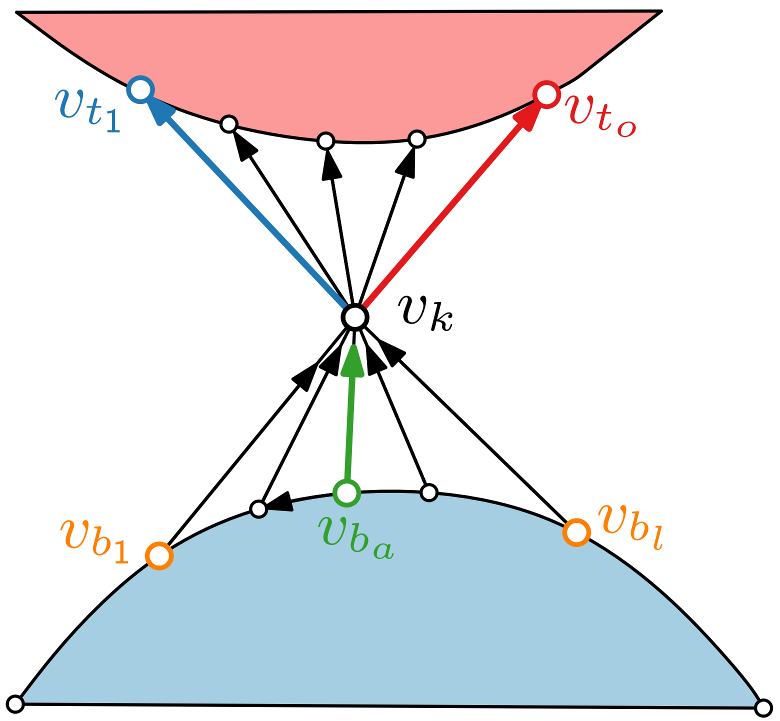

Refined Canonical Order $\to$ REL

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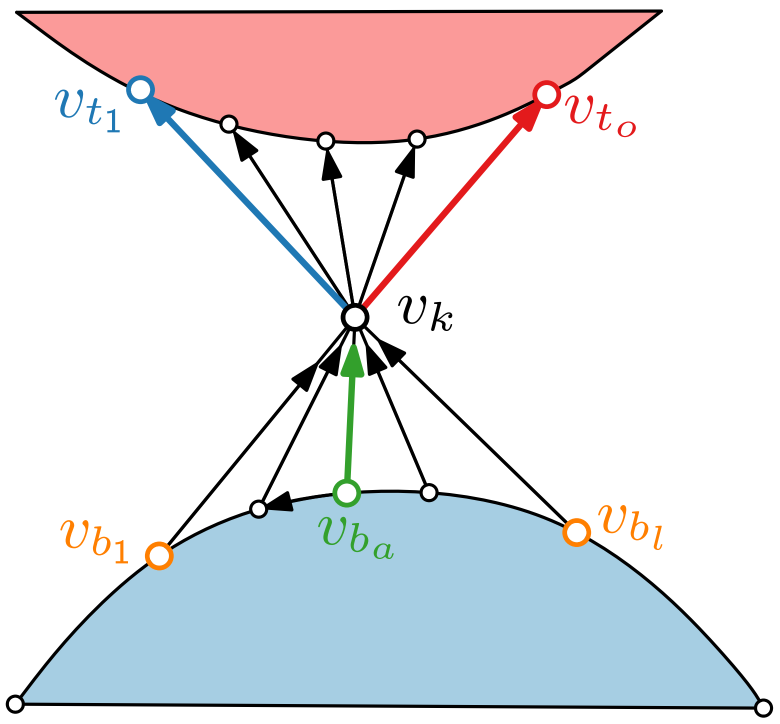

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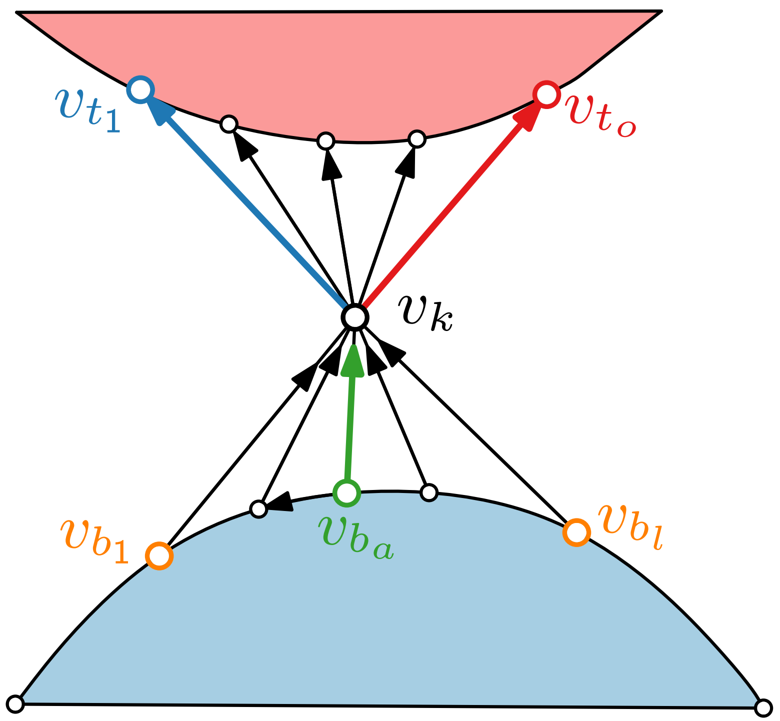

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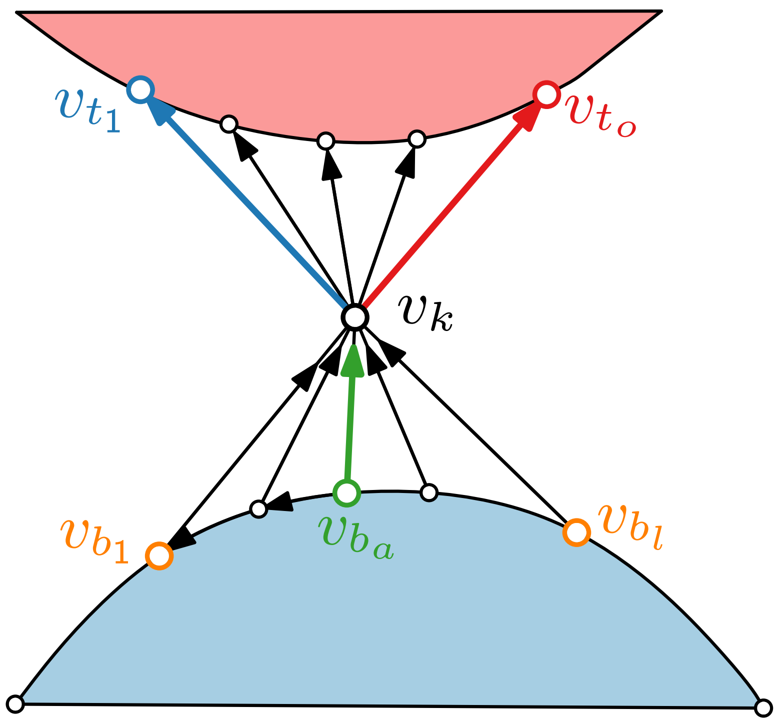

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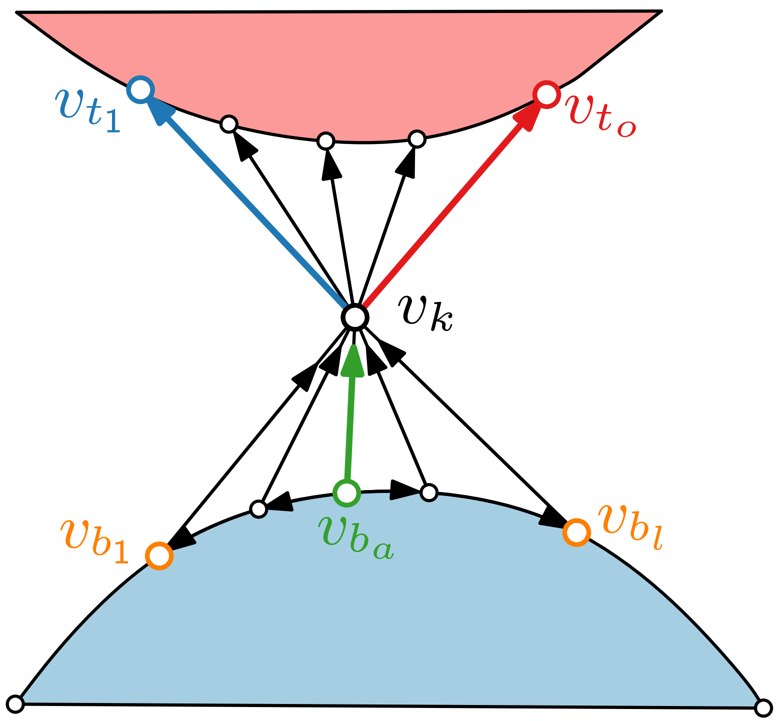
- Analogously, v_{b_i} is the left point of $v_{b_{i+1}}$ for $i \geq a$.



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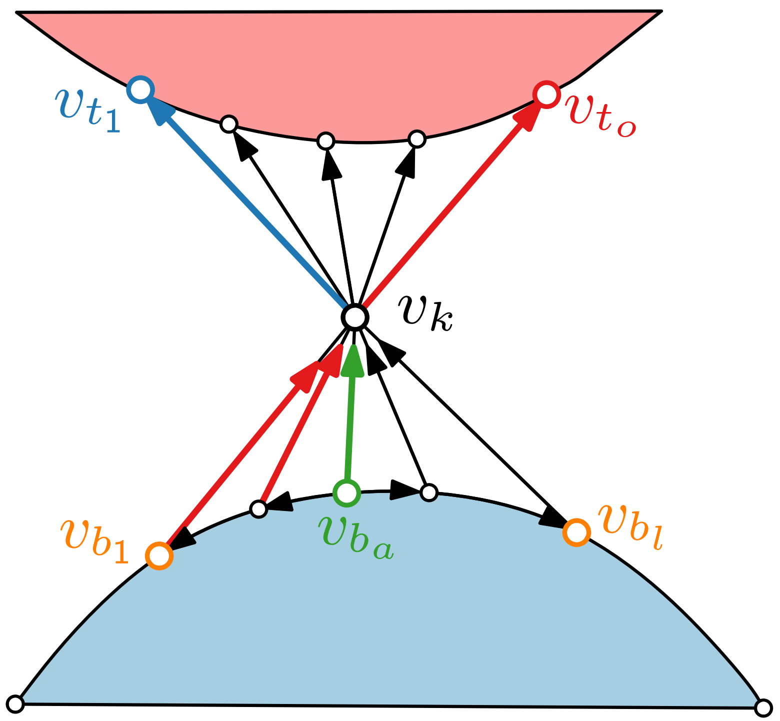

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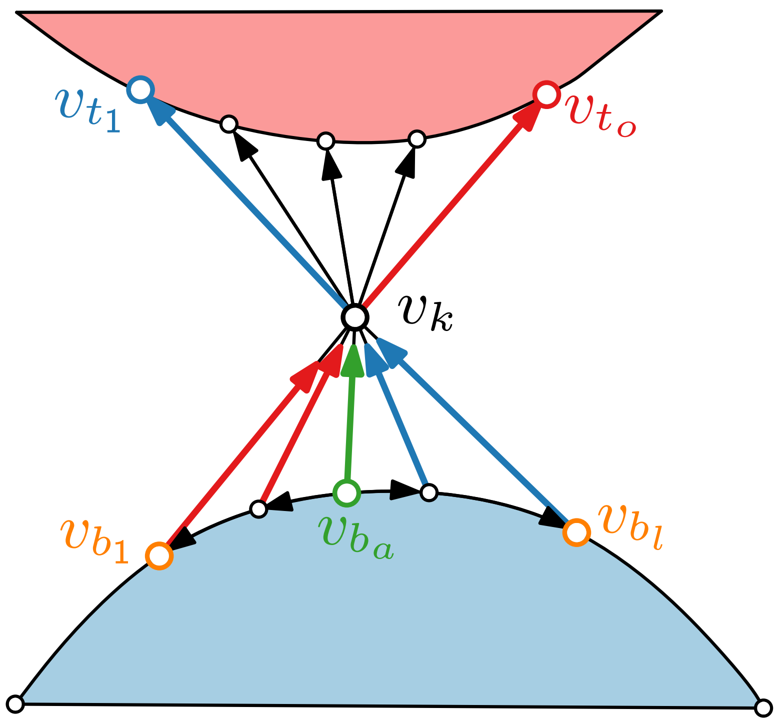

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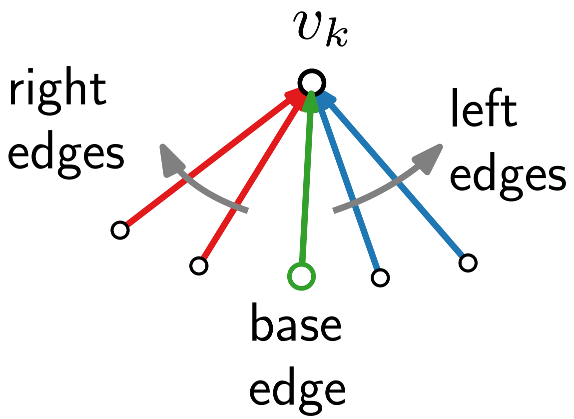
- Edges (v_{b_i}, v_k), $1 \leq i < a-1$, are right edges.
- Similarly, (v_{b_i}, v_k), for $a+1 \leq i \leq l$, are left edges.

Refined Canonical Order → REL



Refined Canonical Order → REL

Coloring.

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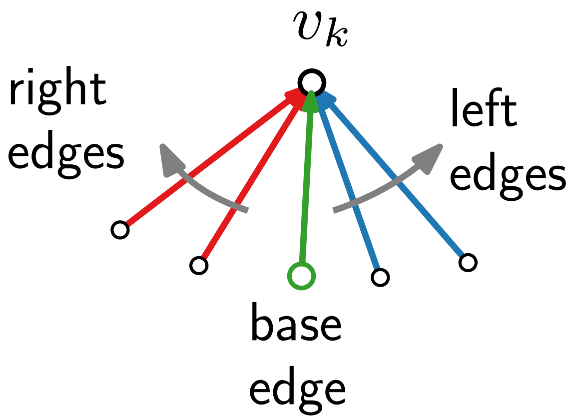

Refined Canonical Order $\rightarrow$ REL

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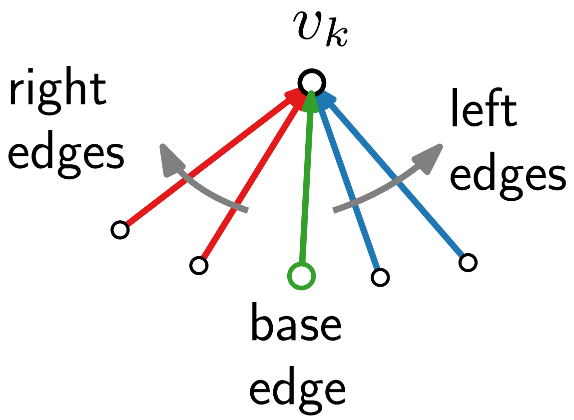

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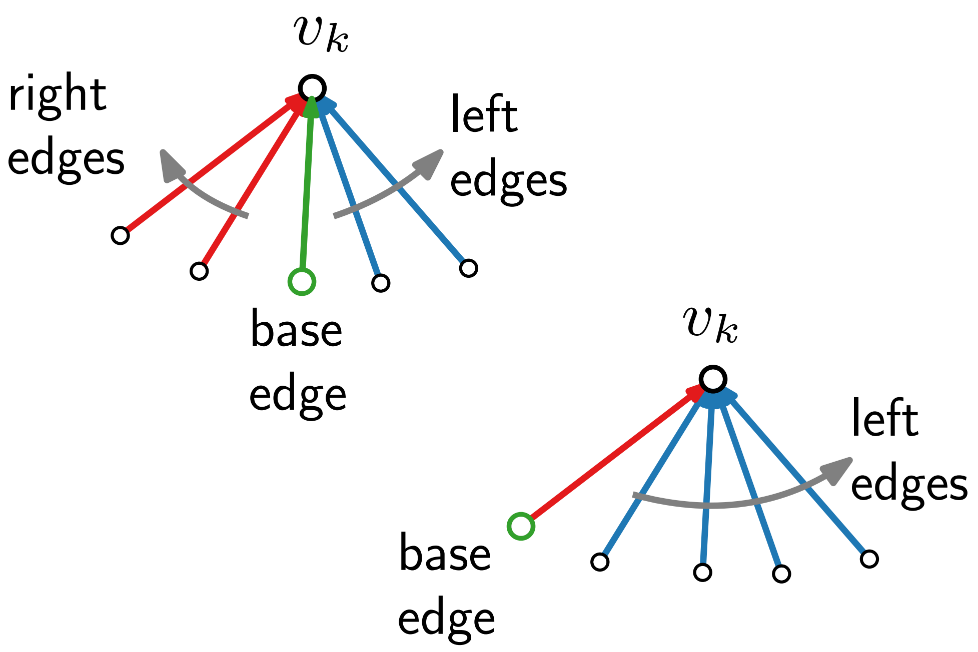

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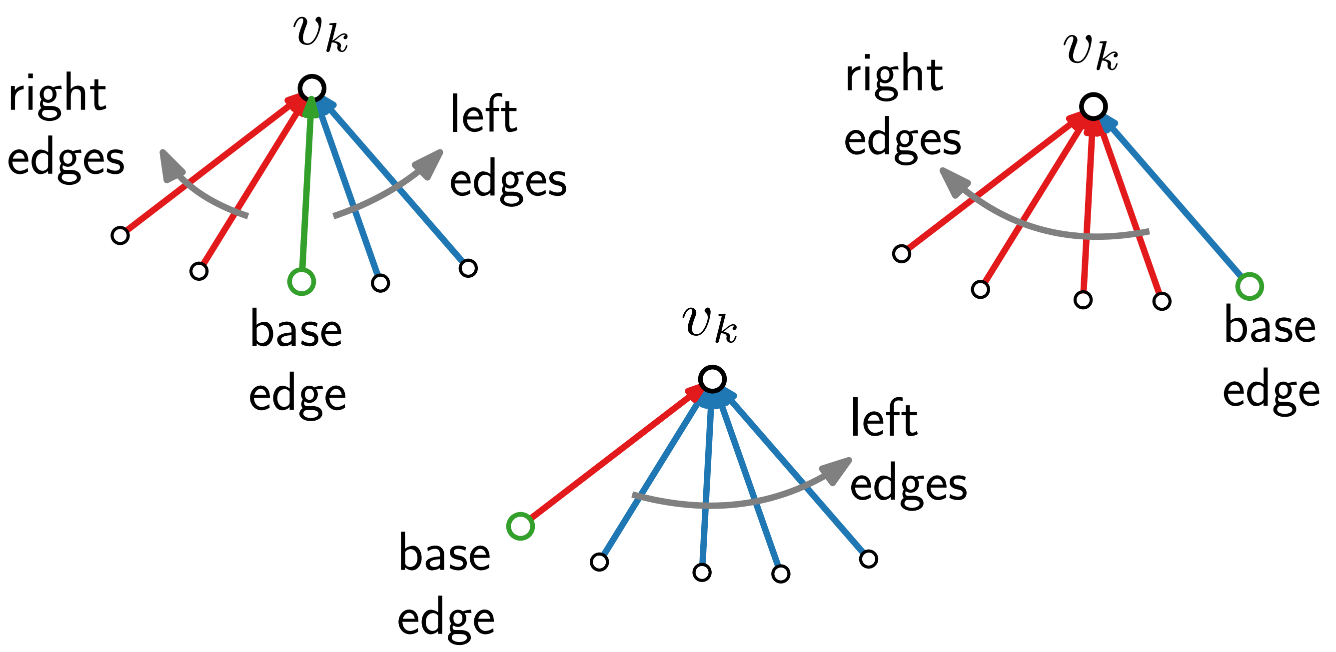

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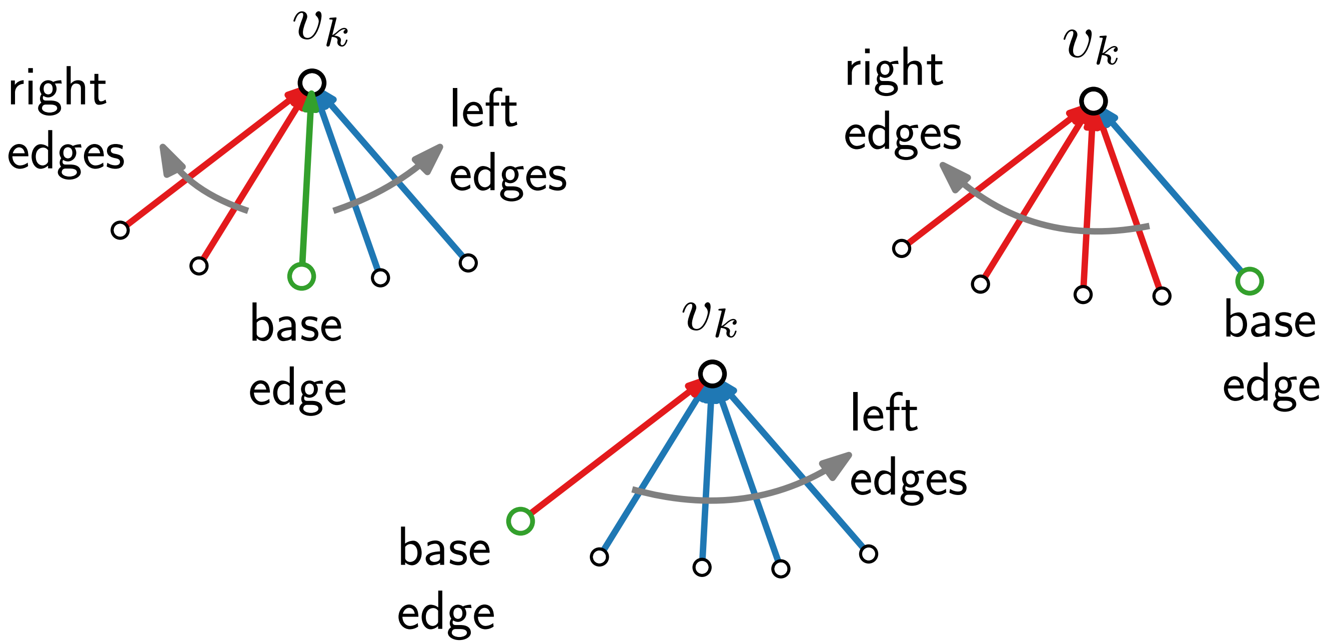

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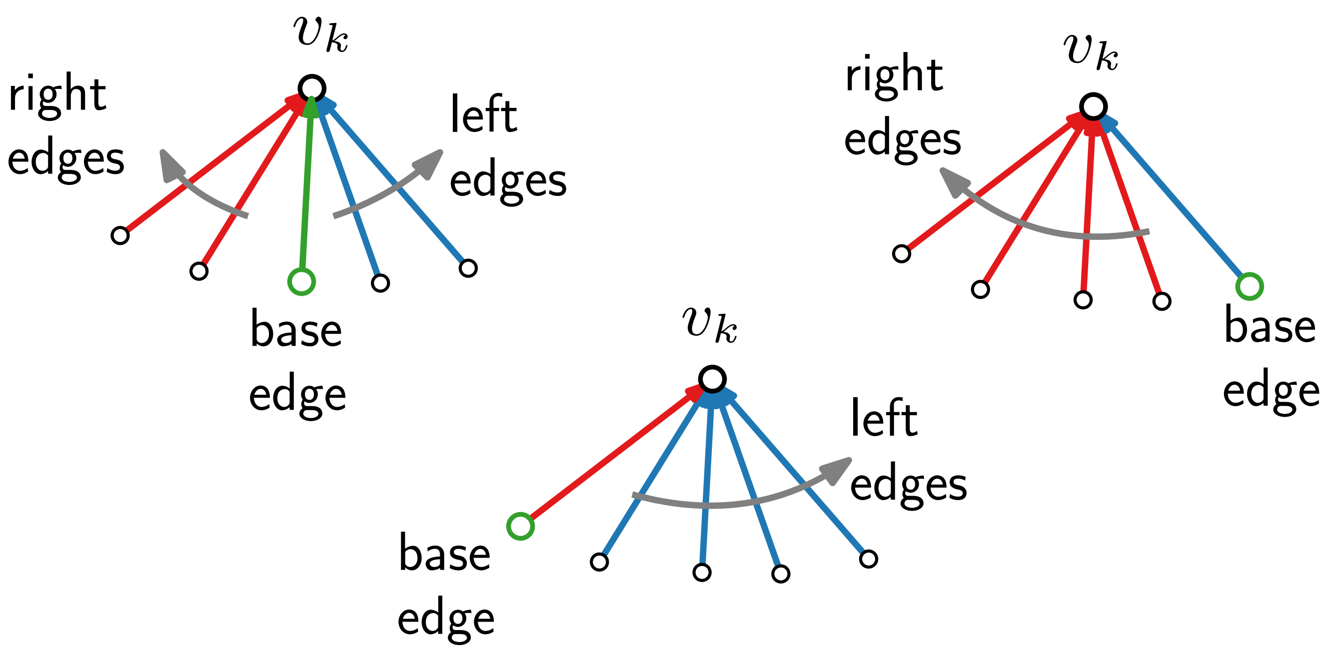

Lemma 3.
$\{T_r, T_b\}$ is a regular edge labeling.

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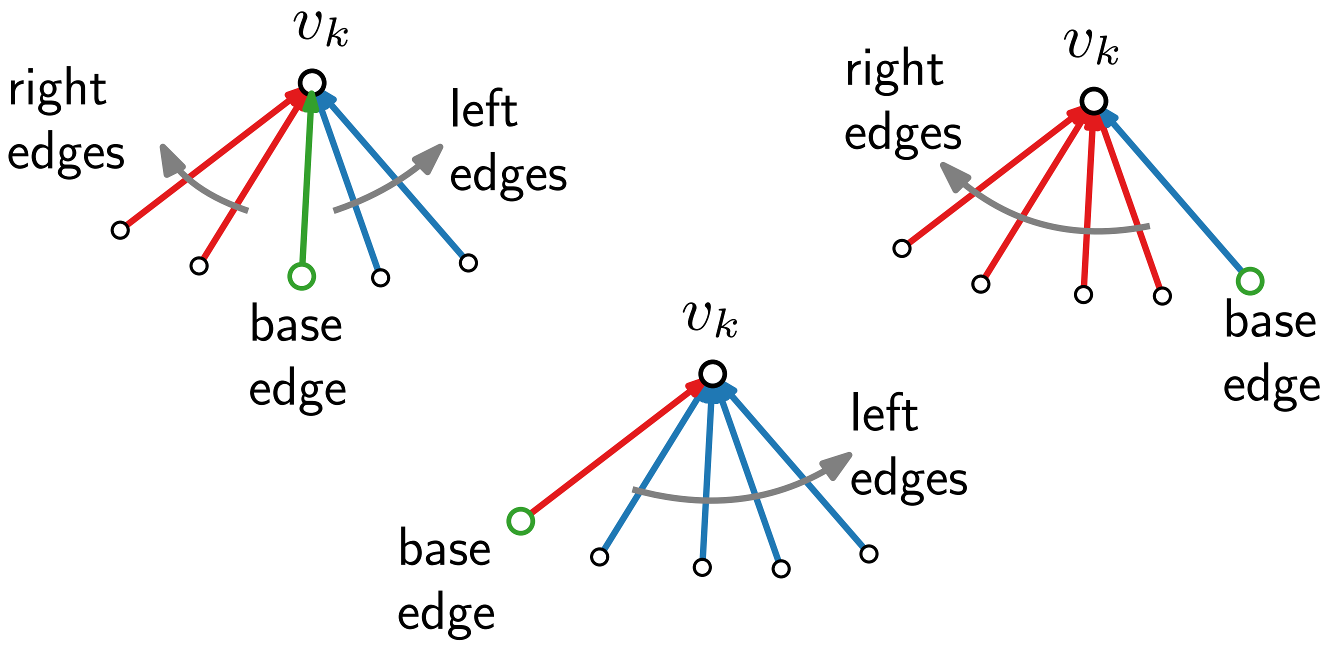

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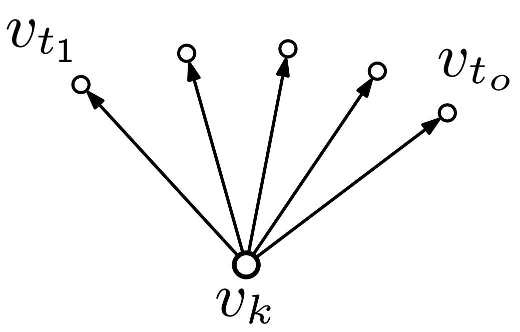

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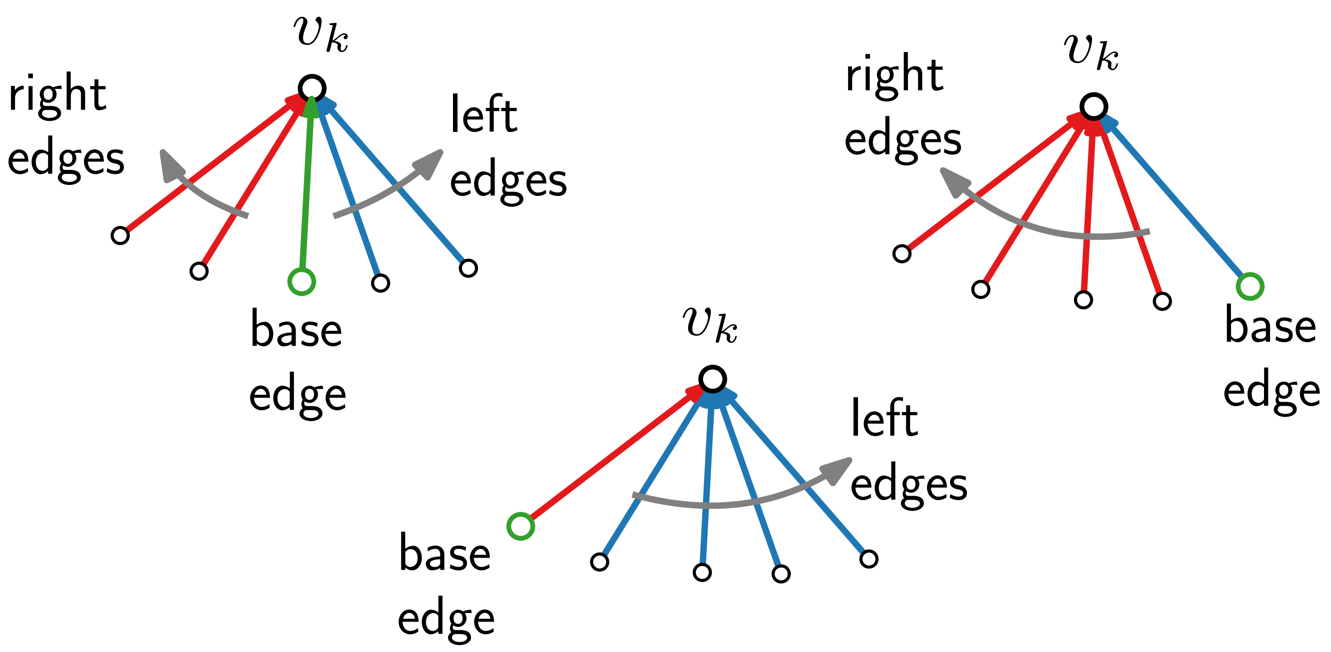

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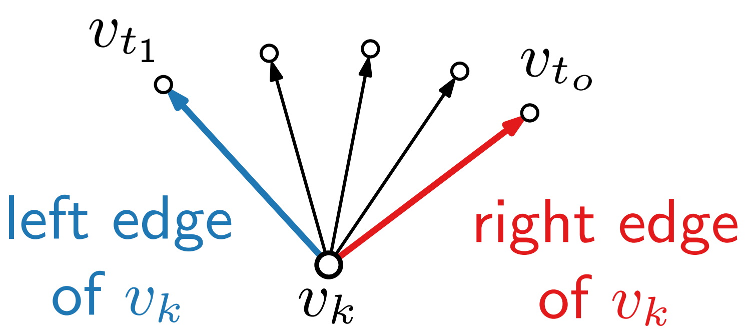
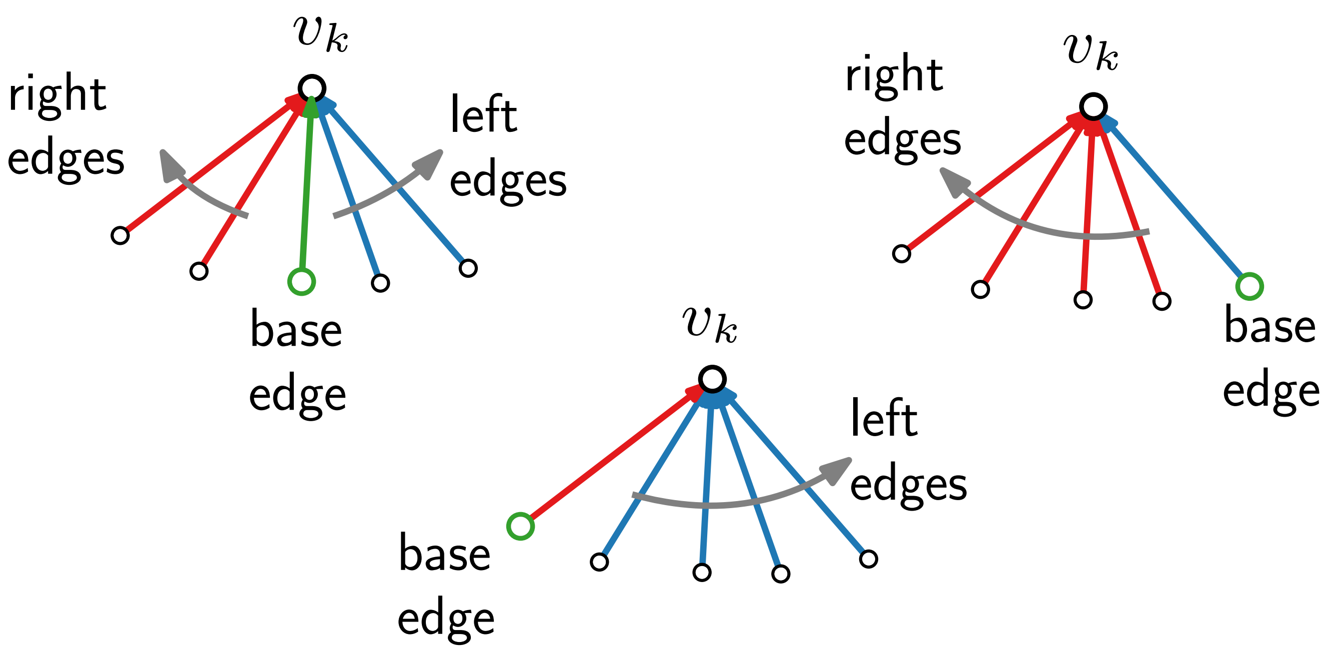


Refined Canonical Order $\rightarrow$ REL



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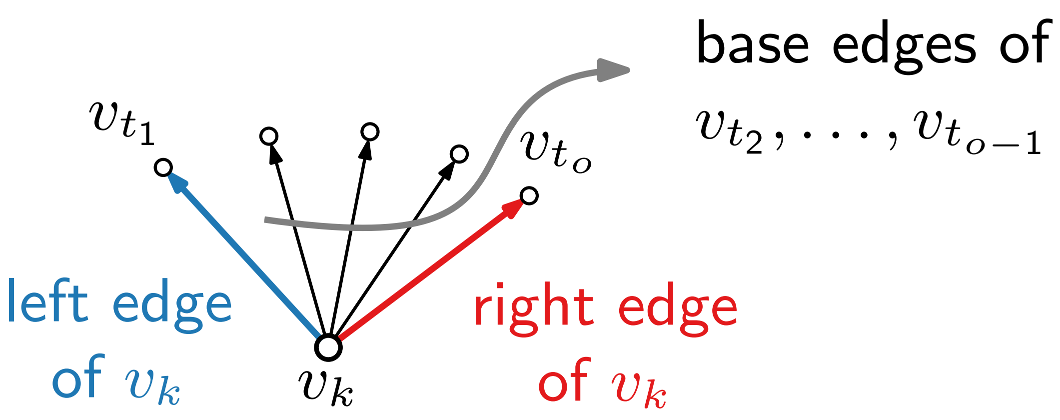

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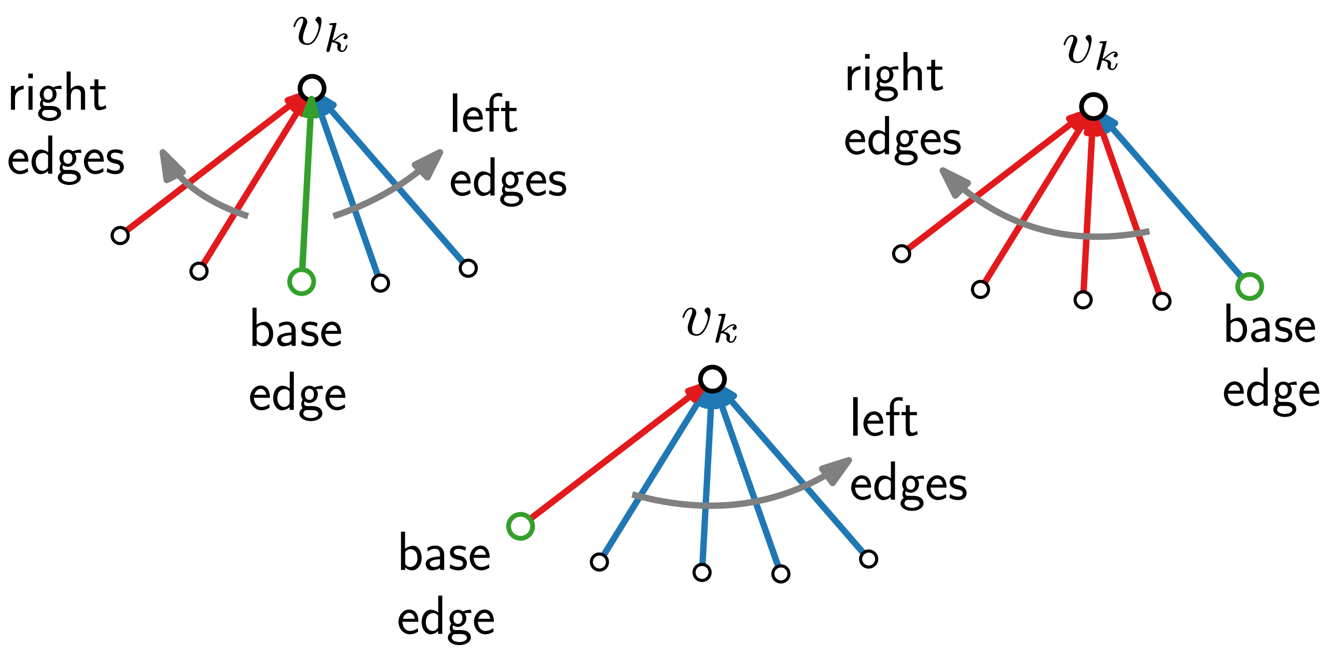

