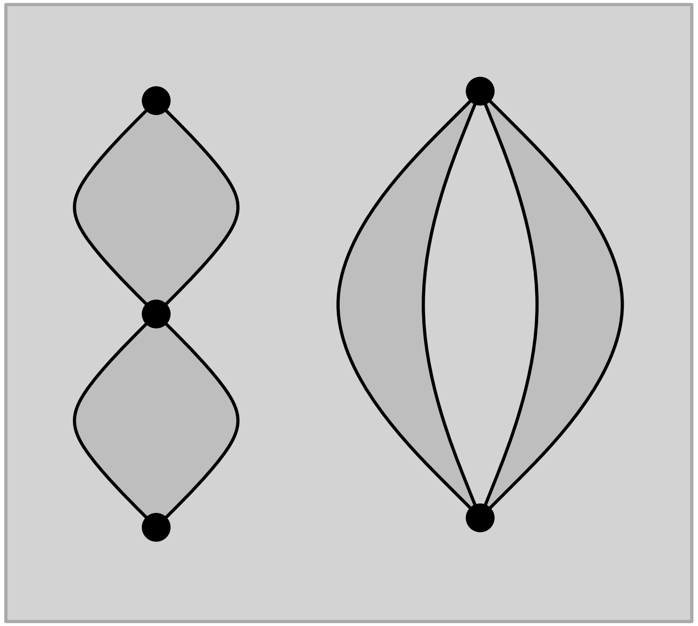
Algorithms for graph visualization

Divide and Conquer - Series-Parallel Graphs

WINTER SEMESTER 2016/2017

Tamara Mchedlidze



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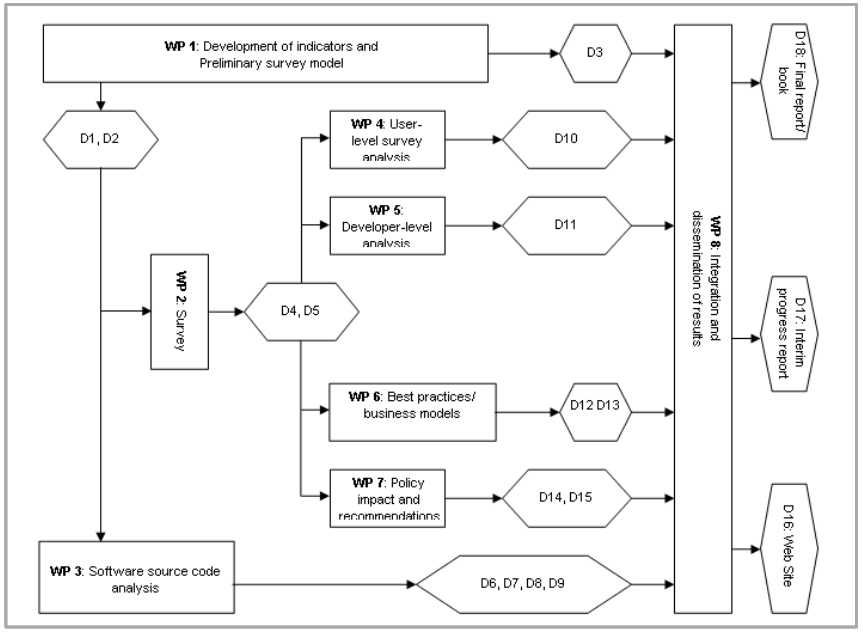
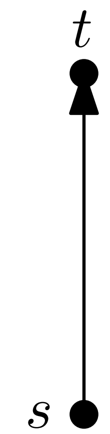


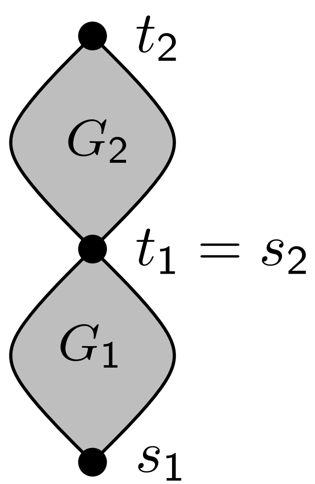
Series-parallel Graphs

Graph G is **series-parallel**, if

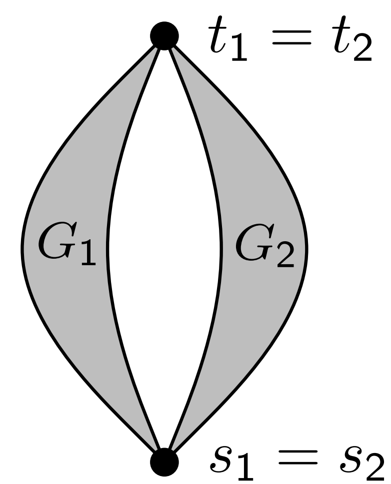
- It contains a single edge (s, t) (s-source, t-sink)
- It consists of two series-parallel graphs G_1, G_2 with sources s_1, s_2 and sinks t_1, t_2 which are combined using one of the following rules:



Series composition:
Identify t_1 and s_2,
s_1 is the source of G, t_2 is the sink of G



Parallel composition:
Identify s_1, s_2 and set it to be source of G
Identify t_1, t_2 and set it to be sink of G



Series-parallel Graphs. Decomposition Tree.

Lemma

Series-parallel graphs are acyclic and planar.

In order to proof this statement we can use a **decomposition tree** of G, which is a binary tree T with nodes of three types: S,P and Q-type.

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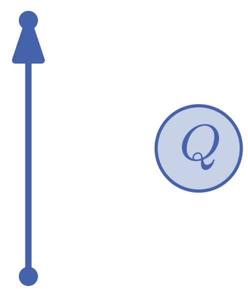

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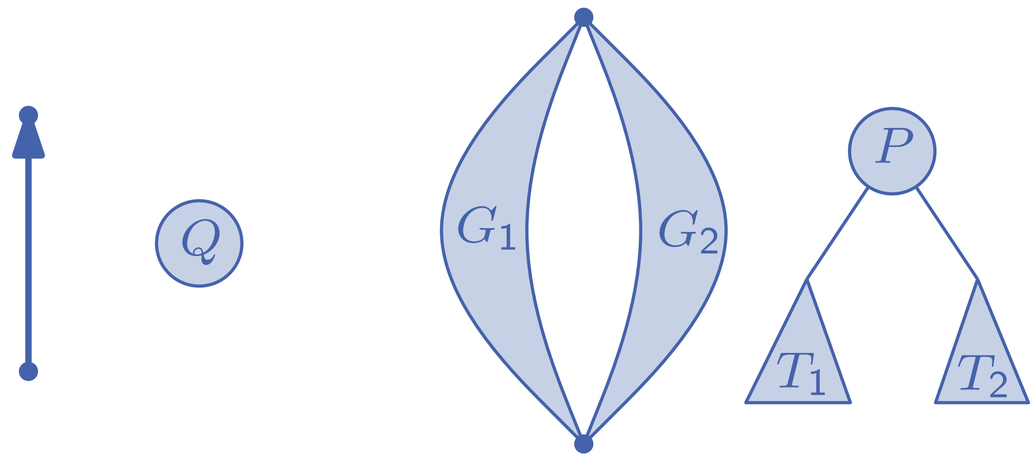
- If G is a parallel composition of G_1 (with tree T_1) and G_2 (with tree T_2), then the root of T is P-node and T_1 is its left subtree, T_2 is its right subtree



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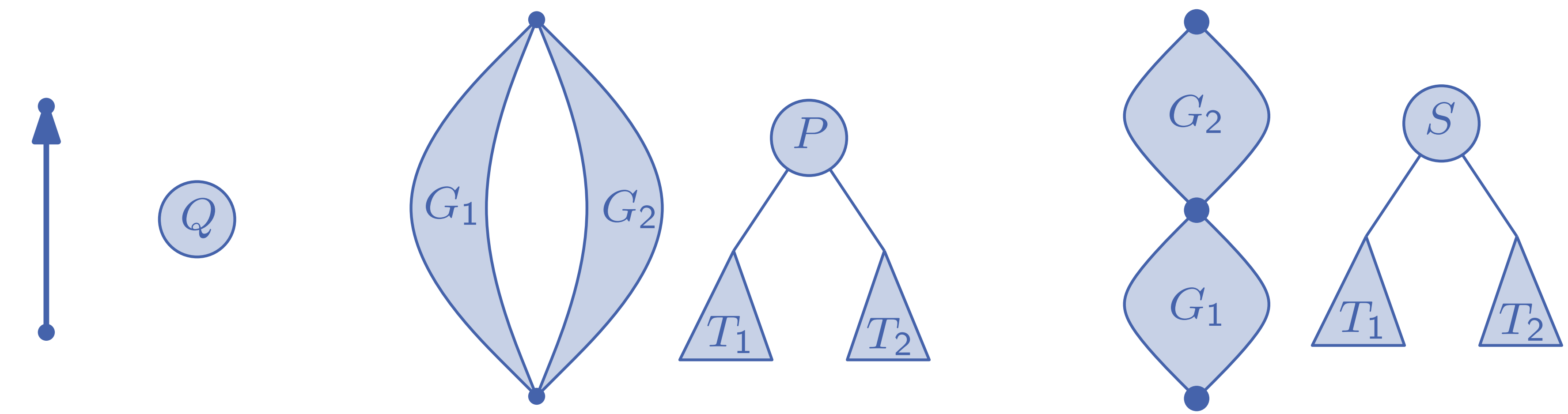

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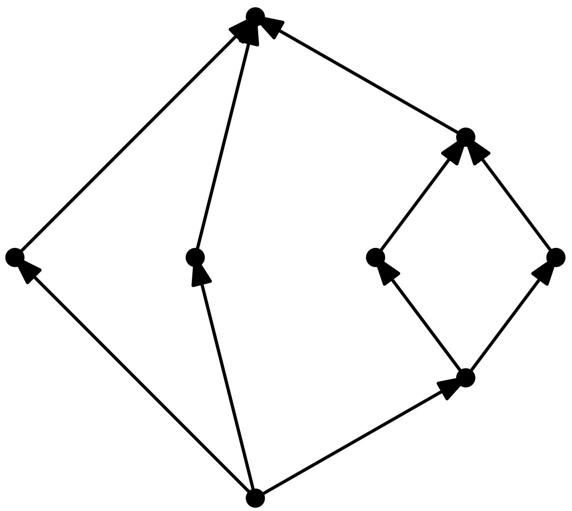

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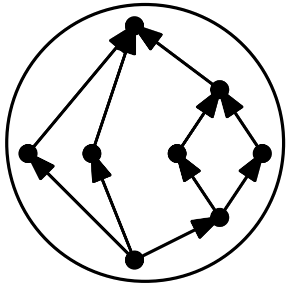

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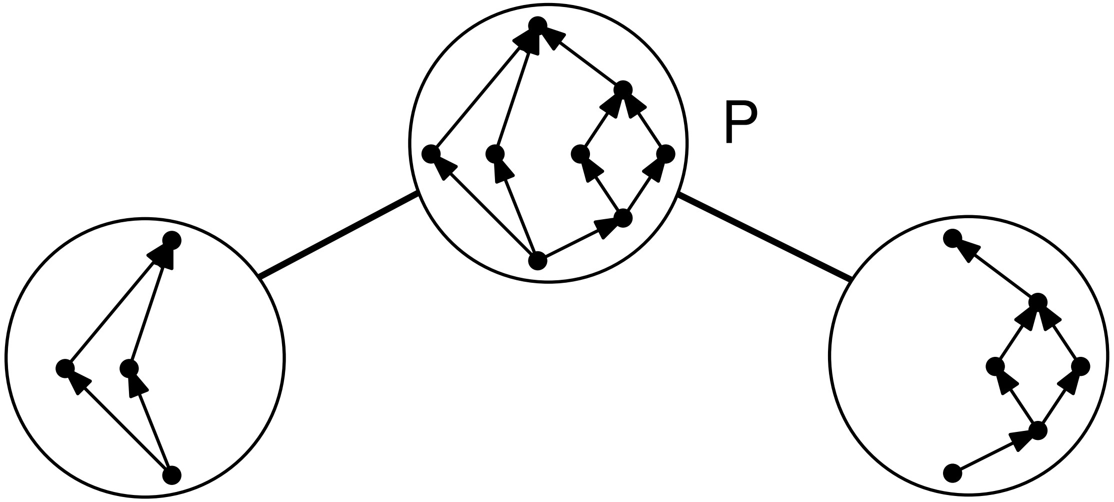

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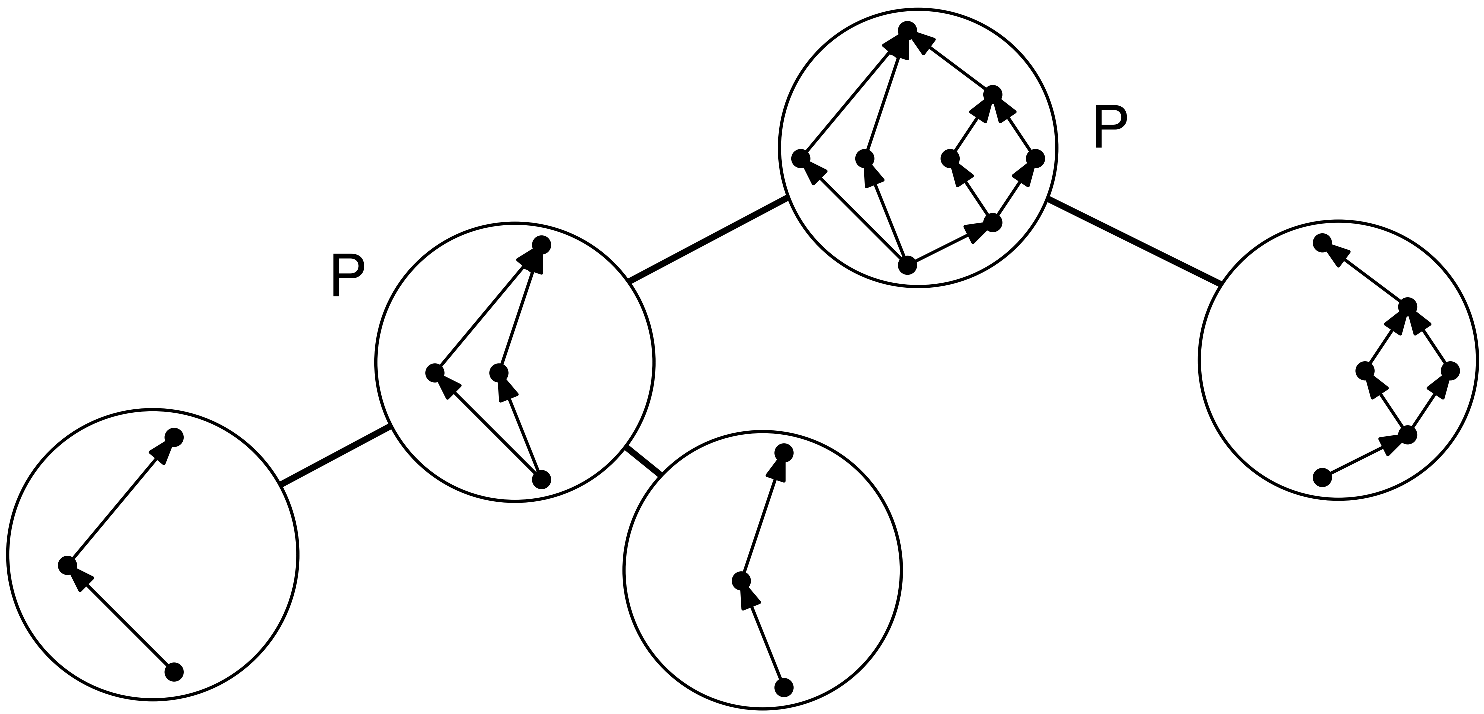

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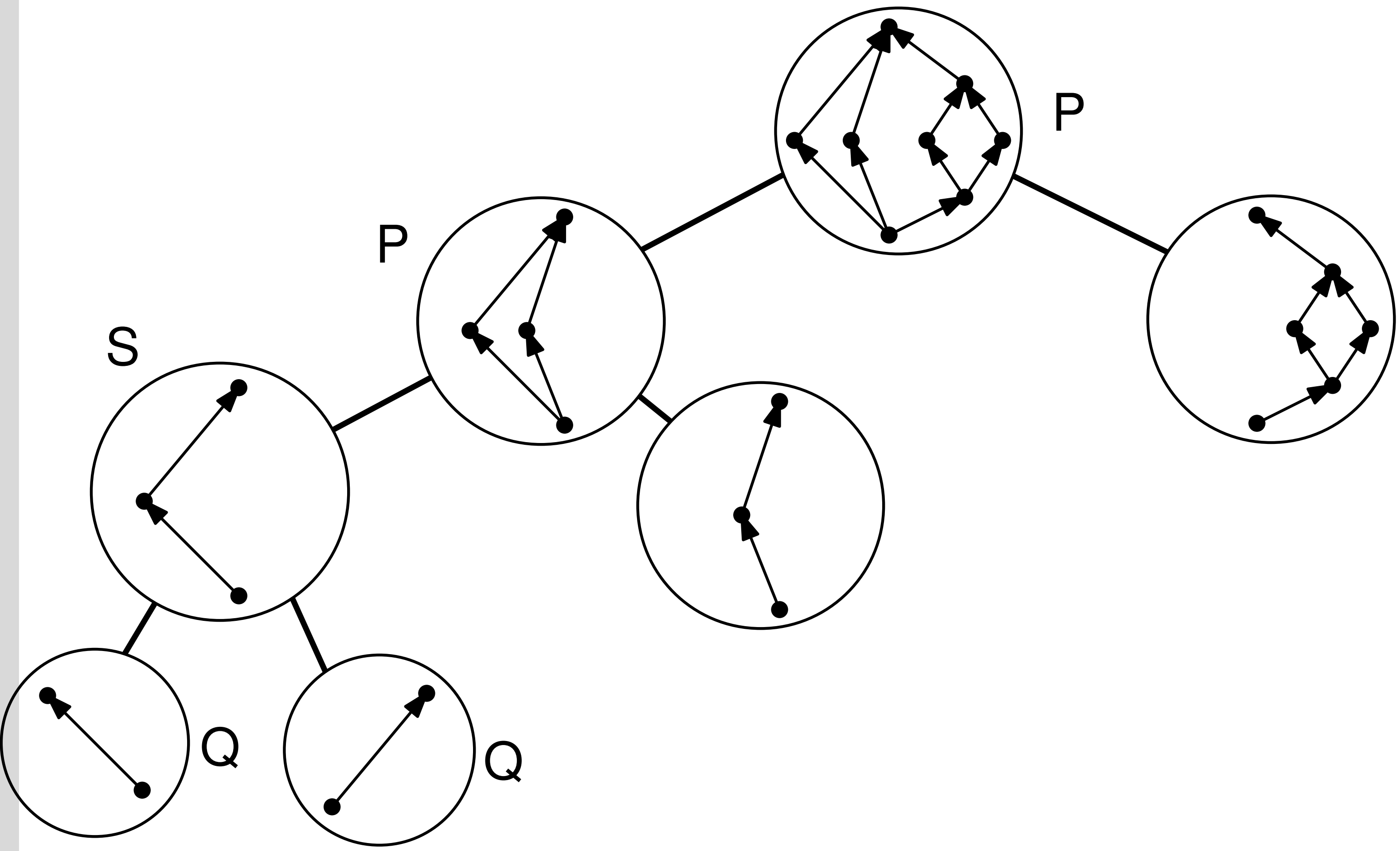

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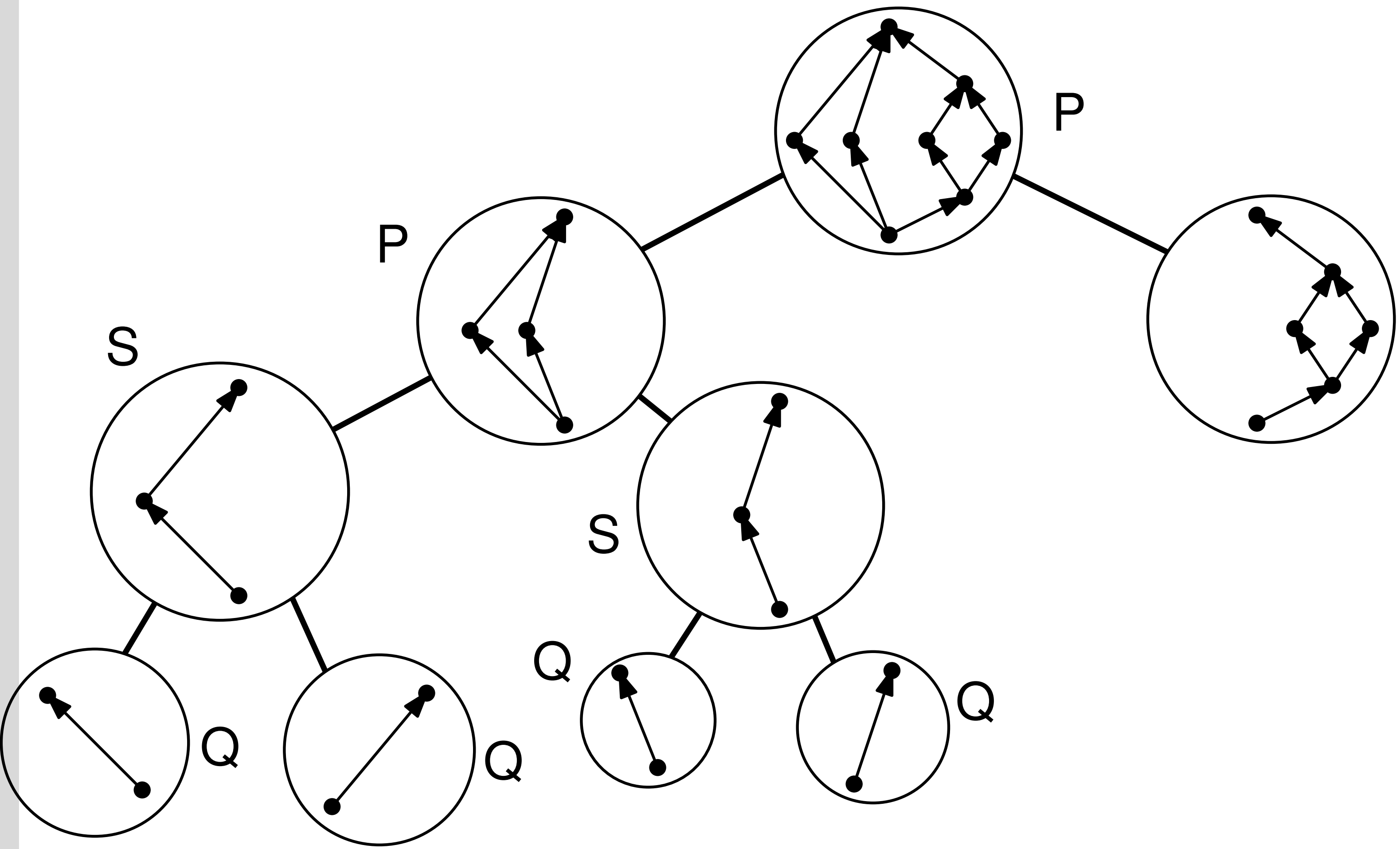

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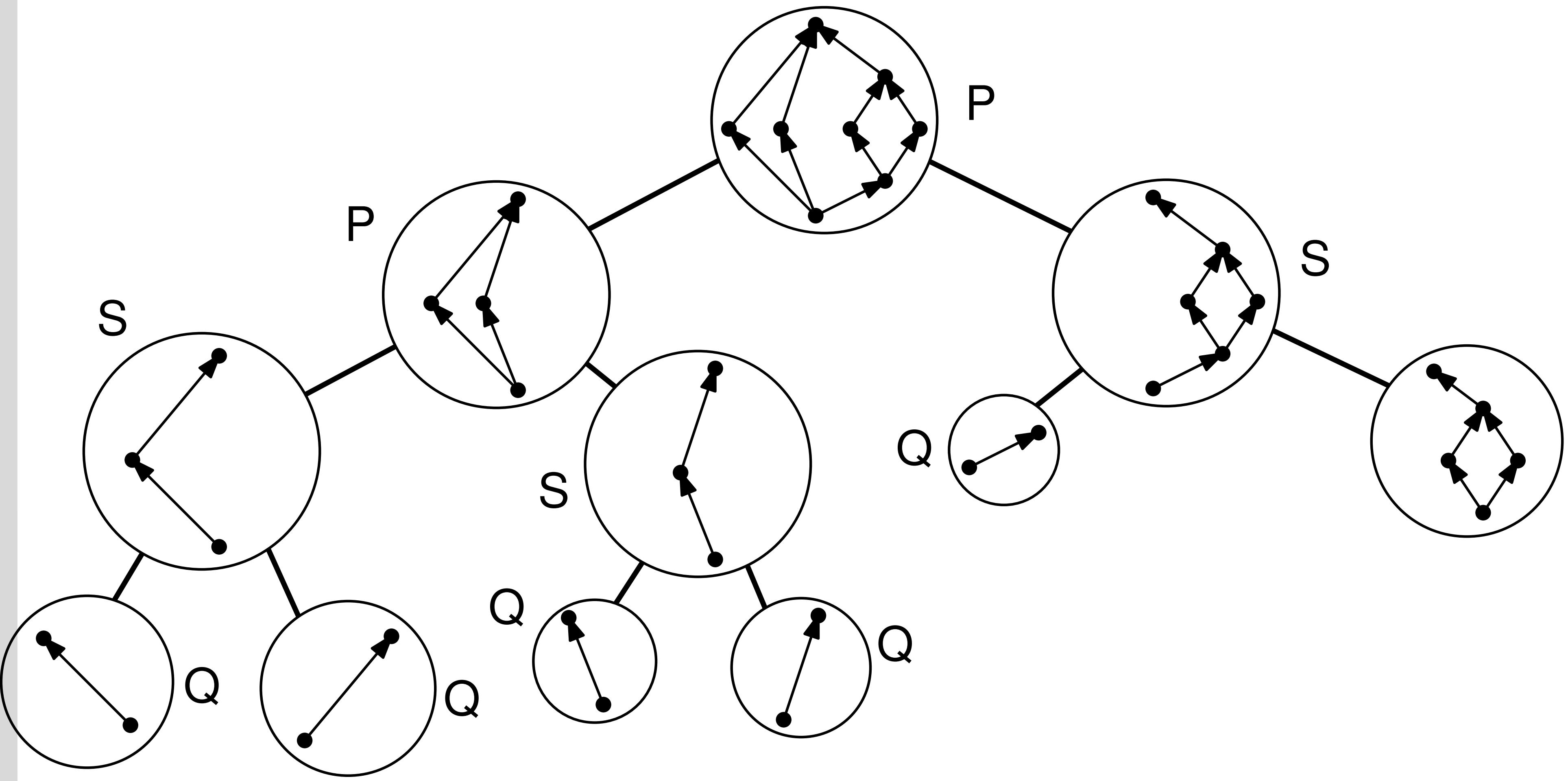

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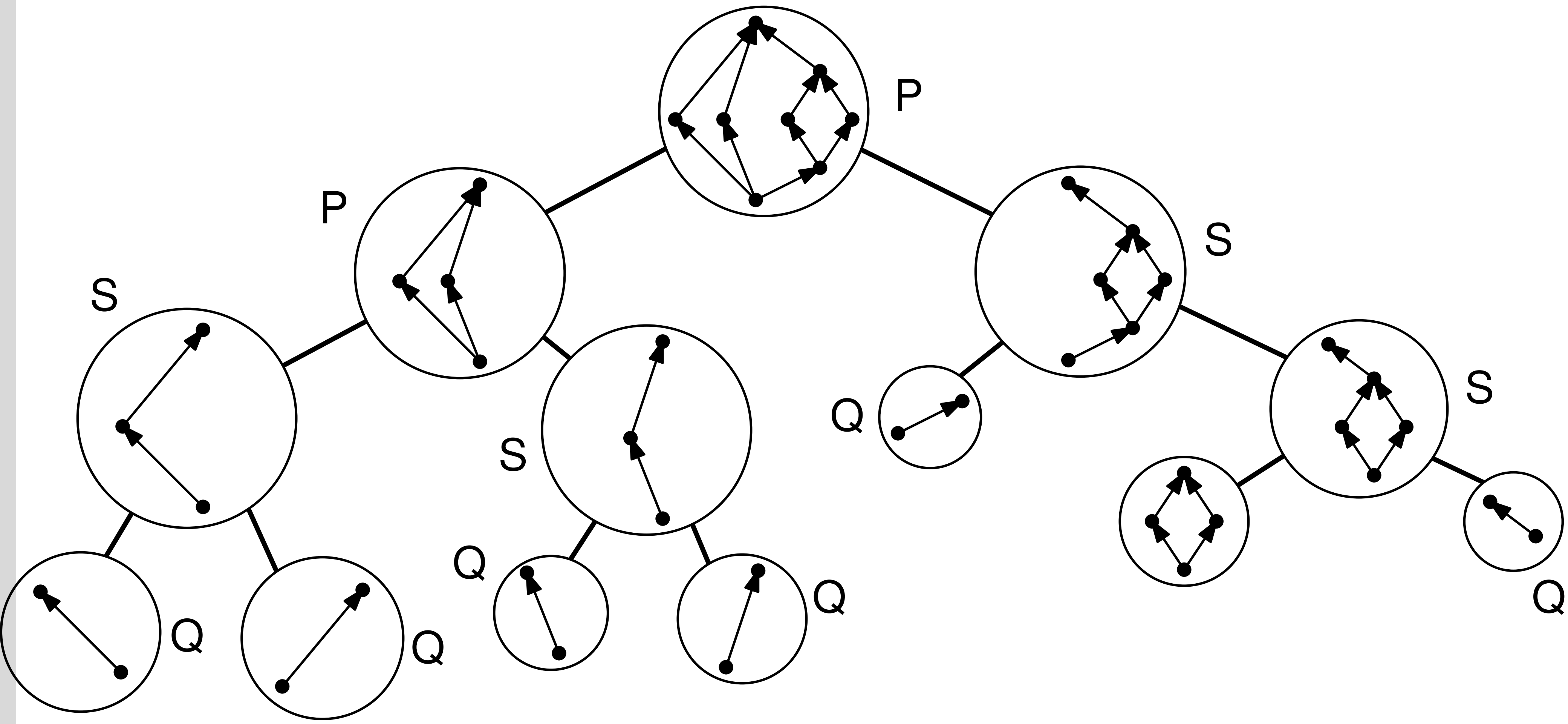