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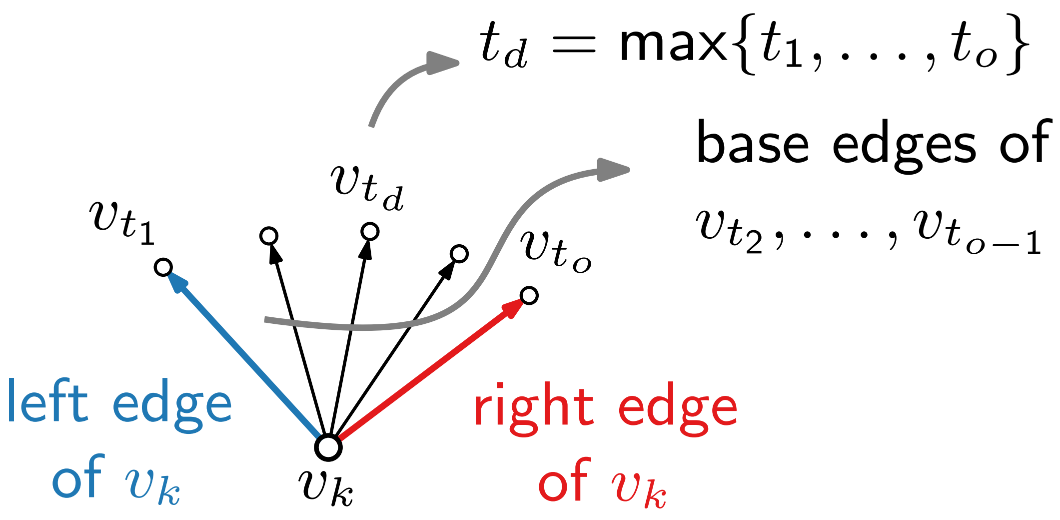

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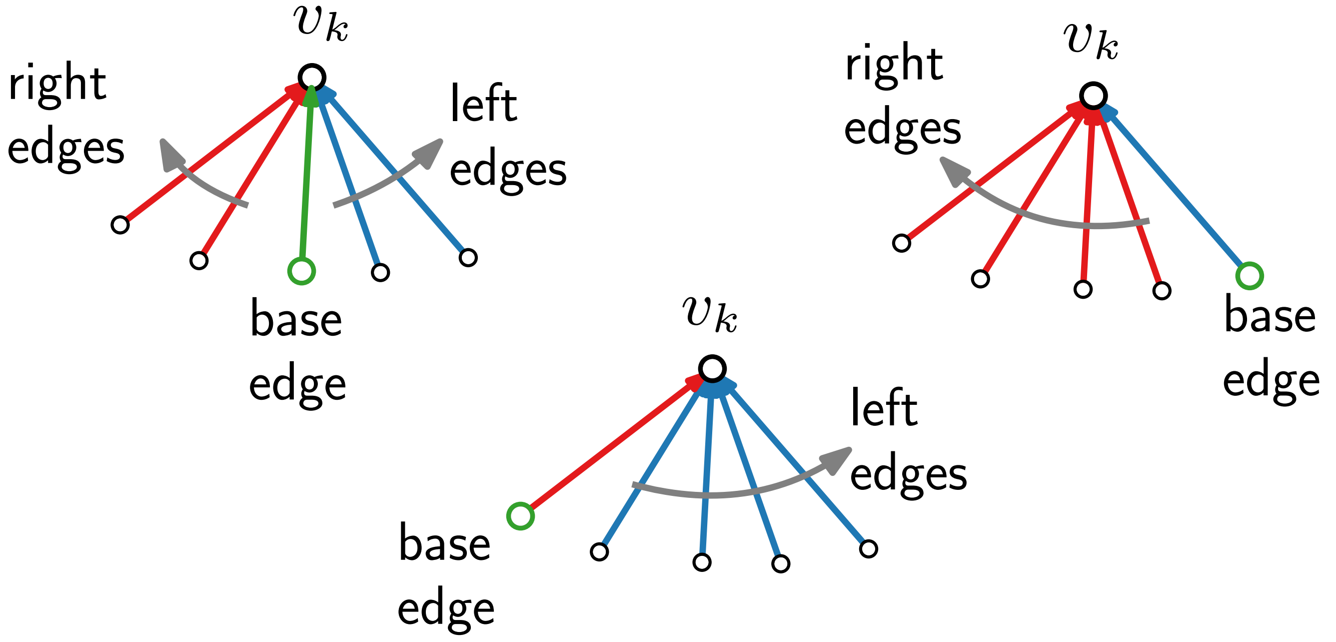

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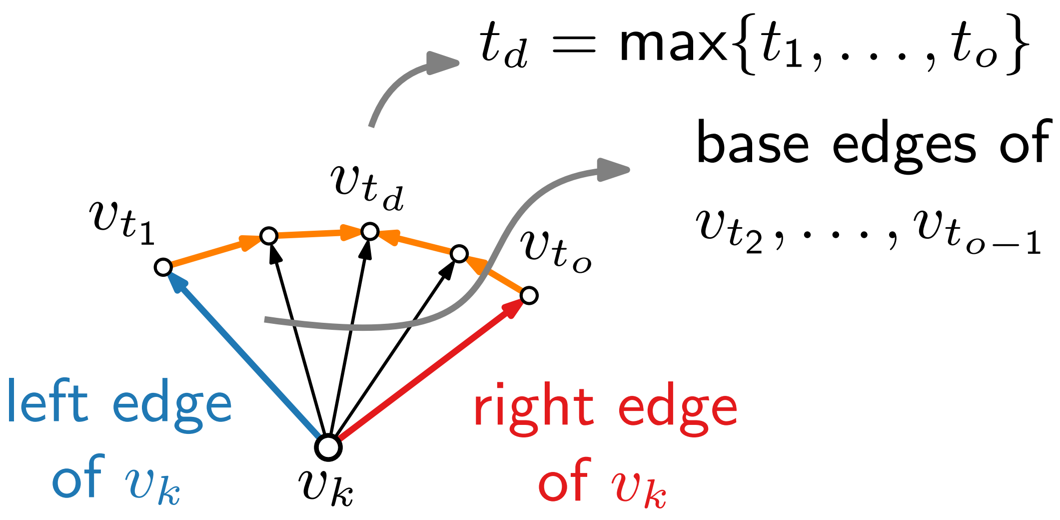
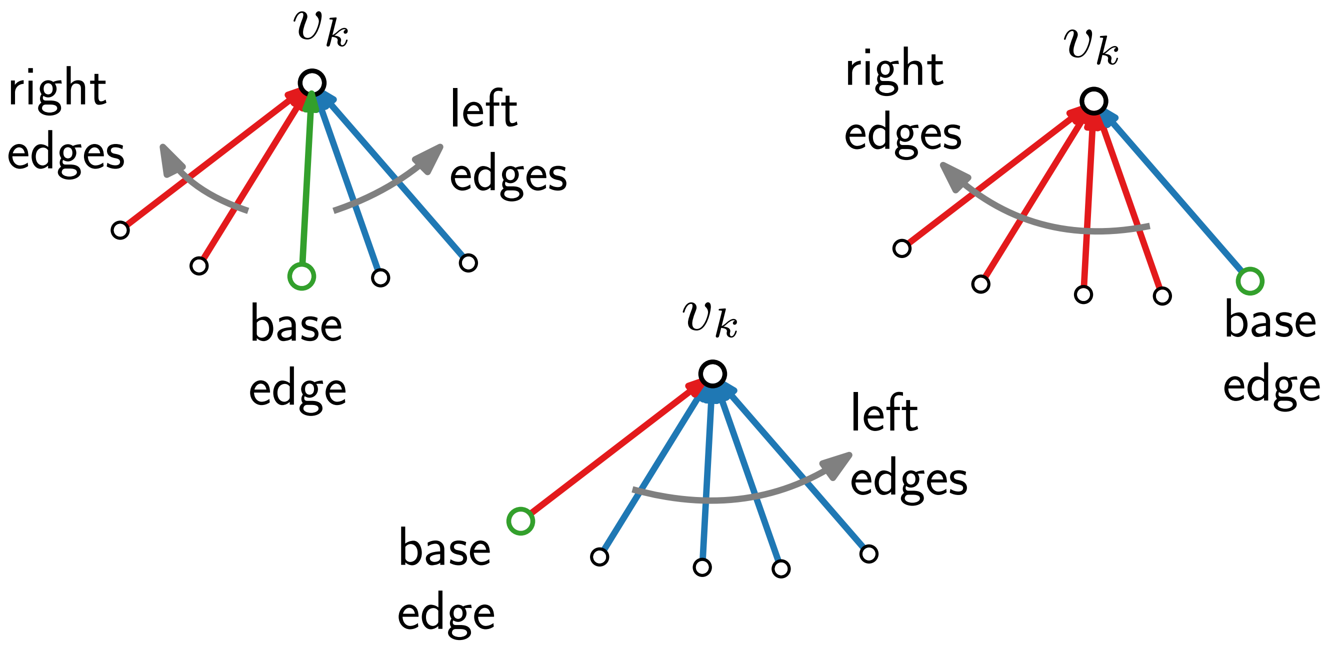


- $t_1 < t_2 < \ldots < t_d$ and $t_d > t_{d+1} > \ldots > t_o$

Refined Canonical Order → REL

Coloring.

- Color right (left) edges in red (blue).
- Color a base edge (v_{b_i}, v_k) red if $i = 1$ and blue if $i = l$ and otherwise arbitrarily.



Let T_r be the red edges and T_b the blue edges.

Lemma 3.
$\{T_r, T_b\}$ is a regular edge labeling.

Proof.

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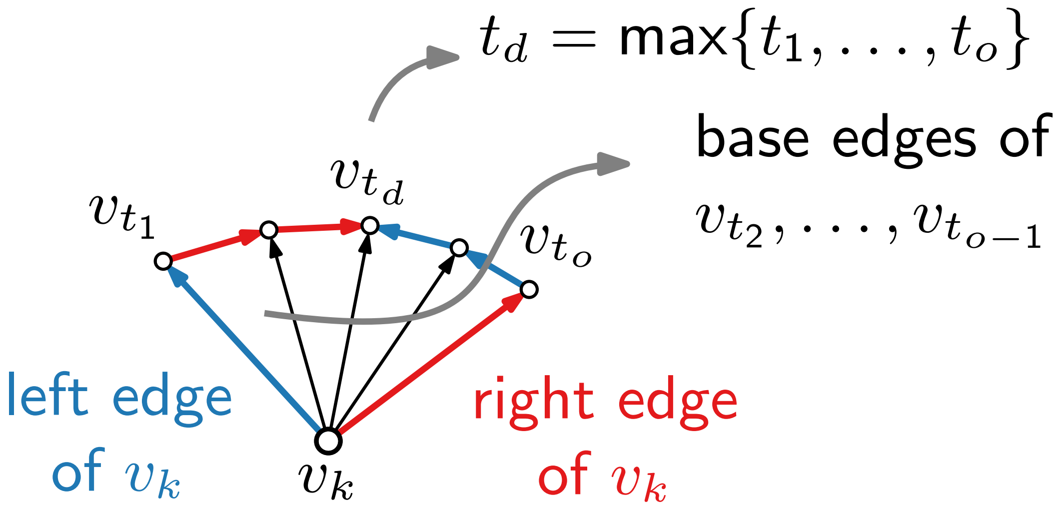

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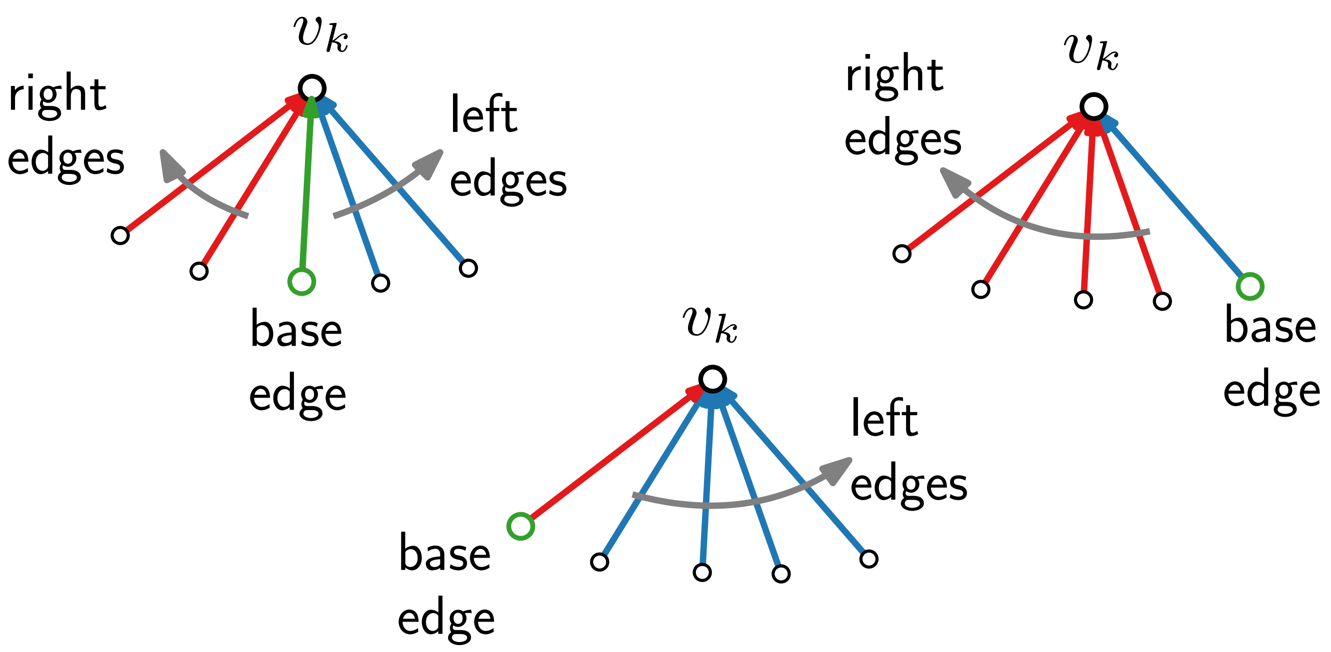

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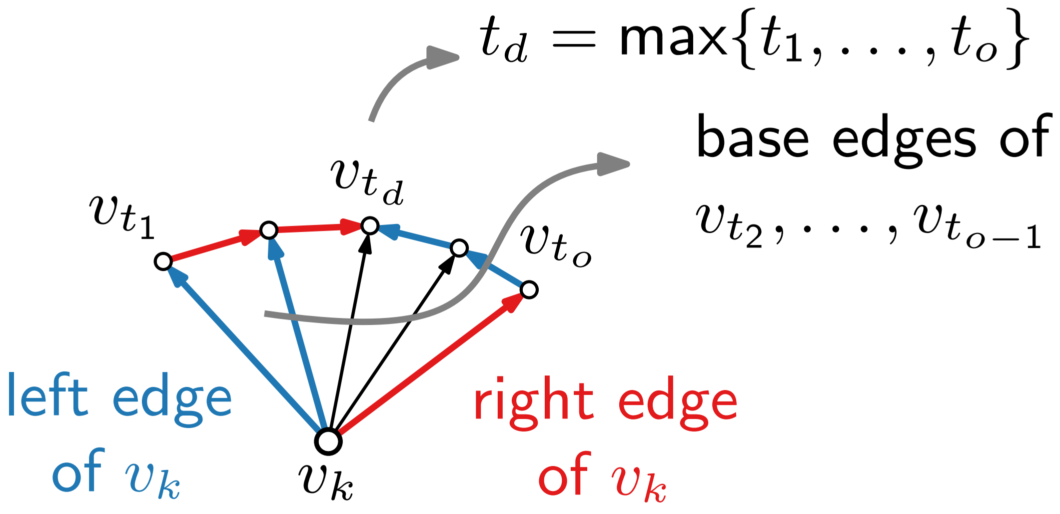
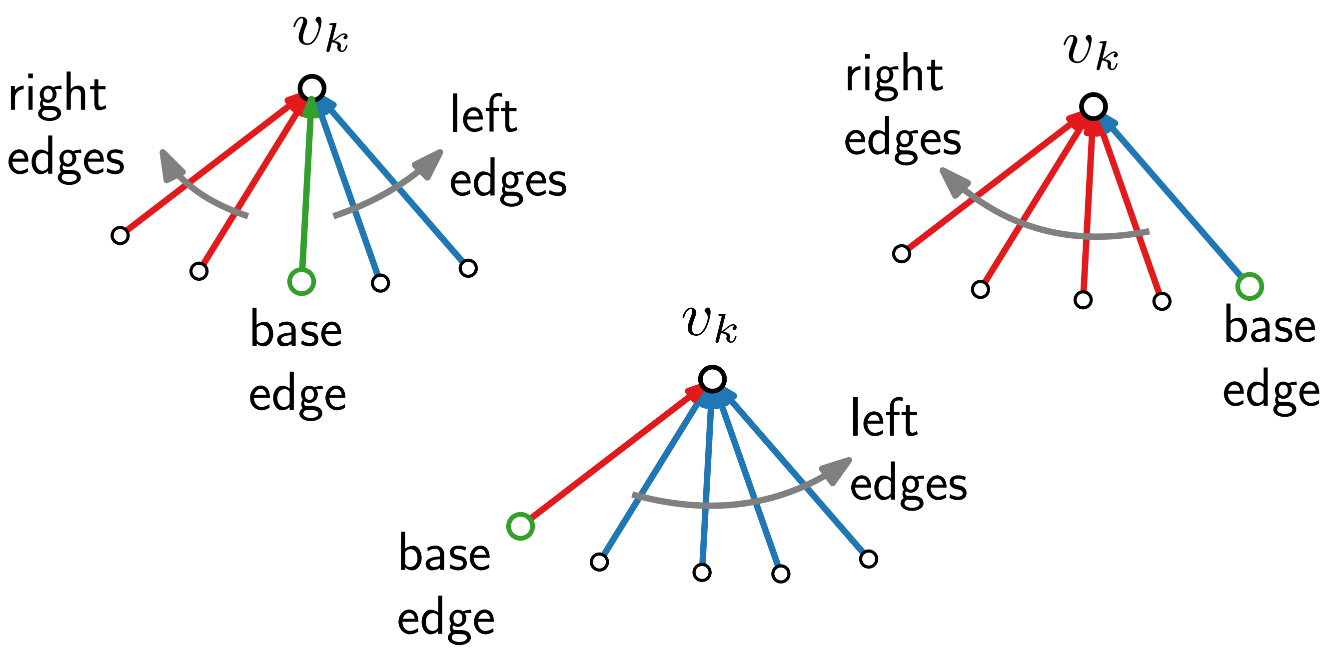


- $t_1 < t_2 < \ldots < t_d$ and $t_d > t_{d+1} > \ldots > t_o$
- (v_k, v_{t_i}), $2 \leq i \leq d - 1$ are blue

Refined Canonical Order → REL



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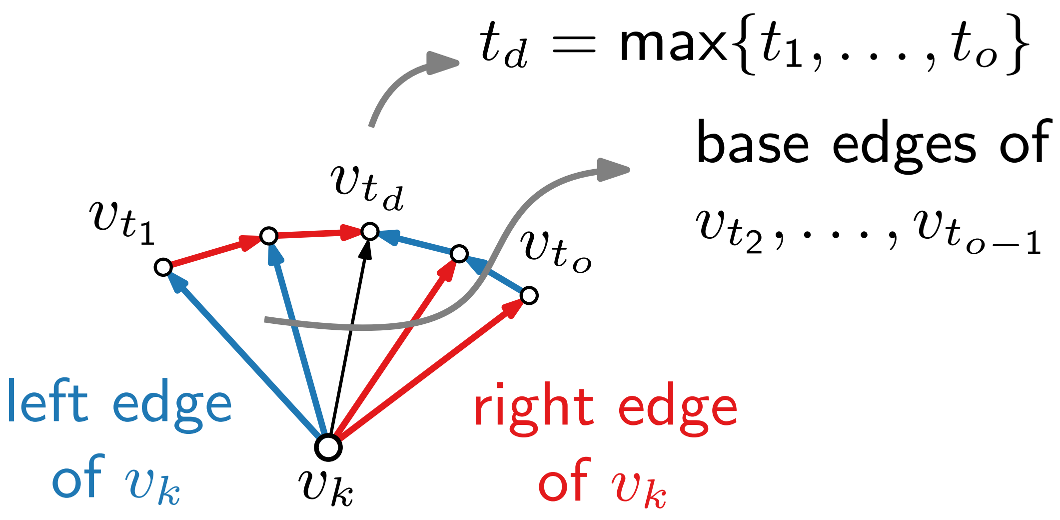

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- (v_k, v_{t_i}), $d+1 \leq i \leq o-1$ are red

Refined Canonical Order → REL

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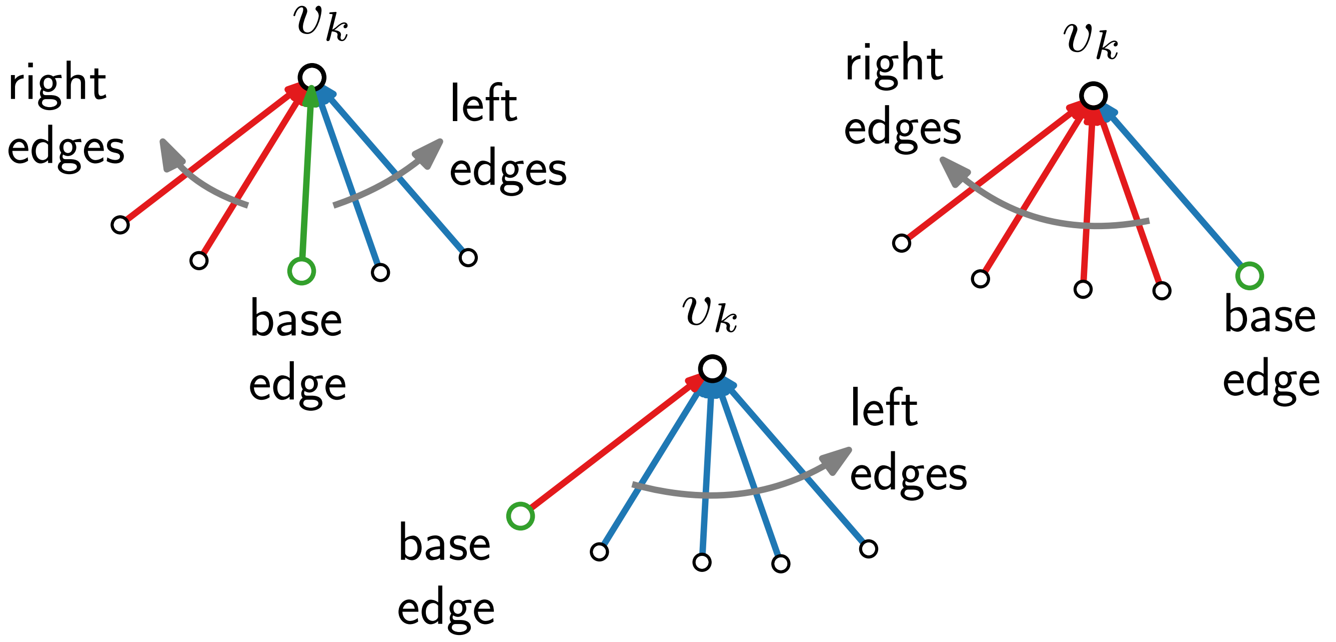
Let T_r be the red edges and T_b the blue edges.



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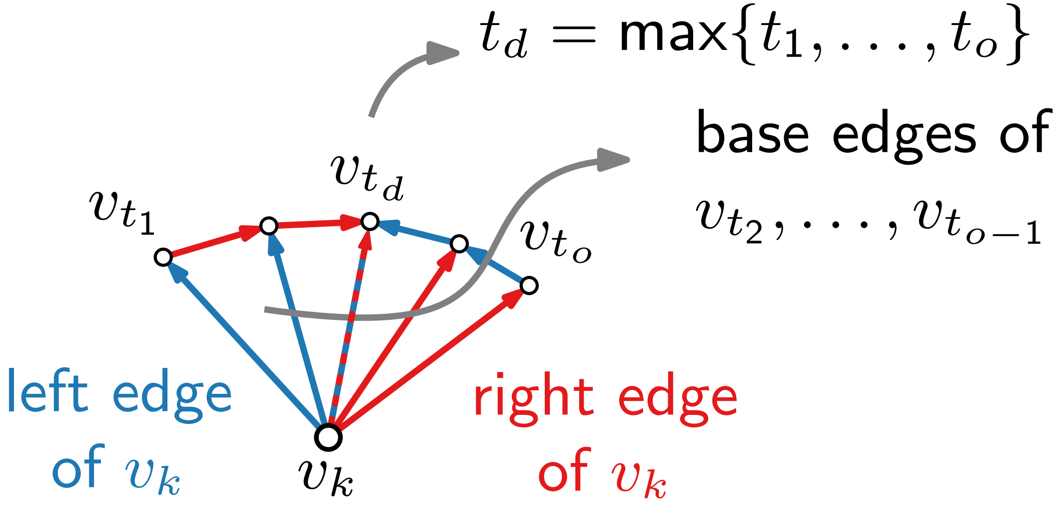
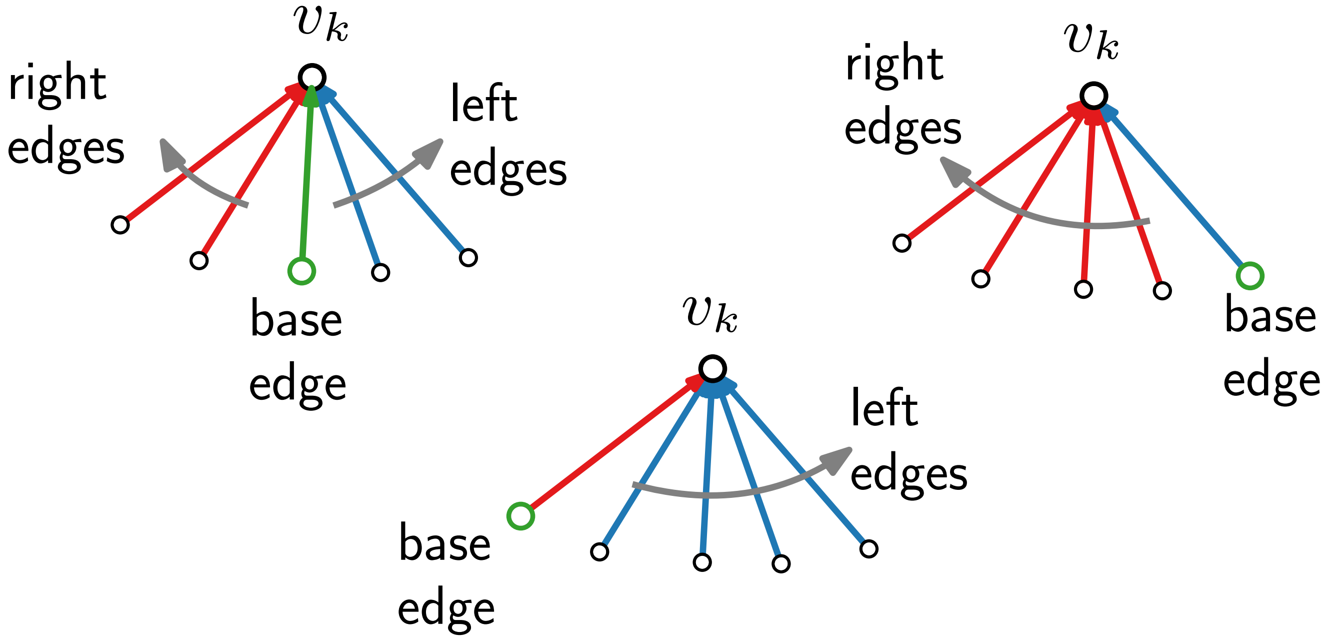


- $t_1 < t_2 < \ldots < t_d$ and $t_d > t_{d+1} > \ldots > t_o$
- (v_k, v_{t_i}), $2 \leq i \leq d-1$ are blue
- (v_k, v_{t_i}), $d+1 \leq i \leq o-1$ are red
- (v_k, v_{t_d}) is either red or blue

Refined Canonical Order → REL



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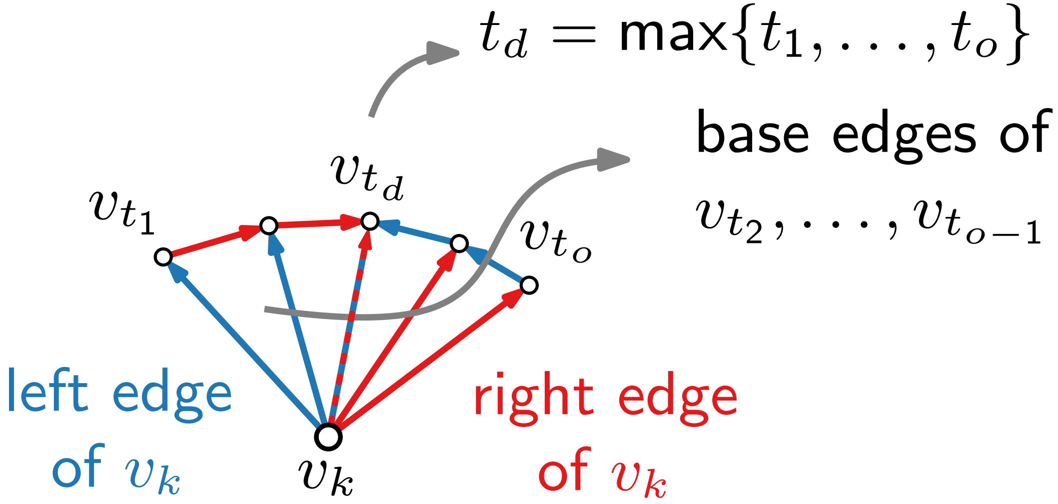

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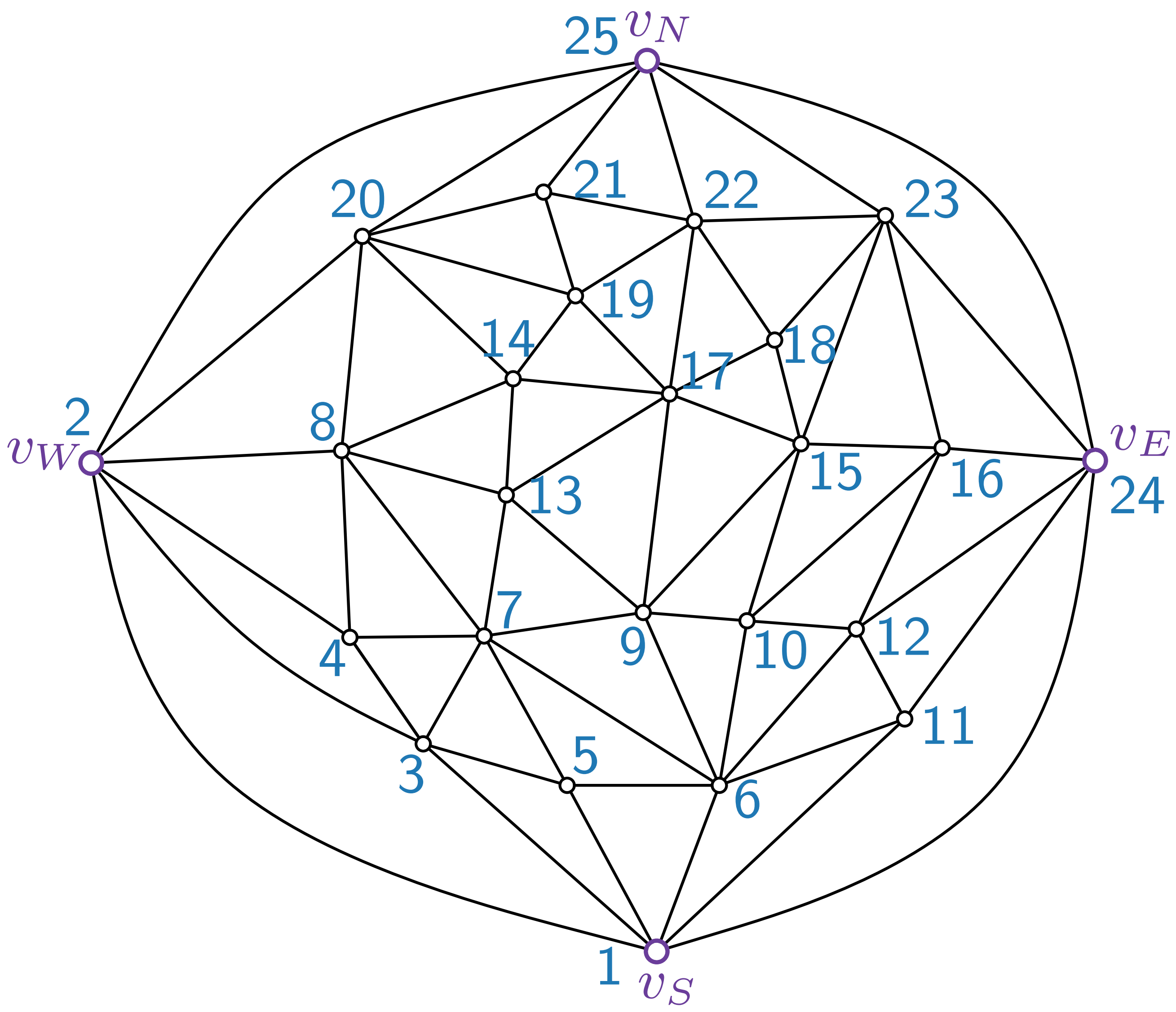
- (v_k, v_{t_d}) is either red or blue

$\Rightarrow$ Circular order of outgoing edges at v_k correct.

From REL to st-Digraphs to Coordinates



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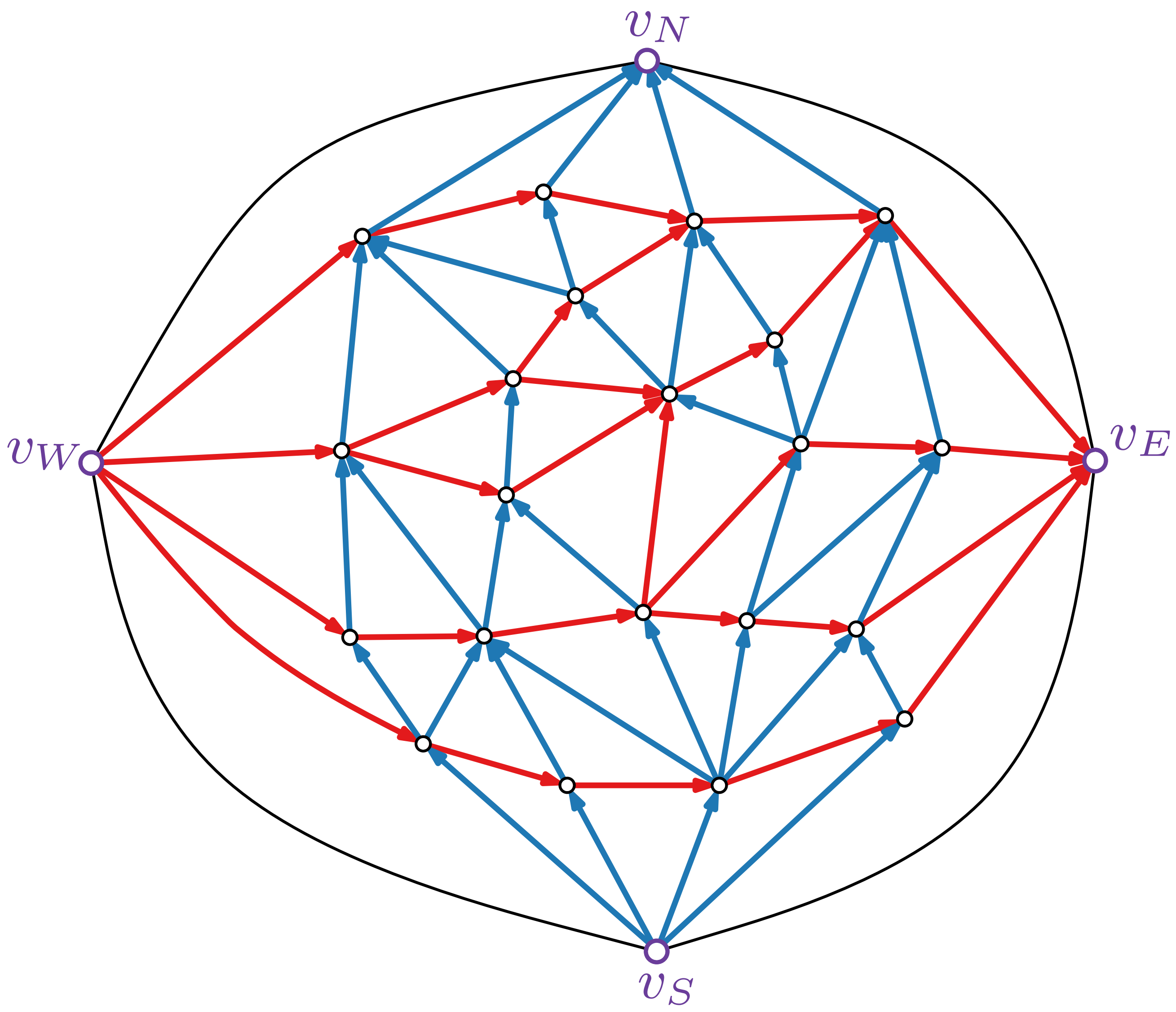
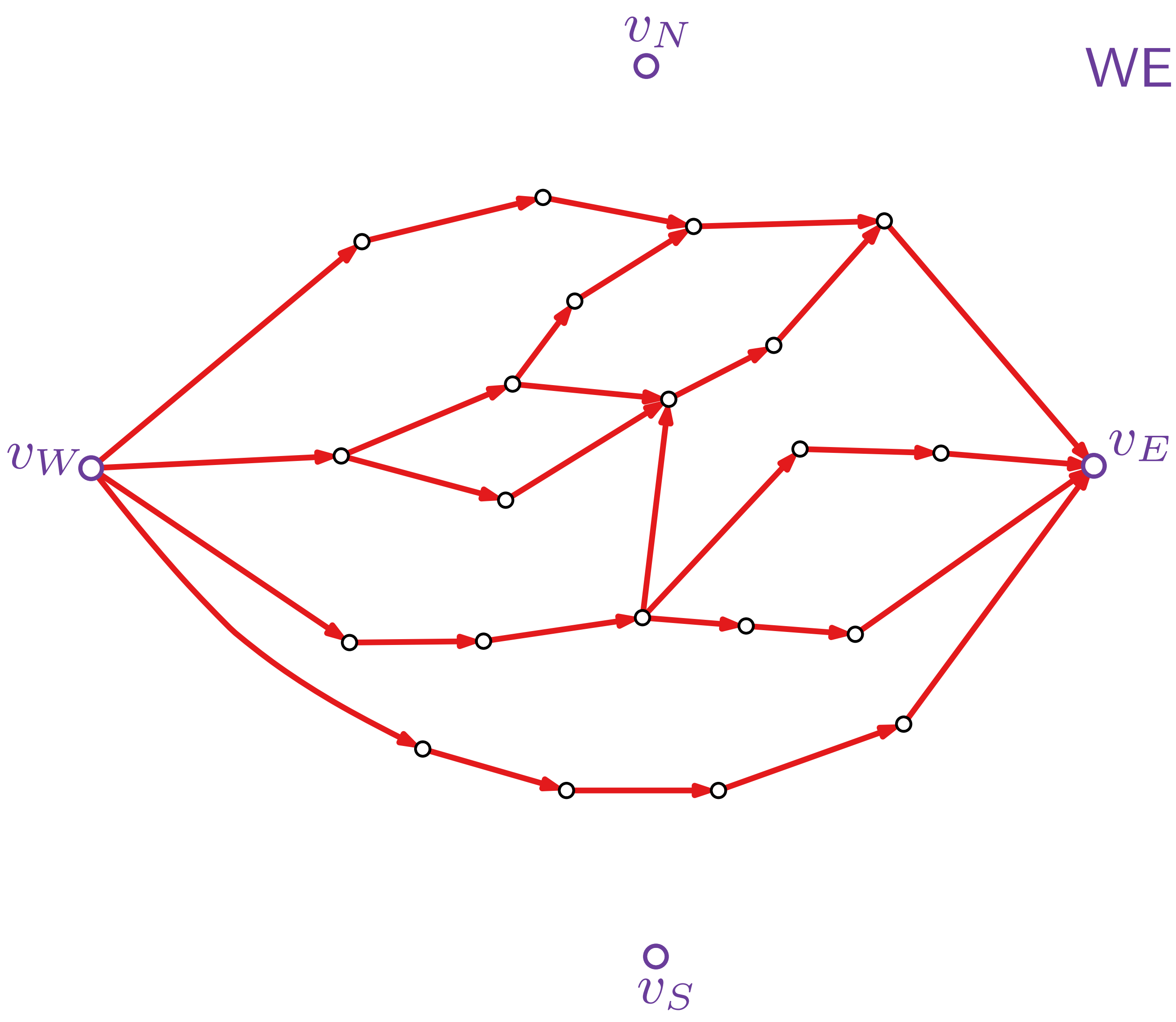
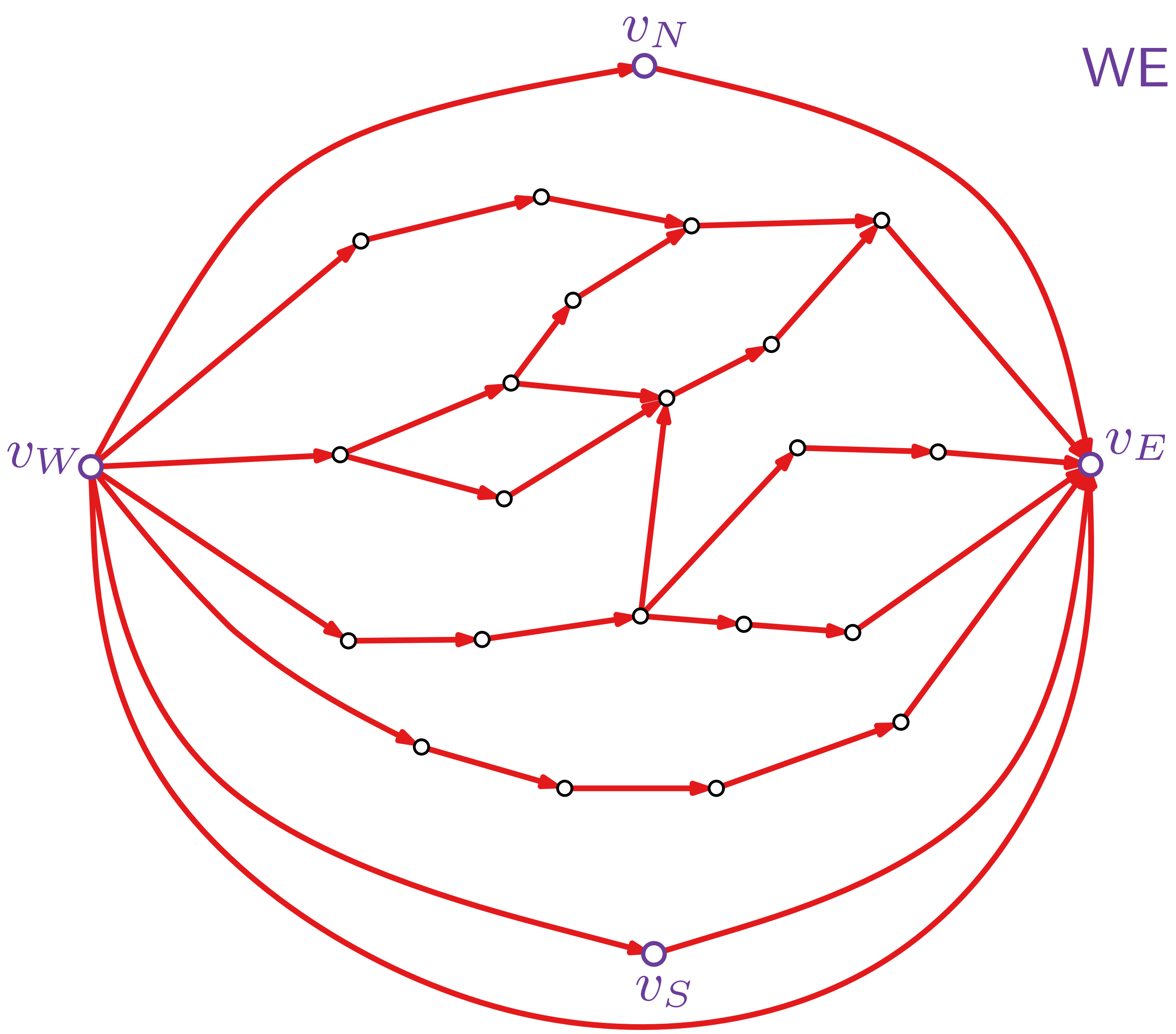