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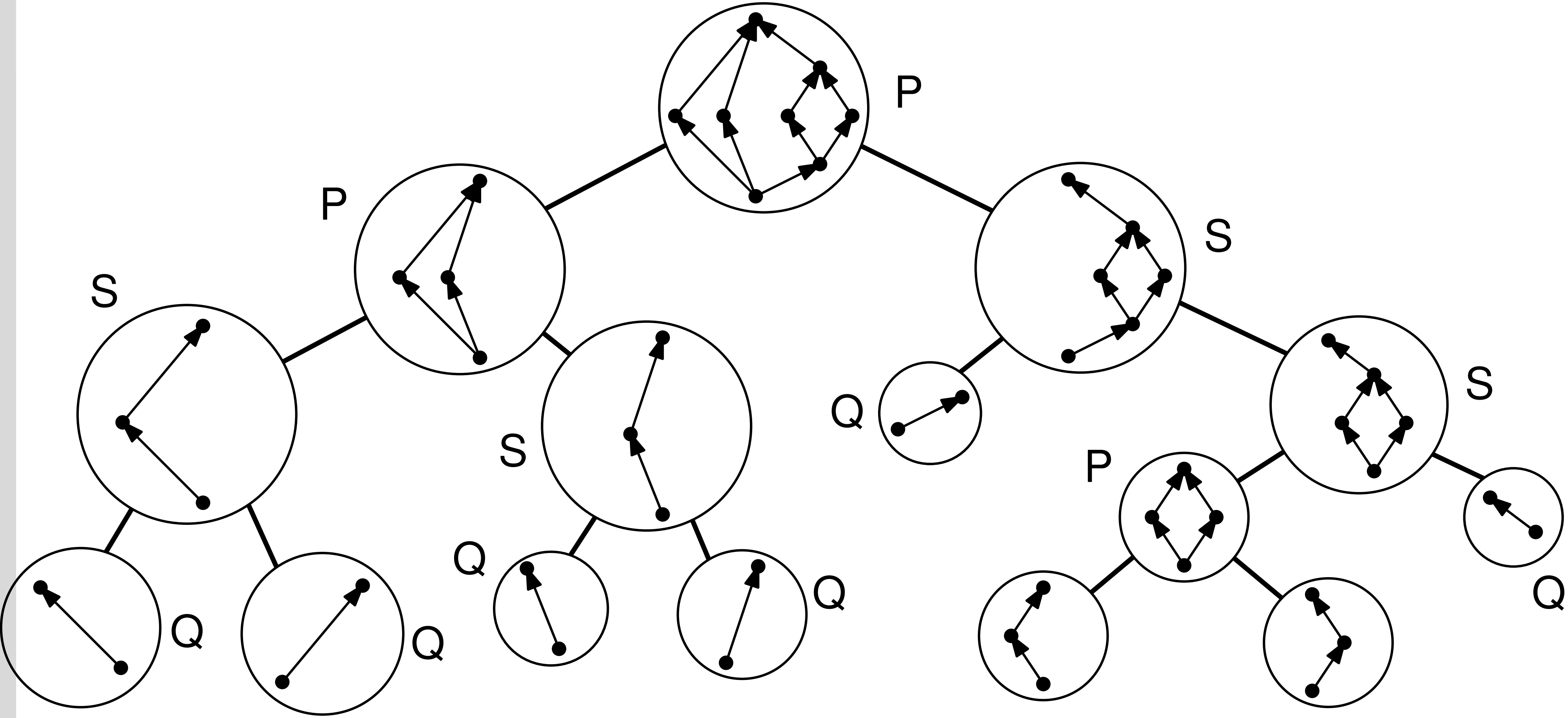

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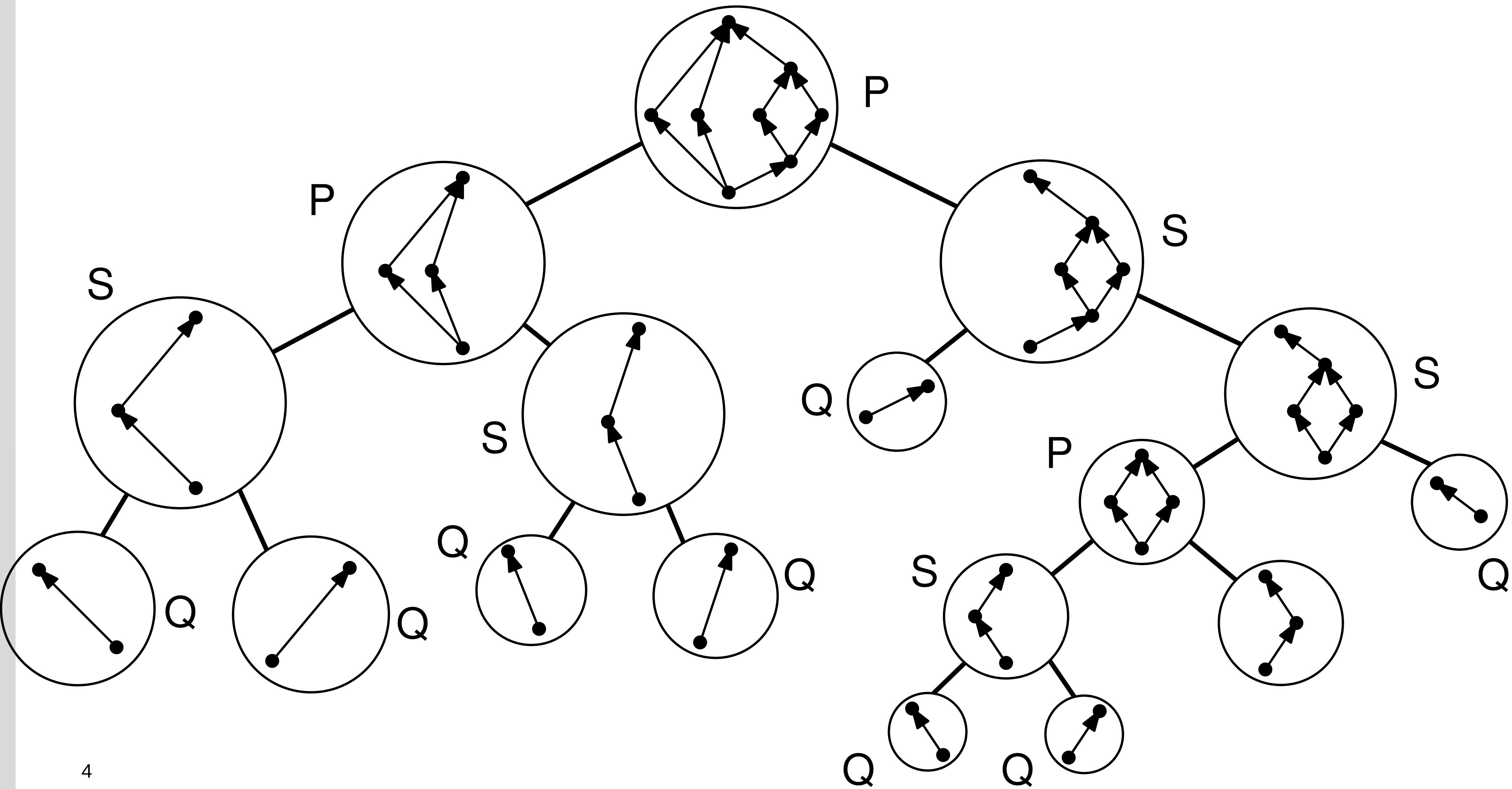

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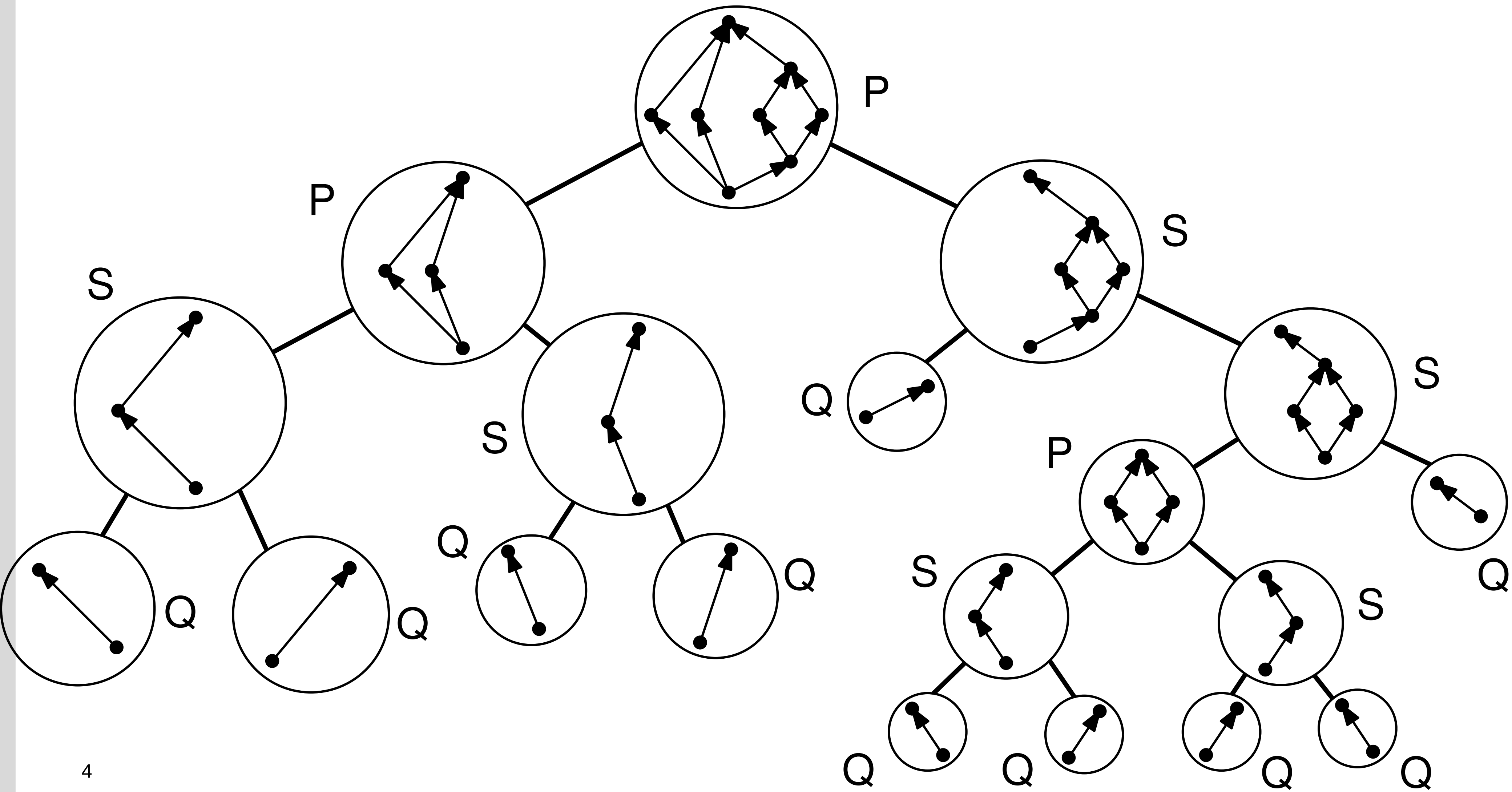
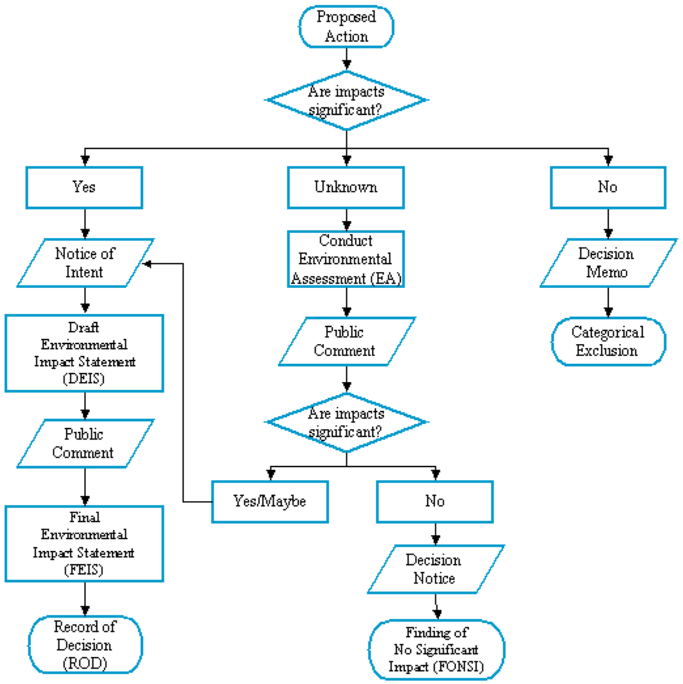
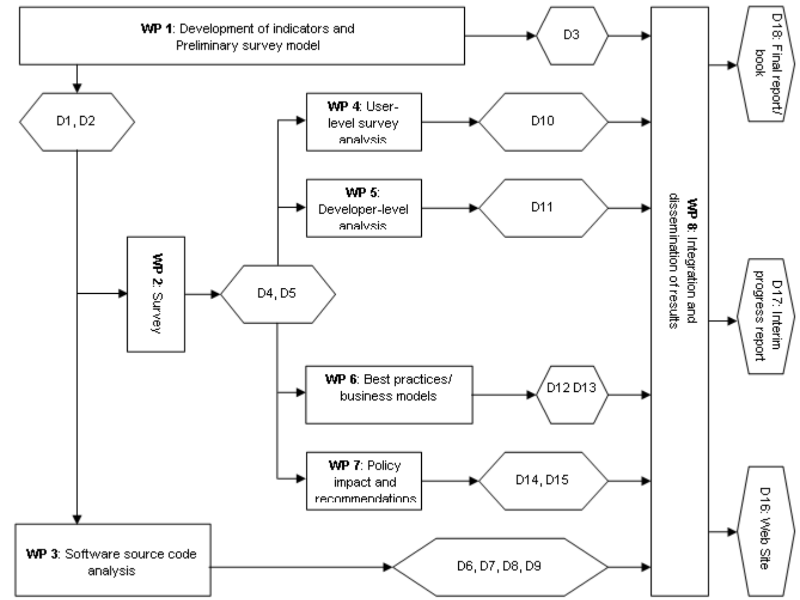


Series-parallel Graphs. Applications.



Flowcharts



PERT-Diagrams

(Program Evaluation and Review Technique)

Series-parallel Graphs. Applications.

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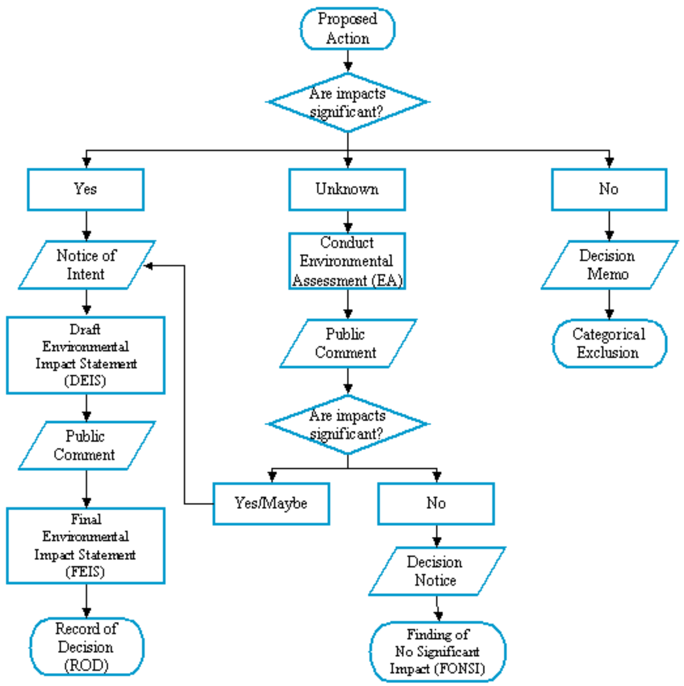

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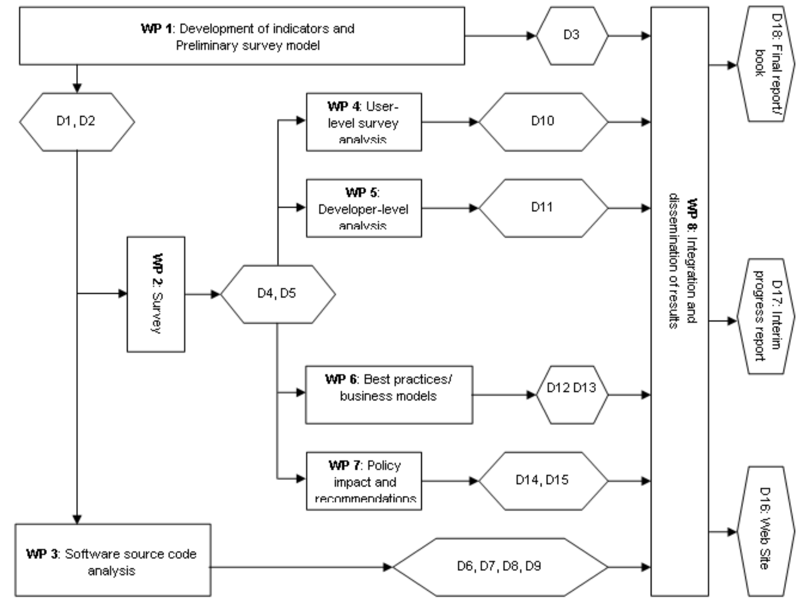