From REL to st-Digraphs to Coordinates



WE network G_{hor}

From REL to st-Digraphs to Coordinates



WE network G_{hor}

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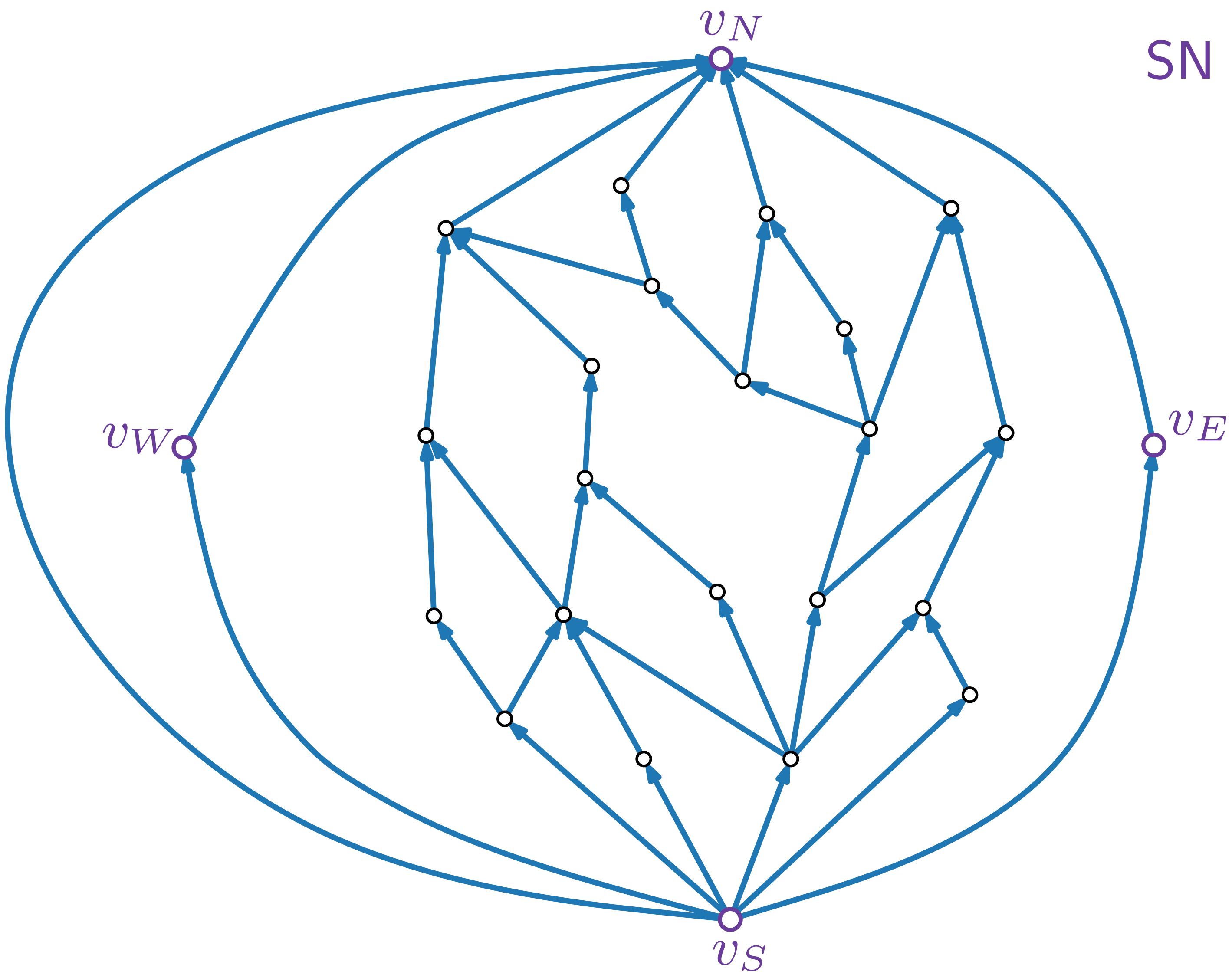
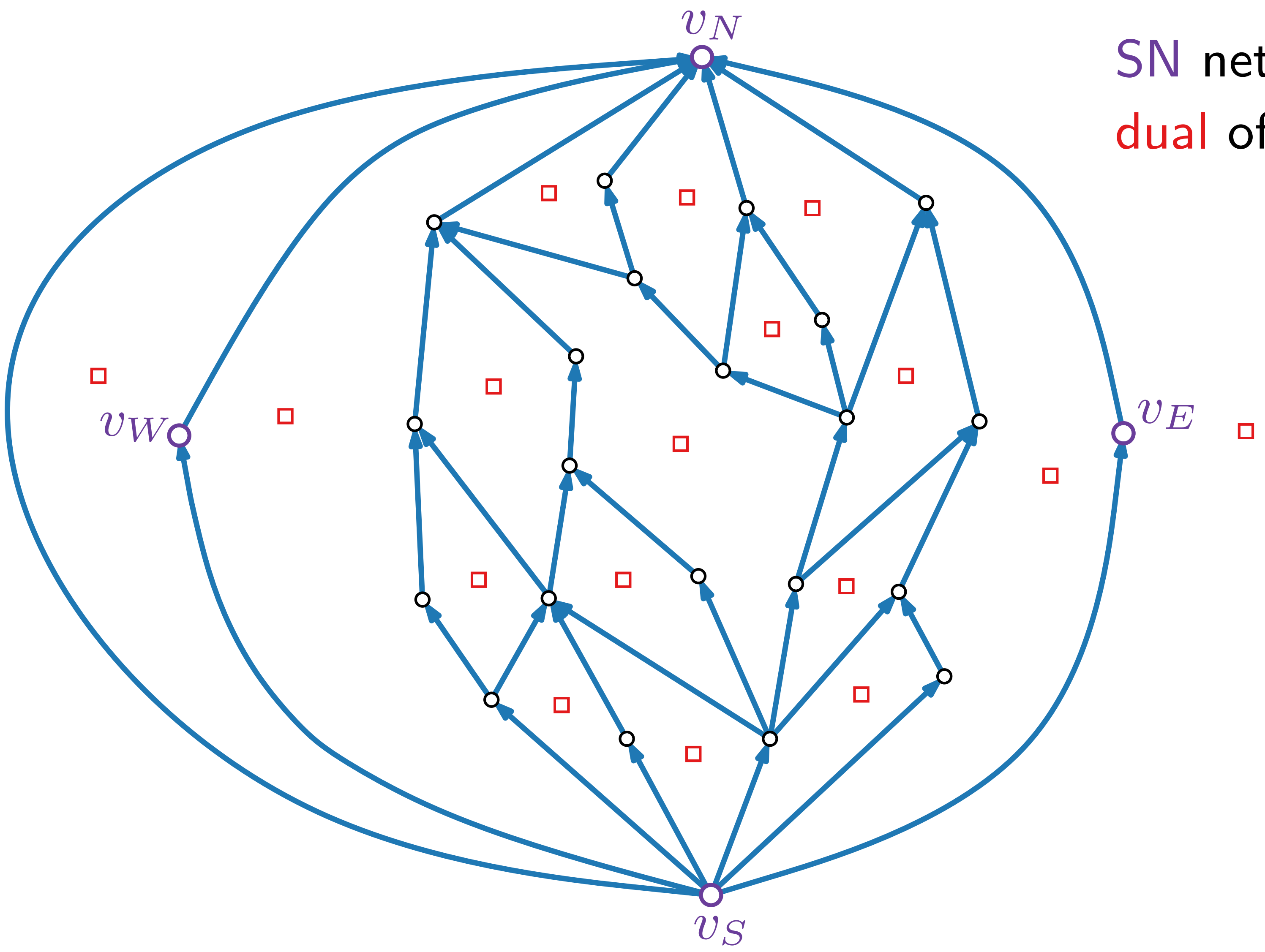


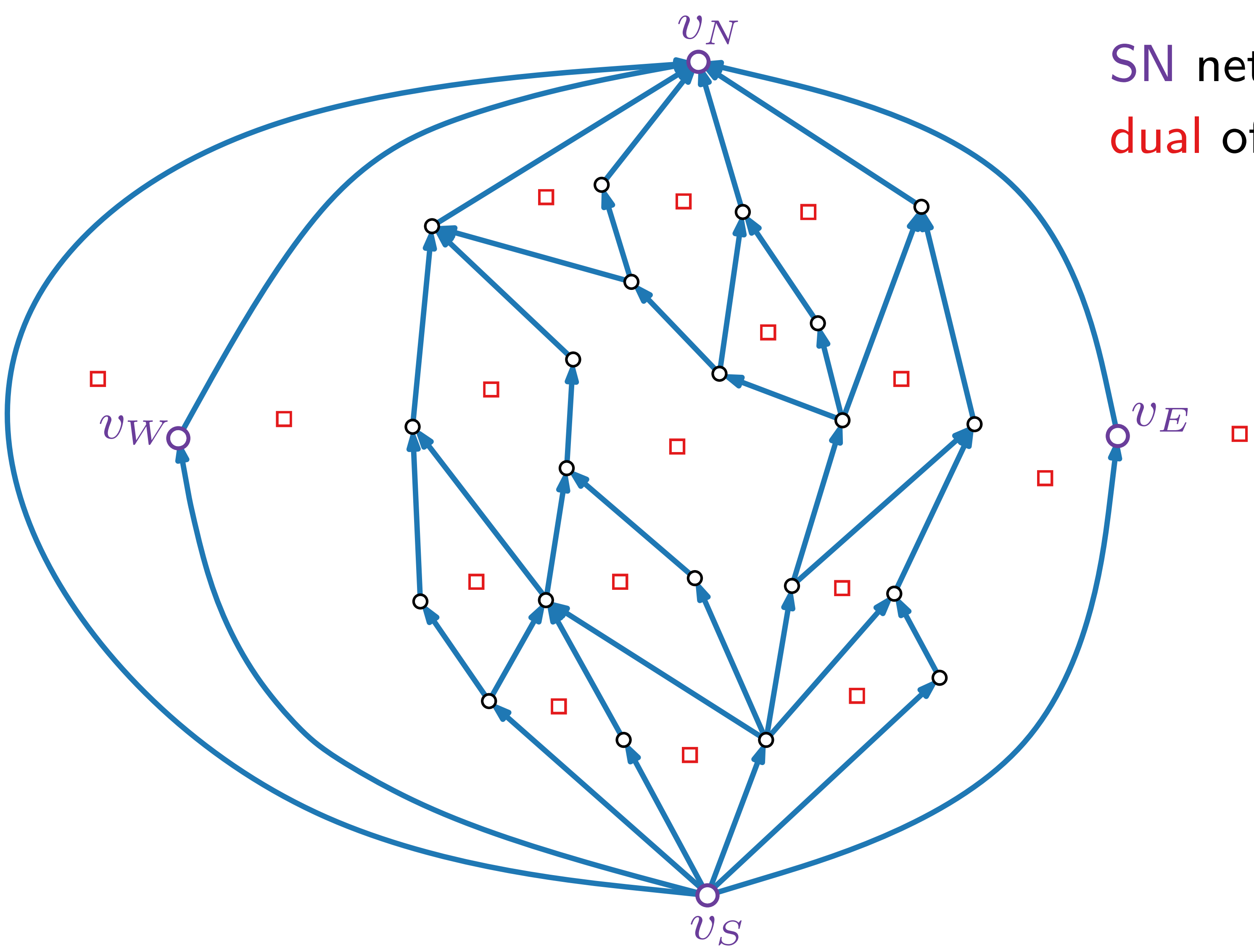
SN network G_{ver}

From REL to st-Digraphs to Coordinates



SN network G_{ver}
dual of G_{ver}

From REL to st-Digraphs to Coordinates



SN network G_{ver}

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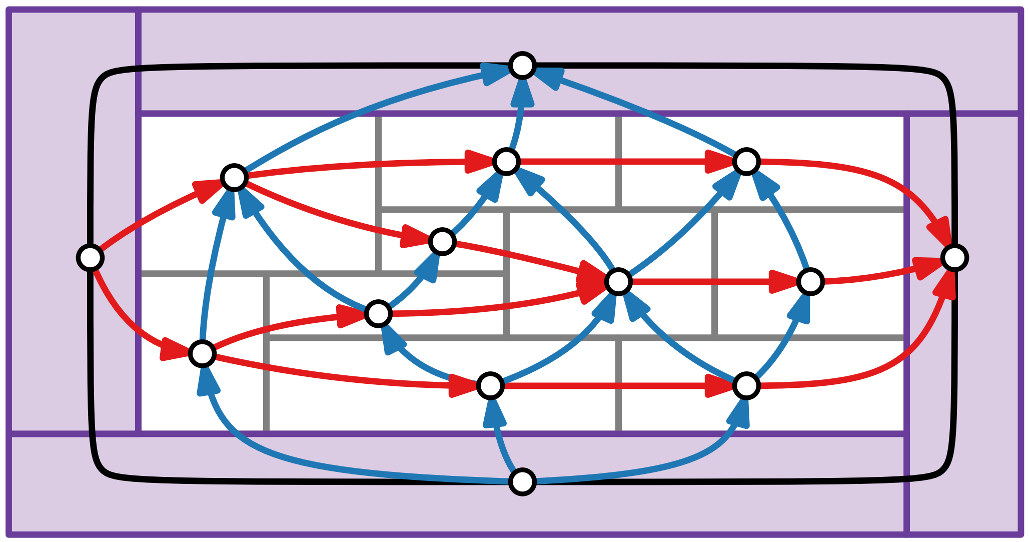

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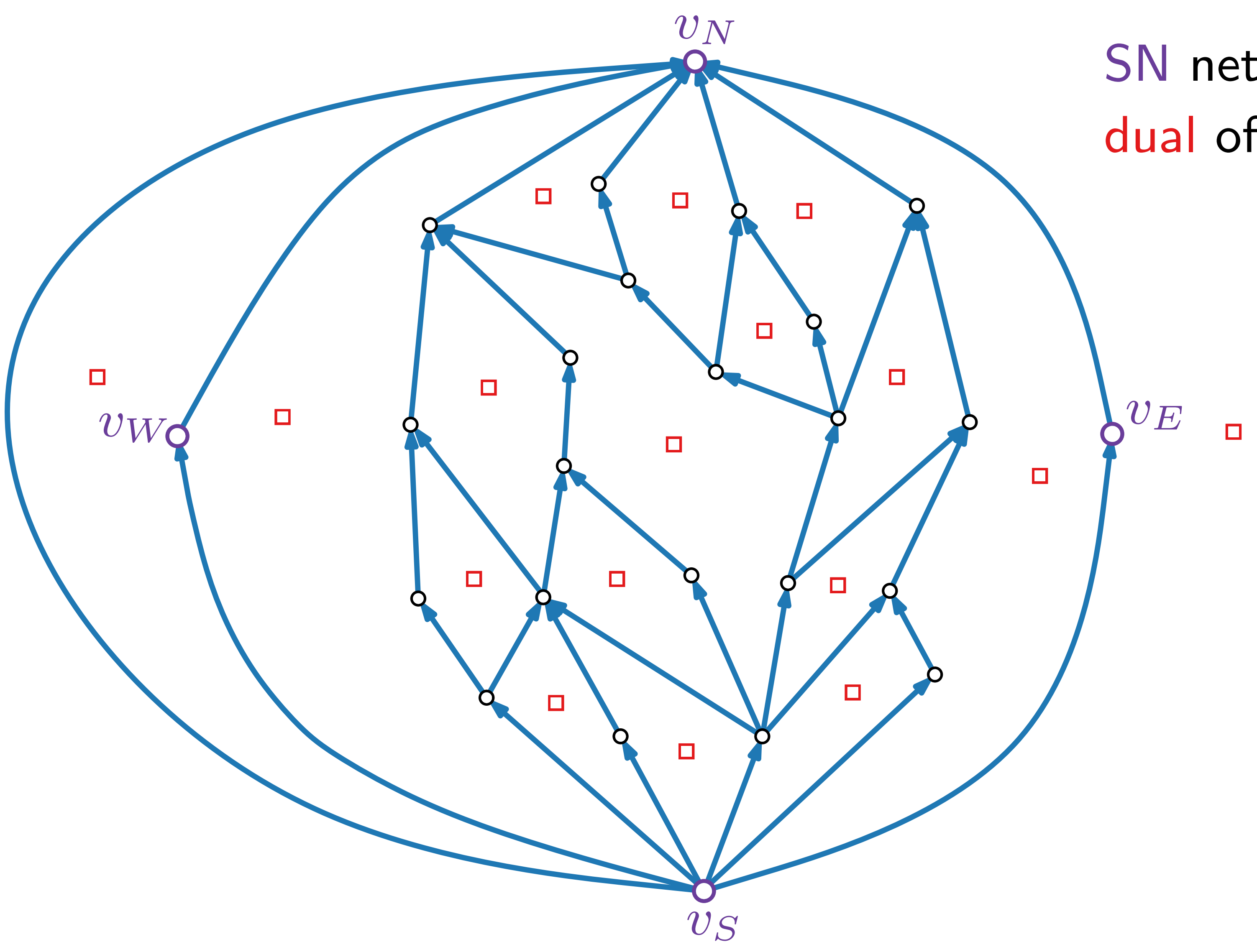

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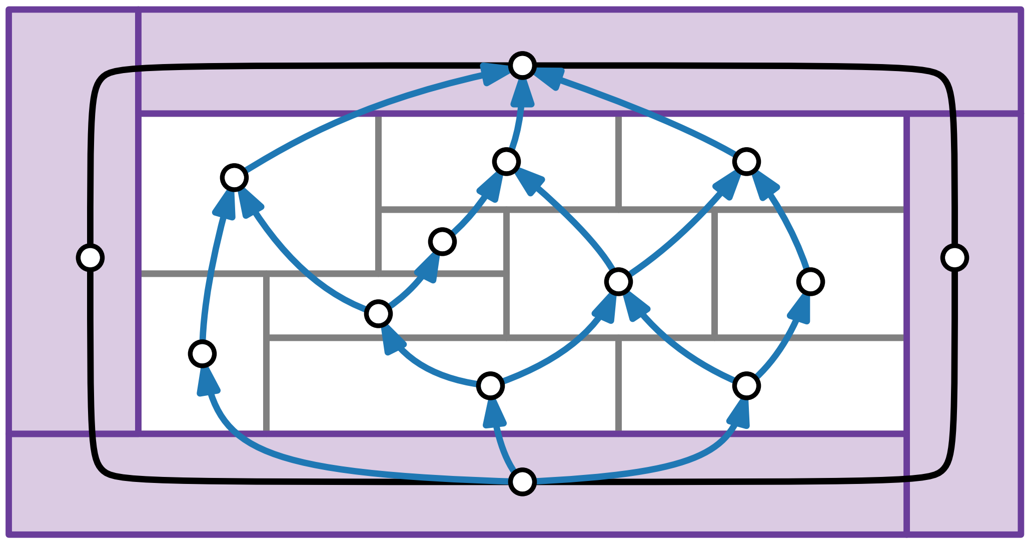

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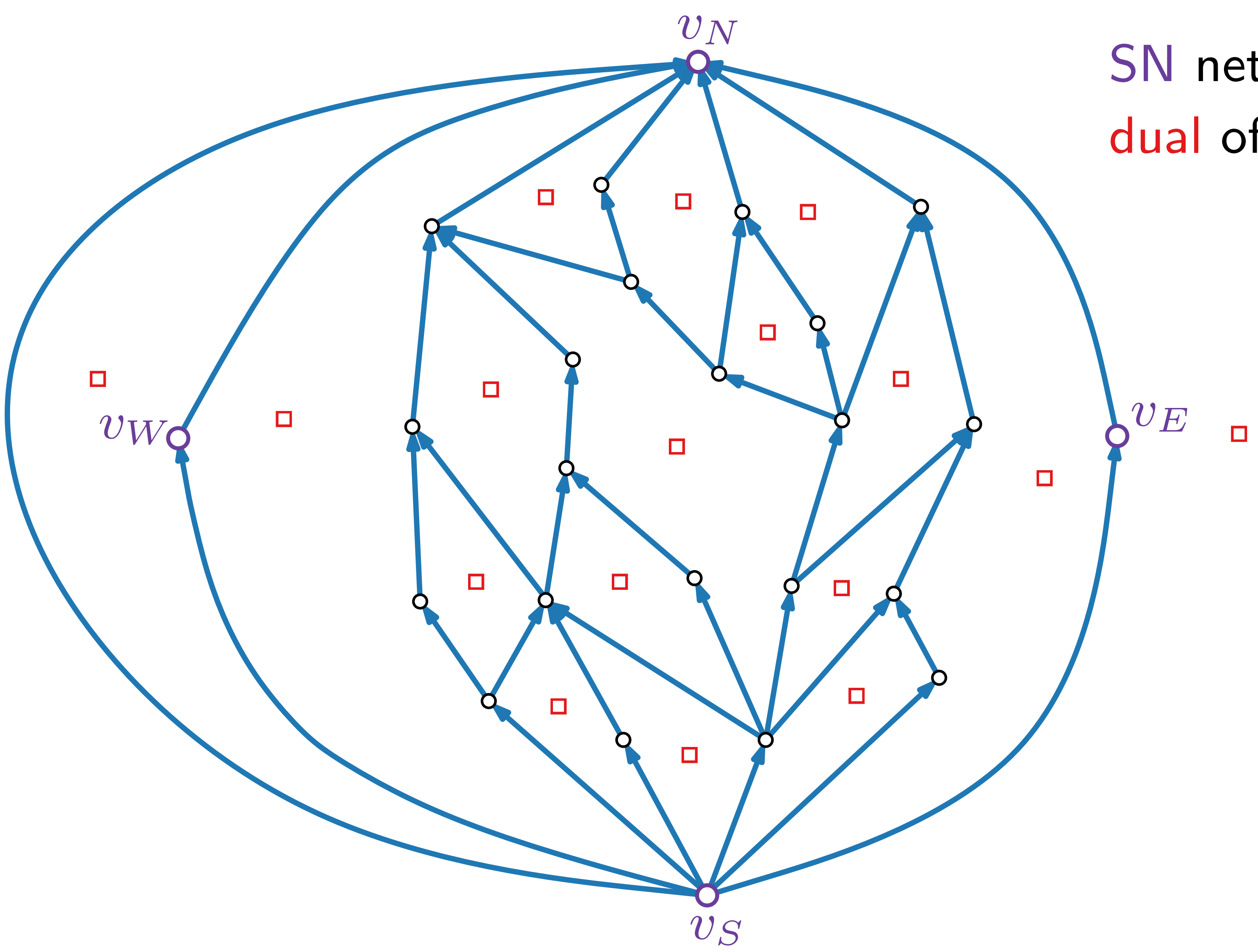
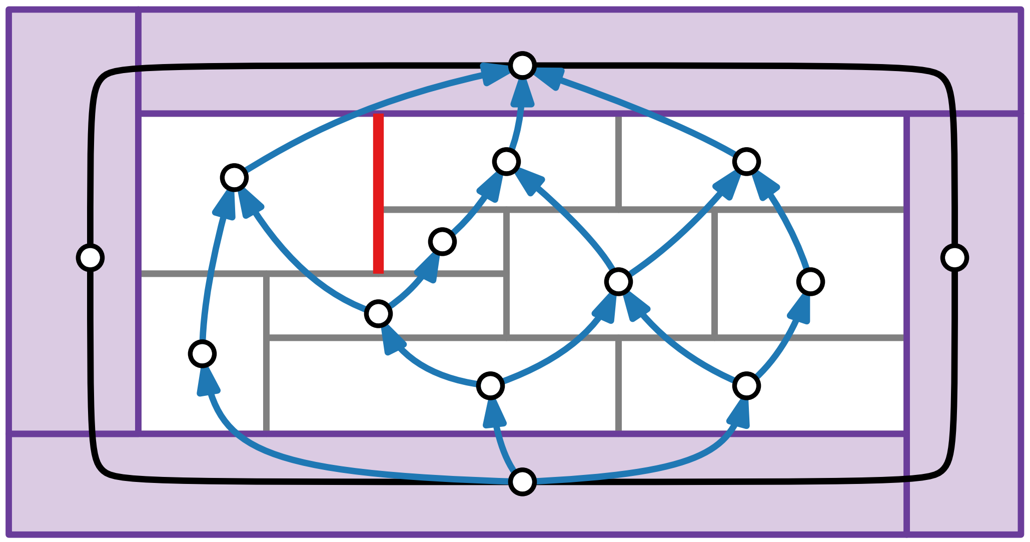


SN network G_{ver}
dual of G_{ver}



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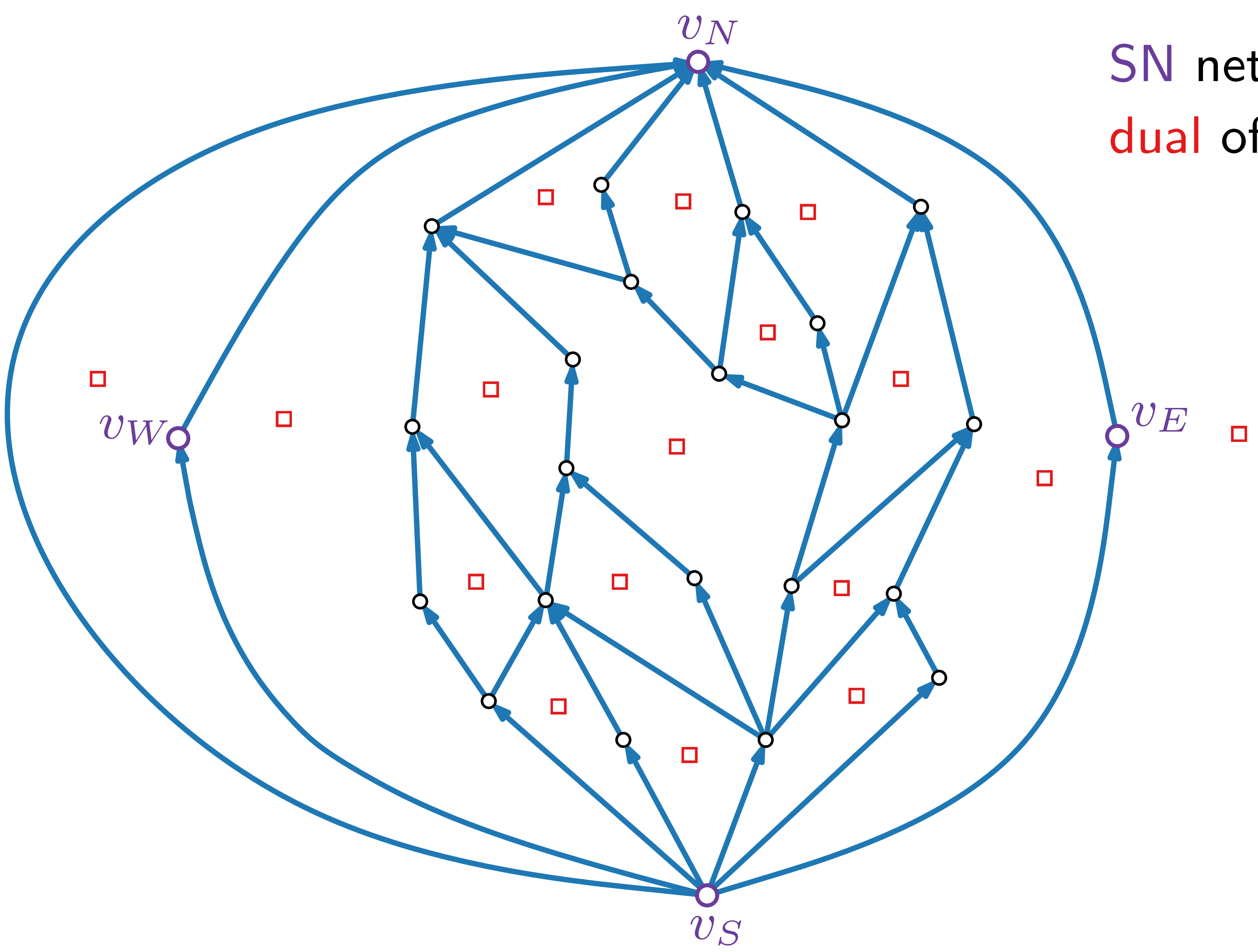

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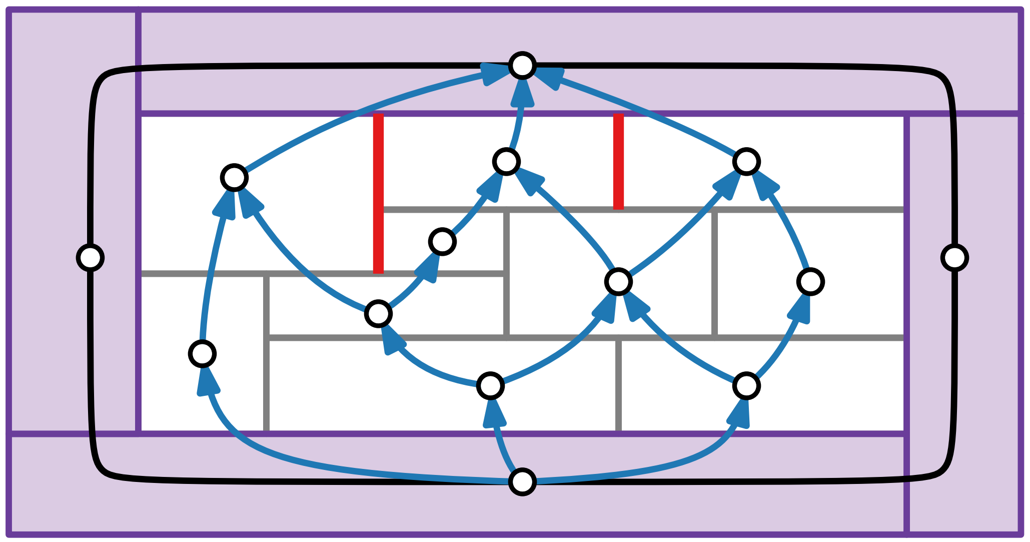

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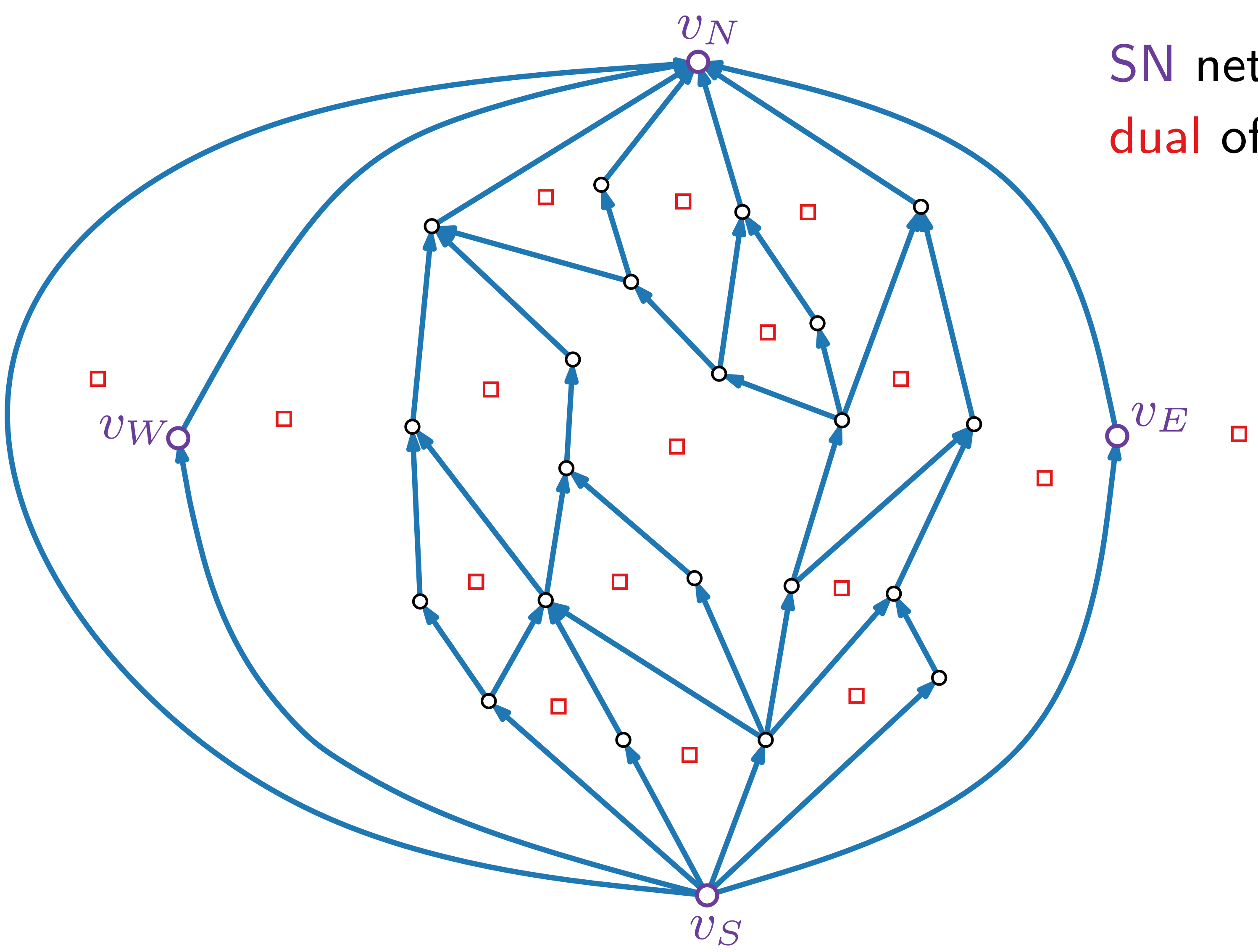

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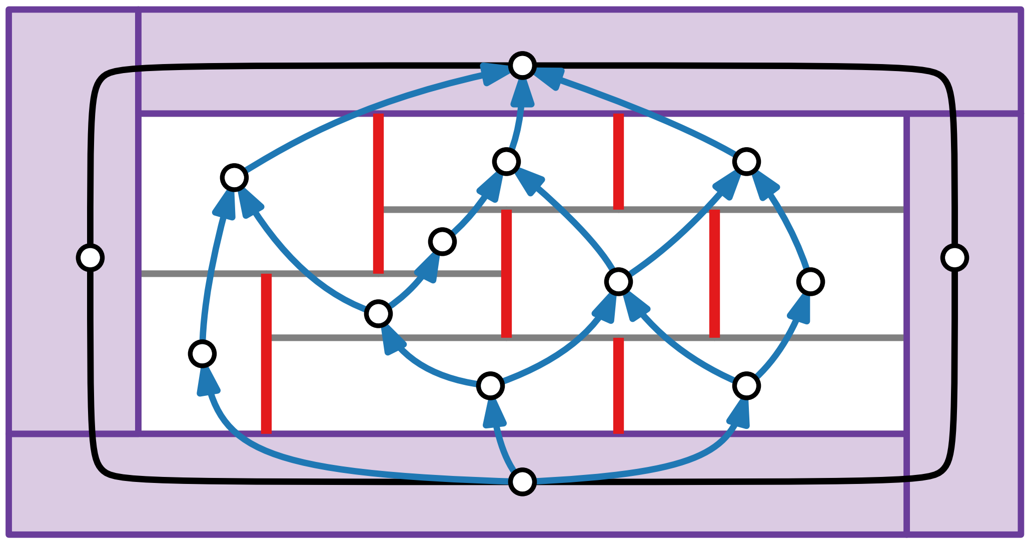