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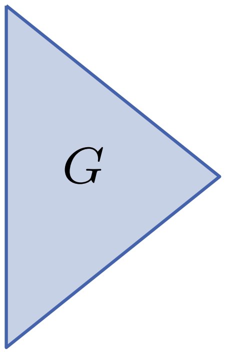
(Program Evaluation and Review Technique)

Computational Complexity: Linear time algorithms for $\mathcal{NP}$-hard problems (e.g. Maximum Matching, Maximum Independent Set, Hamiltonian Completion)

Straight-line Drawing of SP-Graphs

- Draw graph G inside a right-angled isosceles bounding triangle $\Delta(G)$



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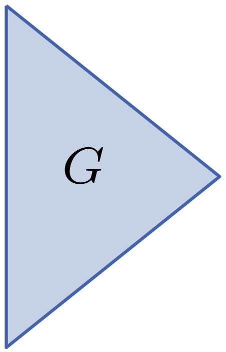

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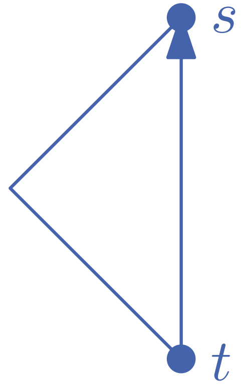

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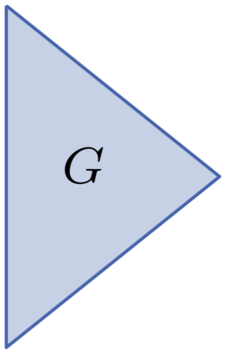

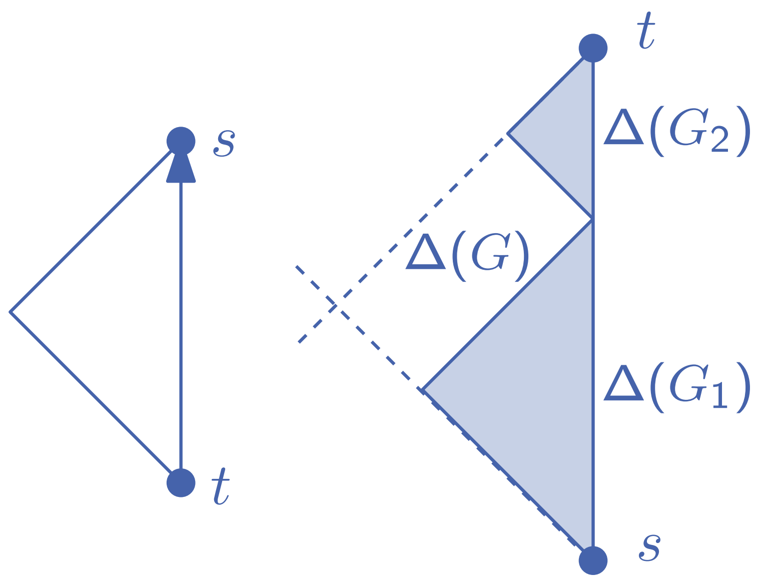

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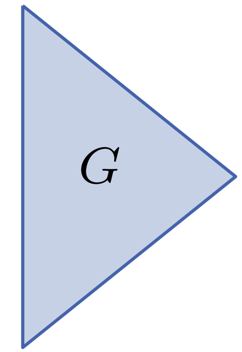

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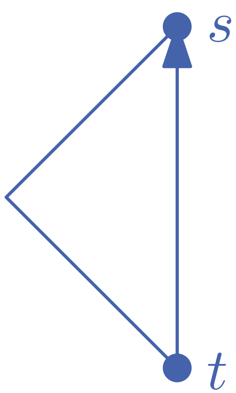

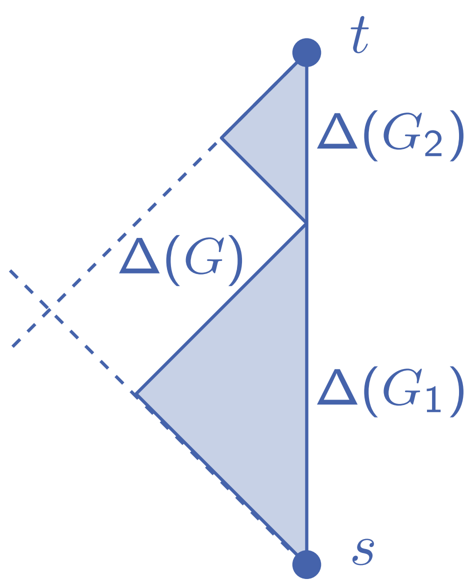

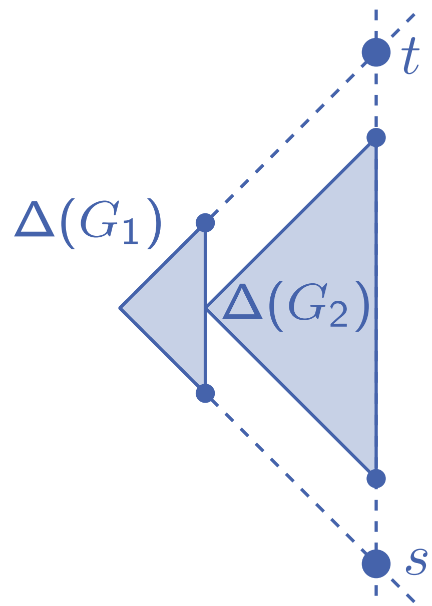

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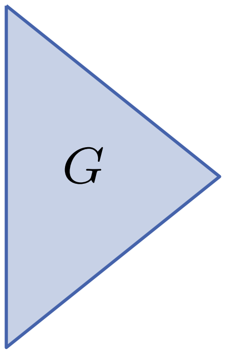

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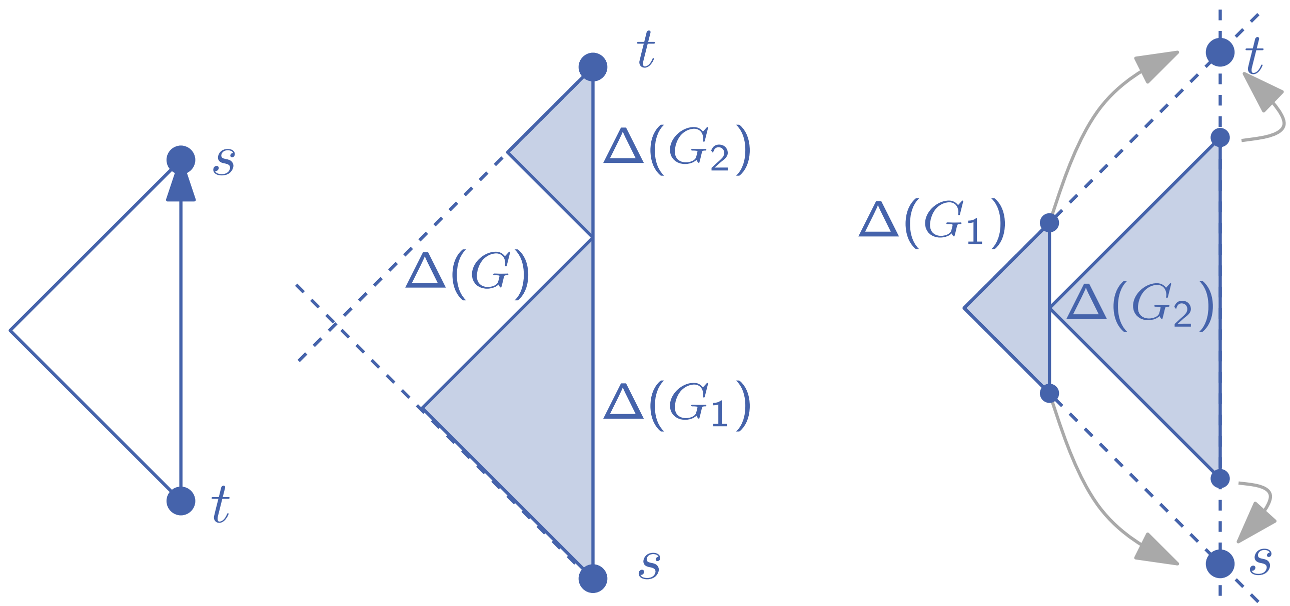

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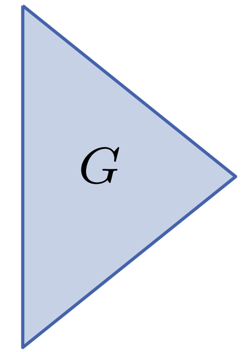

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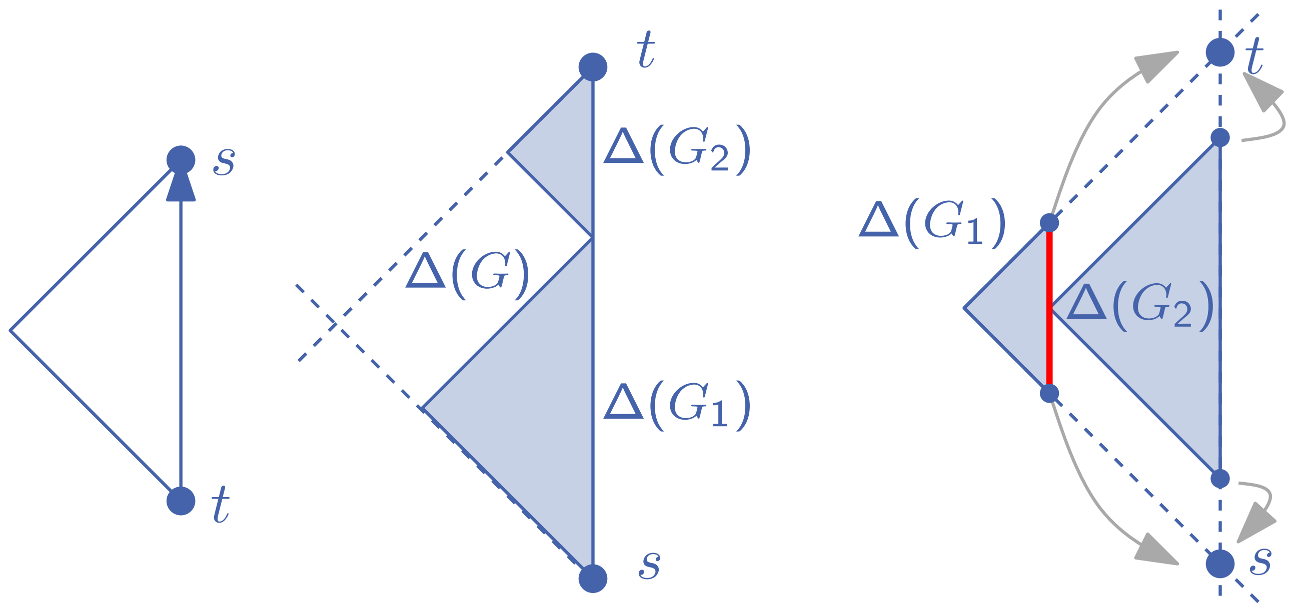

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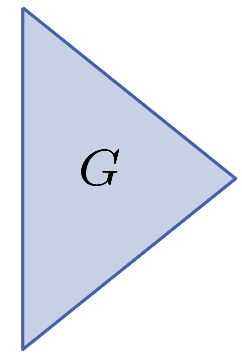

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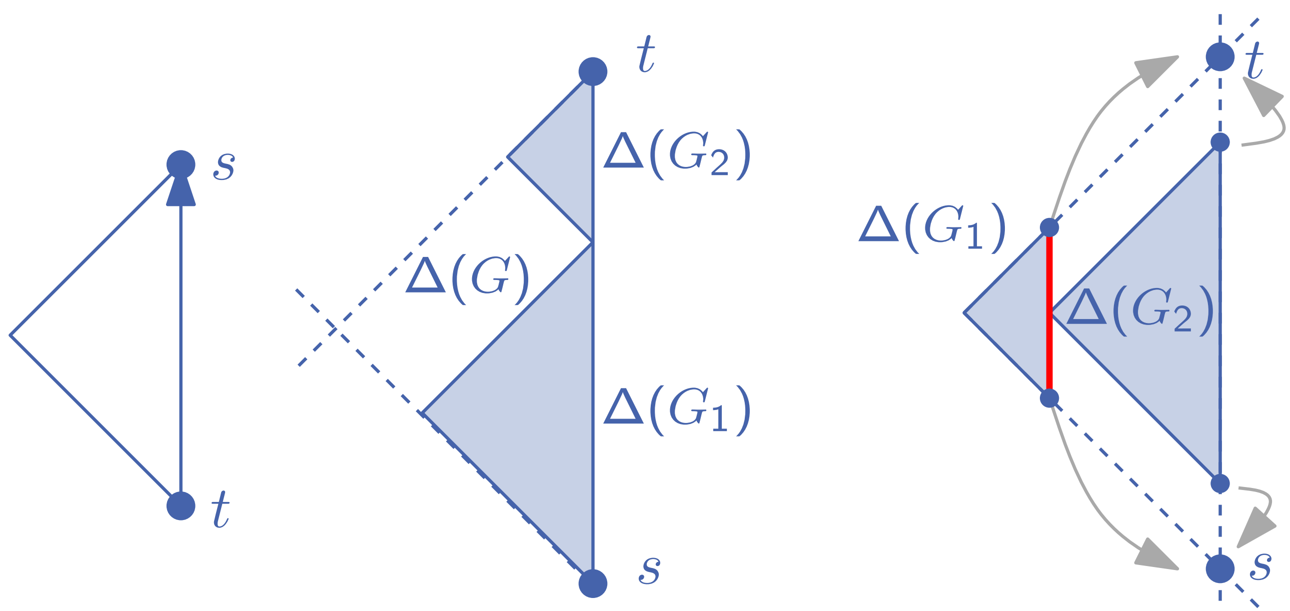

change embedding!