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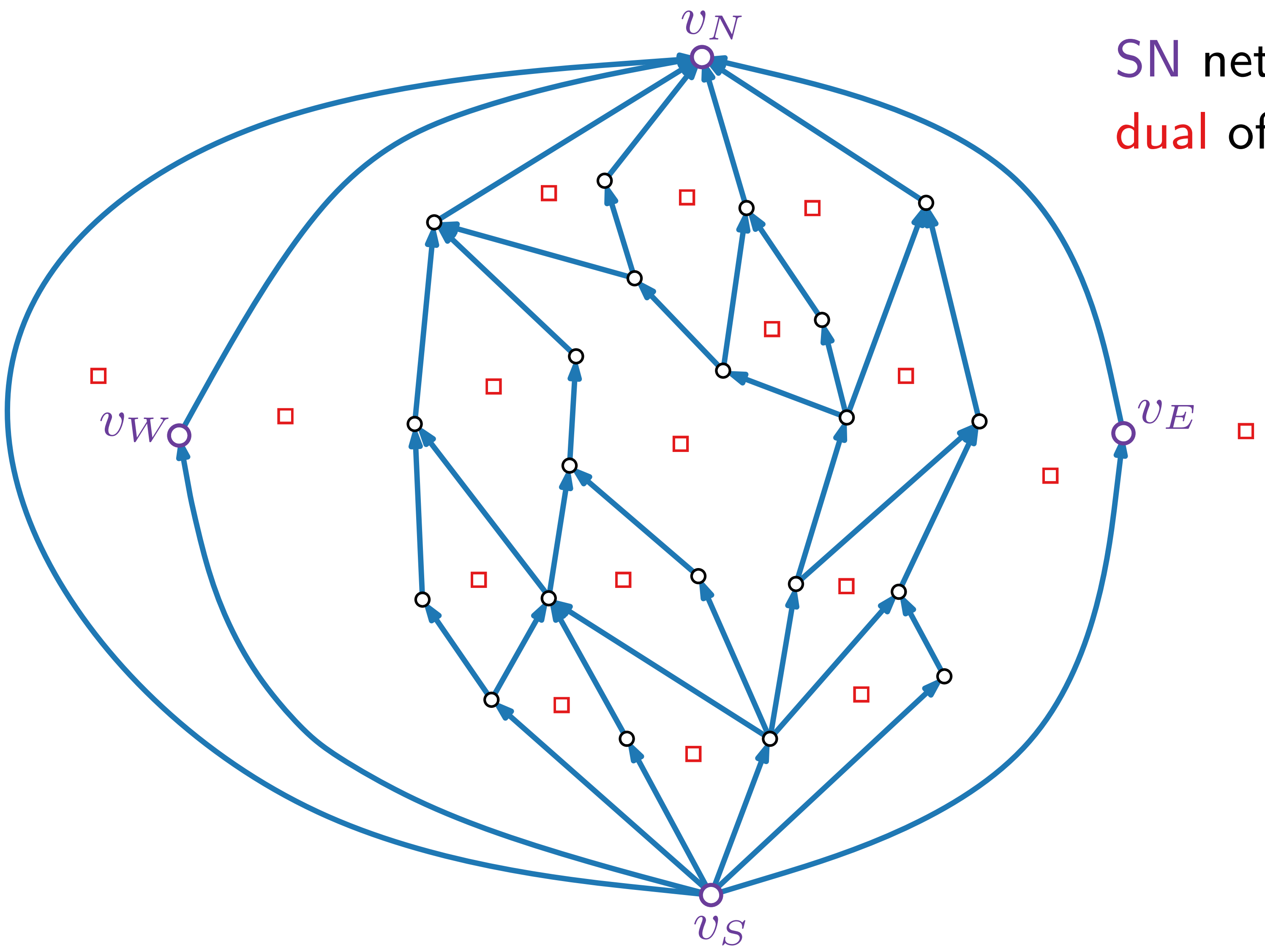

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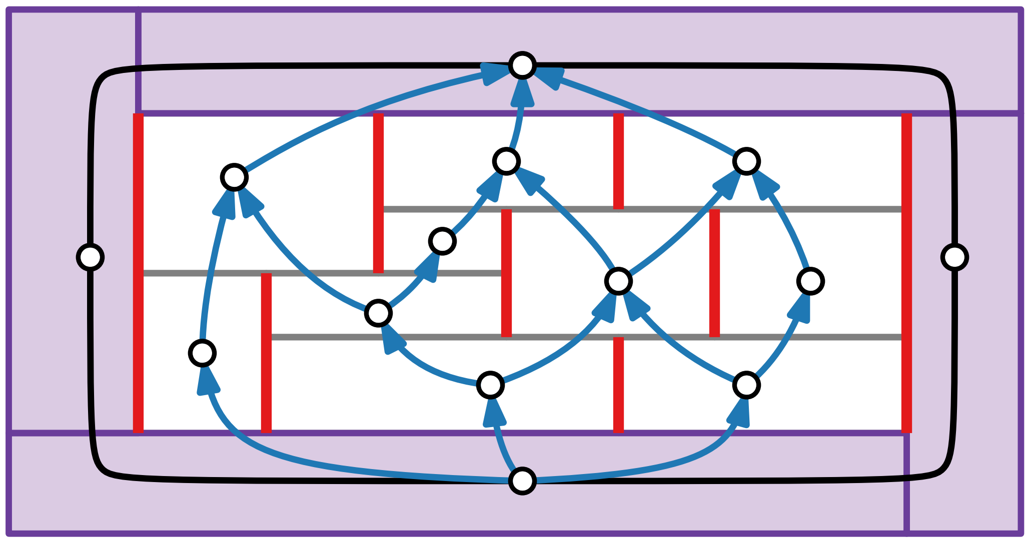

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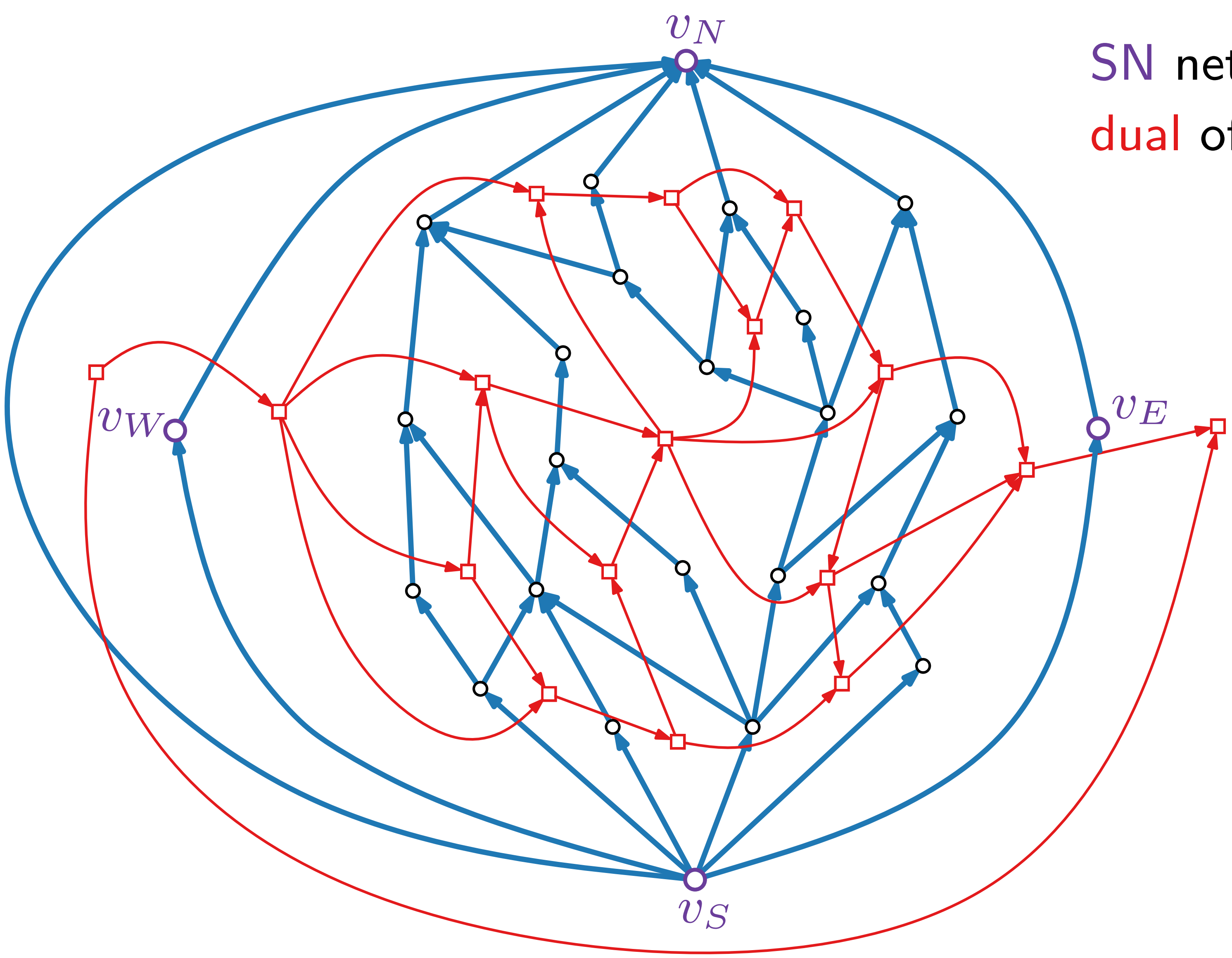

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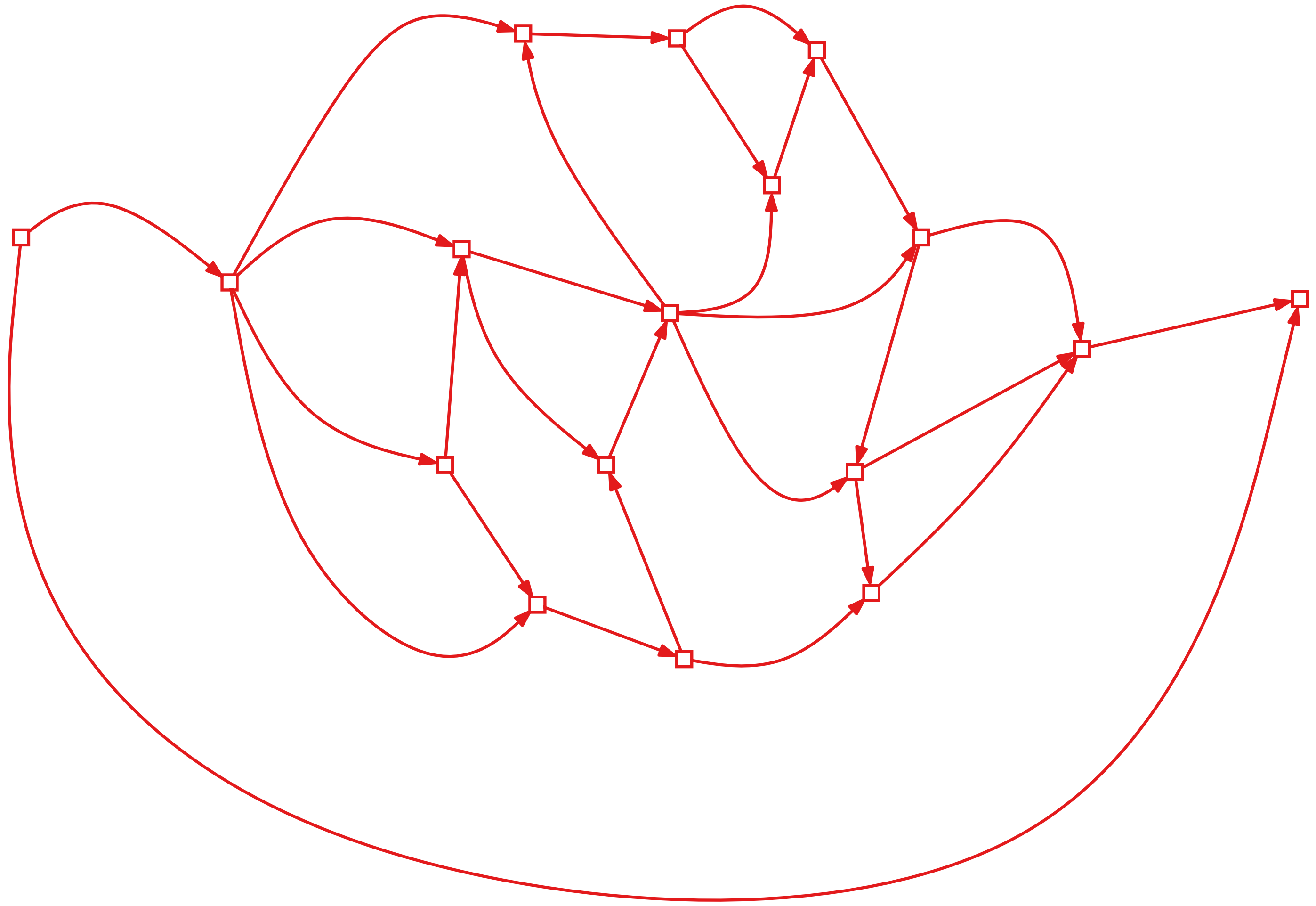

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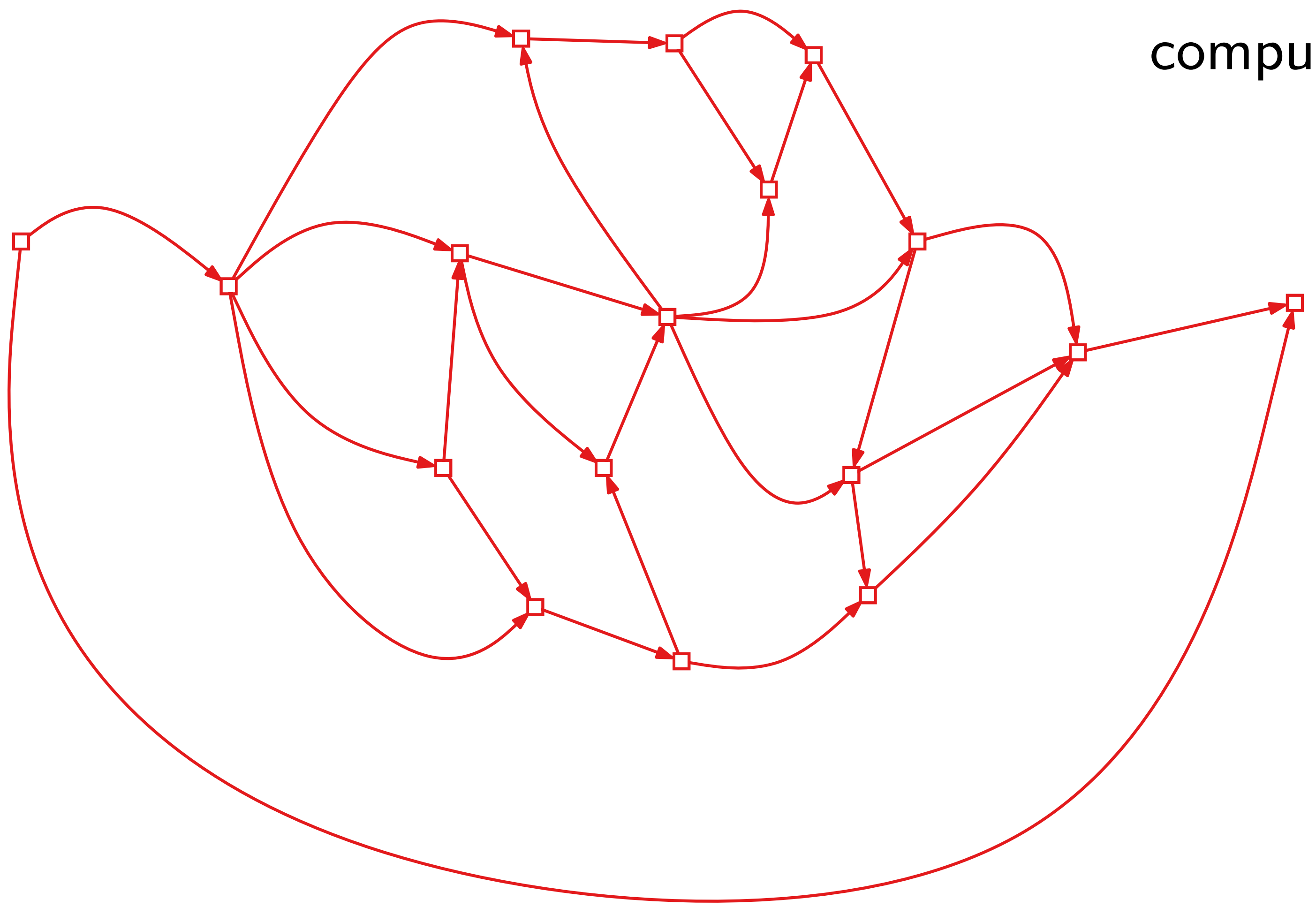
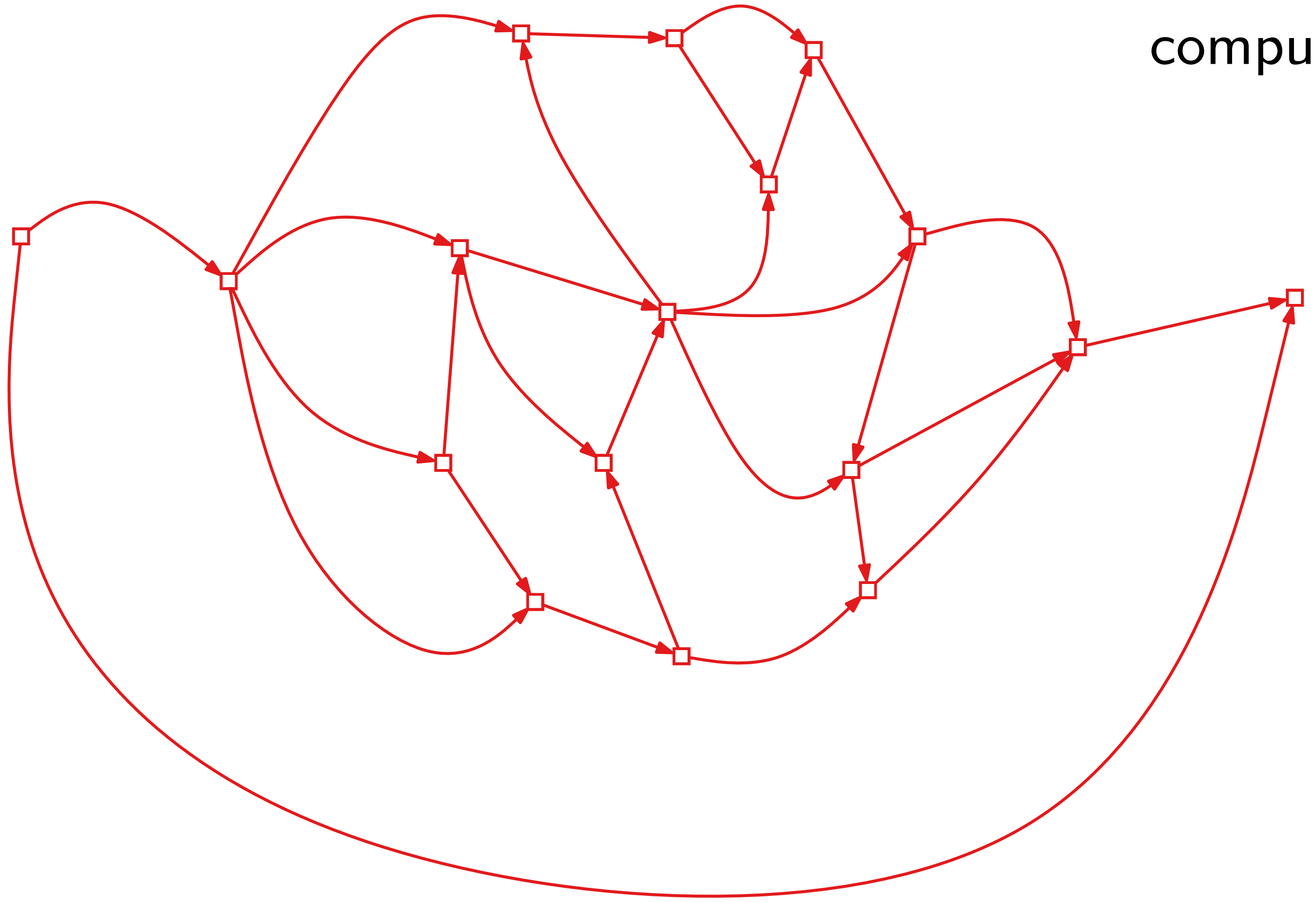


dual of G_{ver}

compute topological order

From REL to st-Digraphs to Coordinates

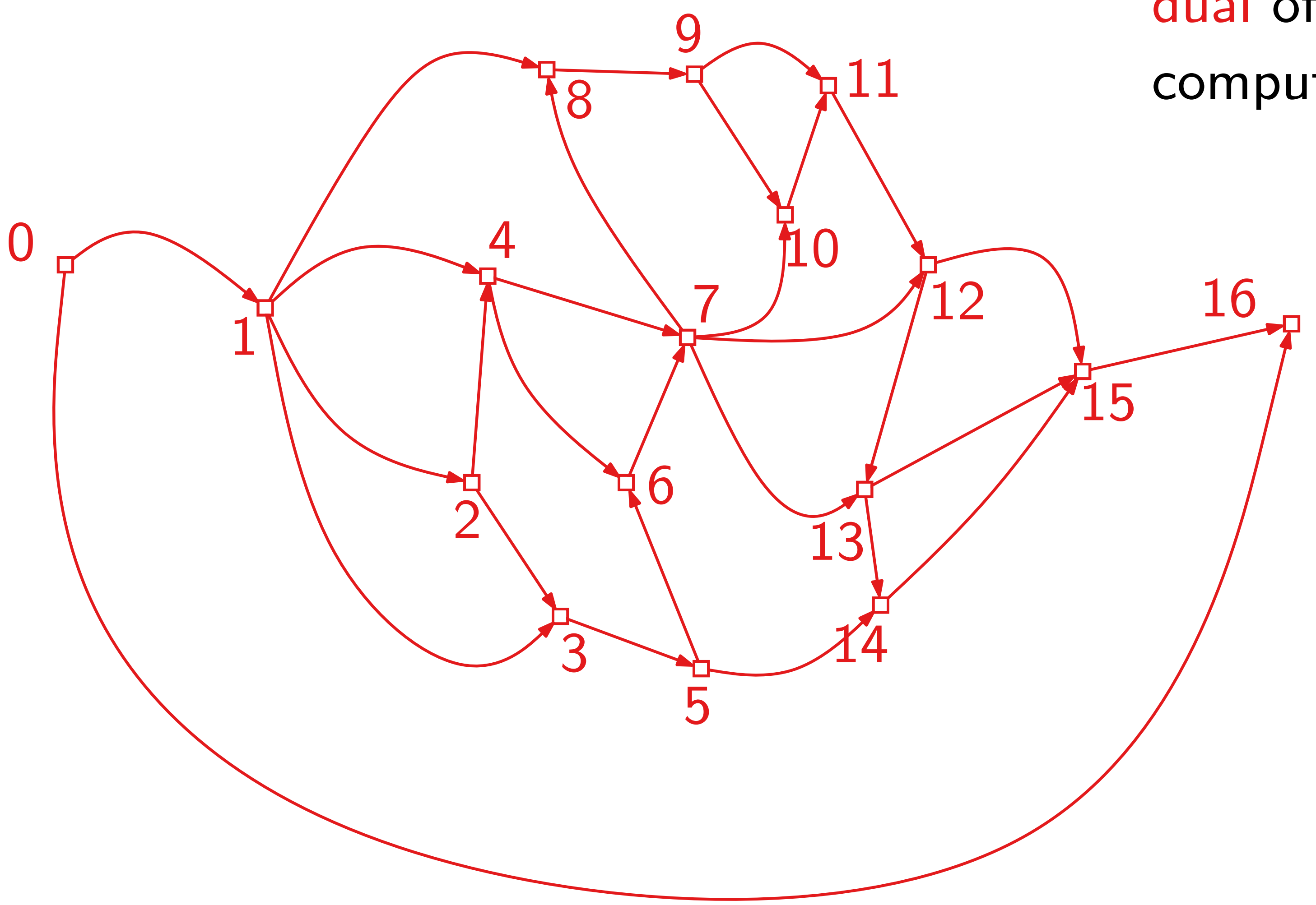


dual of G_{ver}

compute topological order

i.e., linear order of all vertices such that all directed edges point in the same direction

From REL to st-Digraphs to Coordinates



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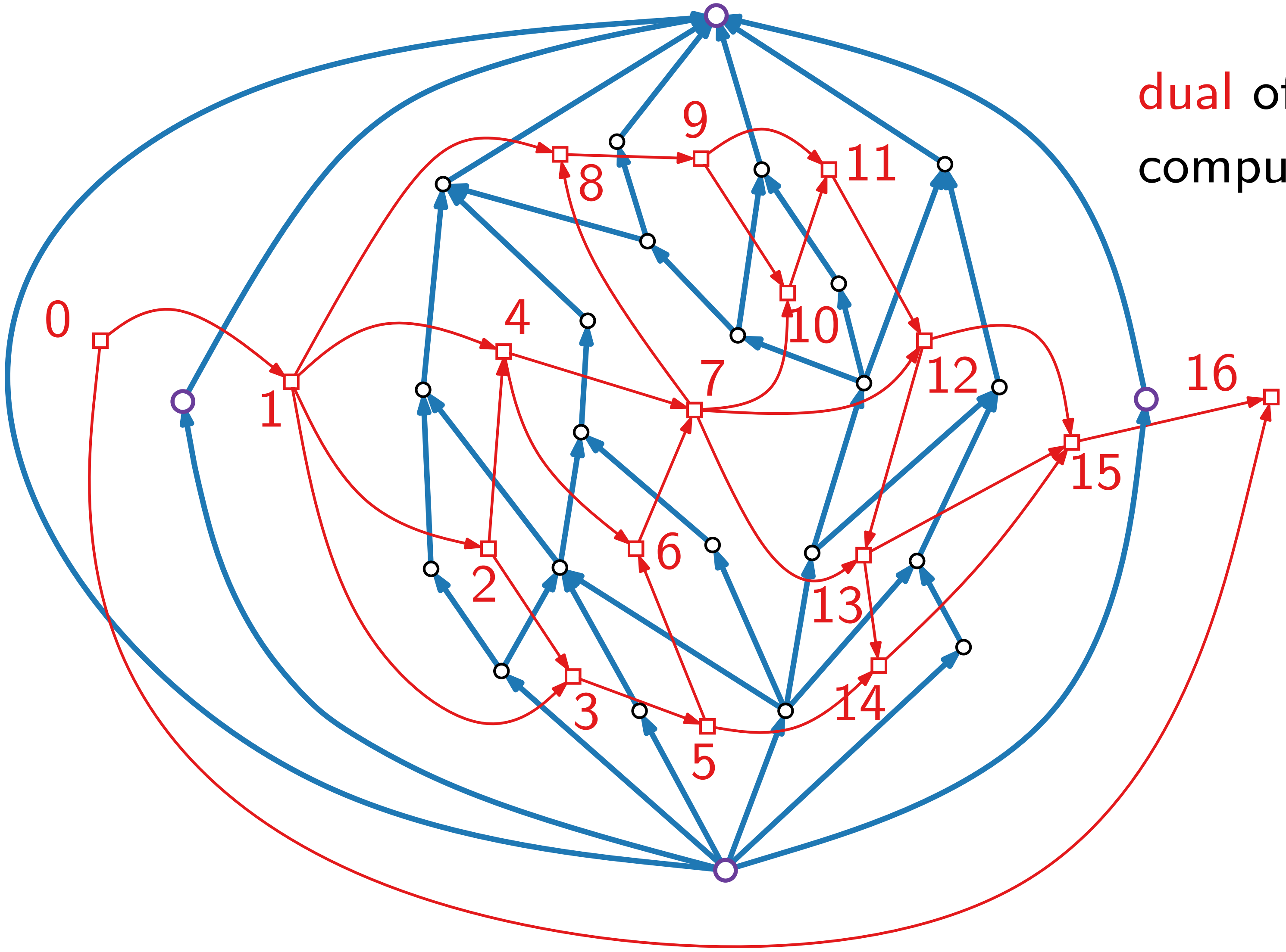

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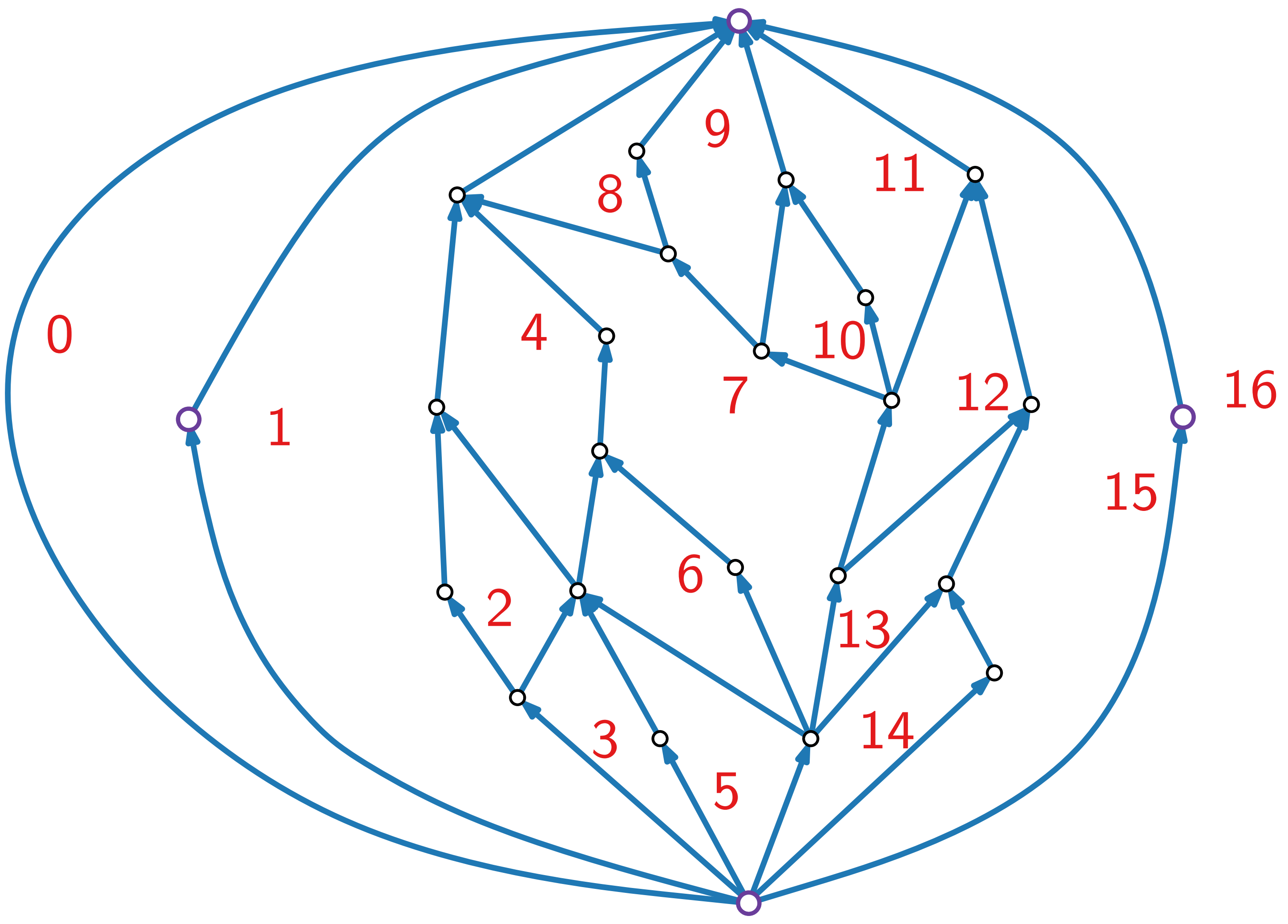

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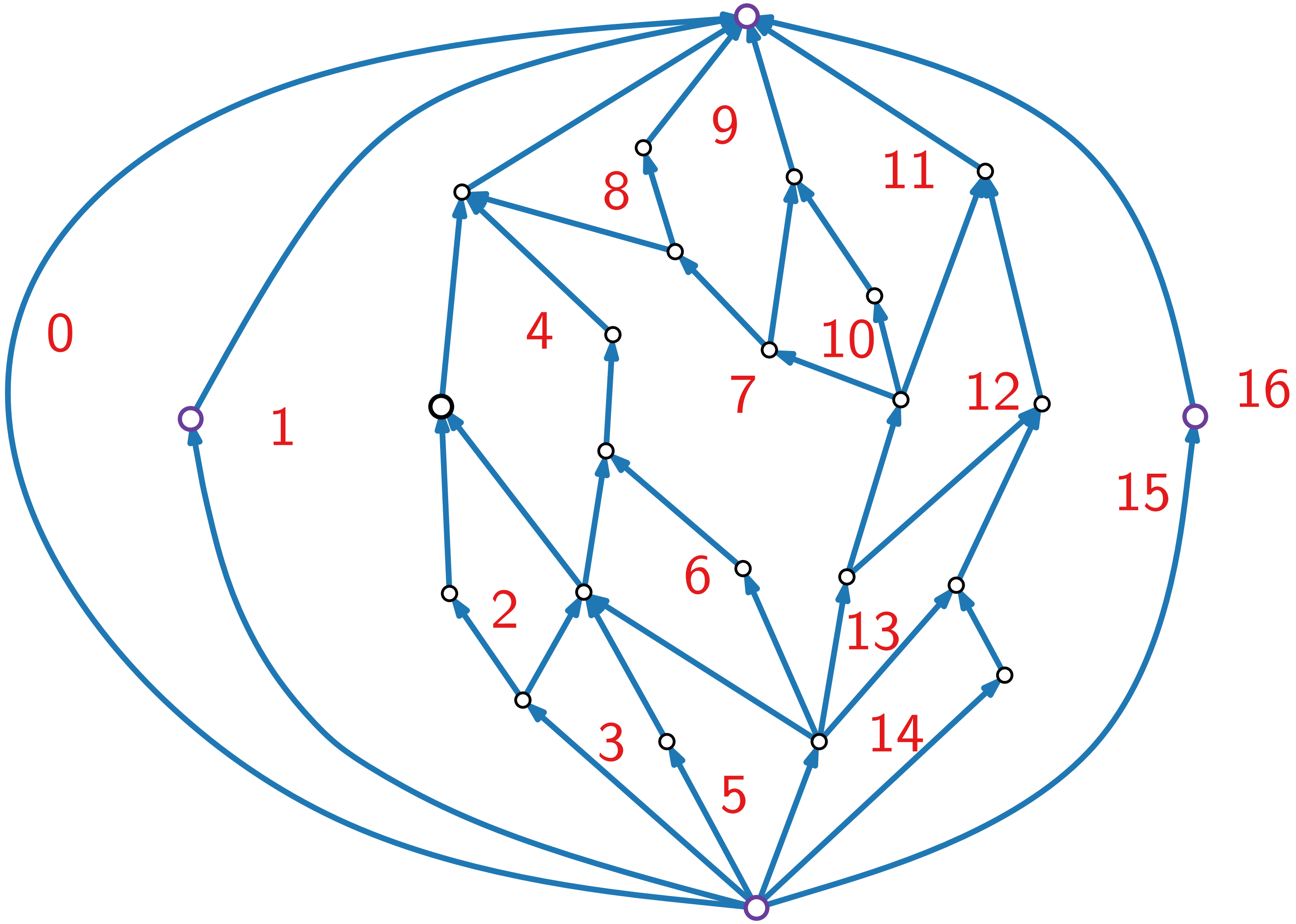

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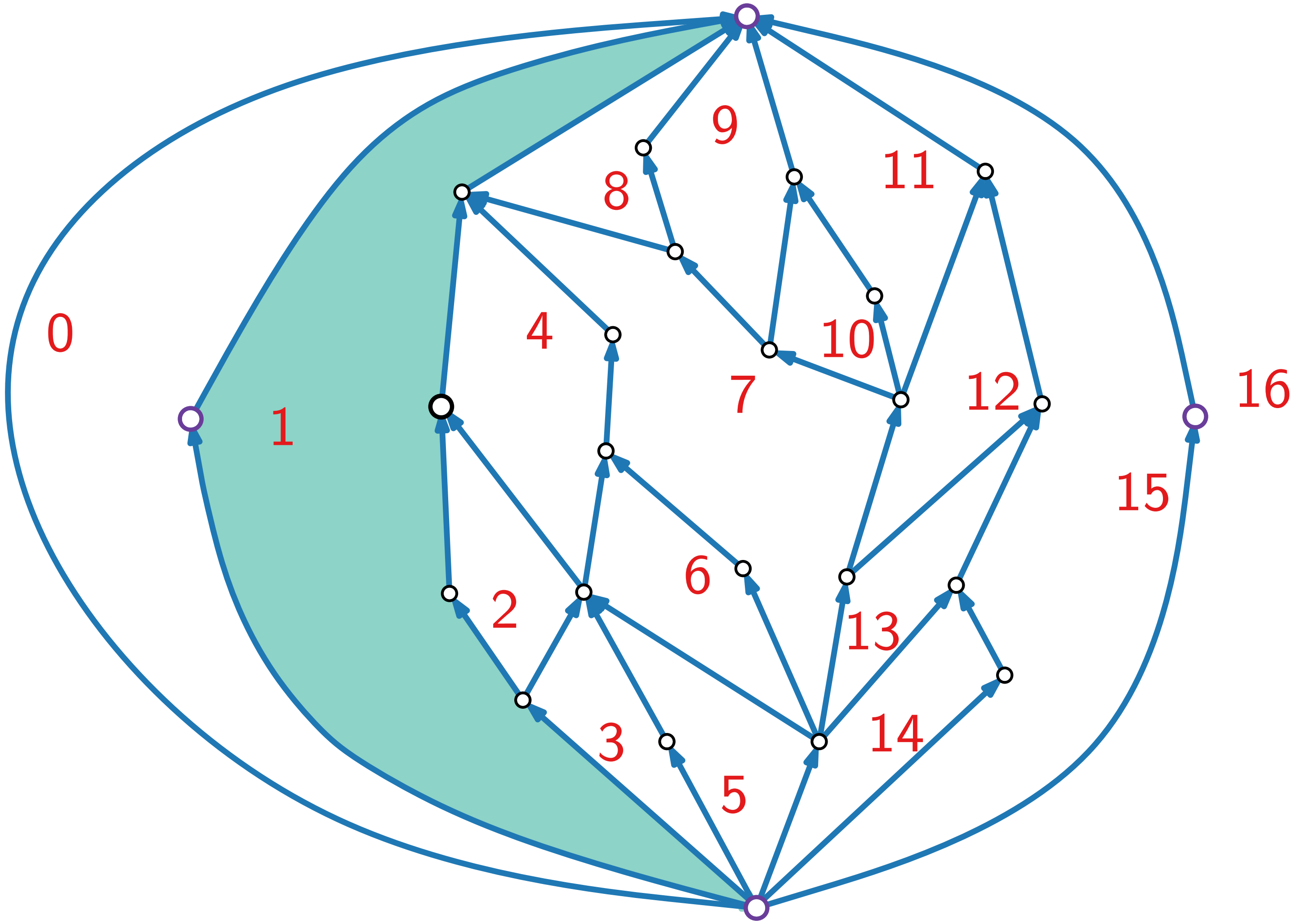

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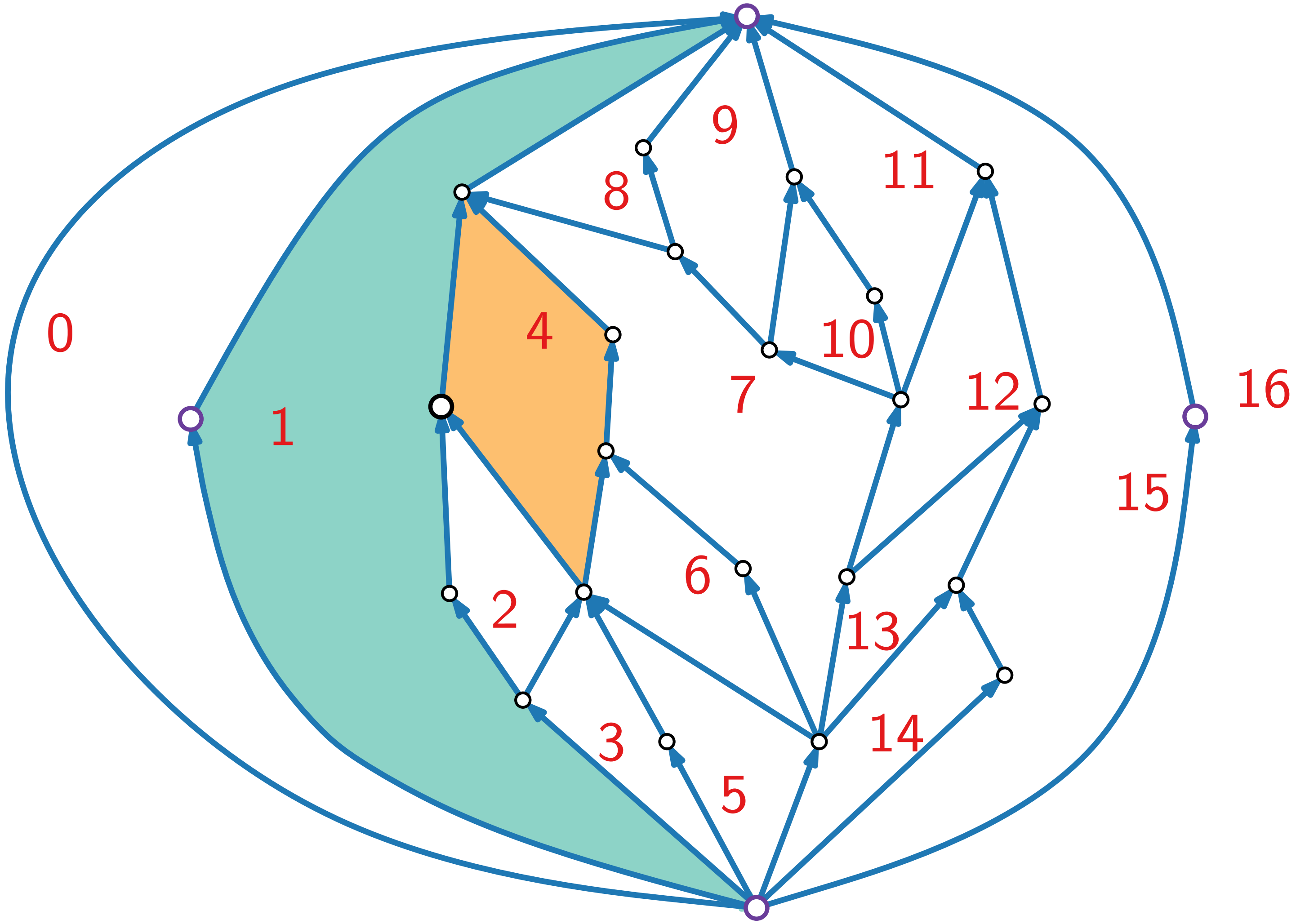

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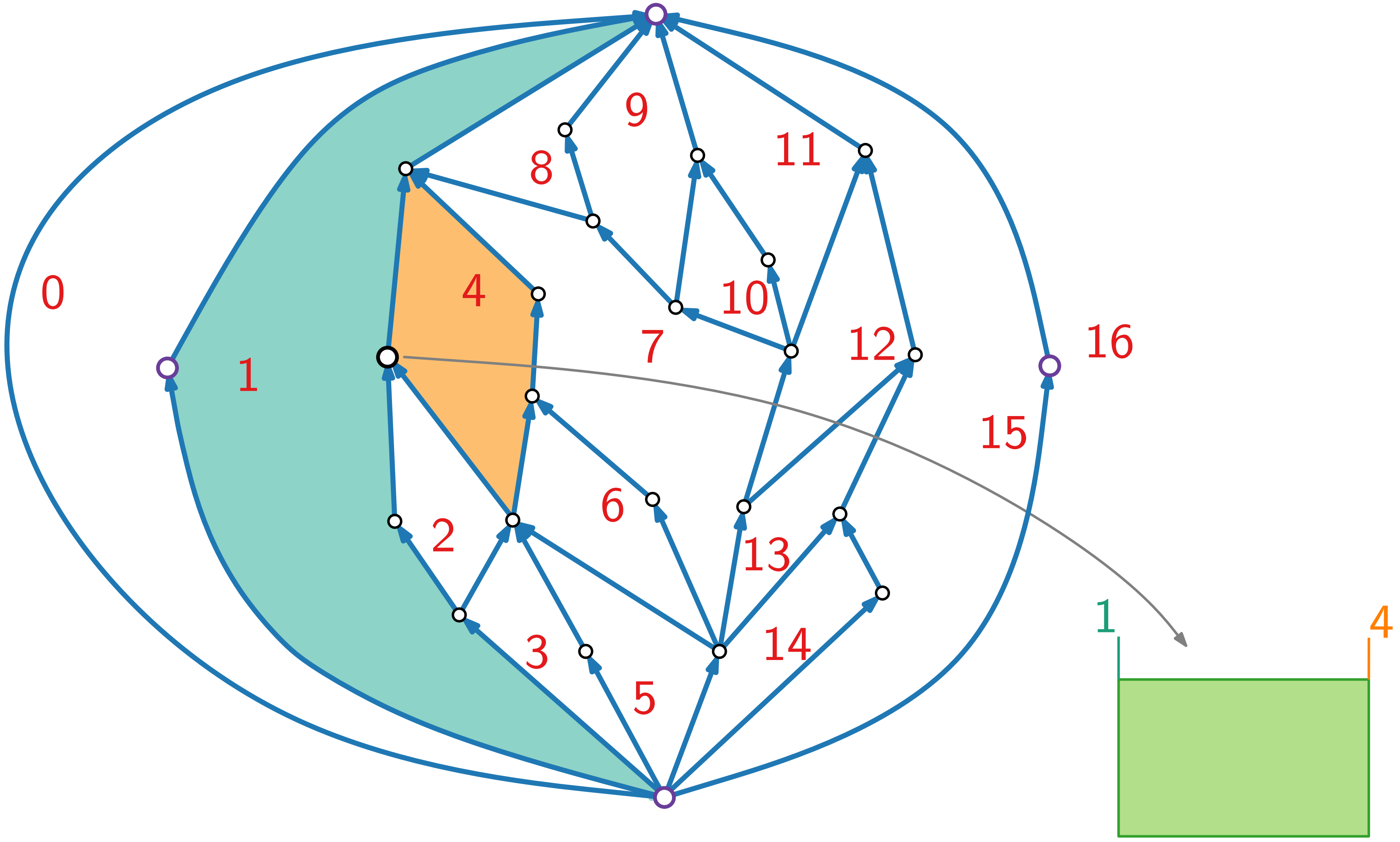

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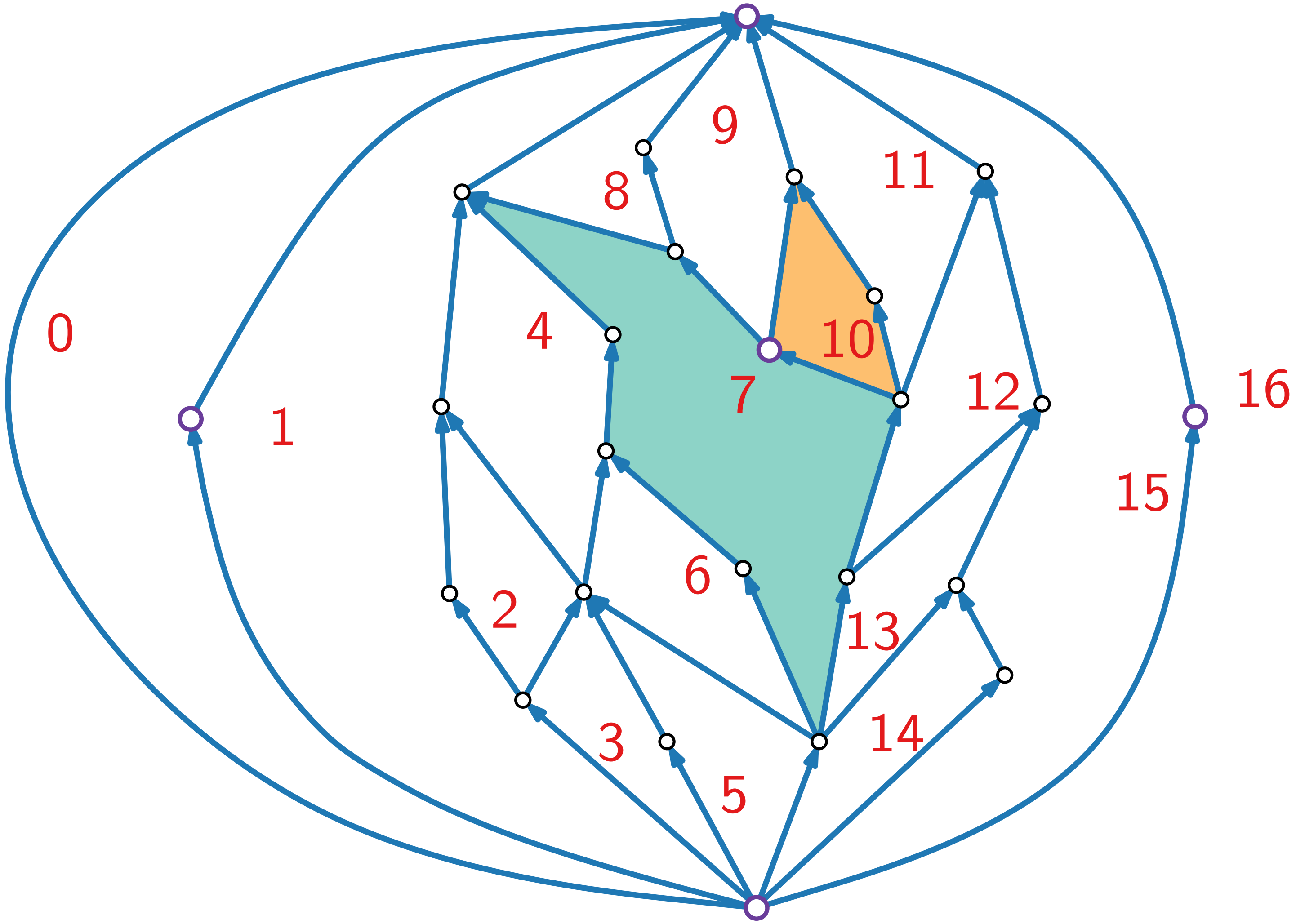

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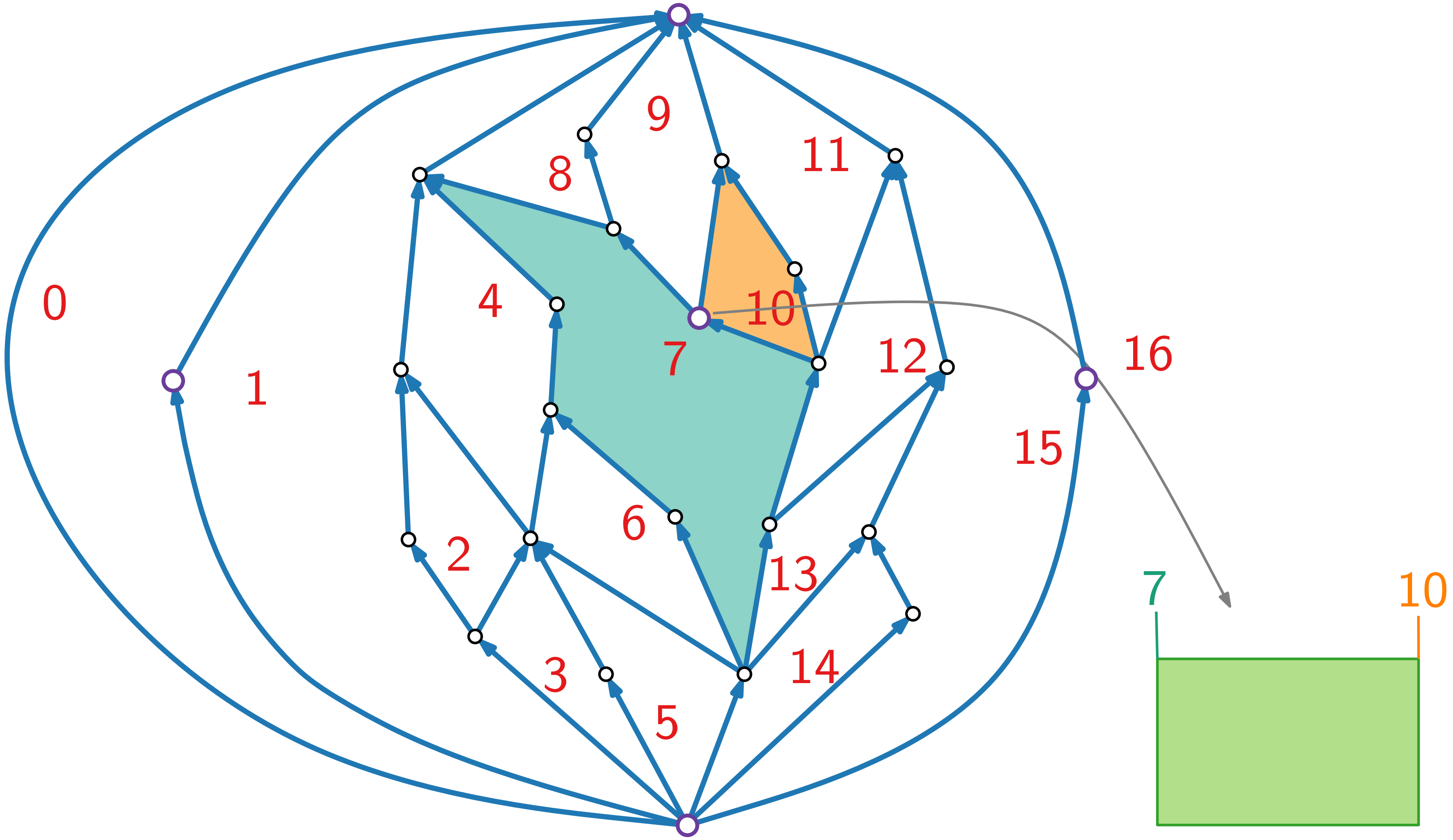

Rectangular Dual Algorithm

For a PTP graph G:

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- Find a REL $\{T_r, T_b\}$ of G.

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- Find a REL $\{T_r, T_b\}$ of G.
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  Set $x_1(v) = f_{\text{ver}}(g)$ and $x_2(v) = f_{\text{ver}}(h)$.

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- Define $x_1(v_N) = 0, x_1(v_S) = 1$ and $x_2(v_N) = \max f_{\text{ver}} - 1, x_2(v_S) = \max f_{\text{ver}}$.

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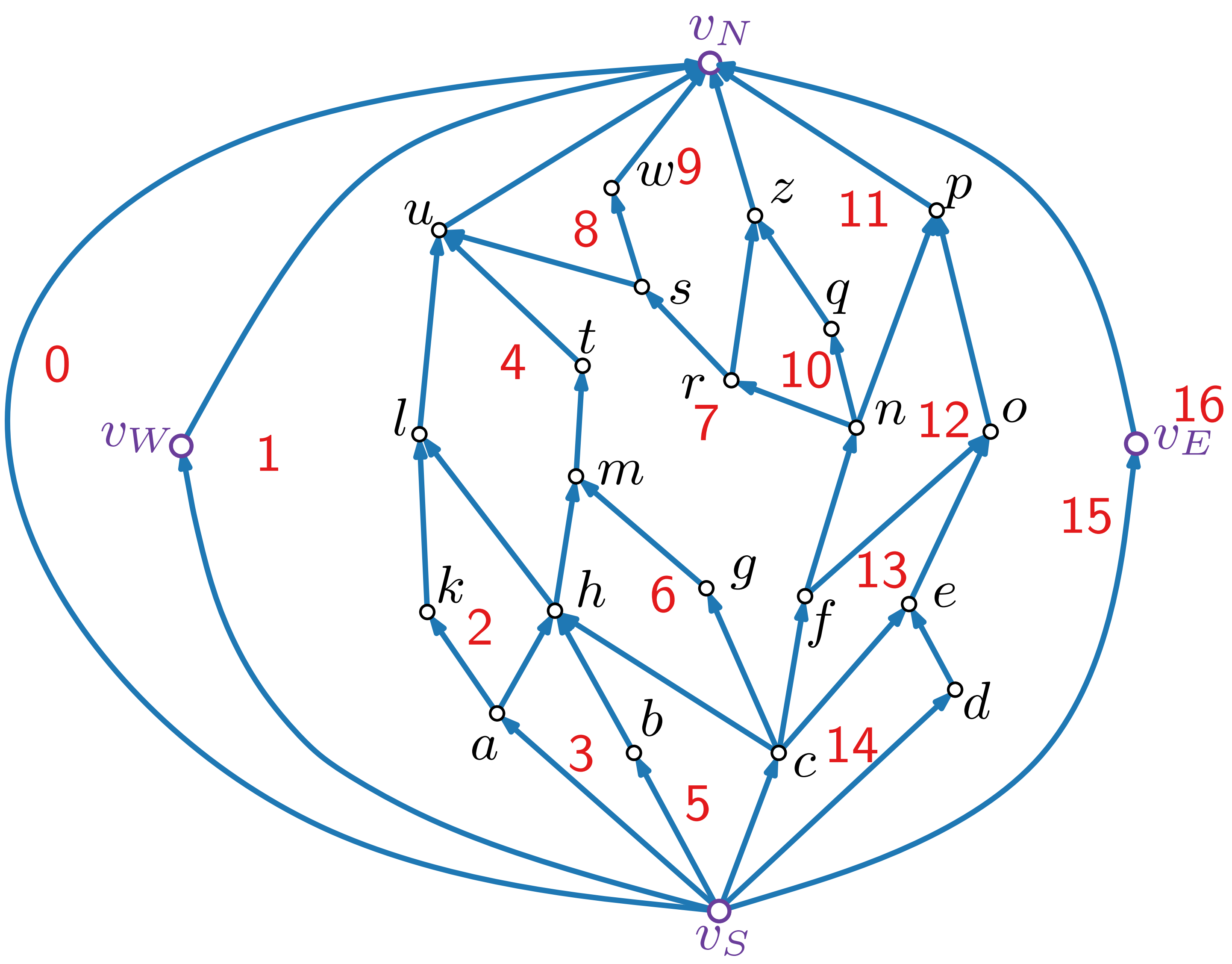
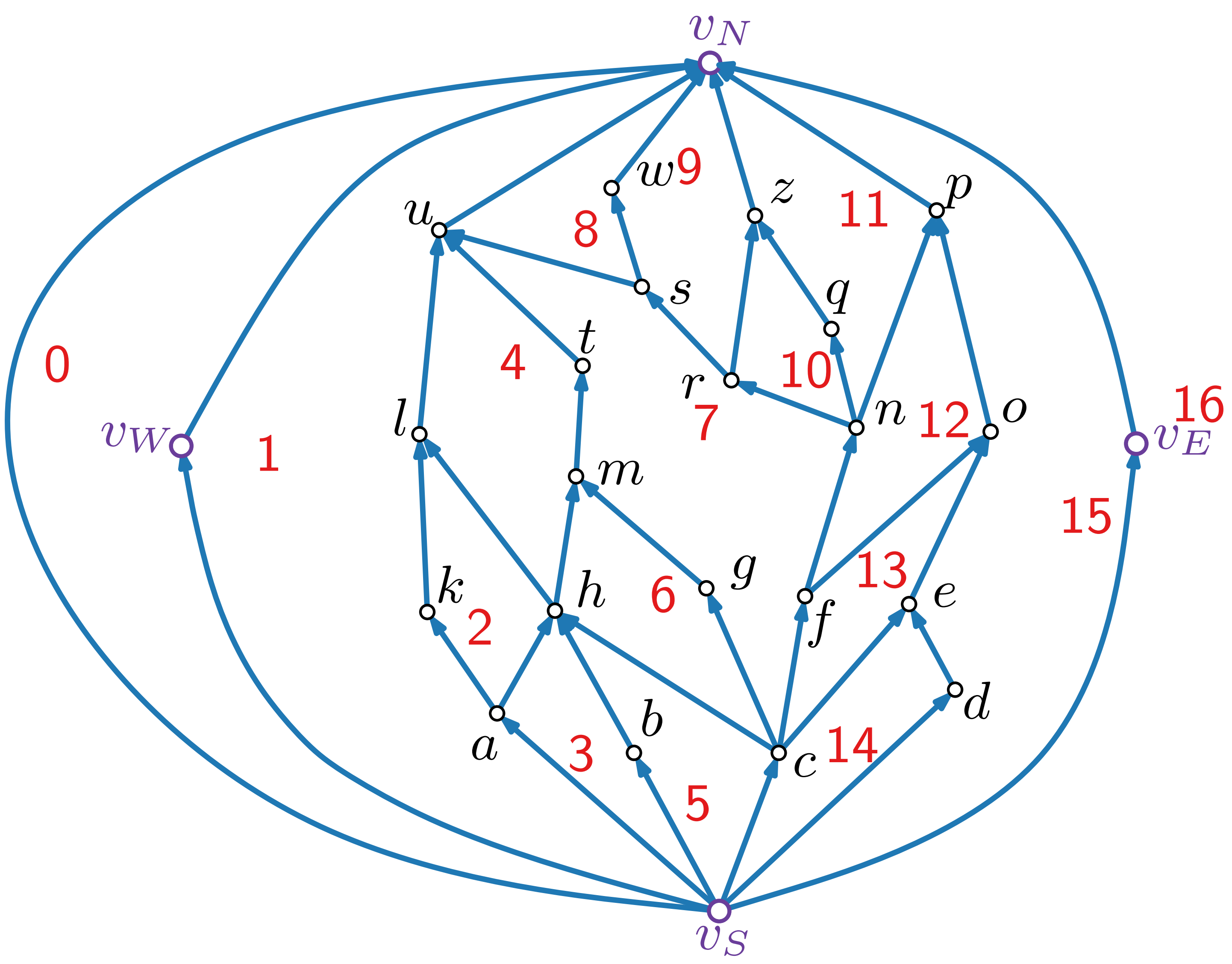
- For each vertex v of G, let $R(v) = [x_1(v), x_2(v)] \times [y_1(v), y_2(v)]$.

Reading off Coordinates to Get Rectangular Dual



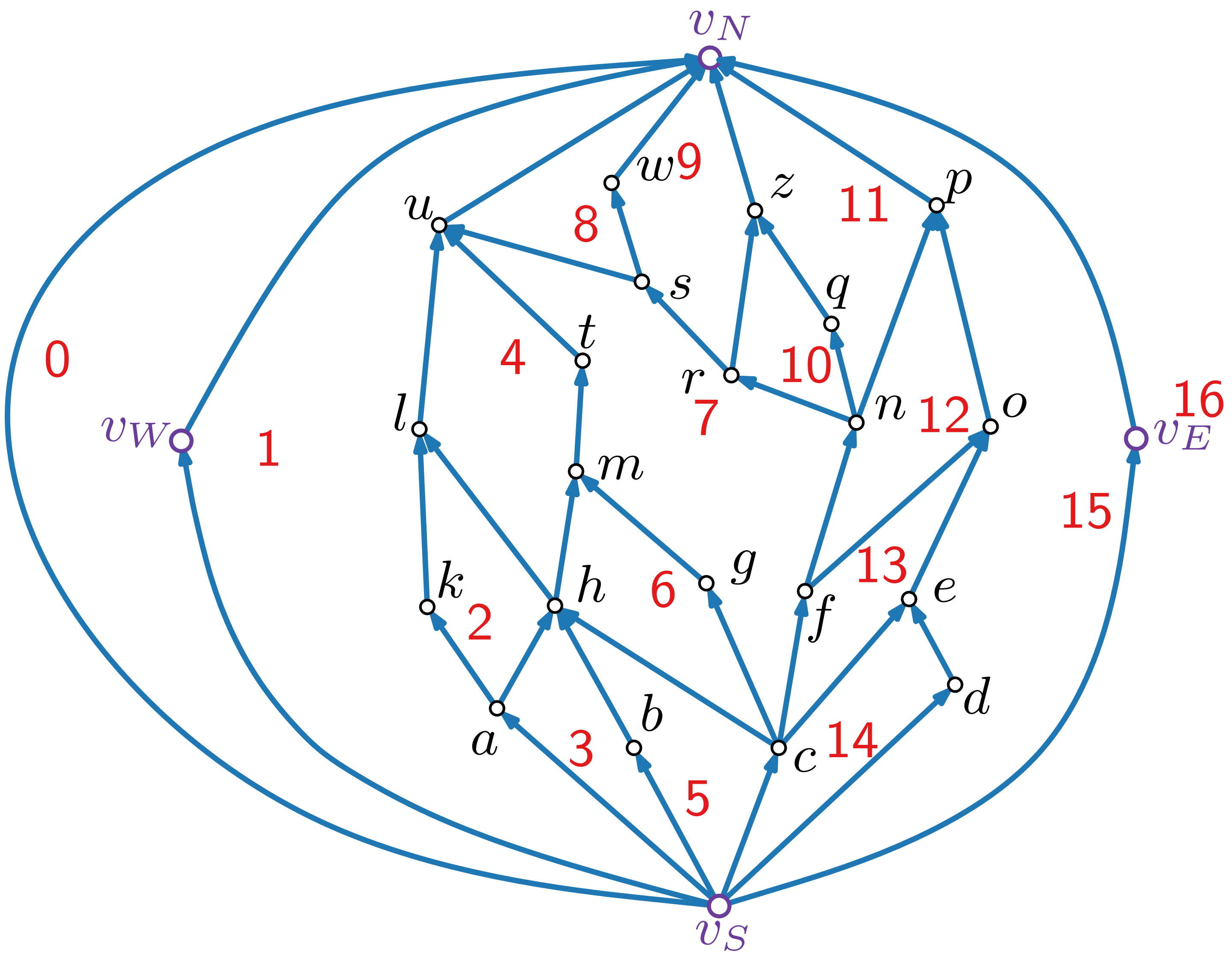
Reading off Coordinates to Get Rectangular Dual