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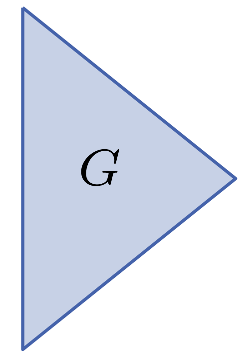

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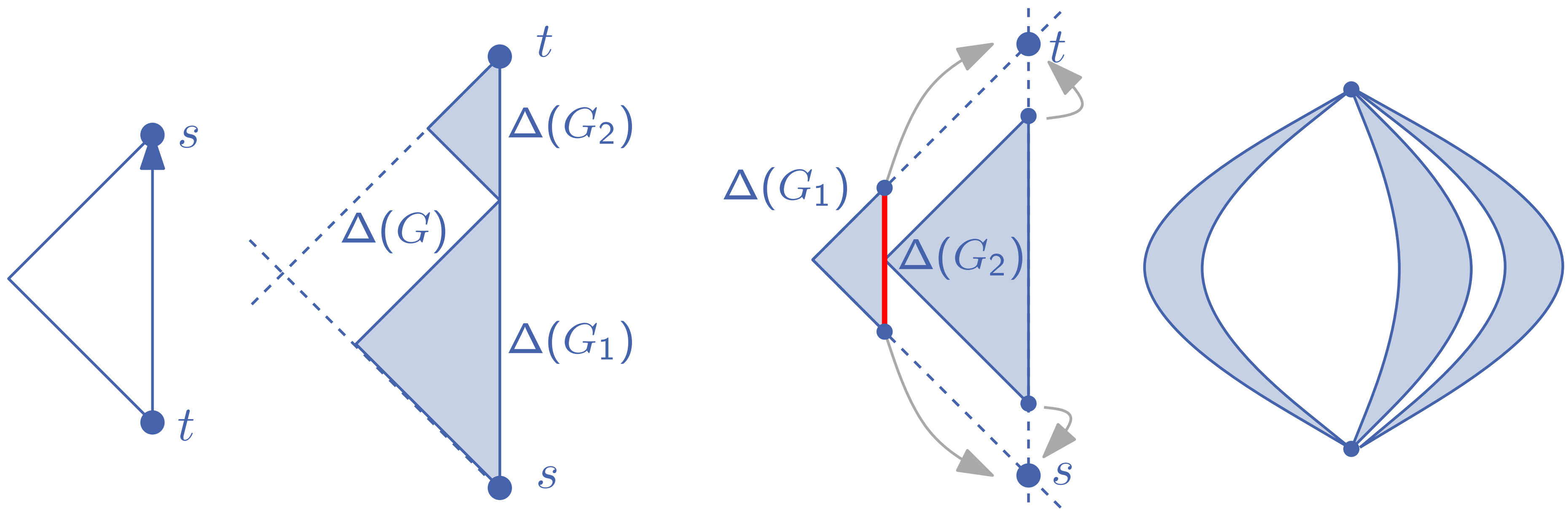

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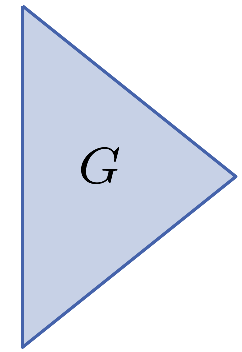

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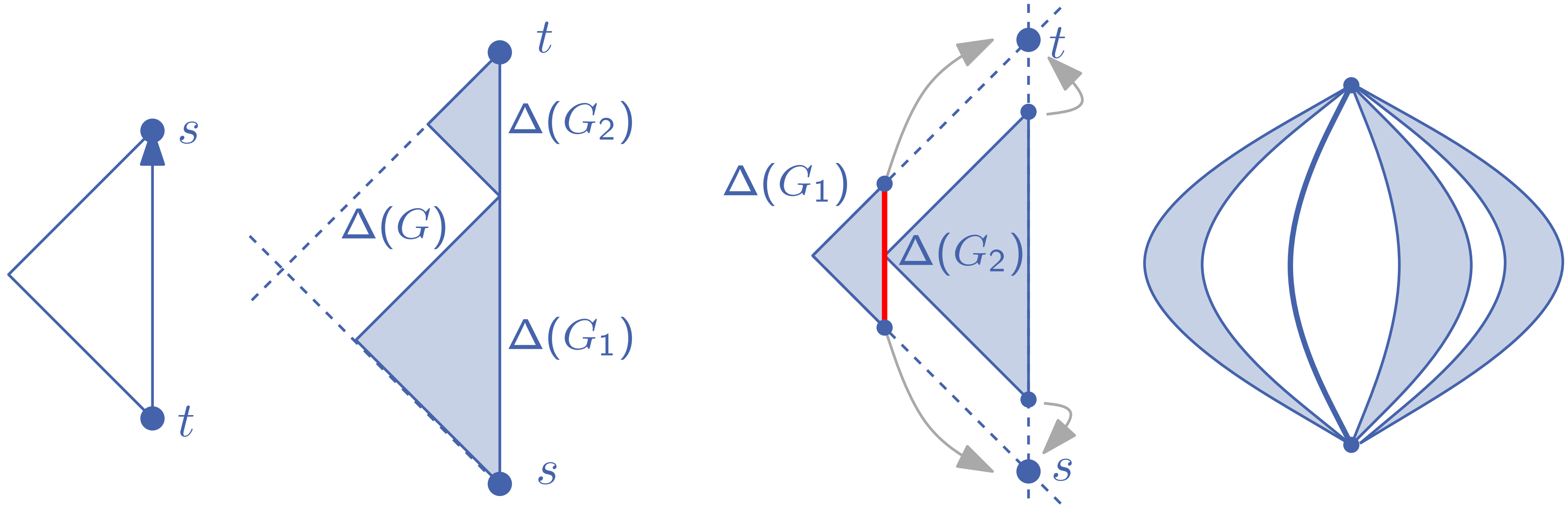

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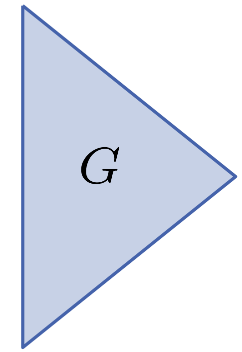

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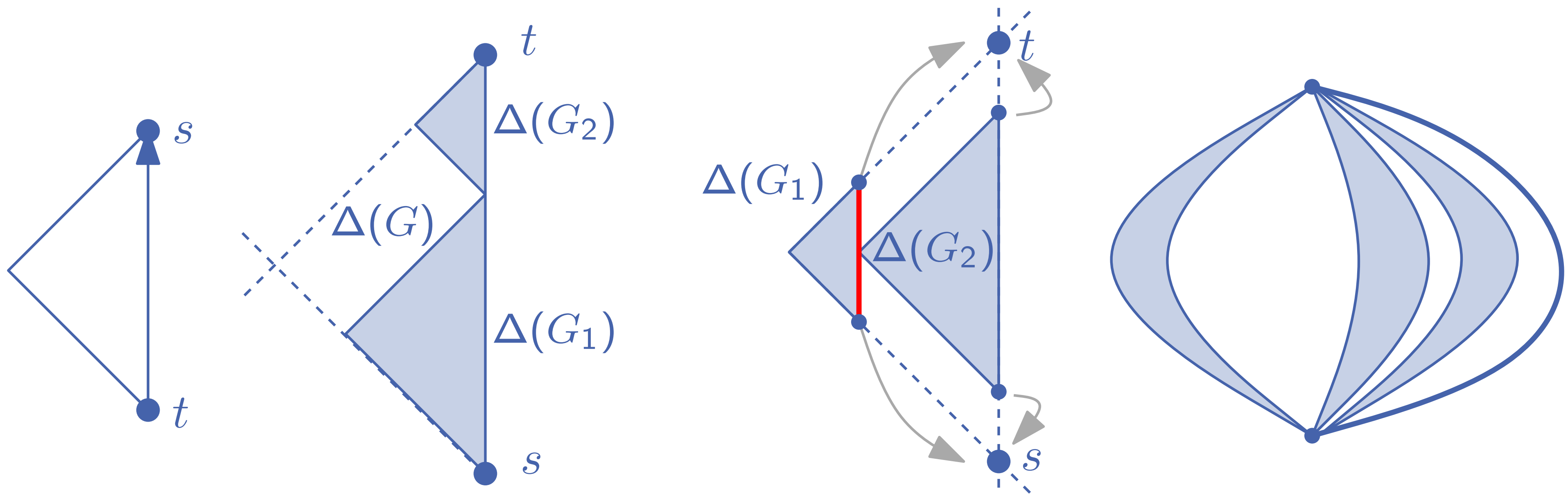

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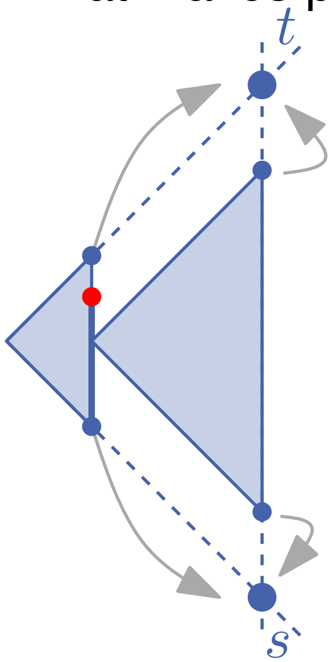

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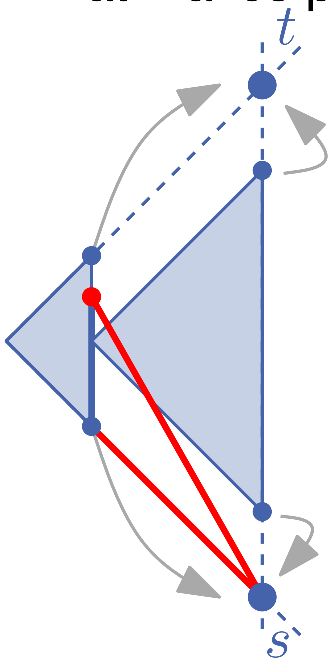

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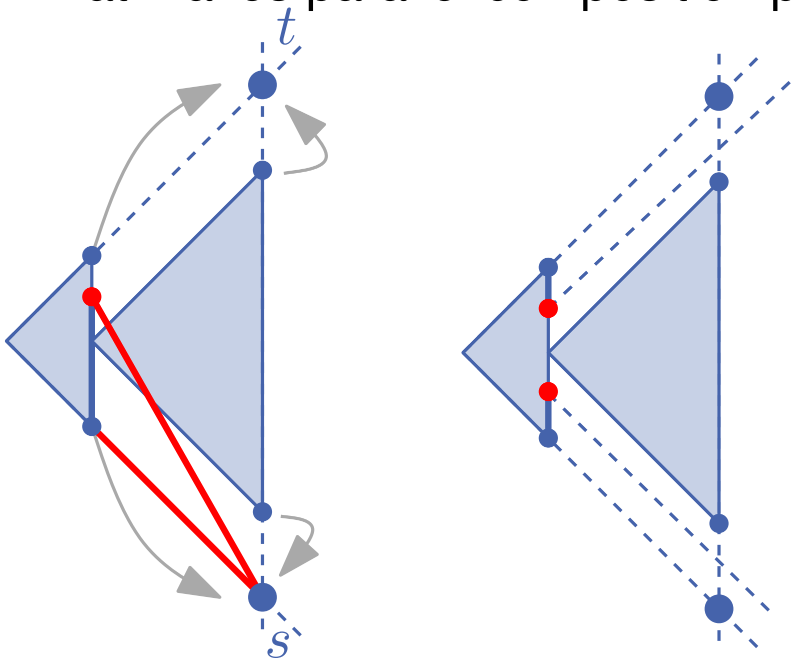

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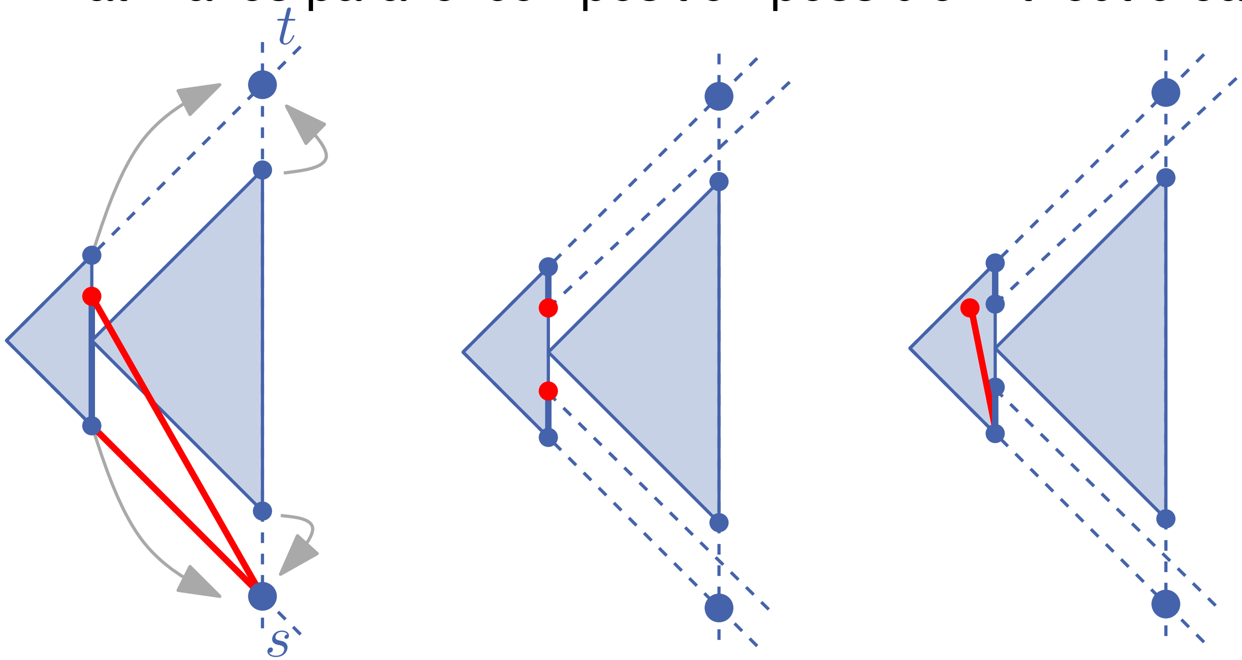

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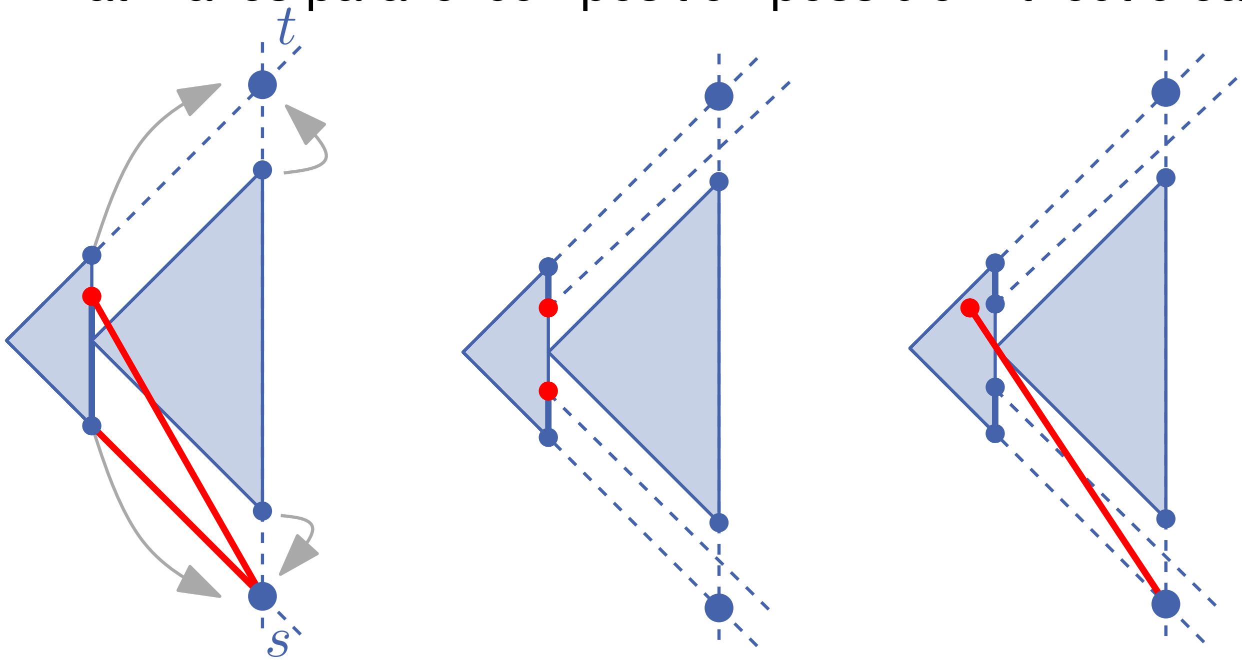