$x_1(v_N) = 0,\ x_2(v_N) = 15$

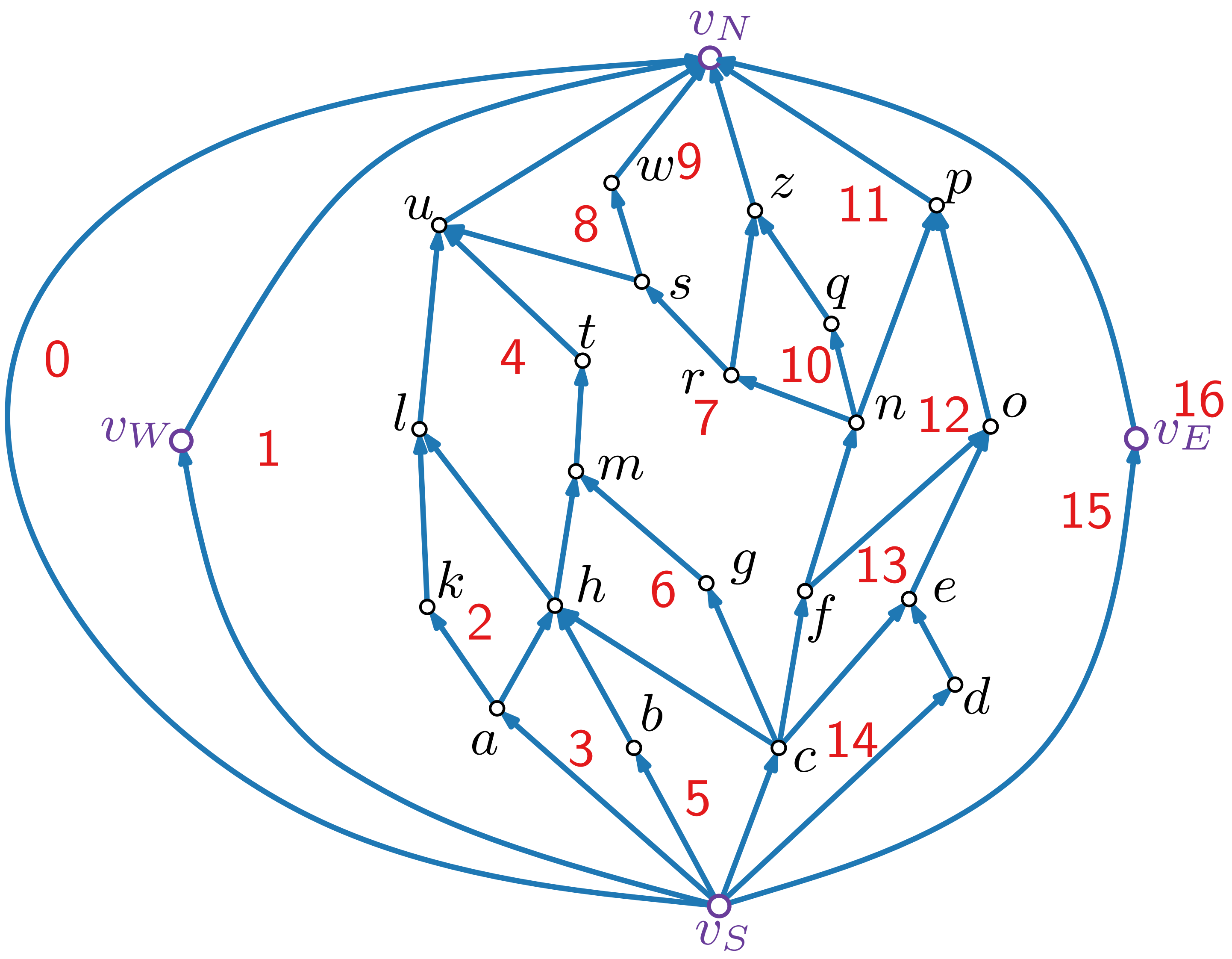


Reading off Coordinates to Get Rectangular Dual

$x_1(v_N) = 0,\ x_2(v_N) = 15$
$x_1(v_S) = 1,\ x_2(v_S) = 16$



Reading off Coordinates to Get Rectangular Dual

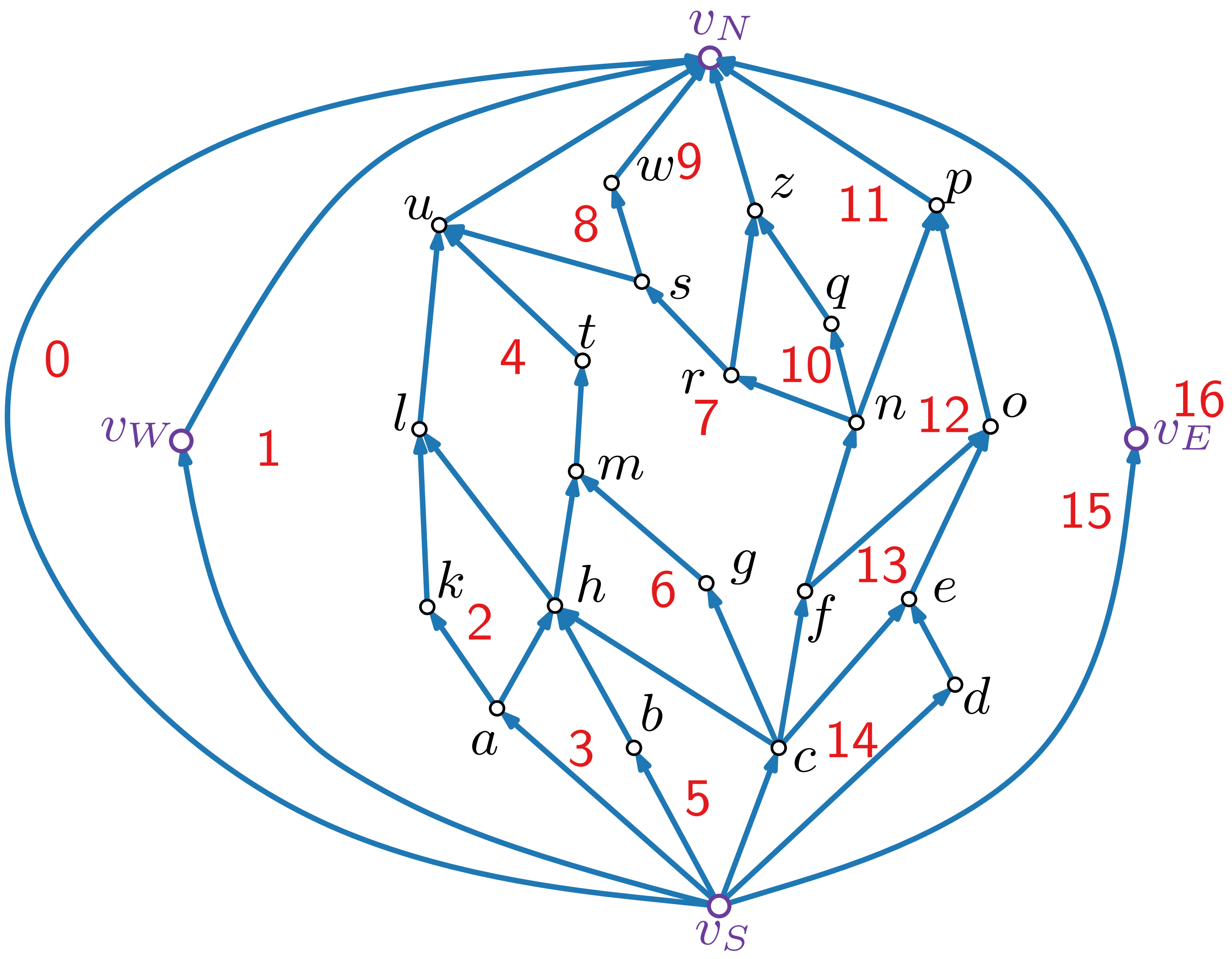


$x_1(v_N) = 0,\ x_2(v_N) = 15$

$x_1(v_S) = 1,\ x_2(v_S) = 16$

$x_1(v_W) = 0, x_2(v_W) = 1$

Reading off Coordinates to Get Rectangular Dual



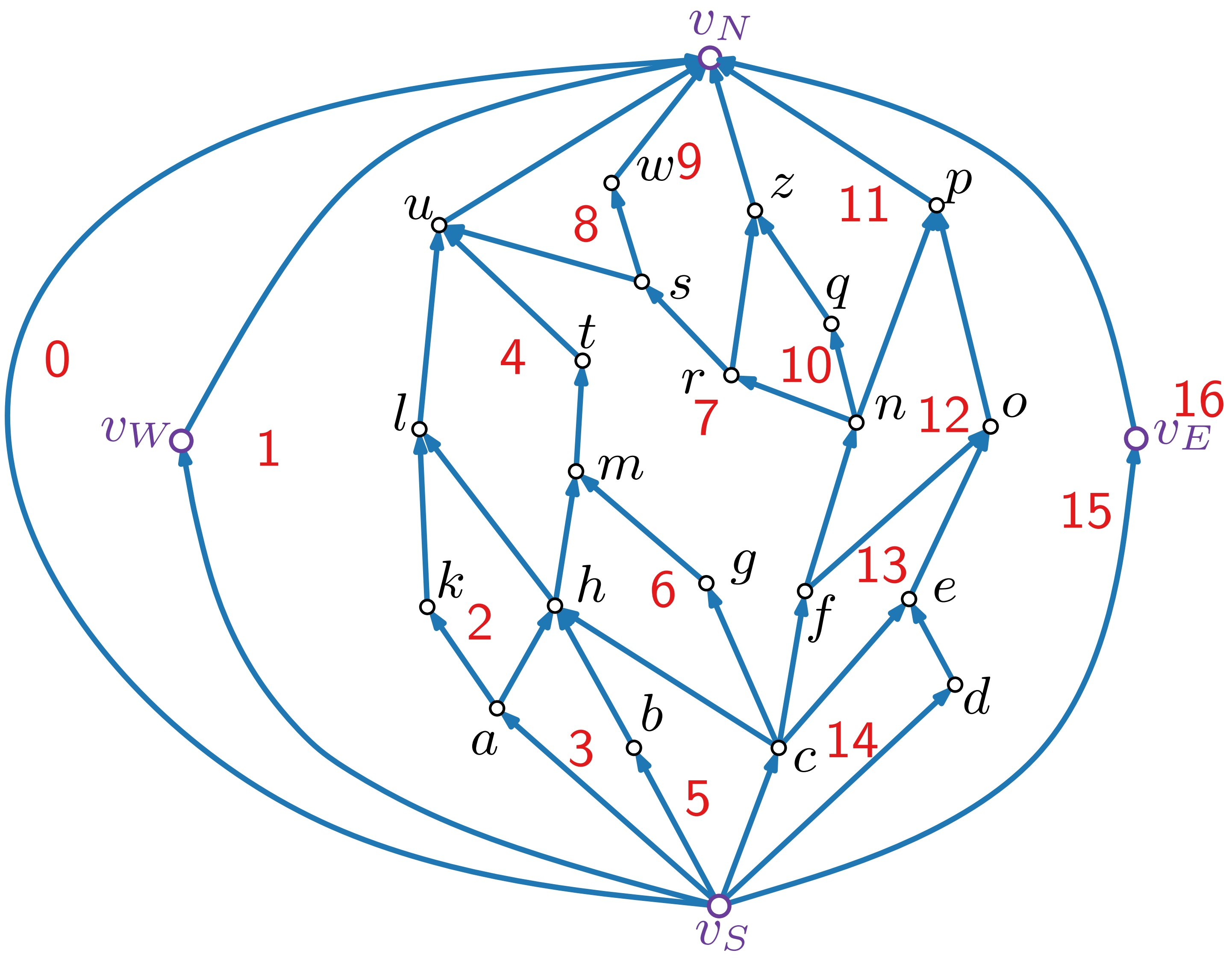
$x_1(v_N) = 0,\ x_2(v_N) = 15$

$x_1(v_S) = 1,\ x_2(v_S) = 16$

$x_1(v_W) = 0, x_2(v_W) = 1$

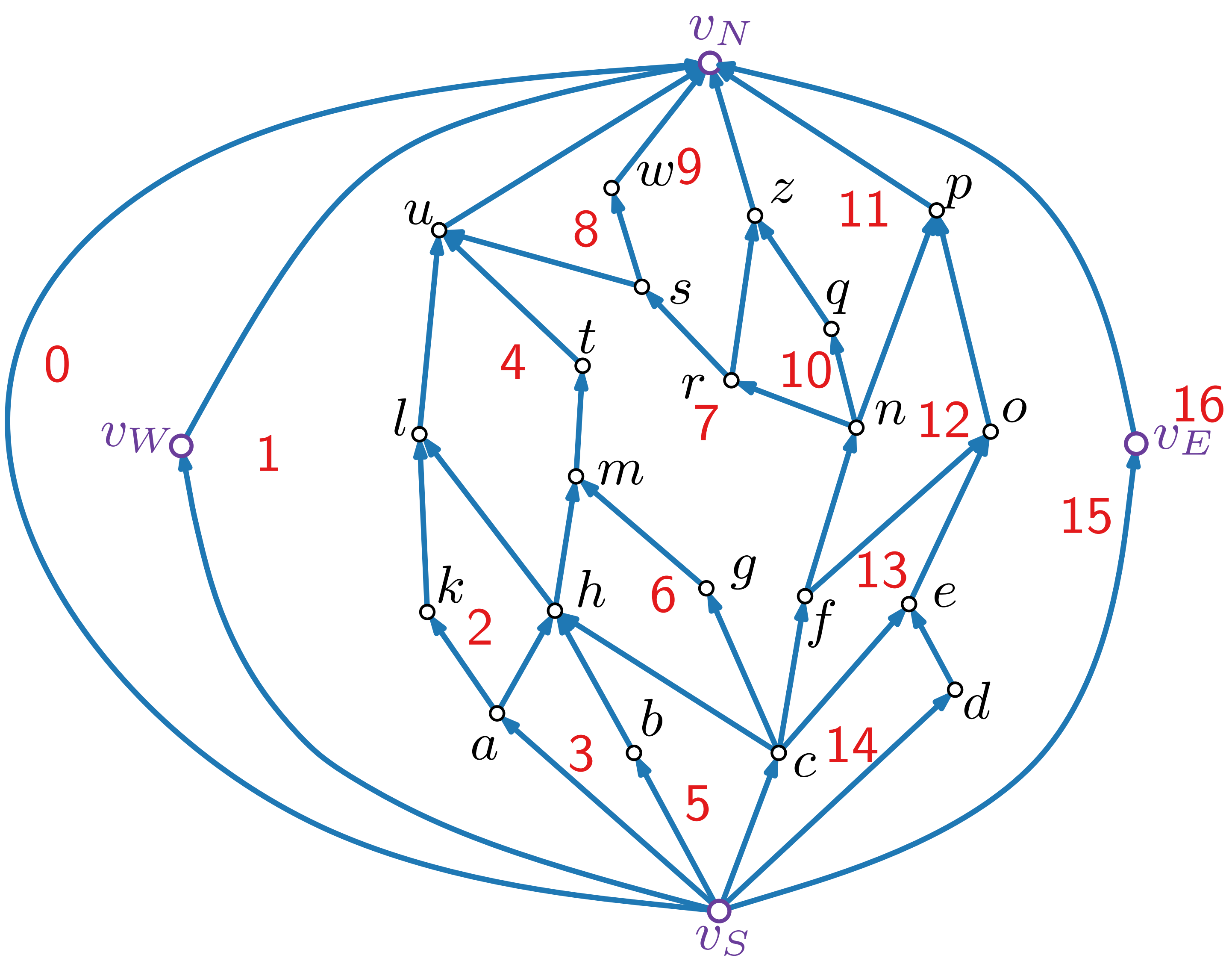
$x_1(v_E) = 15,\ x_2(v_E) = 16$

Reading off Coordinates to Get Rectangular Dual



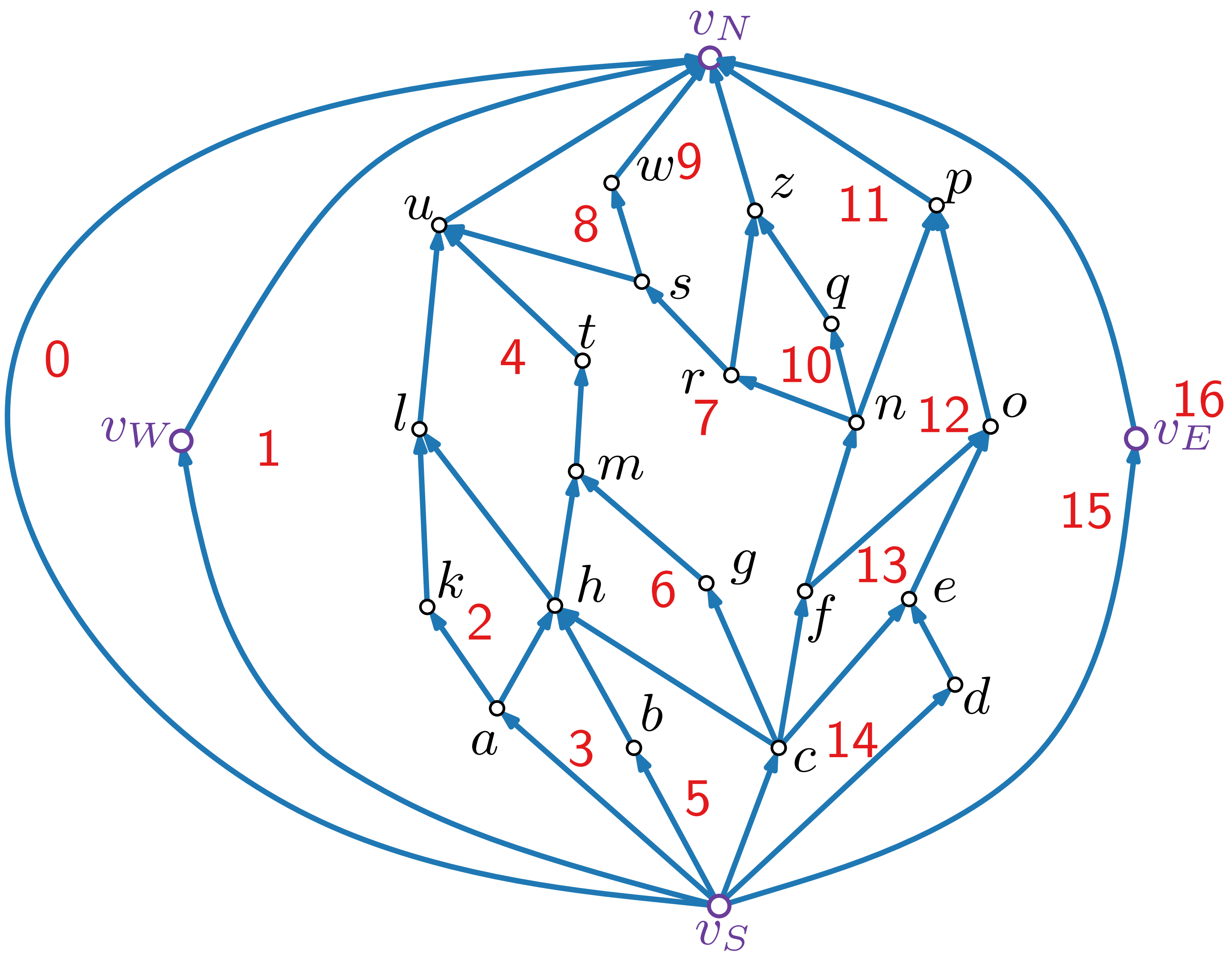
$x_1(v_N) = 0,\ x_2(v_N) = 15$
$x_1(v_S) = 1,\ x_2(v_S) = 16$
$x_1(v_W) = 0, x_2(v_W) = 1$
$x_1(v_E) = 15,\ x_2(v_E) = 16$
$x_1(a) = 1,\ x_2(a) = 3$

Reading off Coordinates to Get Rectangular Dual



$x_1(v_N) = 0,\ x_2(v_N) = 15$
$x_1(v_S) = 1,\ x_2(v_S) = 16$
$x_1(v_W) = 0, x_2(v_W) = 1$
$x_1(v_E) = 15,\ x_2(v_E) = 16$
$x_1(a) = 1,\ x_2(a) = 3$
$x_1(b) = 3,\ x_2(b) = 5$

Reading off Coordinates to Get Rectangular Dual



$x_1(v_N) = 0,\ x_2(v_N) = 15$

$x_1(v_S) = 1,\ x_2(v_S) = 16$

$x_1(v_W) = 0, x_2(v_W) = 1$

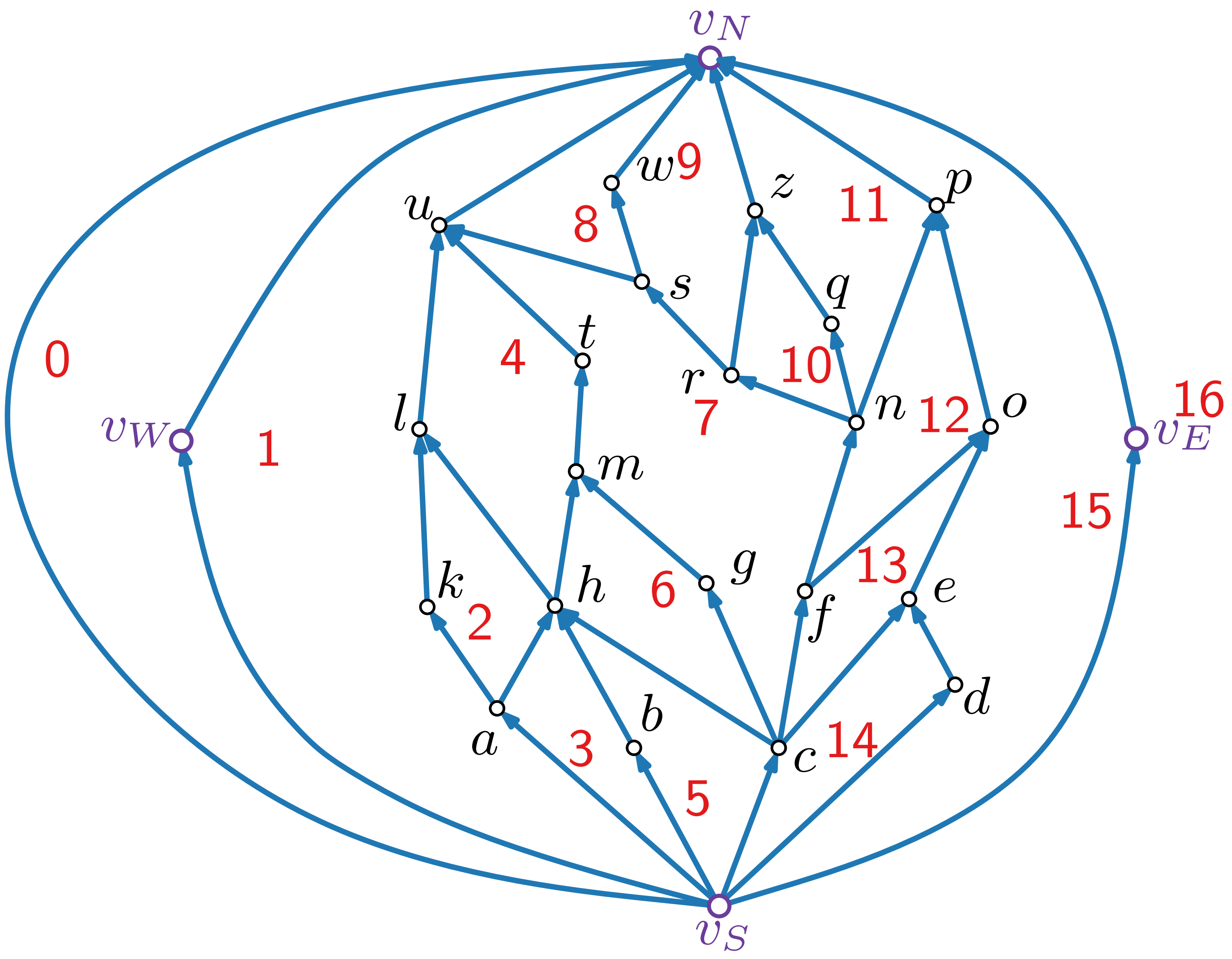
$x_1(v_E) = 15,\ x_2(v_E) = 16$

$x_1(a) = 1,\ x_2(a) = 3$

$x_1(b) = 3,\ x_2(b) = 5$

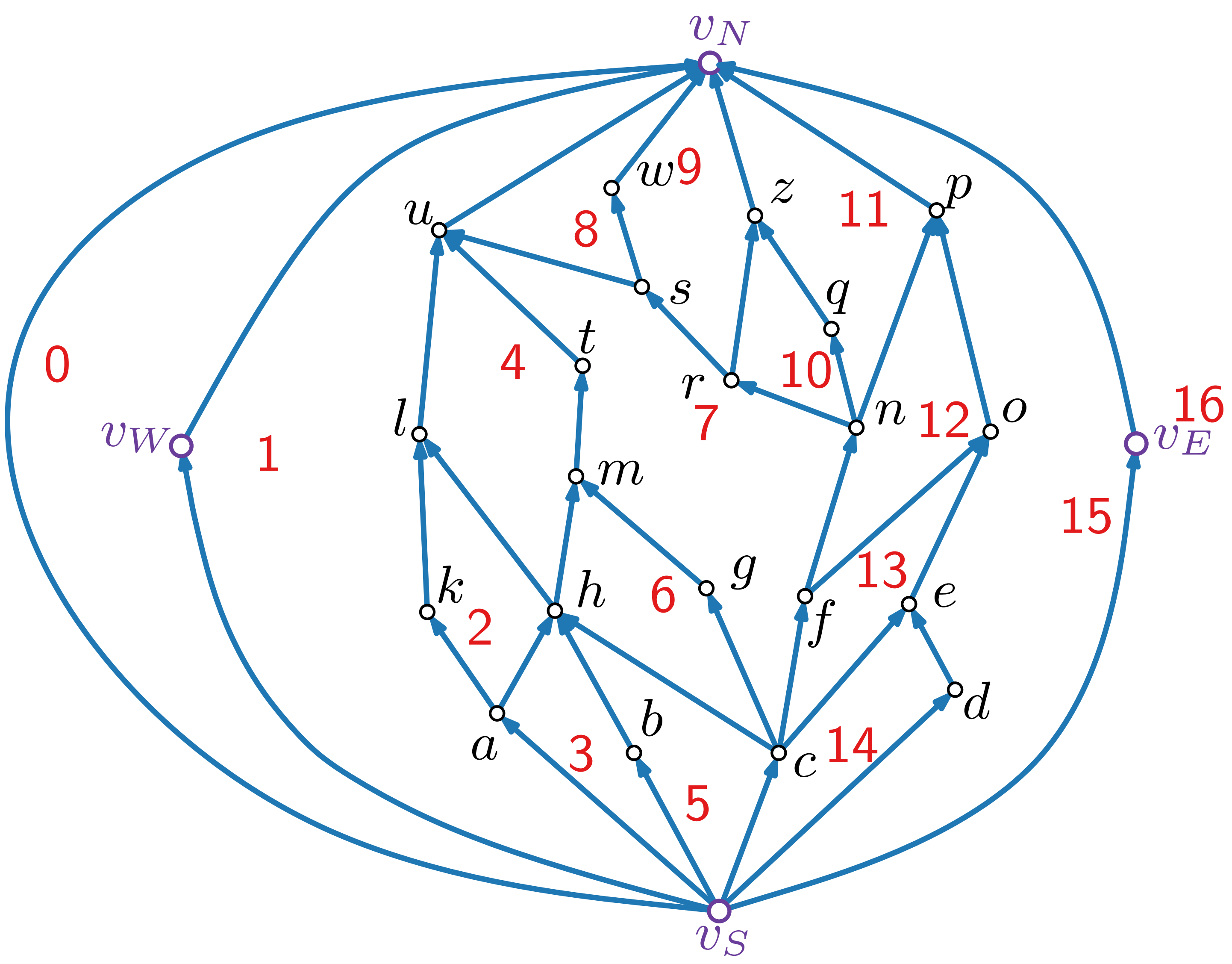
$x_1(c) = 5,\ x_2(c) = 14$

Reading off Coordinates to Get Rectangular Dual



$x_1(v_N) = 0,\ x_2(v_N) = 15$
$x_1(v_S) = 1,\ x_2(v_S) = 16$
$x_1(v_W) = 0, x_2(v_W) = 1$
$x_1(v_E) = 15,\ x_2(v_E) = 16$
$x_1(a) = 1,\ x_2(a) = 3$
$x_1(b) = 3,\ x_2(b) = 5$
$x_1(c) = 5,\ x_2(c) = 14$
$x_1(d) = 14,\ x_2(d) = 15$

Reading off Coordinates to Get Rectangular Dual



$x_1(v_N) = 0,\ x_2(v_N) = 15$

$x_1(v_S) = 1,\ x_2(v_S) = 16$

$x_1(v_W) = 0, x_2(v_W) = 1$

$x_1(v_E) = 15,\ x_2(v_E) = 16$

$x_1(a) = 1,\ x_2(a) = 3$

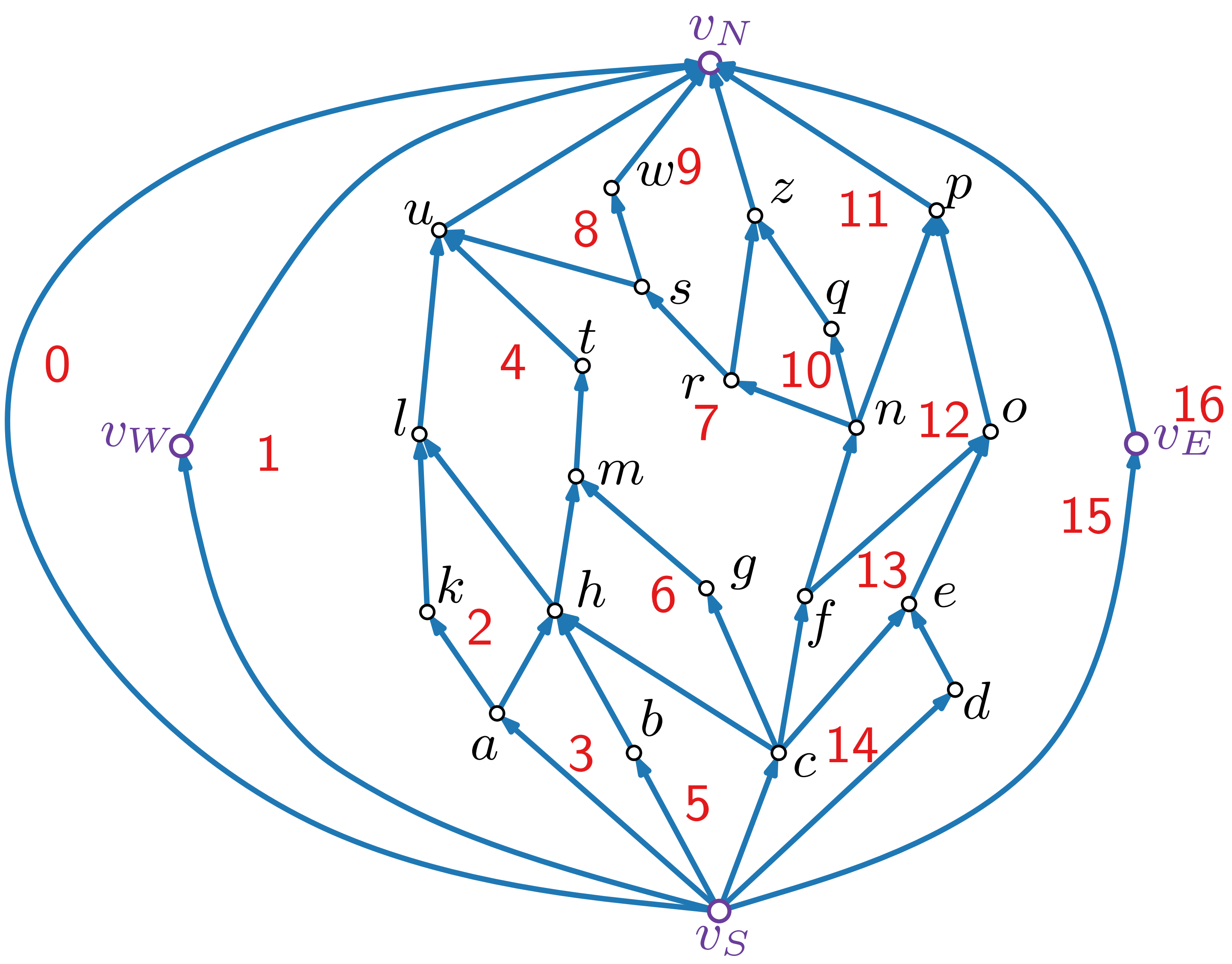
$x_1(b) = 3,\ x_2(b) = 5$

$x_1(c) = 5,\ x_2(c) = 14$

$x_1(d) = 14,\ x_2(d) = 15$

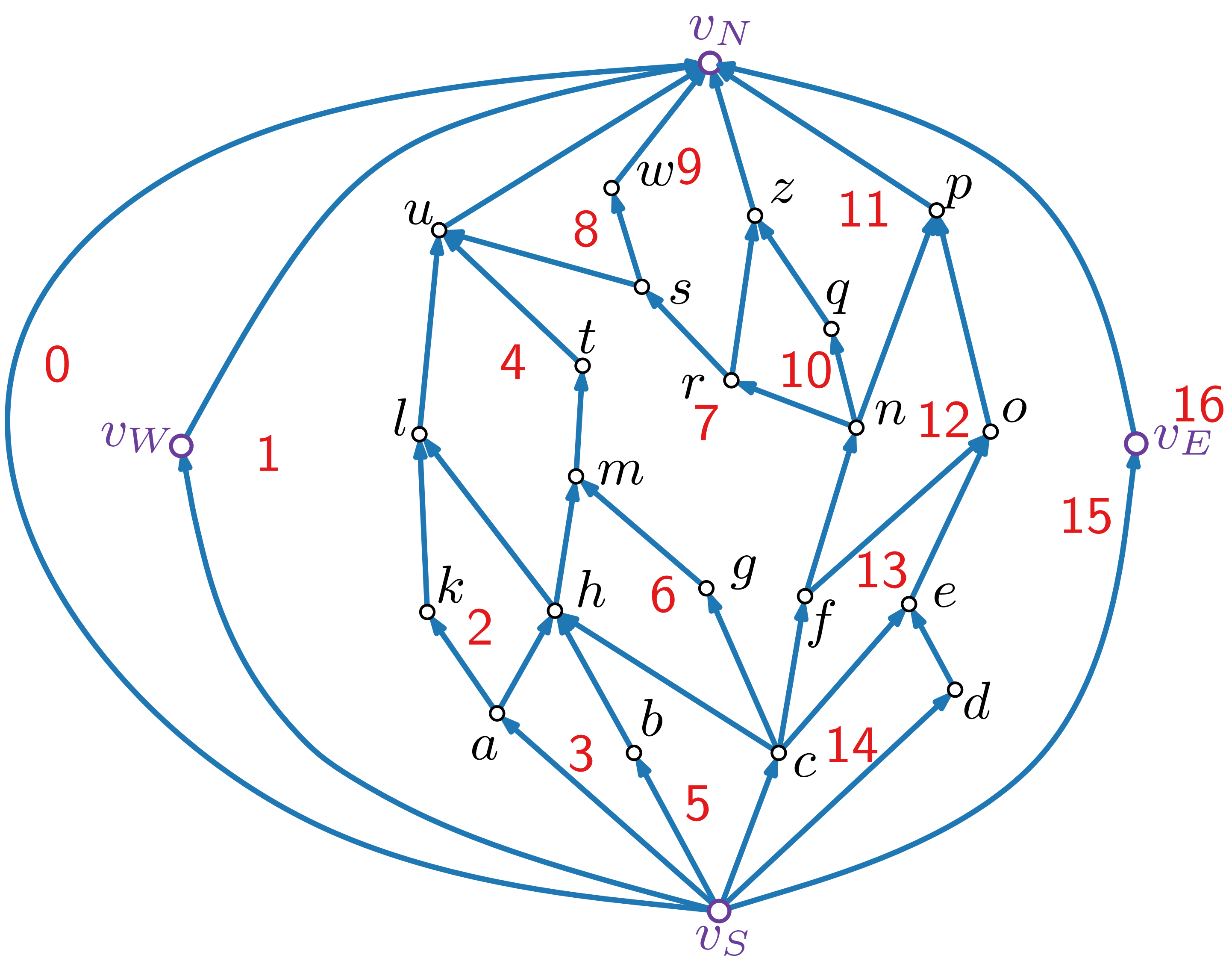
$x_1(e) = 13,\ x_2(e) = 15$

Reading off Coordinates to Get Rectangular Dual



$x_1(v_N) = 0,\ x_2(v_N) = 15$
$x_1(v_S) = 1,\ x_2(v_S) = 16$
$x_1(v_W) = 0, x_2(v_W) = 1$
$x_1(v_E) = 15,\ x_2(v_E) = 16$
$x_1(a) = 1,\ x_2(a) = 3$
$x_1(b) = 3,\ x_2(b) = 5$
$x_1(c) = 5,\ x_2(c) = 14$
$x_1(d) = 14,\ x_2(d) = 15$
$x_1(e) = 13,\ x_2(e) = 15$
...

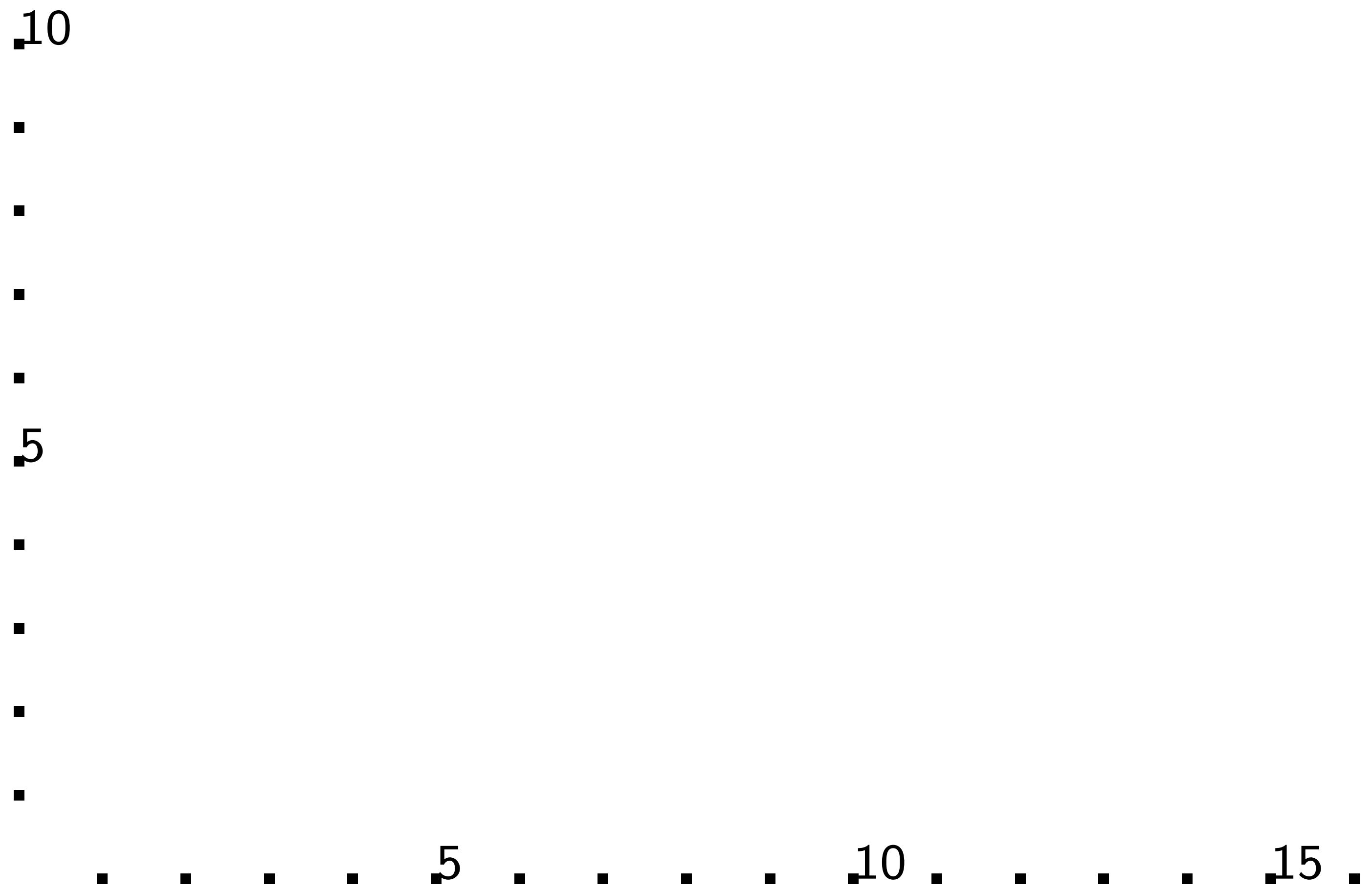
Reading off Coordinates to Get Rectangular Dual



$x_1(v_N) = 0,\ x_2(v_N) = 15$
$x_1(v_S) = 1,\ x_2(v_S) = 16$
$x_1(v_W) = 0, x_2(v_W) = 1$
$x_1(v_E) = 15,\ x_2(v_E) = 16$
$x_1(a) = 1,\ x_2(a) = 3$
$x_1(b) = 3,\ x_2(b) = 5$
$x_1(c) = 5,\ x_2(c) = 14$
$x_1(d) = 14,\ x_2(d) = 15$
$x_1(e) = 13,\ x_2(e) = 15$
...

$y_1(v_W) = 0, y_2(v_W) = 9$
$y_1(v_E) = 1,\ y_2(v_E) = 10$
$y_1(v_N) = 9,\ y_2(v_N) = 10$
$y_1(v_S) = 0,\ y_2(v_S) = 1$
$y_1(a) = 1,\ y_2(a) = 2$
$y_1(b) = 1,\ y_2(b) = 2$
...

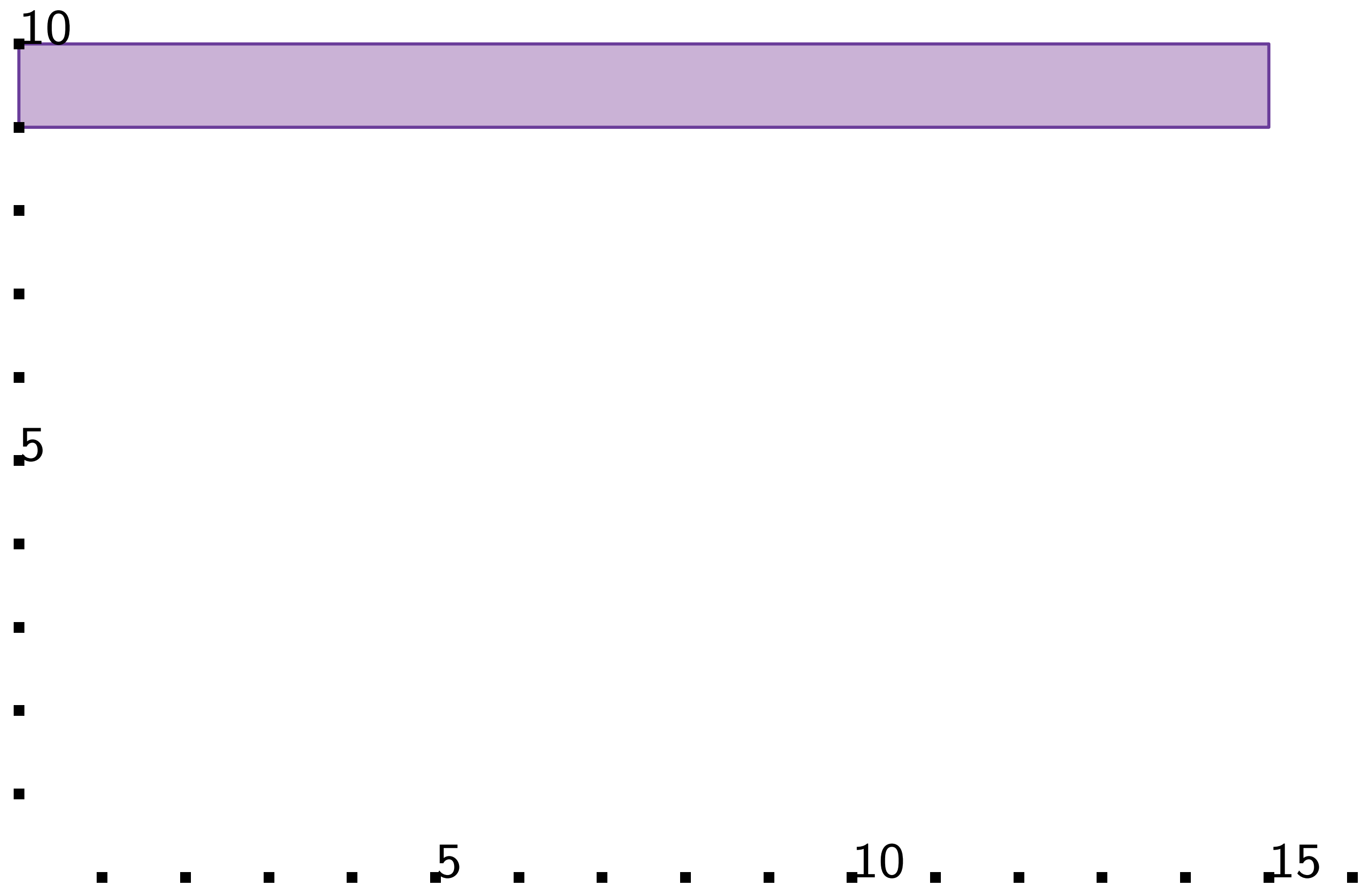
Reading off Coordinates to Get Rectangular Dual



$x_1(v_N) = 0,\ x_2(v_N) = 15$
$x_1(v_S) = 1,\ x_2(v_S) = 16$
$x_1(v_W) = 0, x_2(v_W) = 1$
$x_1(v_E) = 15,\ x_2(v_E) = 16$
$x_1(a) = 1,\ x_2(a) = 3$
$x_1(b) = 3,\ x_2(b) = 5$
$x_1(c) = 5,\ x_2(c) = 14$
$x_1(d) = 14,\ x_2(d) = 15$
$x_1(e) = 13,\ x_2(e) = 15$
...

$y_1(v_W) = 0, y_2(v_W) = 9$
$y_1(v_E) = 1,\ y_2(v_E) = 10$
$y_1(v_N) = 9,\ y_2(v_N) = 10$
$y_1(v_S) = 0,\ y_2(v_S) = 1$
$y_1(a) = 1,\ y_2(a) = 2$
$y_1(b) = 1,\ y_2(b) = 2$
...

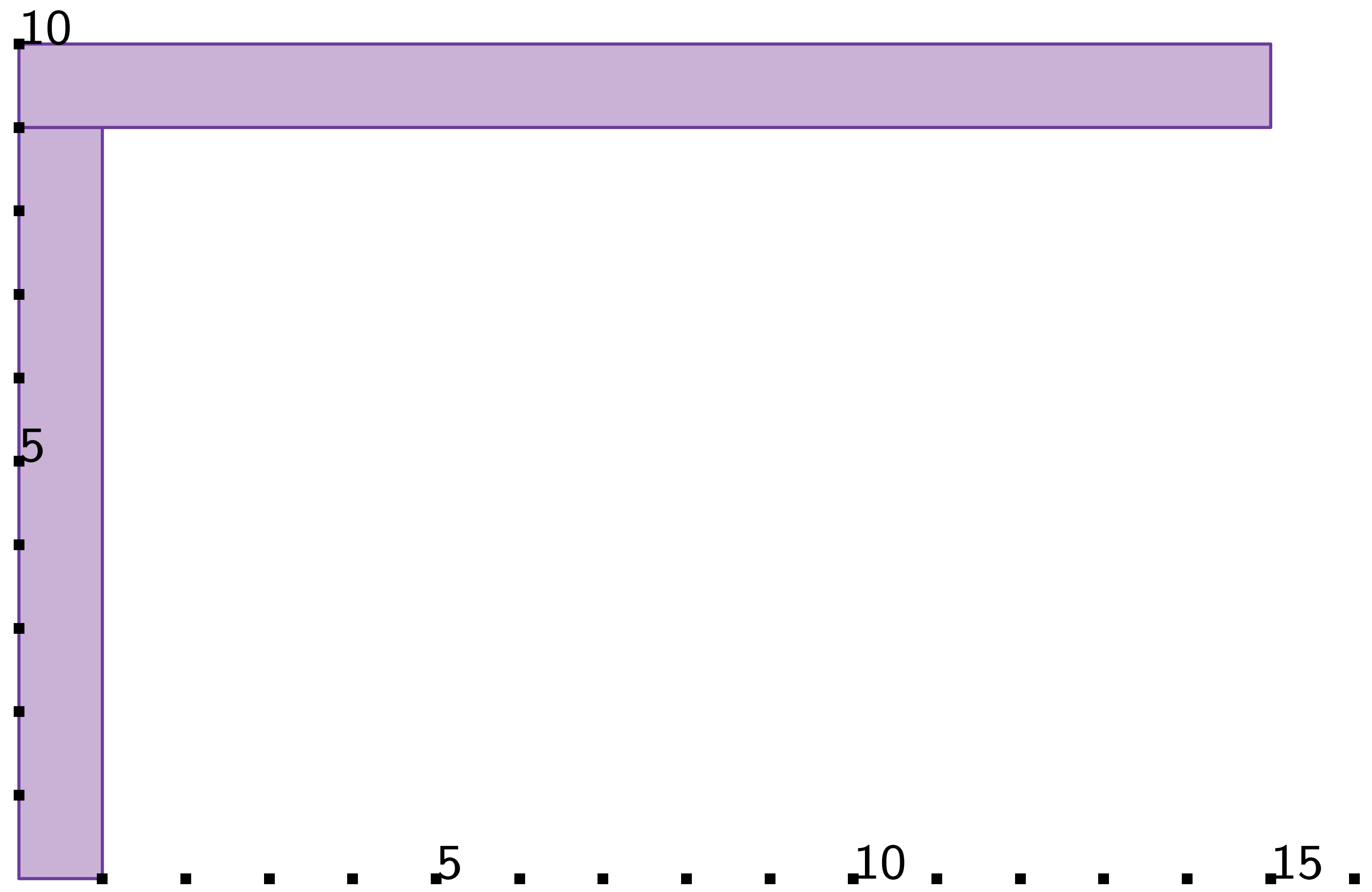
Reading off Coordinates to Get Rectangular Dual



$x_1(v_N) = 0,\ x_2(v_N) = 15$
$x_1(v_S) = 1,\ x_2(v_S) = 16$
$x_1(v_W) = 0, x_2(v_W) = 1$
$x_1(v_E) = 15,\ x_2(v_E) = 16$
$x_1(a) = 1,\ x_2(a) = 3$
$x_1(b) = 3,\ x_2(b) = 5$
$x_1(c) = 5,\ x_2(c) = 14$
$x_1(d) = 14,\ x_2(d) = 15$
$x_1(e) = 13,\ x_2(e) = 15$
$\ldots$

$y_1(v_W) = 0, y_2(v_W) = 9$
$y_1(v_E) = 1,\ y_2(v_E) = 10$
$y_1(v_N) = 9,\ y_2(v_N) = 10$
$y_1(v_S) = 0,\ y_2(v_S) = 1$
$y_1(a) = 1,\ y_2(a) = 2$
$y_1(b) = 1,\ y_2(b) = 2$
$\ldots$

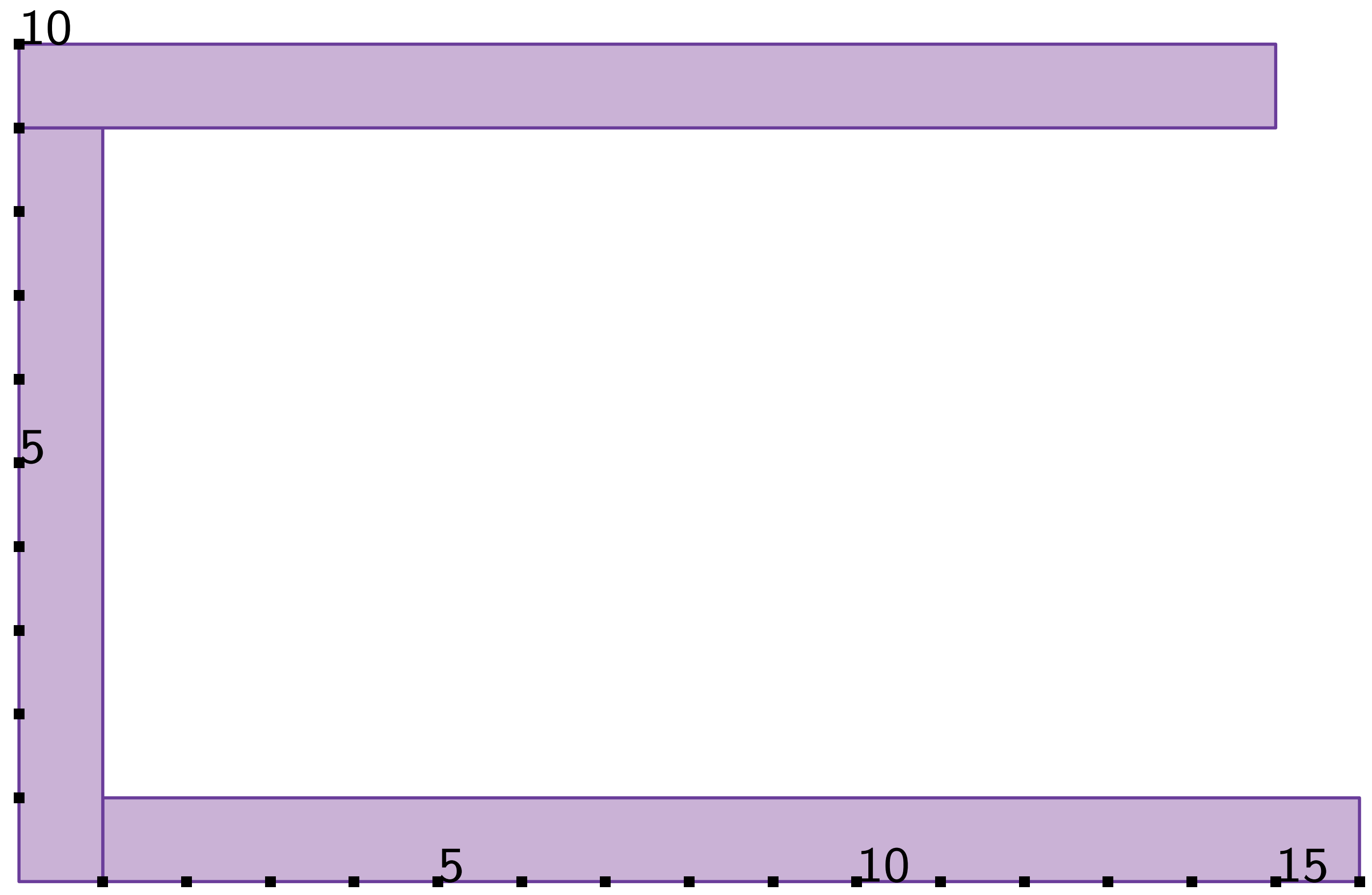
Reading off Coordinates to Get Rectangular Dual



$x_1(v_N) = 0,\ x_2(v_N) = 15$
$x_1(v_S) = 1,\ x_2(v_S) = 16$
$x_1(v_W) = 0, x_2(v_W) = 1$
$x_1(v_E) = 15,\ x_2(v_E) = 16$
$x_1(a) = 1,\ x_2(a) = 3$
$x_1(b) = 3,\ x_2(b) = 5$
$x_1(c) = 5,\ x_2(c) = 14$
$x_1(d) = 14,\ x_2(d) = 15$
$x_1(e) = 13,\ x_2(e) = 15$
$\ldots$

$y_1(v_W) = 0, y_2(v_W) = 9$
$y_1(v_E) = 1,\ y_2(v_E) = 10$
$y_1(v_N) = 9,\ y_2(v_N) = 10$
$y_1(v_S) = 0,\ y_2(v_S) = 1$
$y_1(a) = 1,\ y_2(a) = 2$
$y_1(b) = 1,\ y_2(b) = 2$
$\ldots$

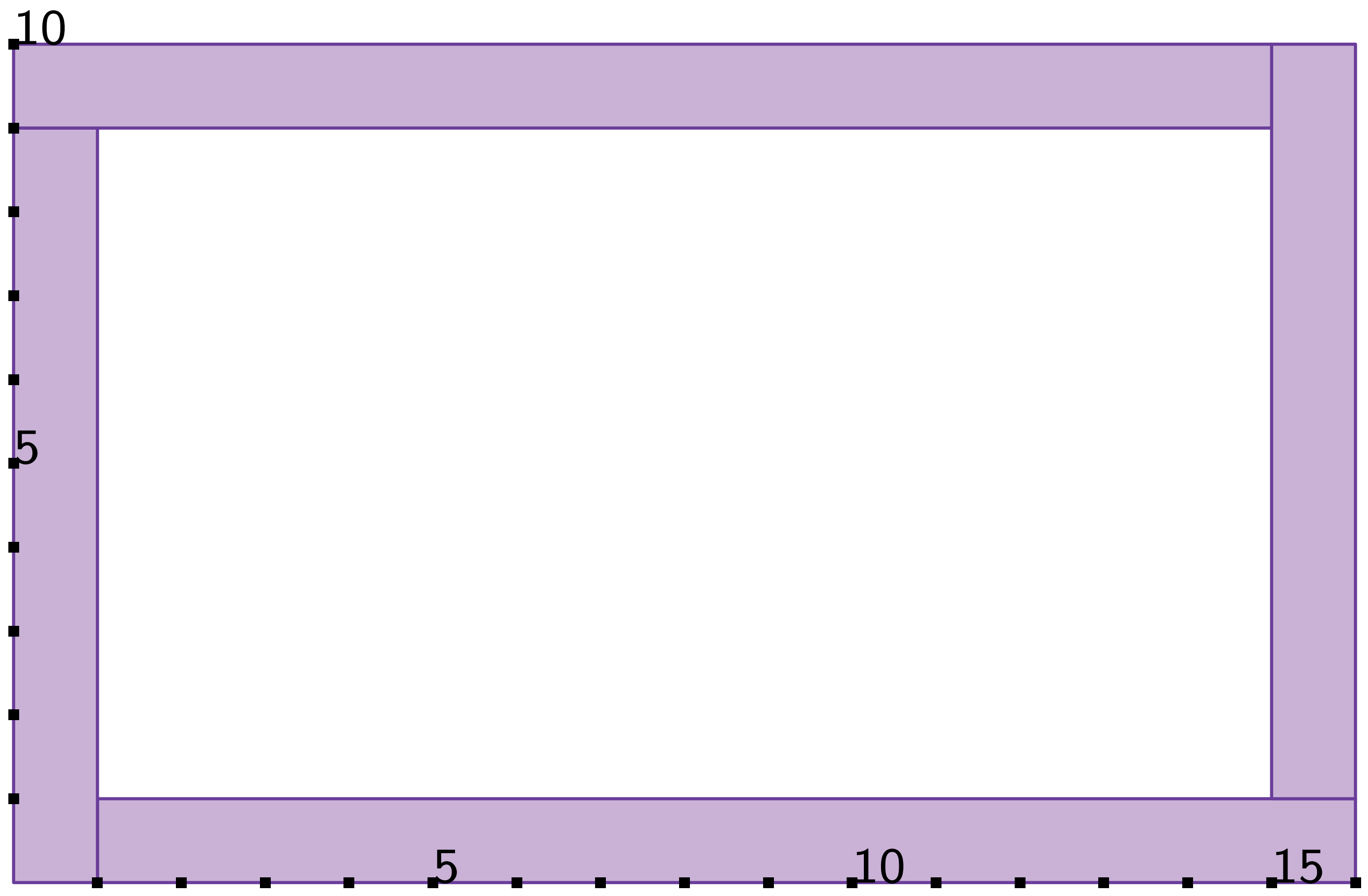
Reading off Coordinates to Get Rectangular Dual



$x_1(v_N) = 0,\ x_2(v_N) = 15$
$x_1(v_S) = 1,\ x_2(v_S) = 16$
$x_1(v_W) = 0, x_2(v_W) = 1$
$x_1(v_E) = 15,\ x_2(v_E) = 16$
$x_1(a) = 1,\ x_2(a) = 3$
$x_1(b) = 3,\ x_2(b) = 5$
$x_1(c) = 5,\ x_2(c) = 14$
$x_1(d) = 14,\ x_2(d) = 15$
$x_1(e) = 13,\ x_2(e) = 15$
$\dots$

$y_1(v_W) = 0, y_2(v_W) = 9$
$y_1(v_E) = 1,\ y_2(v_E) = 10$
$y_1(v_N) = 9,\ y_2(v_N) = 10$
$y_1(v_S) = 0,\ y_2(v_S) = 1$
$y_1(a) = 1,\ y_2(a) = 2$
$y_1(b) = 1,\ y_2(b) = 2$
$\dots$

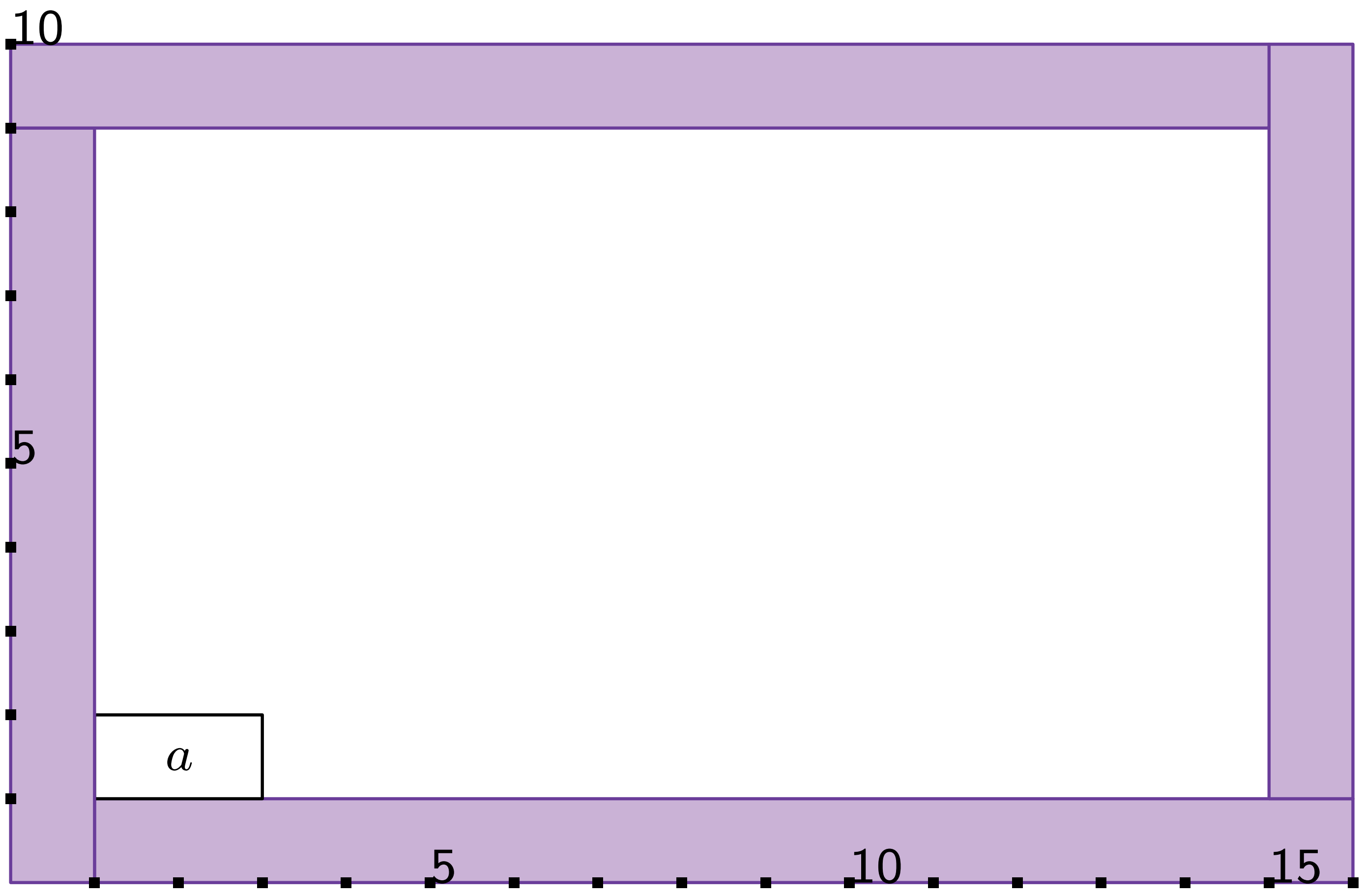
Reading off Coordinates to Get Rectangular Dual



$x_1(v_N) = 0,\ x_2(v_N) = 15$
$x_1(v_S) = 1,\ x_2(v_S) = 16$
$x_1(v_W) = 0, x_2(v_W) = 1$
$x_1(v_E) = 15,\ x_2(v_E) = 16$
$x_1(a) = 1,\ x_2(a) = 3$
$x_1(b) = 3,\ x_2(b) = 5$
$x_1(c) = 5,\ x_2(c) = 14$
$x_1(d) = 14,\ x_2(d) = 15$
$x_1(e) = 13,\ x_2(e) = 15$
...

$y_1(v_W) = 0, y_2(v_W) = 9$
$y_1(v_E) = 1,\ y_2(v_E) = 10$
$y_1(v_N) = 9,\ y_2(v_N) = 10$
$y_1(v_S) = 0,\ y_2(v_S) = 1$
$y_1(a) = 1,\ y_2(a) = 2$
$y_1(b) = 1,\ y_2(b) = 2$
...

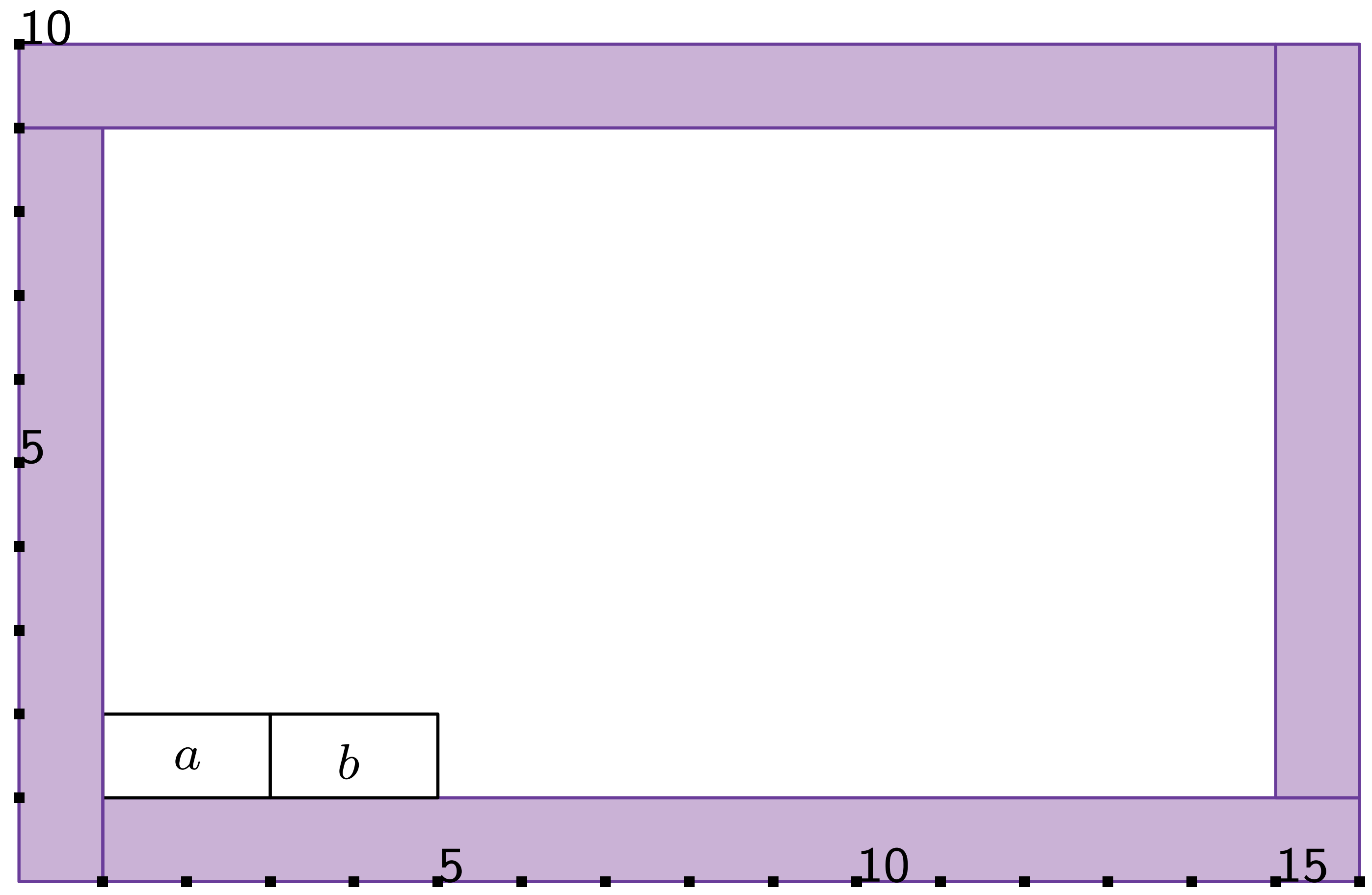
Reading off Coordinates to Get Rectangular Dual



$x_1(v_N) = 0,\ x_2(v_N) = 15$
$x_1(v_S) = 1,\ x_2(v_S) = 16$
$x_1(v_W) = 0, x_2(v_W) = 1$
$x_1(v_E) = 15,\ x_2(v_E) = 16$
$x_1(a) = 1,\ x_2(a) = 3$
$x_1(b) = 3,\ x_2(b) = 5$
$x_1(c) = 5,\ x_2(c) = 14$
$x_1(d) = 14,\ x_2(d) = 15$
$x_1(e) = 13,\ x_2(e) = 15$
...

$y_1(v_W) = 0, y_2(v_W) = 9$
$y_1(v_E) = 1,\ y_2(v_E) = 10$
$y_1(v_N) = 9,\ y_2(v_N) = 10$
$y_1(v_S) = 0,\ y_2(v_S) = 1$
$y_1(a) = 1,\ y_2(a) = 2$
$y_1(b) = 1,\ y_2(b) = 2$
...

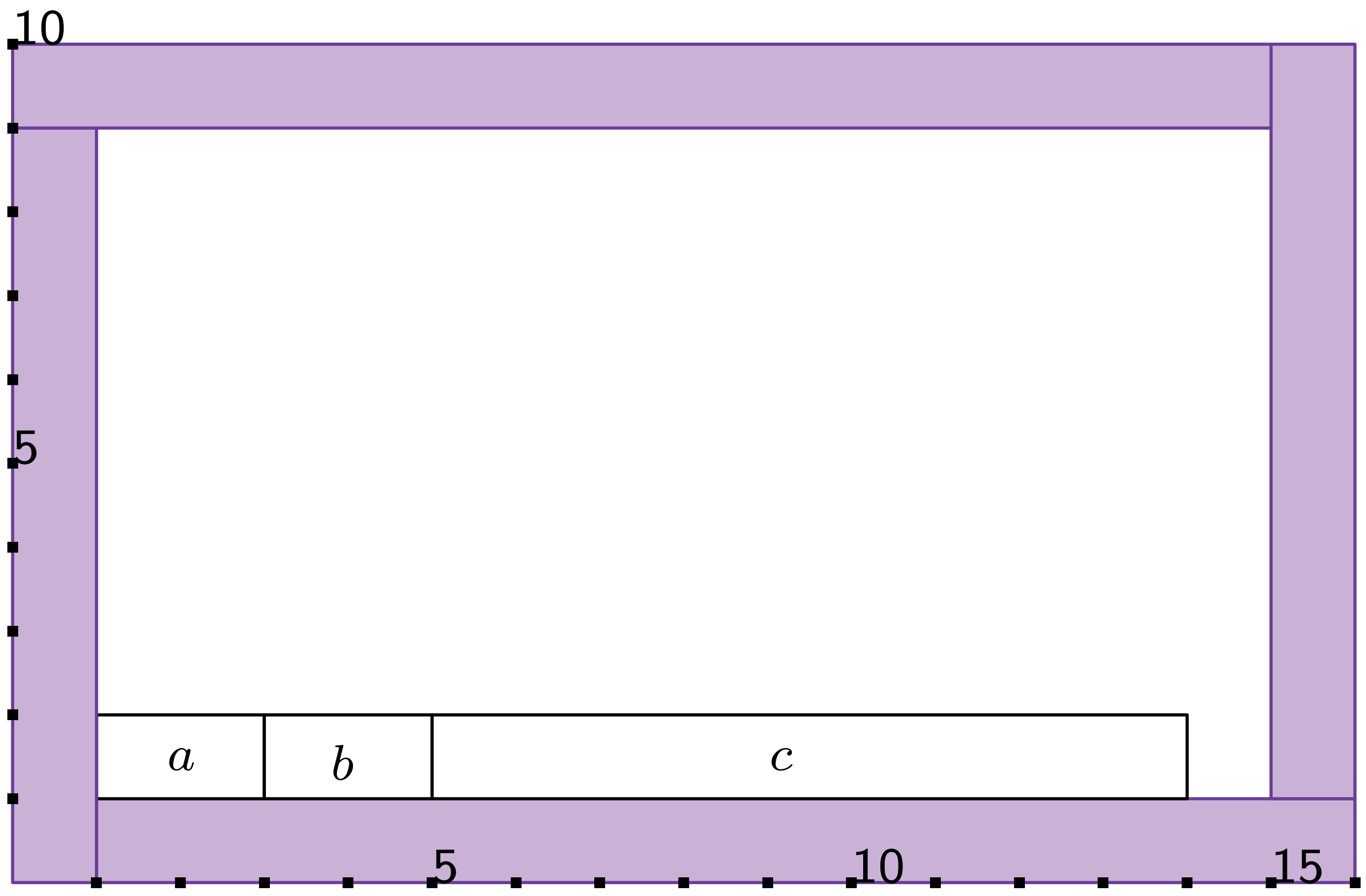
Reading off Coordinates to Get Rectangular Dual



$x_1(v_N) = 0,\ x_2(v_N) = 15$
$x_1(v_S) = 1,\ x_2(v_S) = 16$
$x_1(v_W) = 0, x_2(v_W) = 1$
$x_1(v_E) = 15,\ x_2(v_E) = 16$
$x_1(a) = 1,\ x_2(a) = 3$
$x_1(b) = 3,\ x_2(b) = 5$
$x_1(c) = 5,\ x_2(c) = 14$
$x_1(d) = 14,\ x_2(d) = 15$
$x_1(e) = 13,\ x_2(e) = 15$
$\ldots$

$y_1(v_W) = 0, y_2(v_W) = 9$
$y_1(v_E) = 1,\ y_2(v_E) = 10$
$y_1(v_N) = 9,\ y_2(v_N) = 10$
$y_1(v_S) = 0,\ y_2(v_S) = 1$
$y_1(a) = 1,\ y_2(a) = 2$
$y_1(b) = 1,\ y_2(b) = 2$
$\ldots$

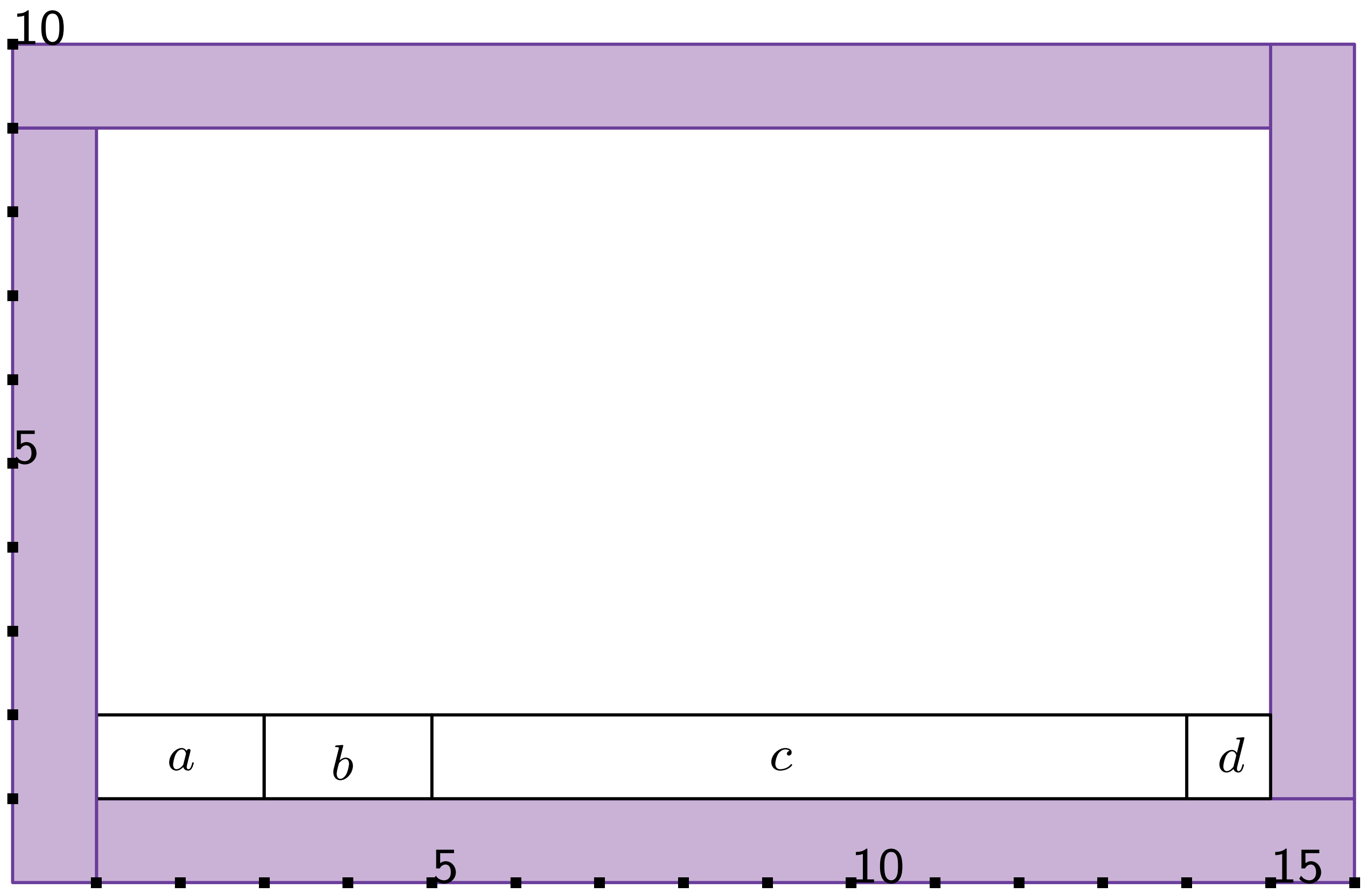
Reading off Coordinates to Get Rectangular Dual



$x_1(v_N) = 0,\ x_2(v_N) = 15$
$x_1(v_S) = 1,\ x_2(v_S) = 16$
$x_1(v_W) = 0, x_2(v_W) = 1$
$x_1(v_E) = 15,\ x_2(v_E) = 16$
$x_1(a) = 1,\ x_2(a) = 3$
$x_1(b) = 3,\ x_2(b) = 5$
$x_1(c) = 5,\ x_2(c) = 14$
$x_1(d) = 14,\ x_2(d) = 15$
$x_1(e) = 13,\ x_2(e) = 15$
$\dots$

$y_1(v_W) = 0, y_2(v_W) = 9$
$y_1(v_E) = 1,\ y_2(v_E) = 10$
$y_1(v_N) = 9,\ y_2(v_N) = 10$
$y_1(v_S) = 0,\ y_2(v_S) = 1$
$y_1(a) = 1,\ y_2(a) = 2$
$y_1(b) = 1,\ y_2(b) = 2$
$\dots$

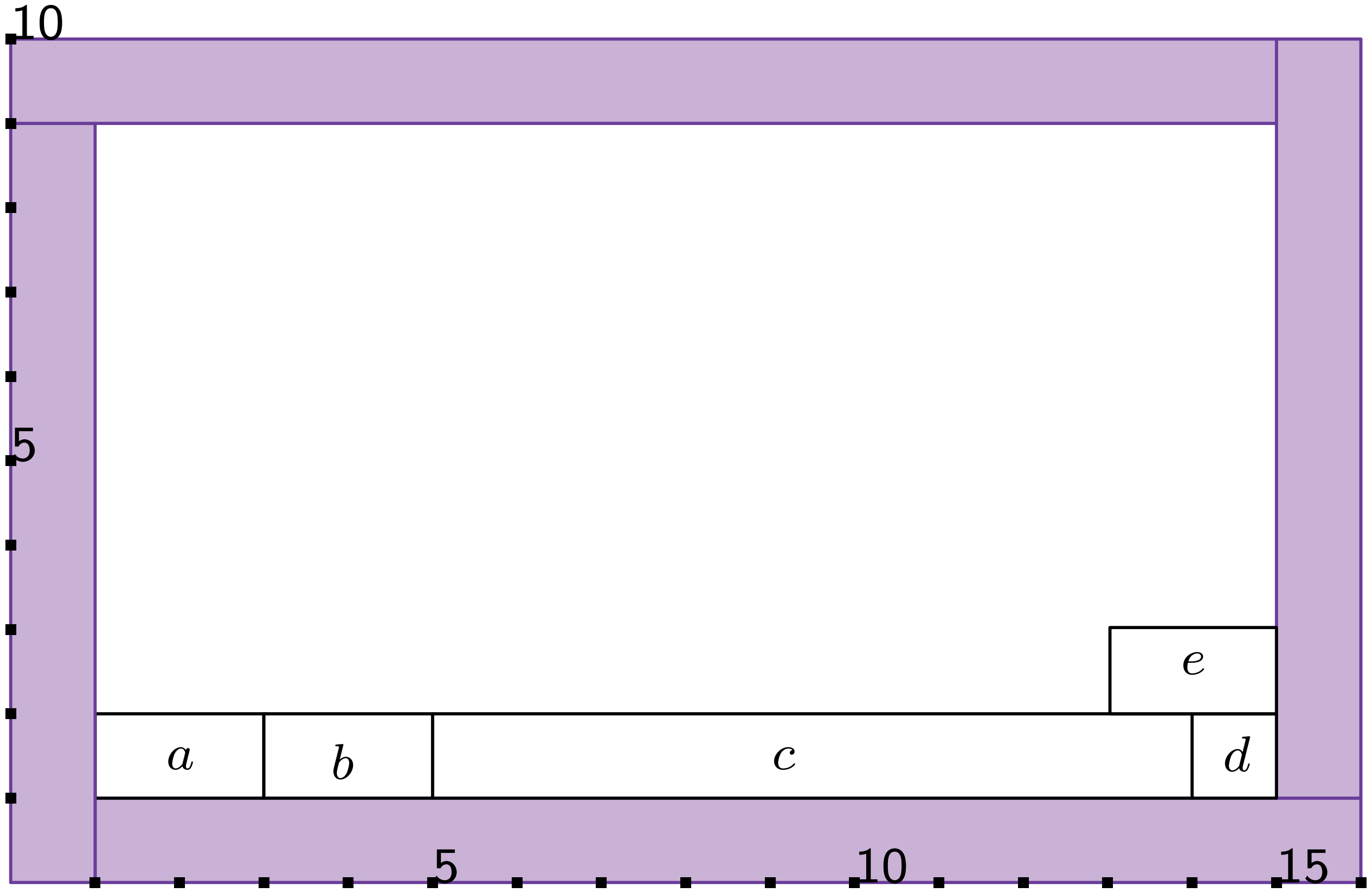
Reading off Coordinates to Get Rectangular Dual



$x_1(v_N) = 0,\ x_2(v_N) = 15$
$x_1(v_S) = 1,\ x_2(v_S) = 16$
$x_1(v_W) = 0, x_2(v_W) = 1$
$x_1(v_E) = 15,\ x_2(v_E) = 16$
$x_1(a) = 1,\ x_2(a) = 3$
$x_1(b) = 3,\ x_2(b) = 5$
$x_1(c) = 5,\ x_2(c) = 14$
$x_1(d) = 14,\ x_2(d) = 15$
$x_1(e) = 13,\ x_2(e) = 15$
$\ldots$

$y_1(v_W) = 0, y_2(v_W) = 9$
$y_1(v_E) = 1,\ y_2(v_E) = 10$
$y_1(v_N) = 9,\ y_2(v_N) = 10$
$y_1(v_S) = 0,\ y_2(v_S) = 1$
$y_1(a) = 1,\ y_2(a) = 2$
$y_1(b) = 1,\ y_2(b) = 2$
$\ldots$

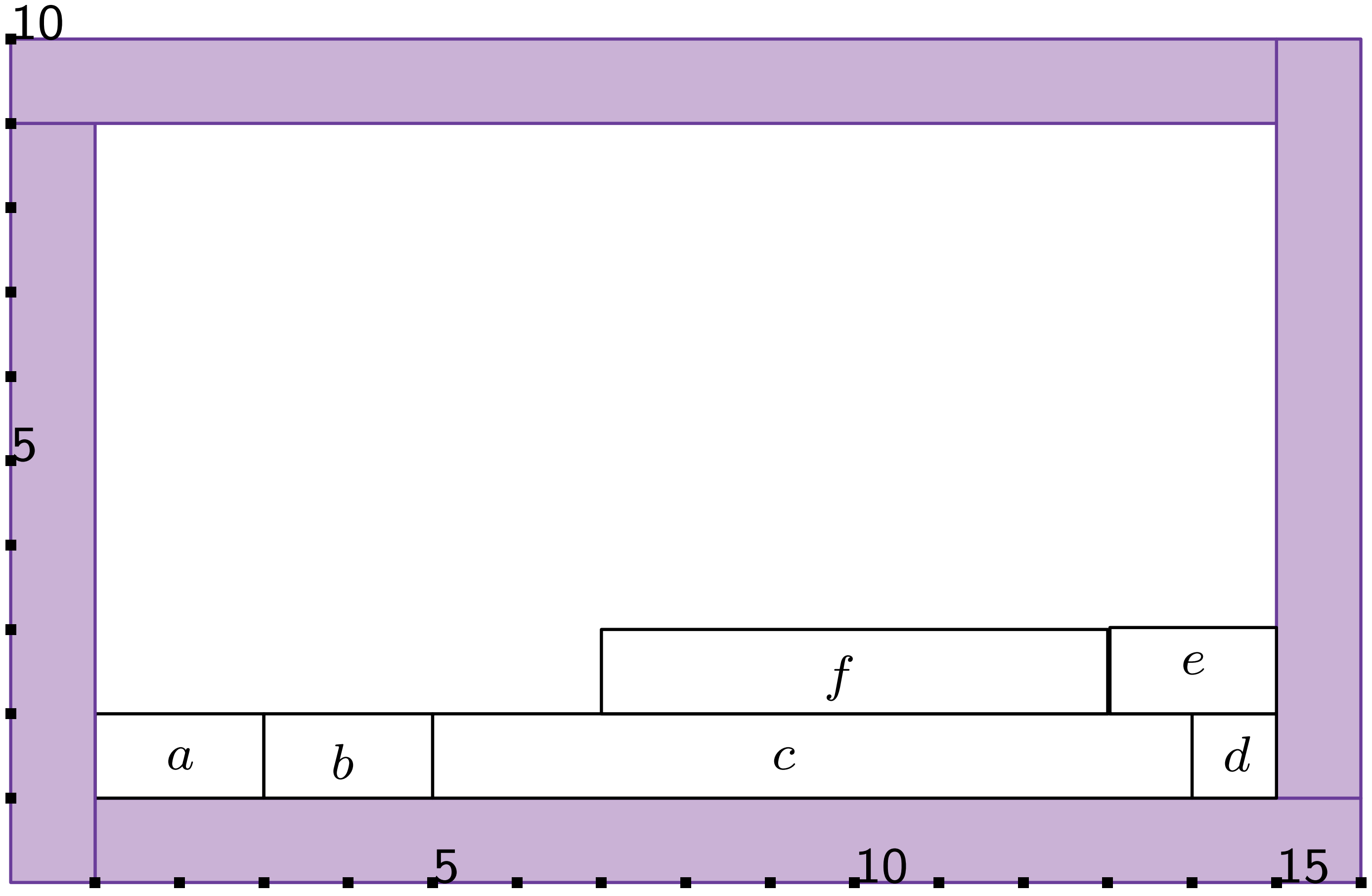
Reading off Coordinates to Get Rectangular Dual



$$x_1(v_N) = 0,\ x_2(v_N) = 15$$
$$x_1(v_S) = 1,\ x_2(v_S) = 16$$
$$x_1(v_W) = 0, x_2(v_W) = 1$$
$$x_1(v_E) = 15,\ x_2(v_E) = 16$$
$$x_1(a) = 1,\ x_2(a) = 3$$
$$x_1(b) = 3,\ x_2(b) = 5$$
$$x_1(c) = 5,\ x_2(c) = 14$$
$$x_1(d) = 14,\ x_2(d) = 15$$
$$x_1(e) = 13,\ x_2(e) = 15$$
$$\dots$$

$$y_1(v_W) = 0, y_2(v_W) = 9$$
$$y_1(v_E) = 1,\ y_2(v_E) = 10$$
$$y_1(v_N) = 9,\ y_2(v_N) = 10$$
$$y_1(v_S) = 0,\ y_2(v_S) = 1$$
$$y_1(a) = 1,\ y_2(a) = 2$$
$$y_1(b) = 1,\ y_2(b) = 2$$
$$\dots$$

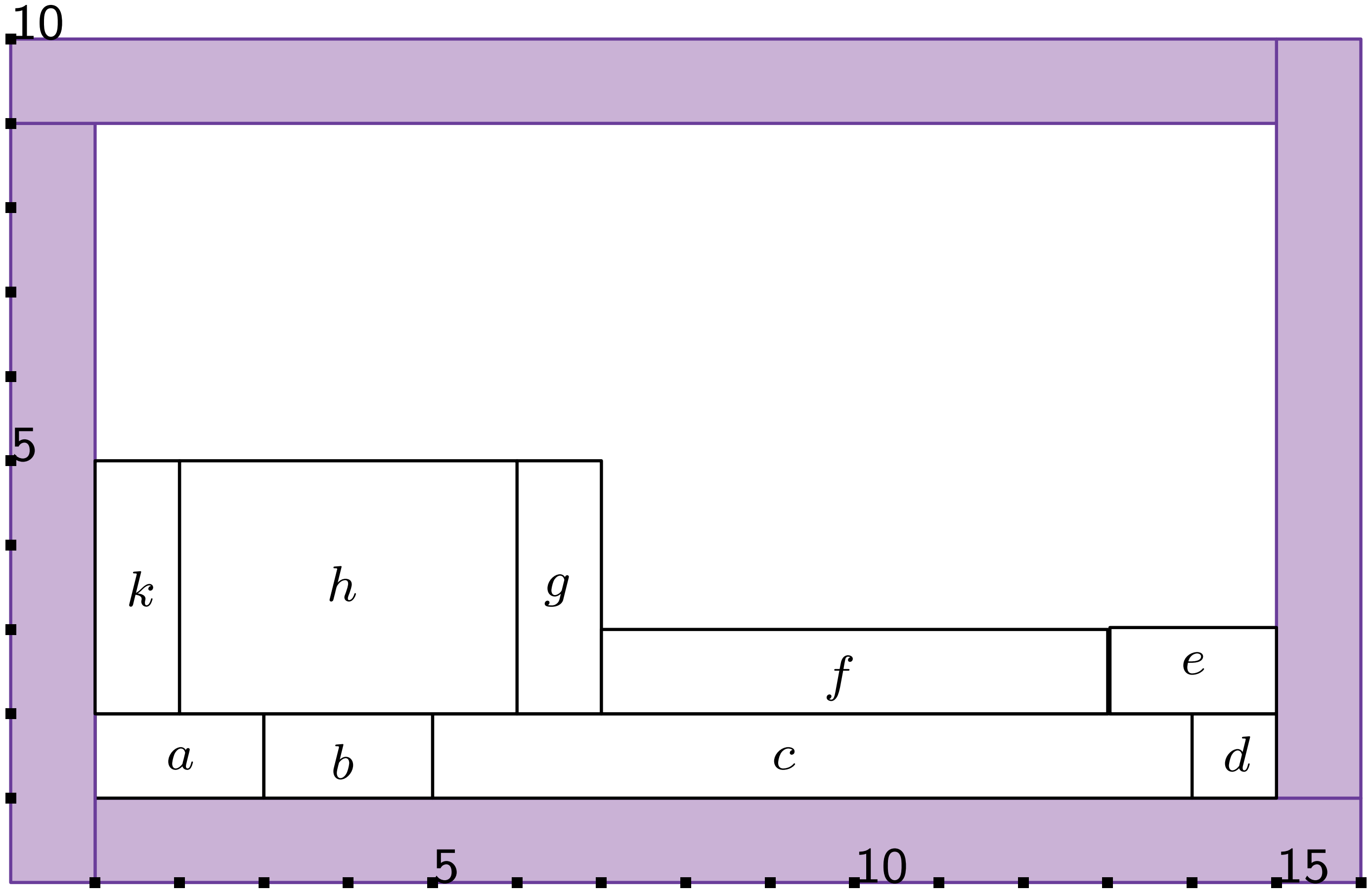
Reading off Coordinates to Get Rectangular Dual