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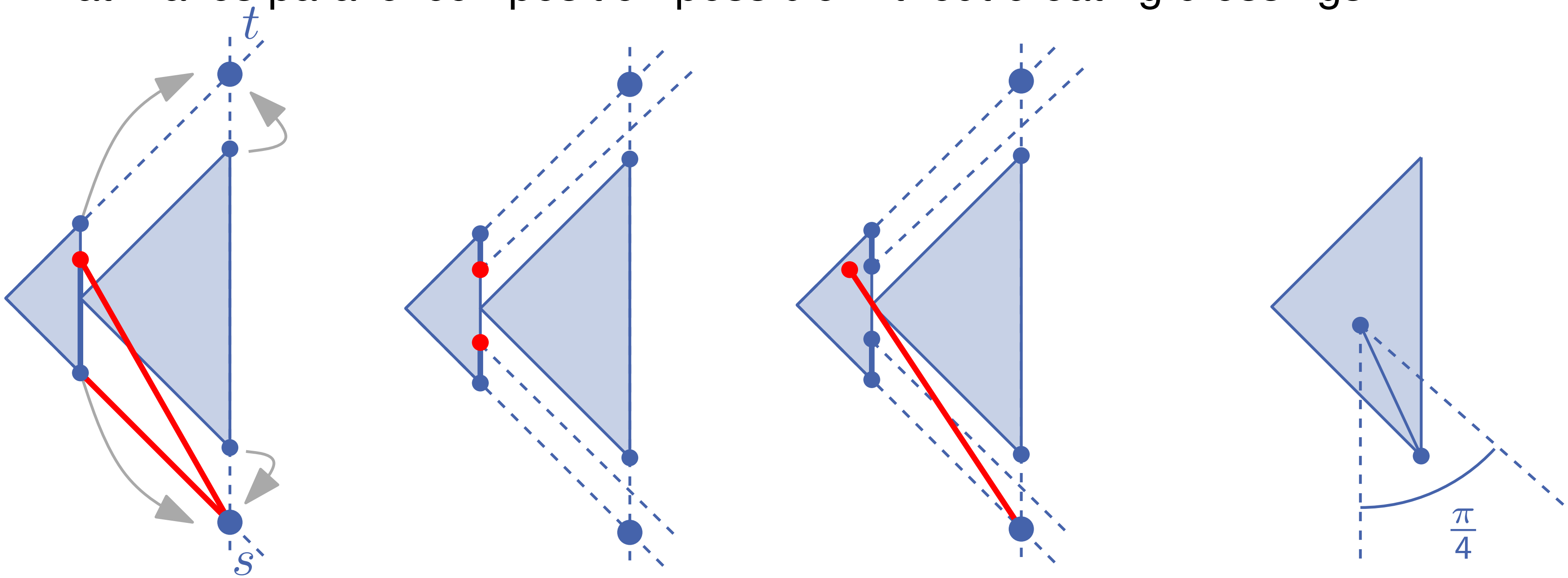

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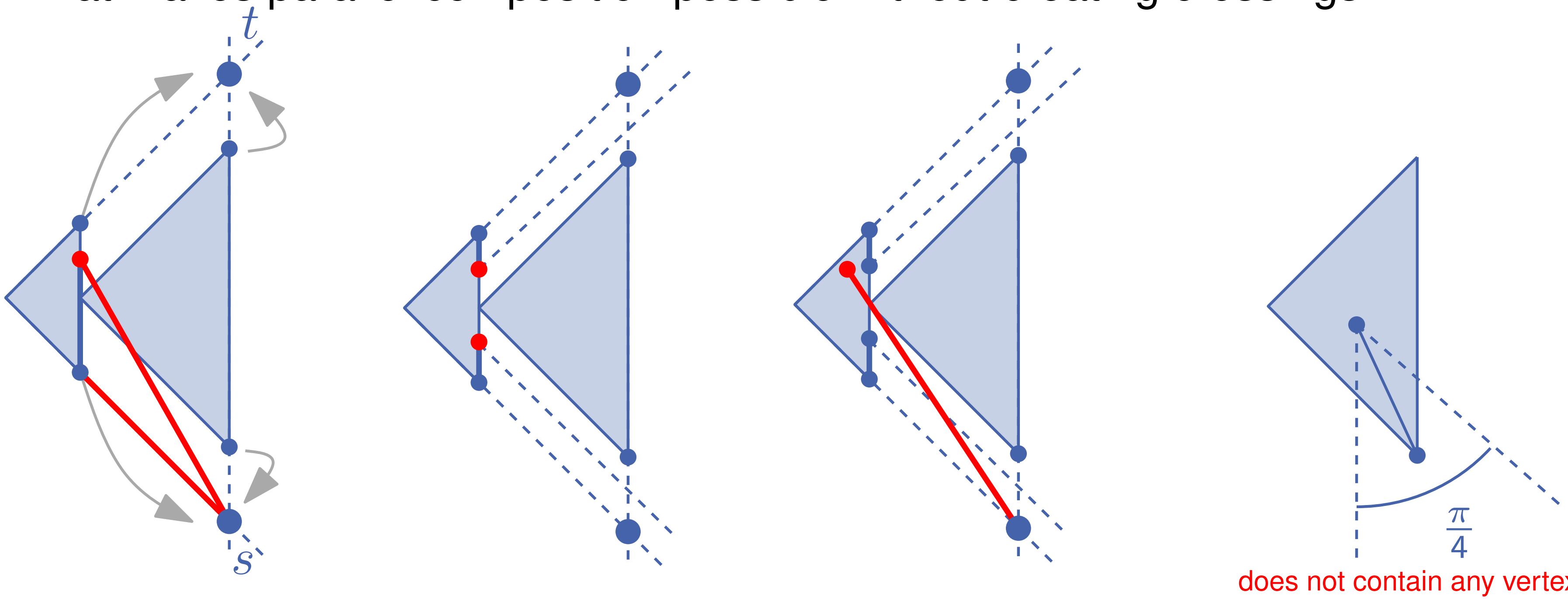

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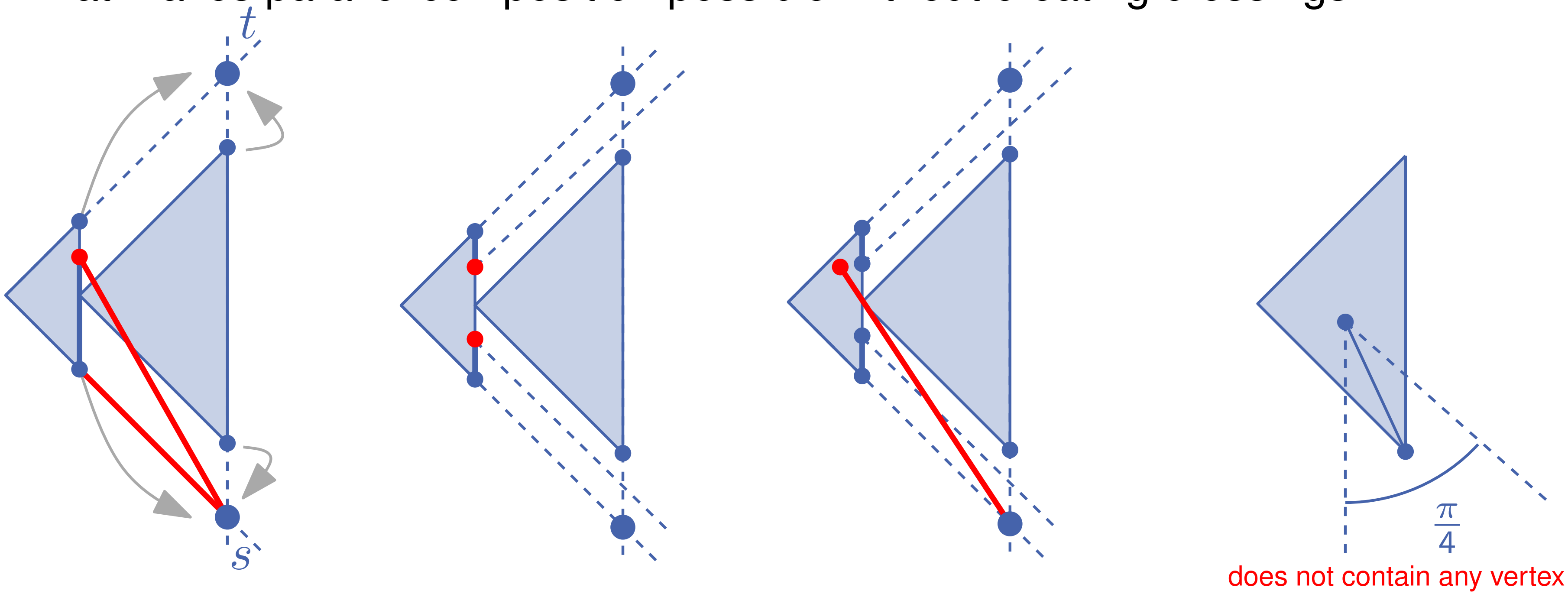

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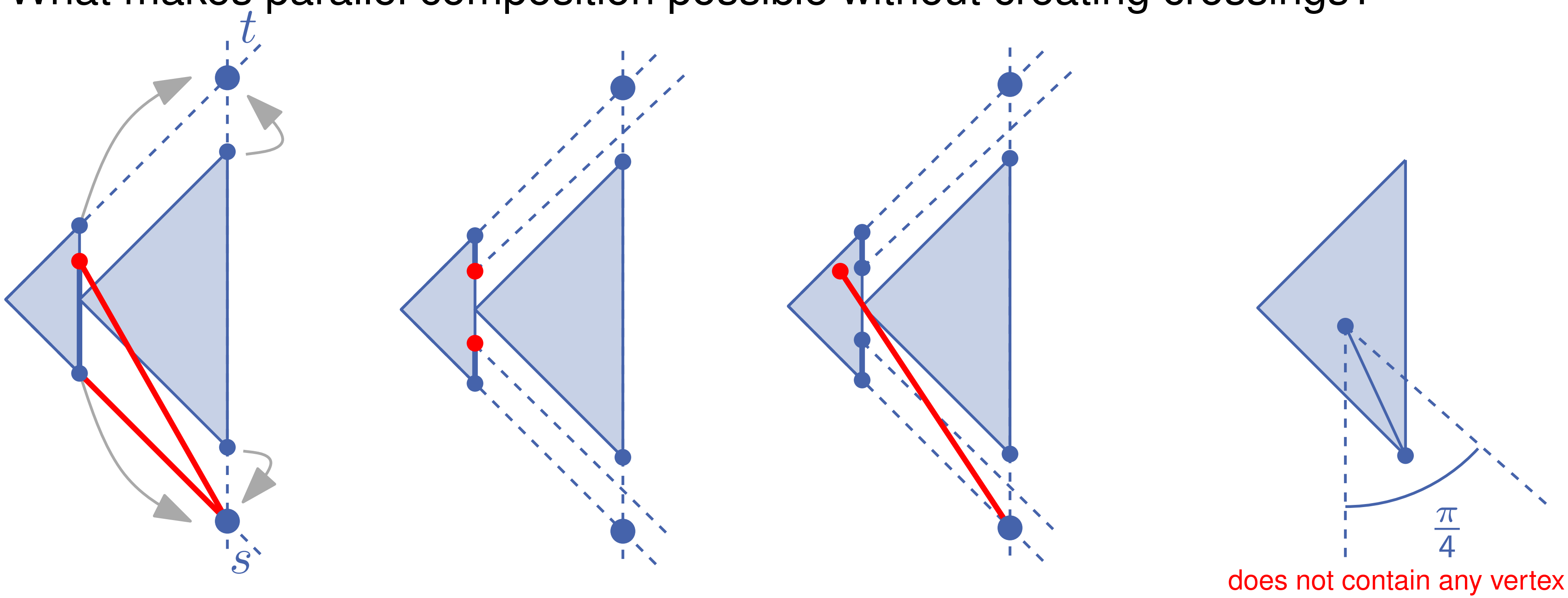

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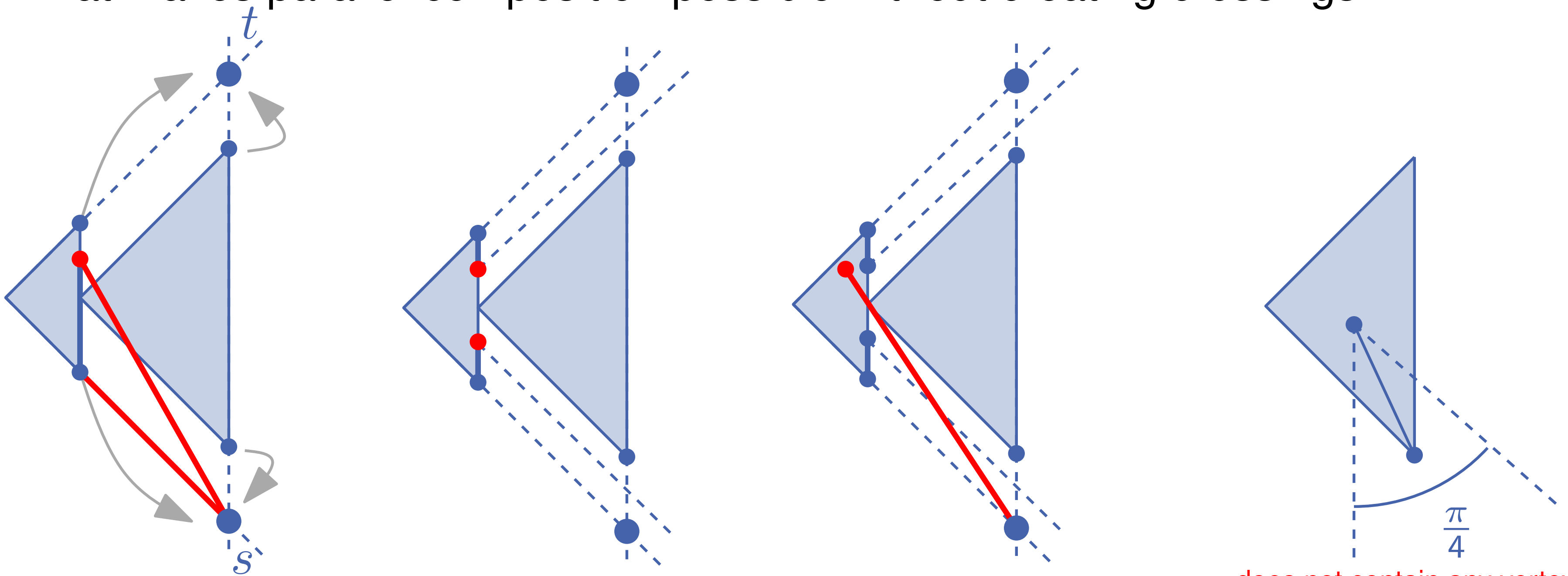

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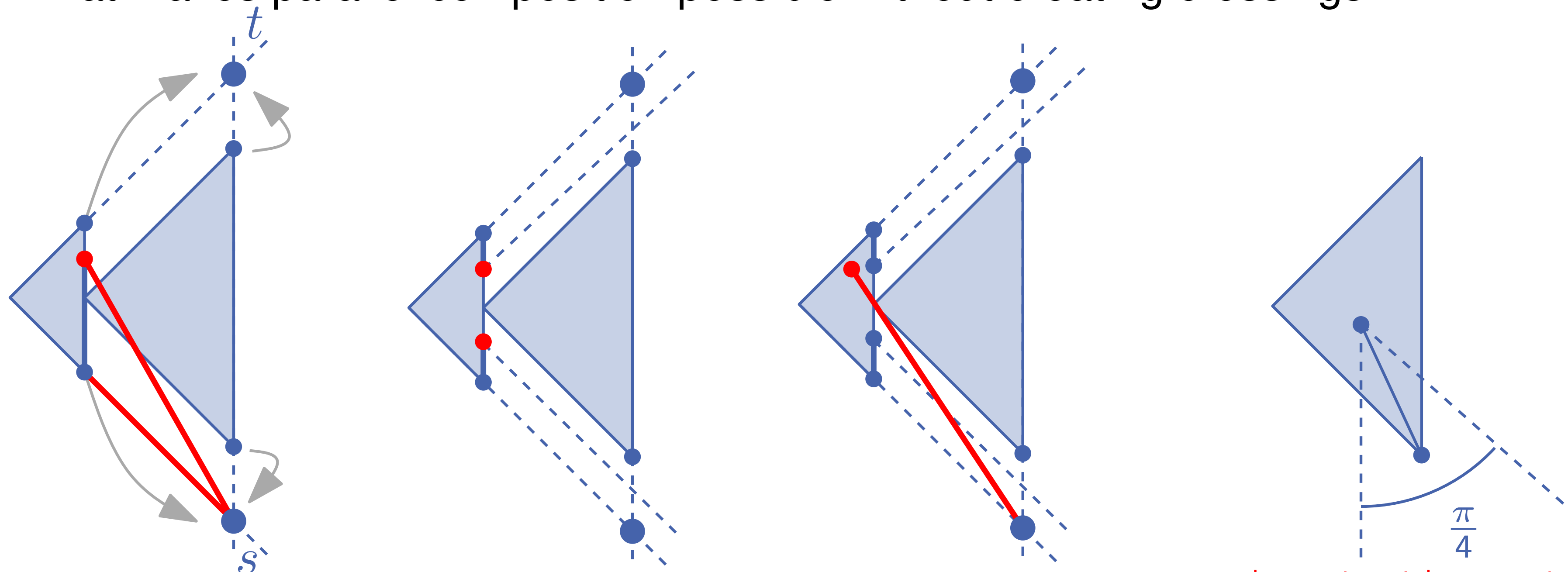

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Theorem

A series-parallel graph G (**with variable embedding**) admits an **upward** planar straigh-line drawing with $O(n^2)$ area. The isomorphic componencts of G have congruent drawings up to a translation.