$x_1(v_N) = 0,\ x_2(v_N) = 15$
$x_1(v_S) = 1,\ x_2(v_S) = 16$
$x_1(v_W) = 0, x_2(v_W) = 1$
$x_1(v_E) = 15,\ x_2(v_E) = 16$
$x_1(a) = 1,\ x_2(a) = 3$
$x_1(b) = 3,\ x_2(b) = 5$
$x_1(c) = 5,\ x_2(c) = 14$
$x_1(d) = 14,\ x_2(d) = 15$
$x_1(e) = 13,\ x_2(e) = 15$
$\dots$

$y_1(v_W) = 0, y_2(v_W) = 9$
$y_1(v_E) = 1,\ y_2(v_E) = 10$
$y_1(v_N) = 9,\ y_2(v_N) = 10$
$y_1(v_S) = 0,\ y_2(v_S) = 1$
$y_1(a) = 1,\ y_2(a) = 2$
$y_1(b) = 1,\ y_2(b) = 2$
$\dots$

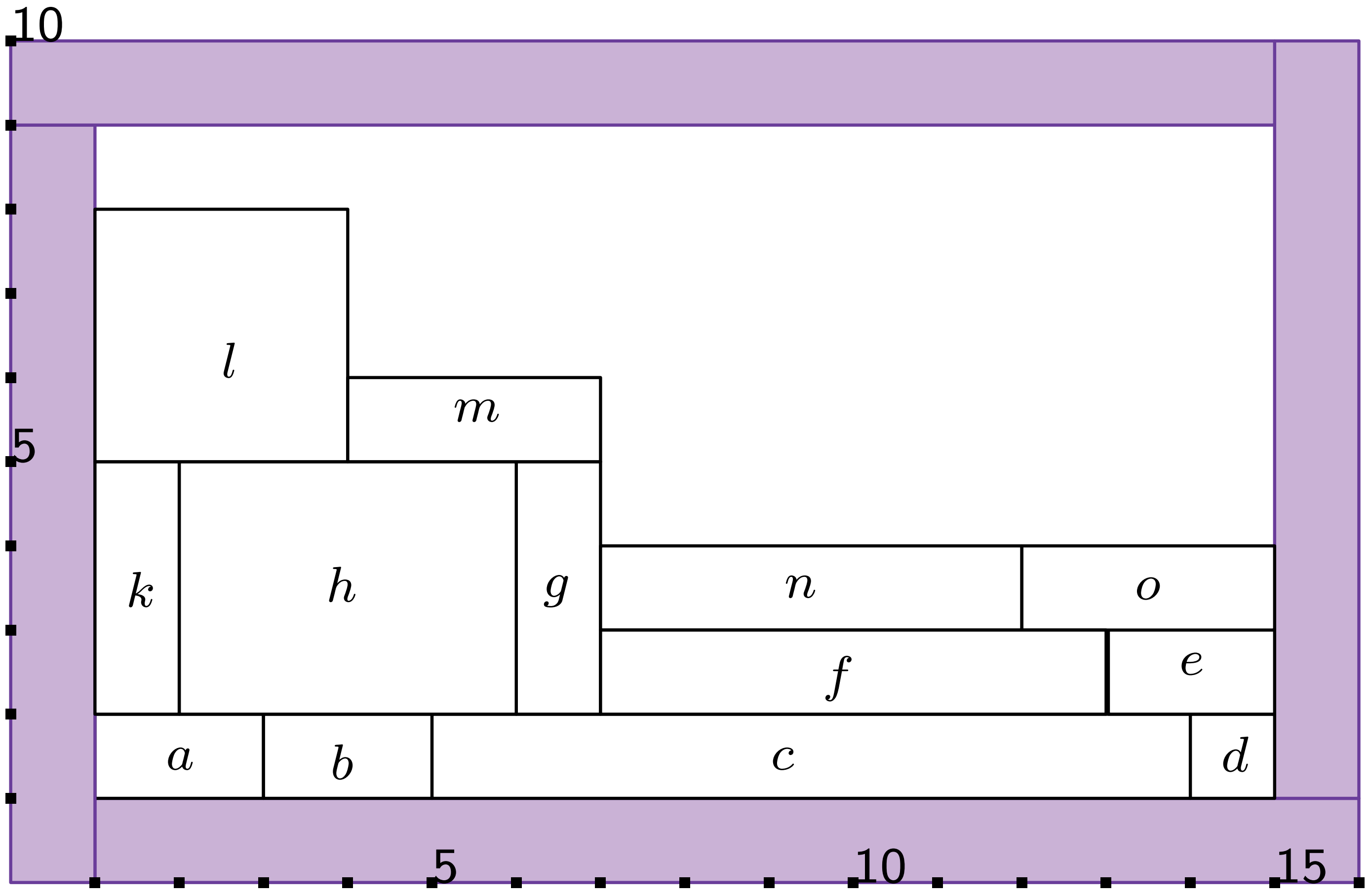
Reading off Coordinates to Get Rectangular Dual



$x_1(v_N) = 0,\ x_2(v_N) = 15$
$x_1(v_S) = 1,\ x_2(v_S) = 16$
$x_1(v_W) = 0, x_2(v_W) = 1$
$x_1(v_E) = 15,\ x_2(v_E) = 16$
$x_1(a) = 1,\ x_2(a) = 3$
$x_1(b) = 3,\ x_2(b) = 5$
$x_1(c) = 5,\ x_2(c) = 14$
$x_1(d) = 14,\ x_2(d) = 15$
$x_1(e) = 13,\ x_2(e) = 15$
$\ldots$

$y_1(v_W) = 0, y_2(v_W) = 9$
$y_1(v_E) = 1,\ y_2(v_E) = 10$
$y_1(v_N) = 9,\ y_2(v_N) = 10$
$y_1(v_S) = 0,\ y_2(v_S) = 1$
$y_1(a) = 1,\ y_2(a) = 2$
$y_1(b) = 1,\ y_2(b) = 2$
$\ldots$

Reading off Coordinates to Get Rectangular Dual



$x_1(v_N) = 0,\ x_2(v_N) = 15$
$x_1(v_S) = 1,\ x_2(v_S) = 16$
$x_1(v_W) = 0, x_2(v_W) = 1$
$x_1(v_E) = 15,\ x_2(v_E) = 16$
$x_1(a) = 1,\ x_2(a) = 3$
$x_1(b) = 3,\ x_2(b) = 5$
$x_1(c) = 5,\ x_2(c) = 14$
$x_1(d) = 14,\ x_2(d) = 15$
$x_1(e) = 13,\ x_2(e) = 15$
...

$y_1(v_W) = 0, y_2(v_W) = 9$
$y_1(v_E) = 1,\ y_2(v_E) = 10$
$y_1(v_N) = 9,\ y_2(v_N) = 10$
$y_1(v_S) = 0,\ y_2(v_S) = 1$
$y_1(a) = 1,\ y_2(a) = 2$
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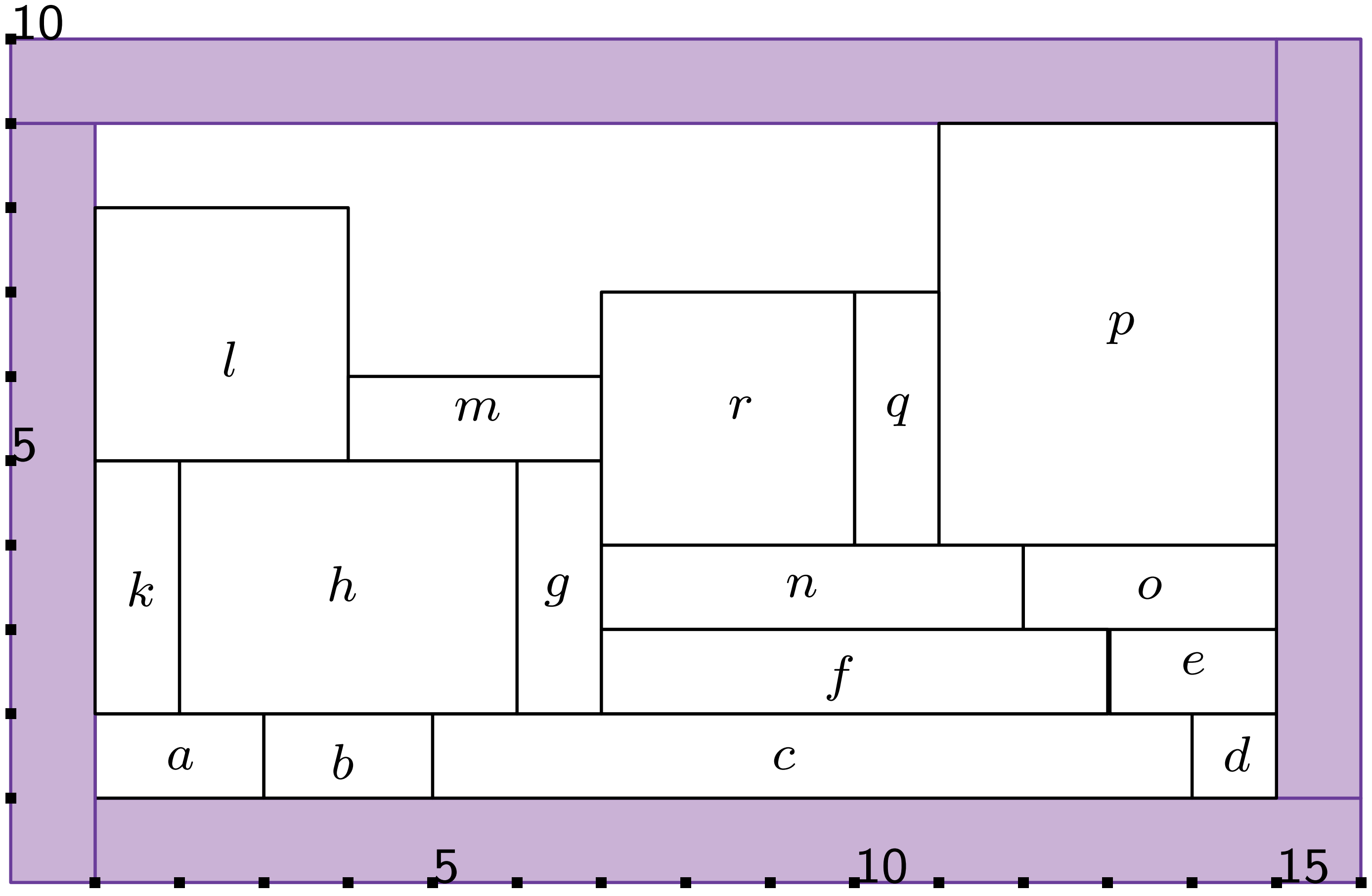
Reading off Coordinates to Get Rectangular Dual



$x_1(v_N) = 0,\ x_2(v_N) = 15$
$x_1(v_S) = 1,\ x_2(v_S) = 16$
$x_1(v_W) = 0, x_2(v_W) = 1$
$x_1(v_E) = 15,\ x_2(v_E) = 16$
$x_1(a) = 1,\ x_2(a) = 3$
$x_1(b) = 3,\ x_2(b) = 5$
$x_1(c) = 5,\ x_2(c) = 14$
$x_1(d) = 14,\ x_2(d) = 15$
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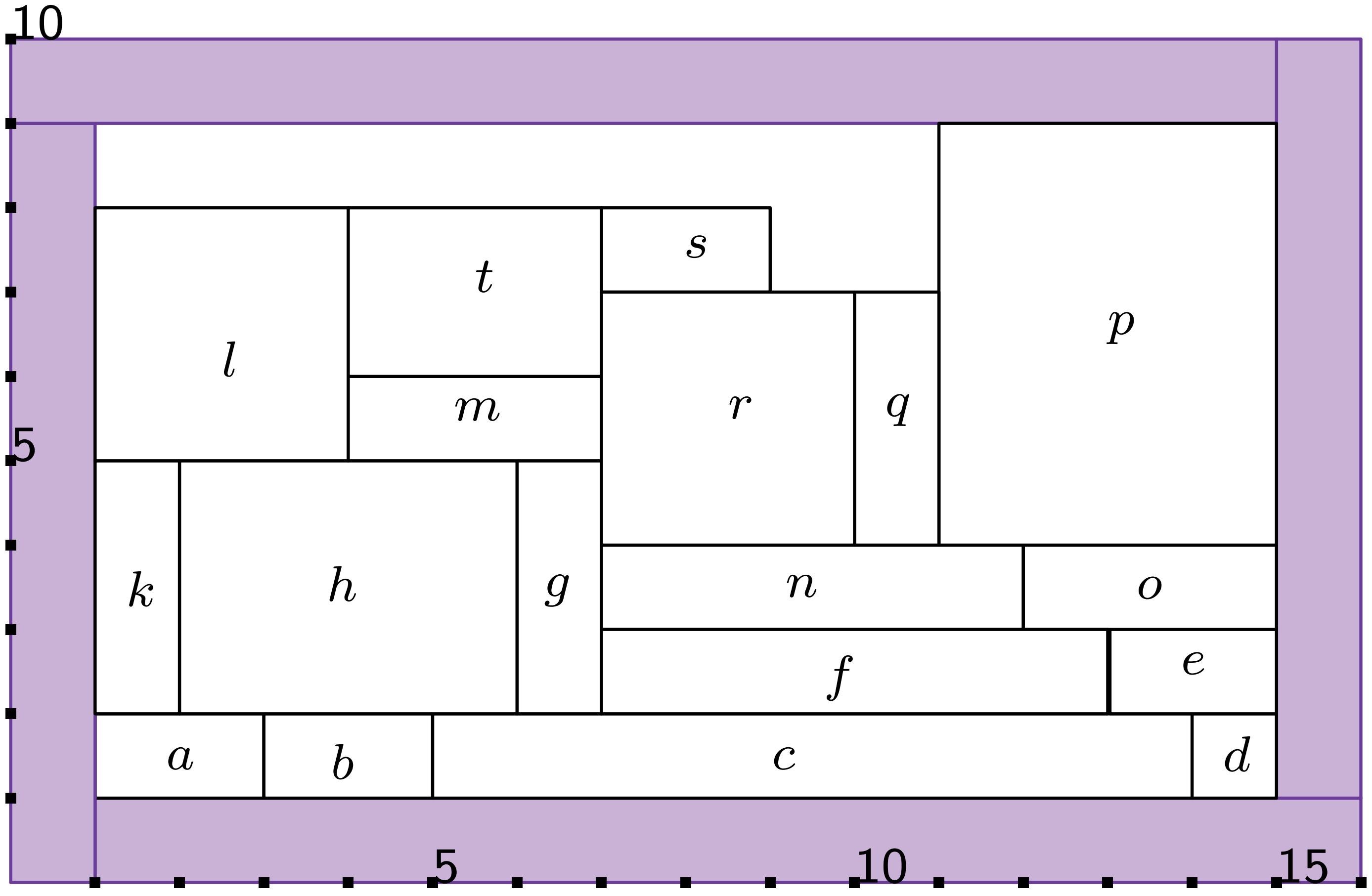

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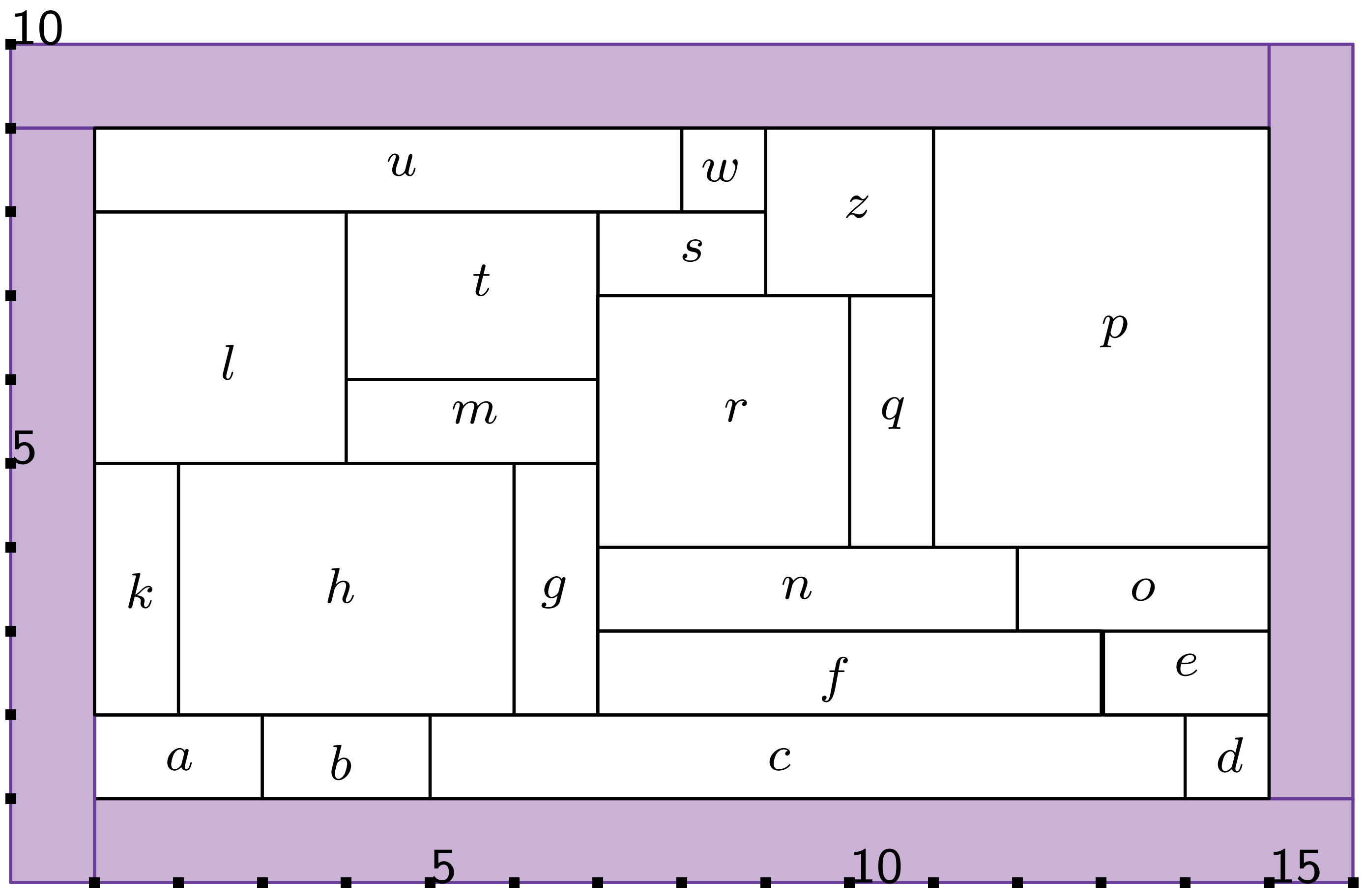

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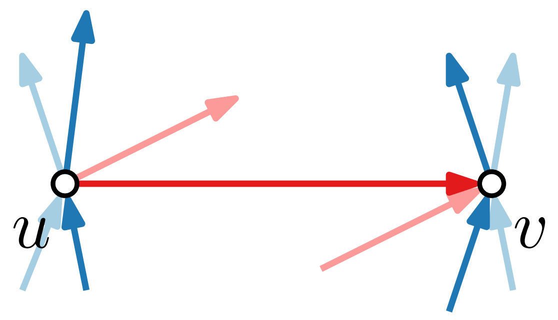

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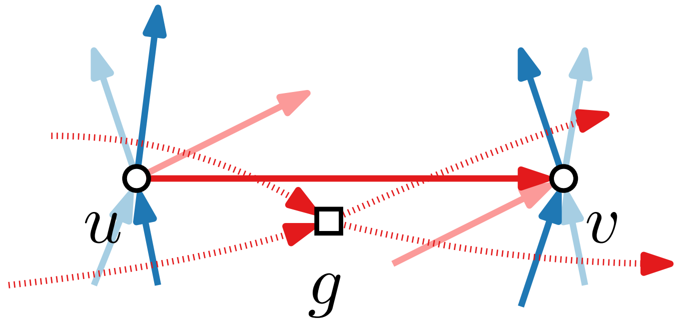

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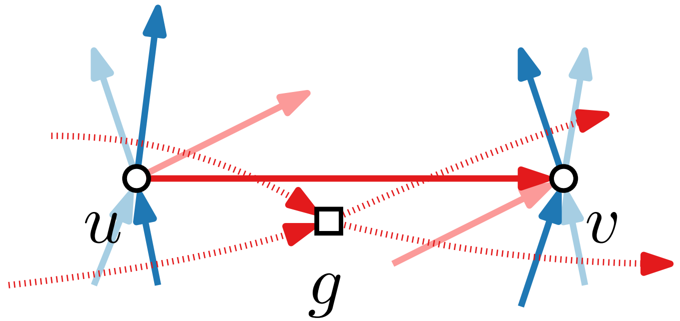

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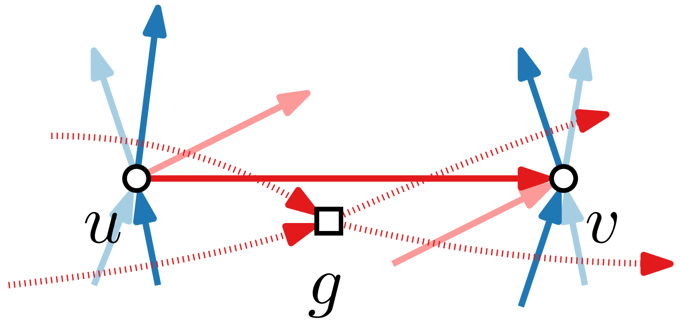

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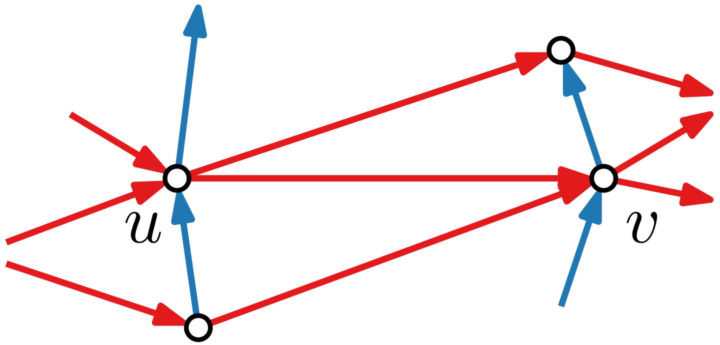

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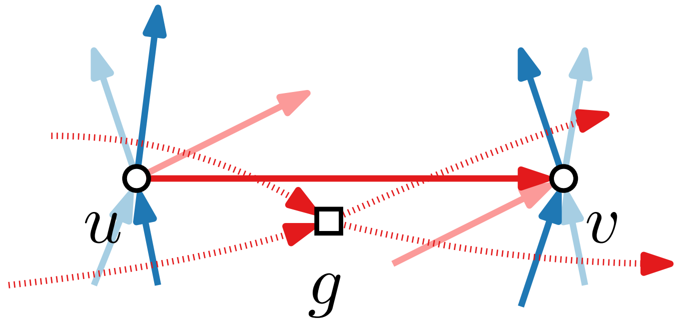

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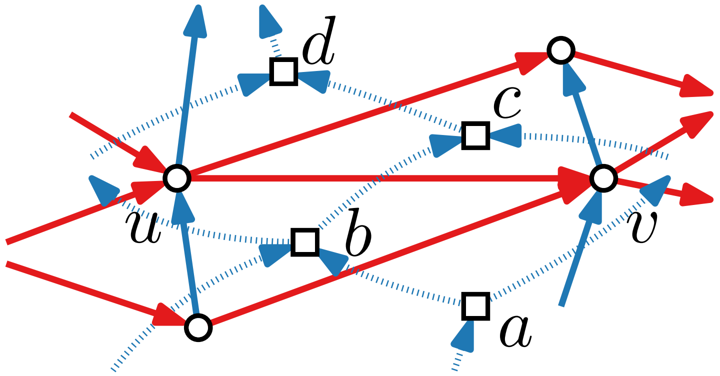

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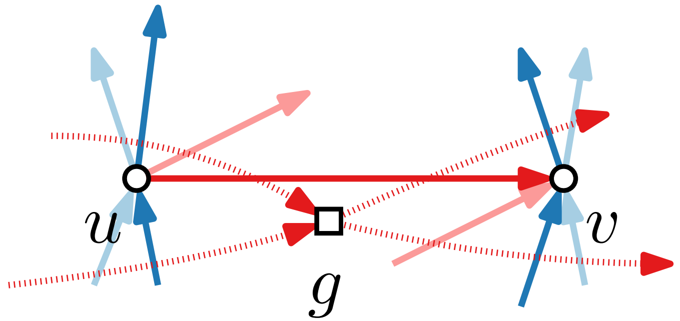

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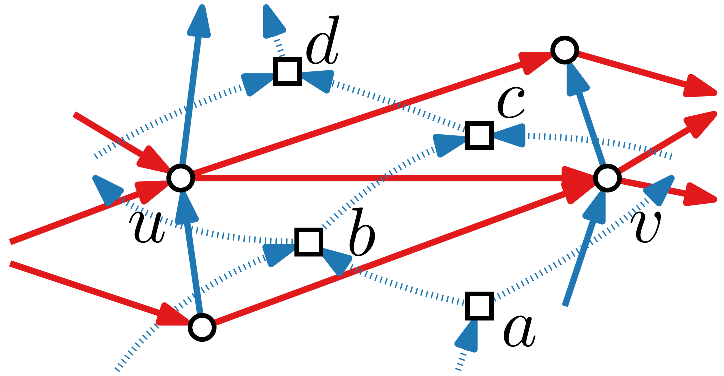

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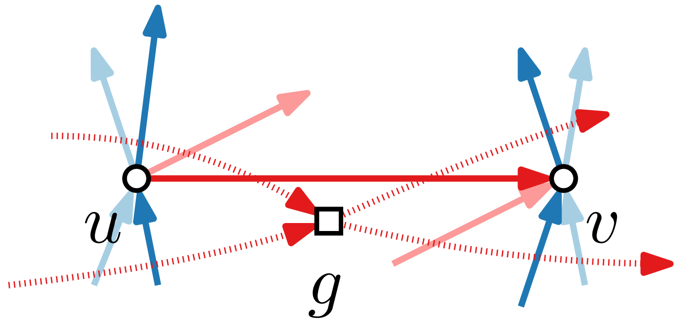

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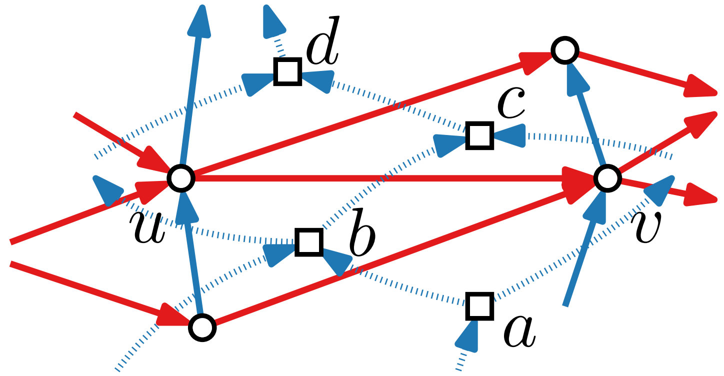

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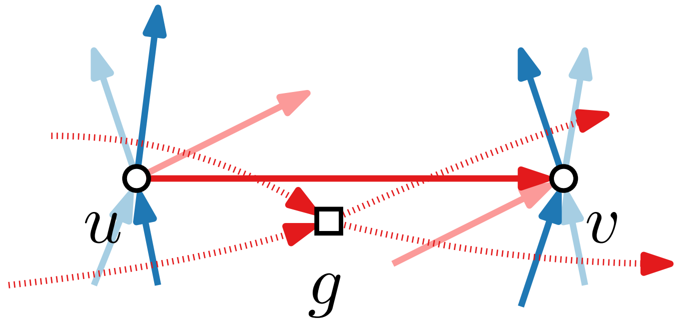

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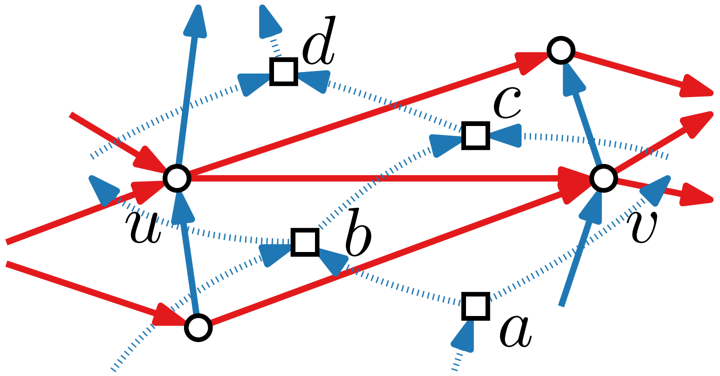

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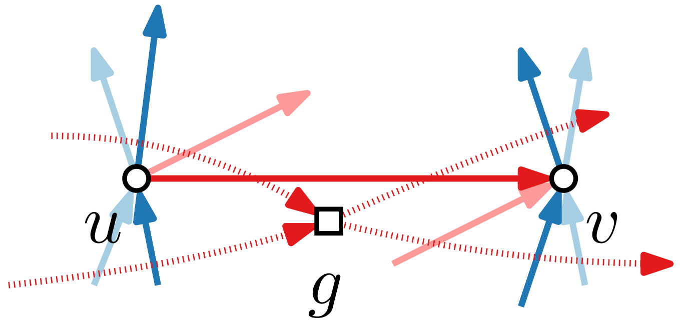

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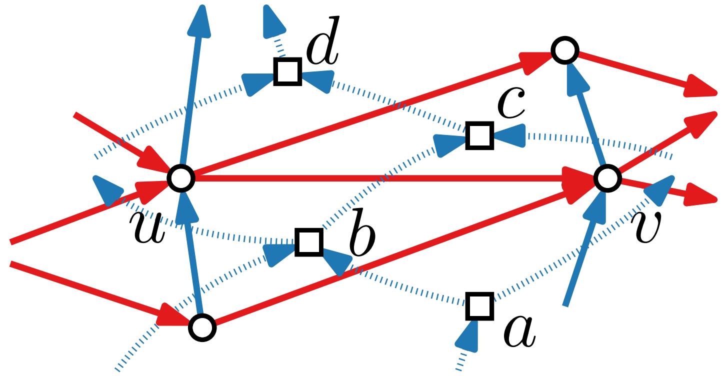

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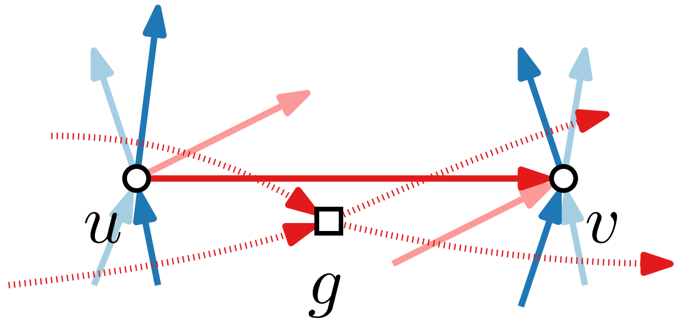

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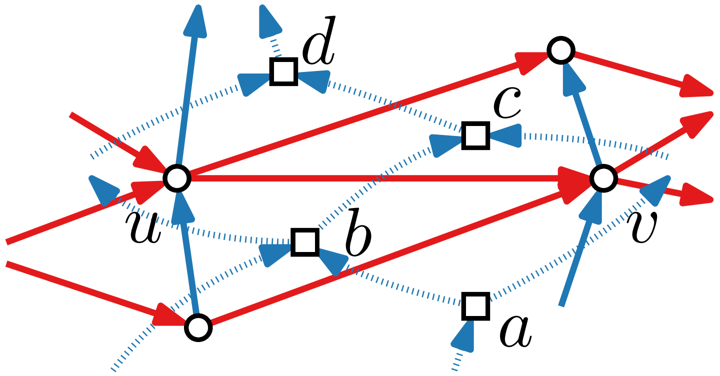

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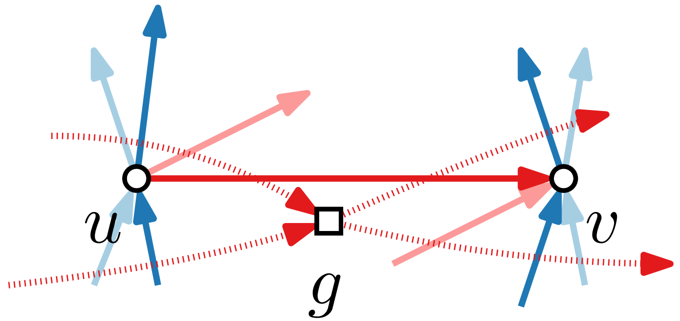

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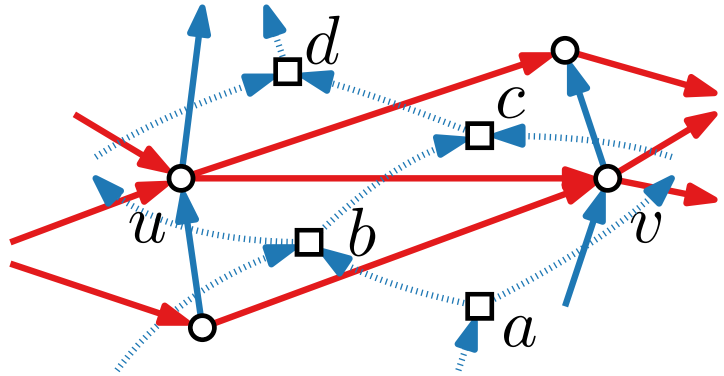

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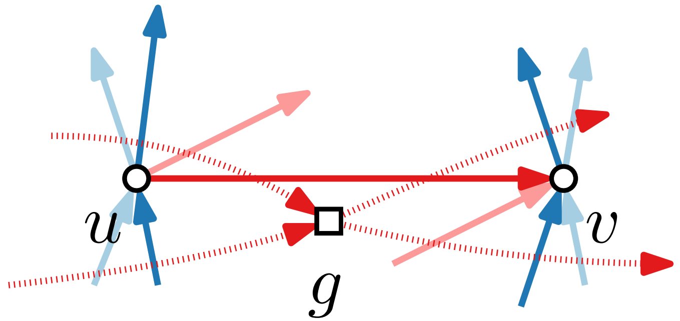

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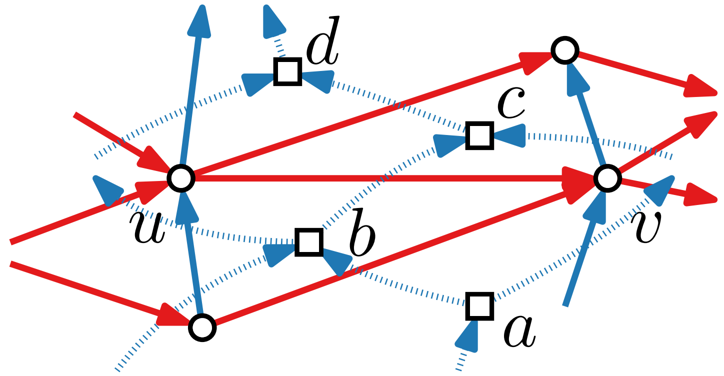

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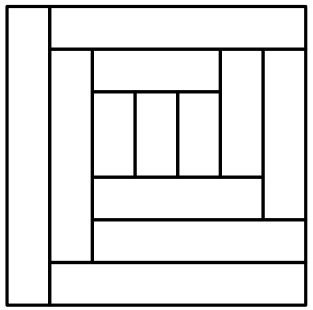

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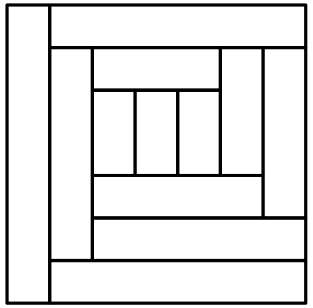

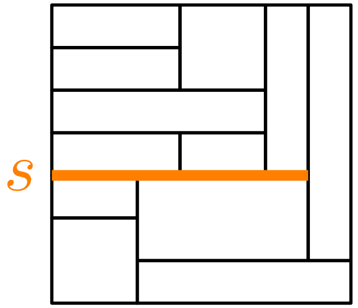

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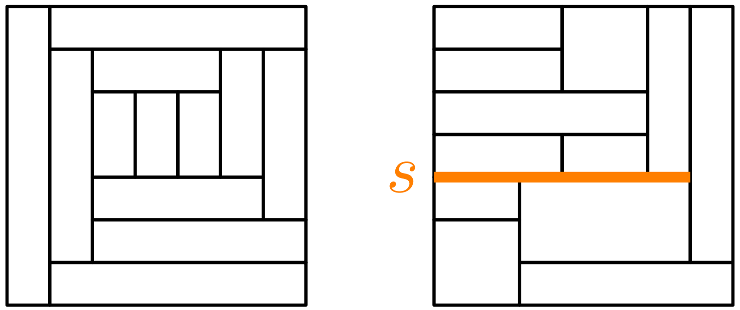

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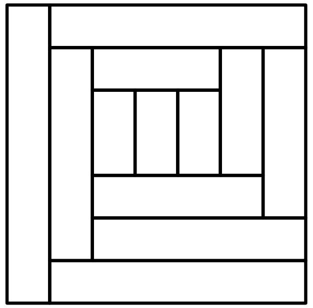

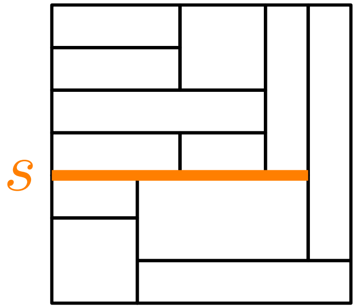

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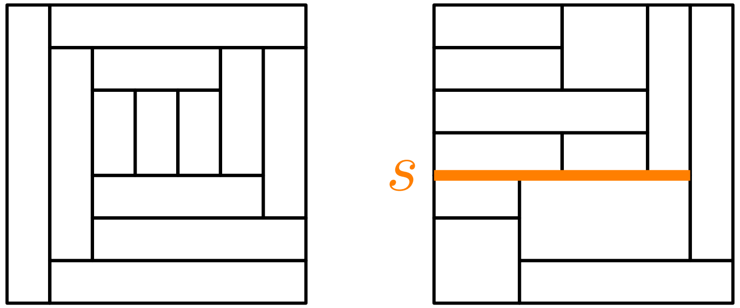

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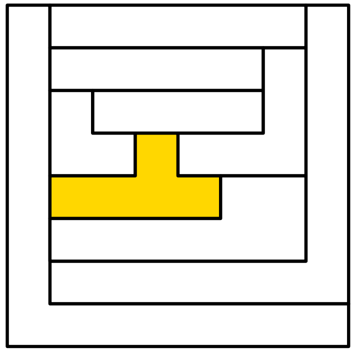

Literature

Construction of triangle contact representations based on

- [de Fraysseix, Ossona de Mendez, Rosenstiehl '94] On Triangle Contact Graphs

Construction of rectangular dual based on

- [He '93] On Finding the Rectangular Duals of Planar Triangulated Graphs
- [Kant, He '94] Two algorithms for finding rectangular duals of planar graphs

and originally from

- [Koźmiński, Kinnen '85] Rectangular Duals of Planar Graphs