Lower Bound for the Area

Theorem [Bertolazzi et al. 94]

There exists a $2n$-vertex series-parallel graph G_n such that any upward planar drawing of G_n respecting embedding requires area $\Omega(4^n)$.

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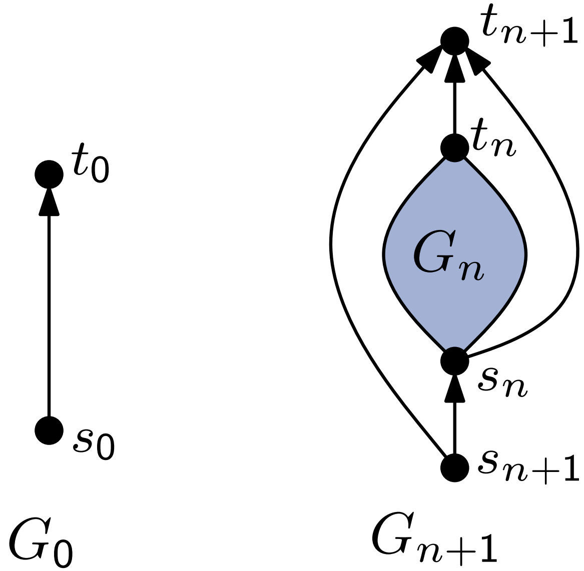

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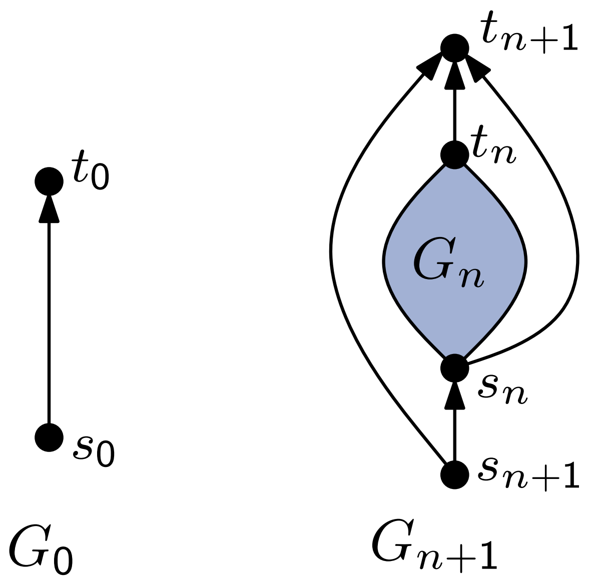

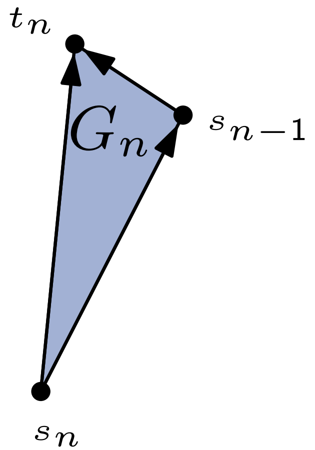

Lower Bound for the Area

Theorem [Bertolazzi et al. 94]

There exists a $2n$-vertex series-parallel graph G_n such that any upward planar drawing of G_n respecting embedding requires area $\Omega(4^n)$.

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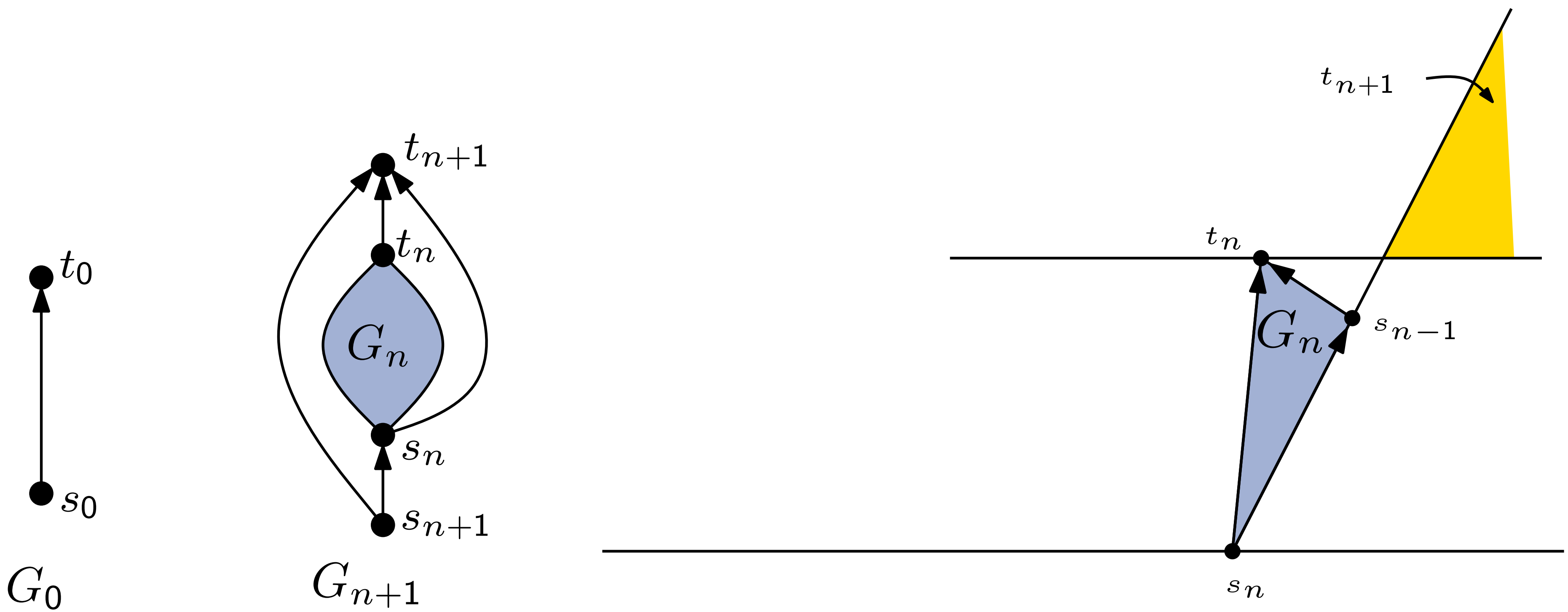

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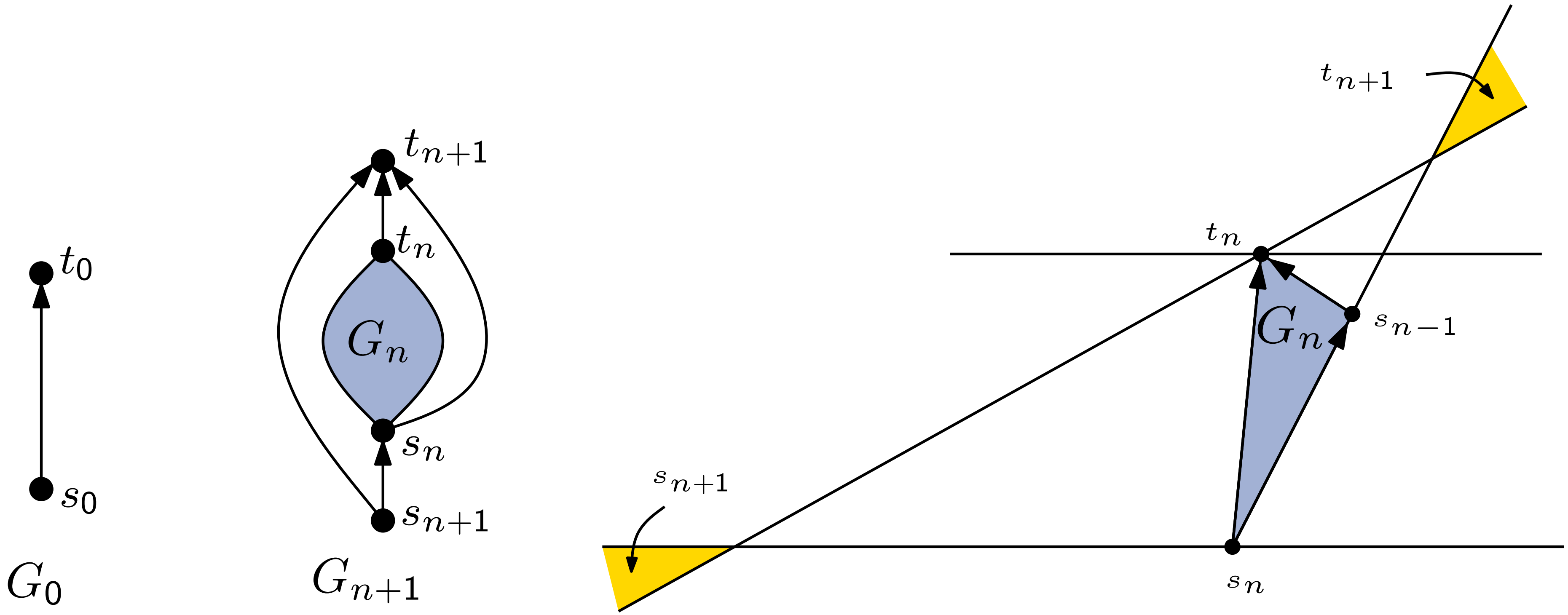

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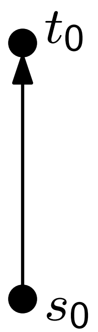

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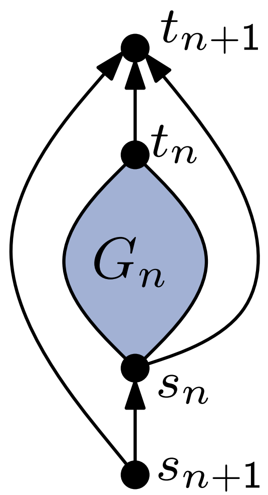
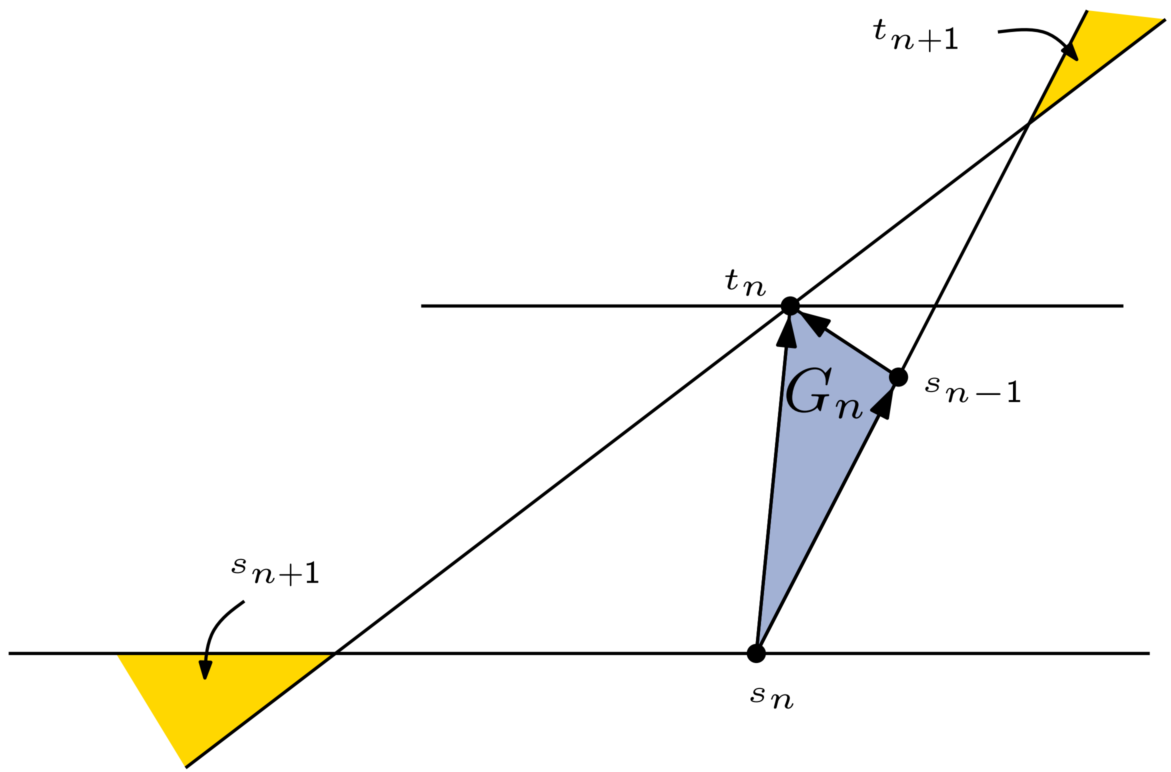


G_{n+1}



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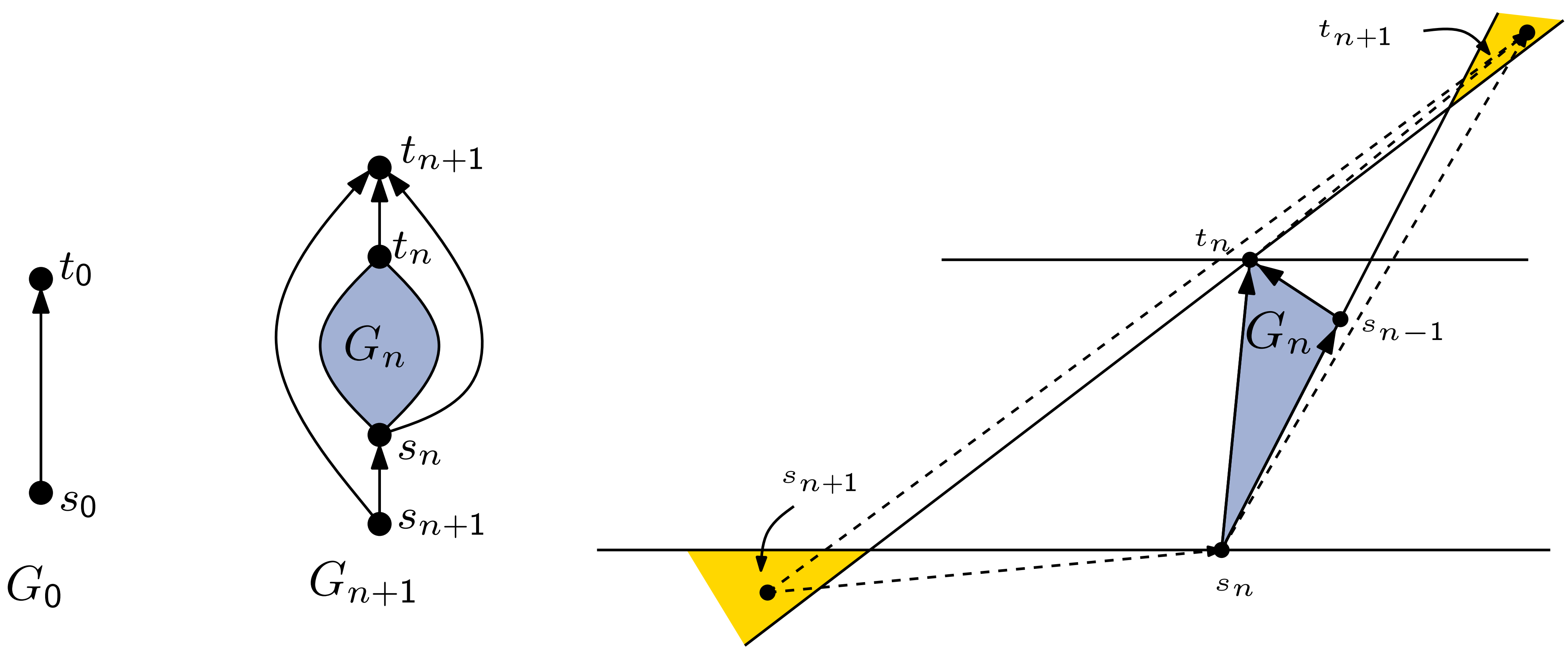

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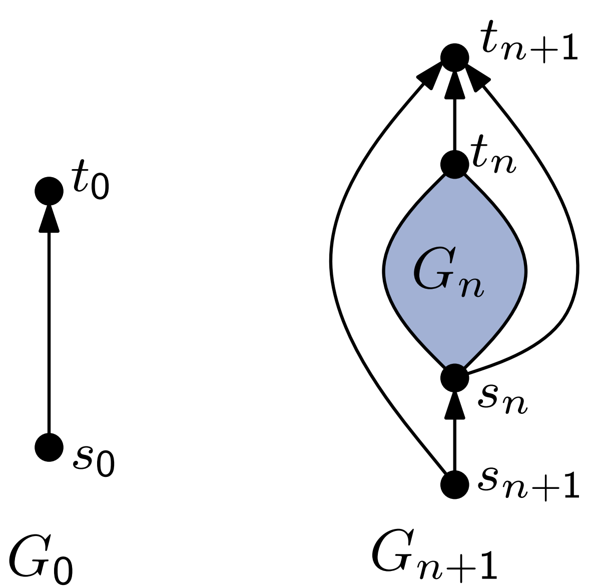

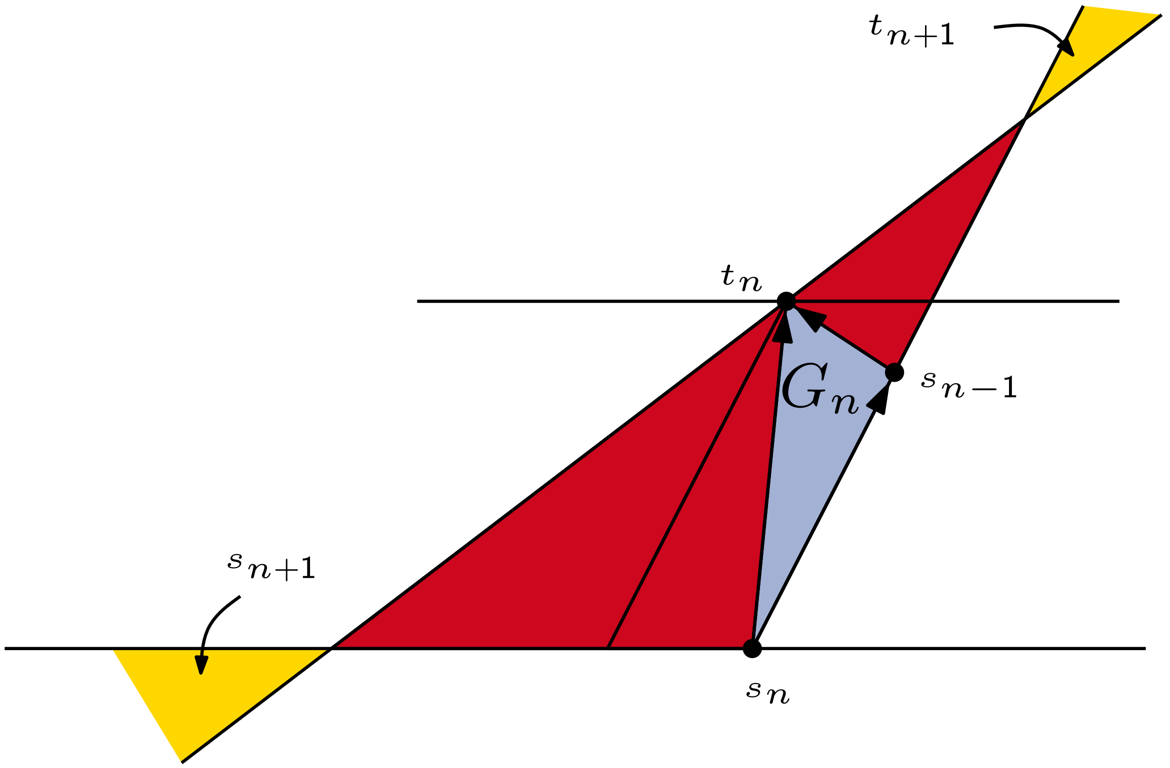

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Karlsruhe Institute of Technology

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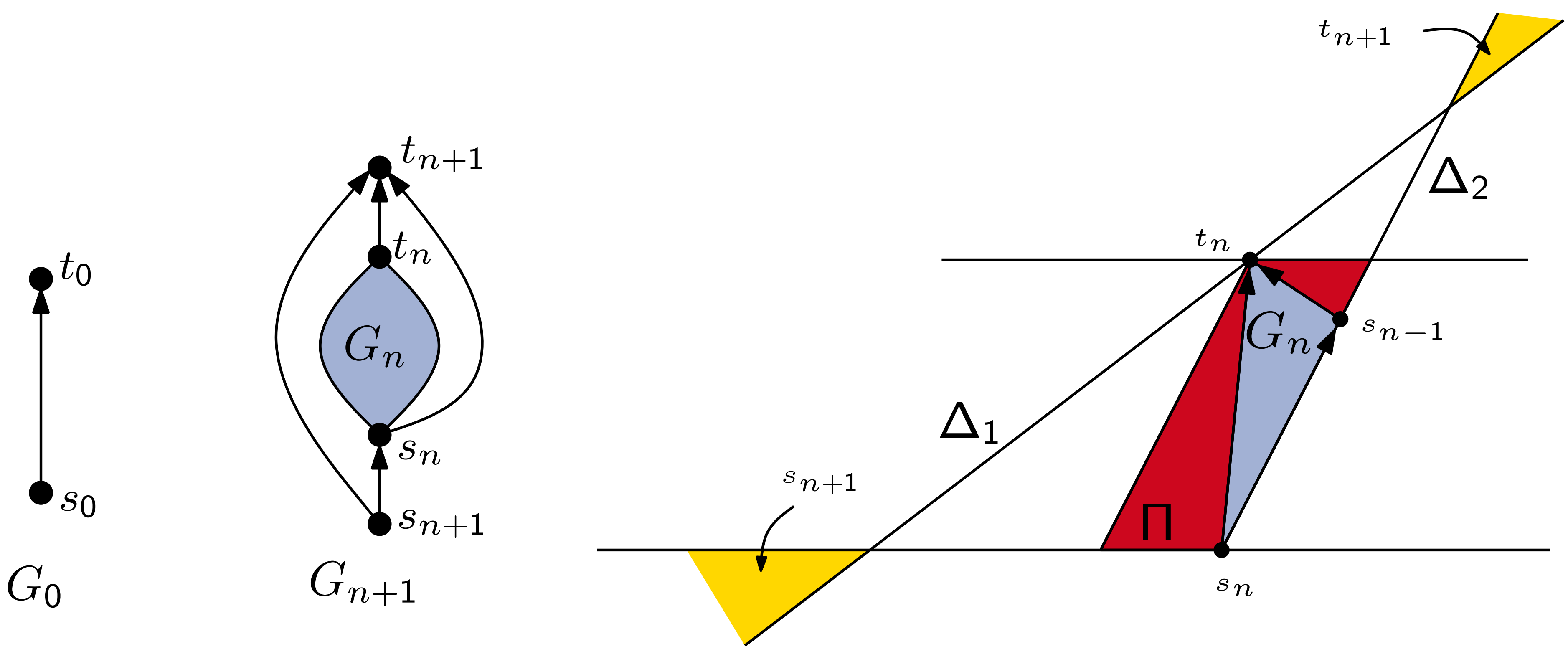

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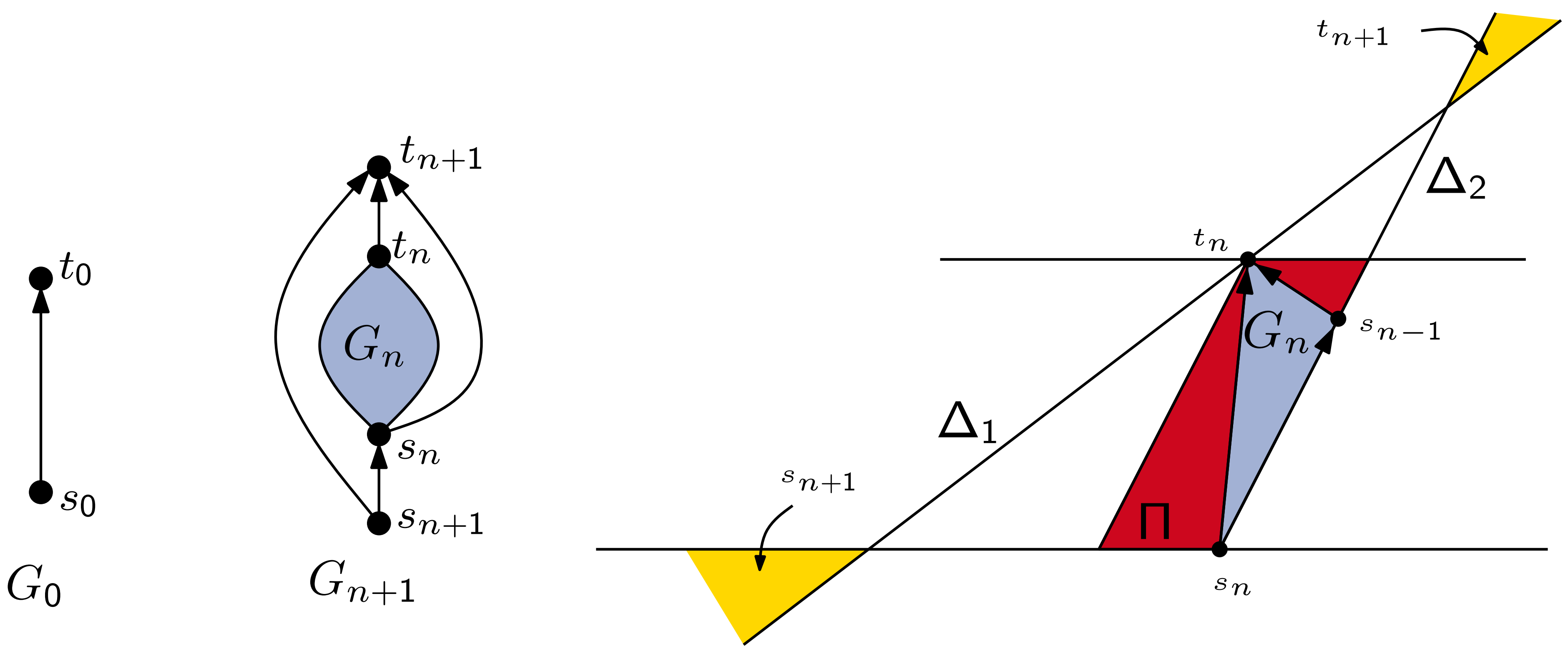
Proof:

- We have that: $Area(\Pi) > 2 \cdot Area(G_n)$



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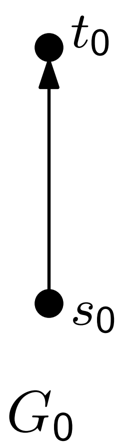

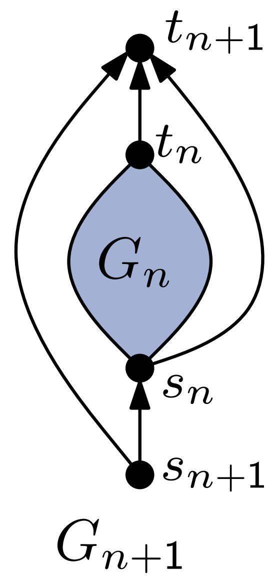

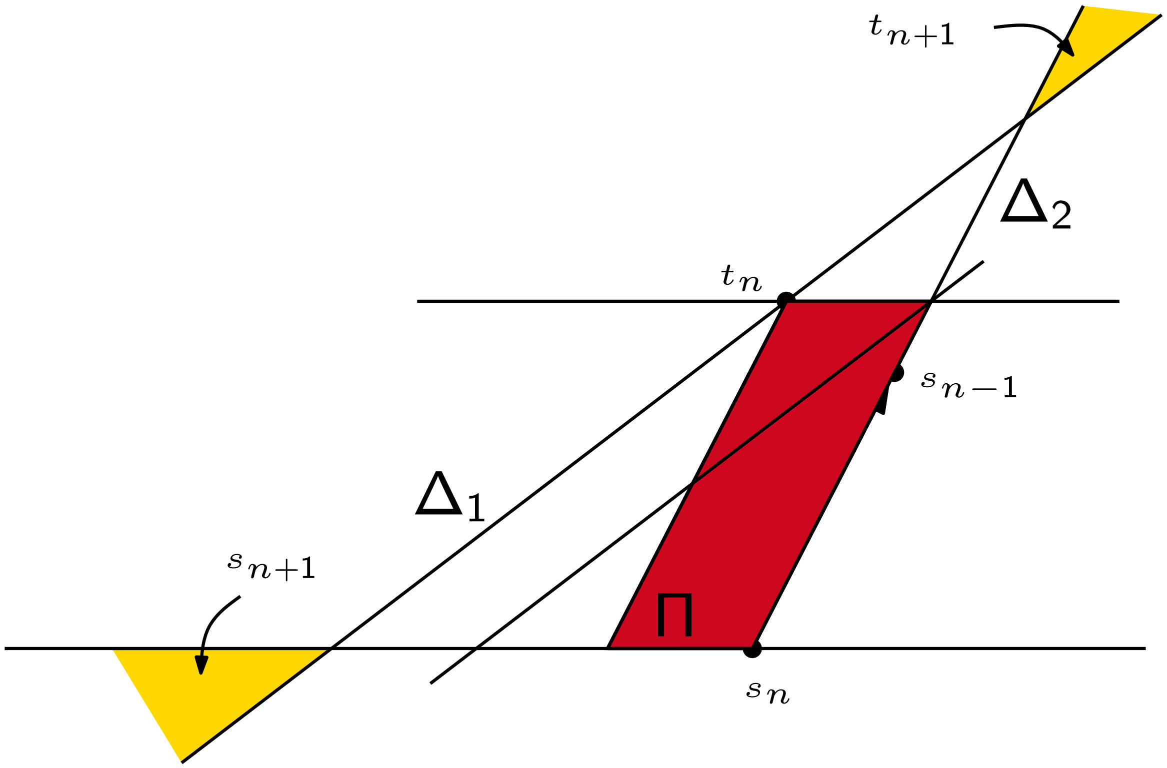

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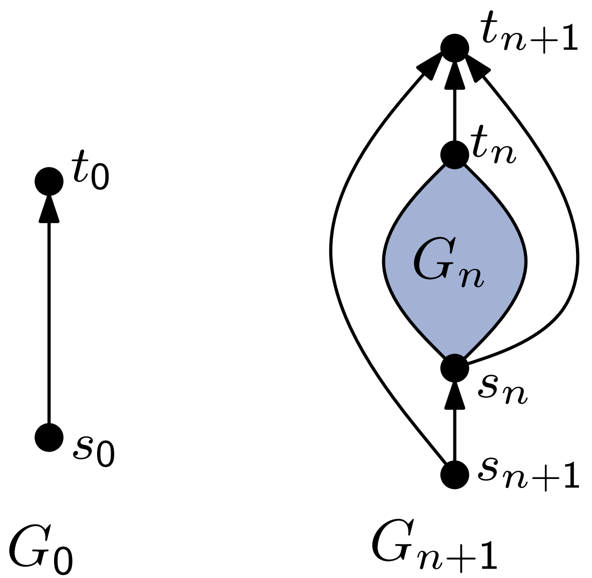

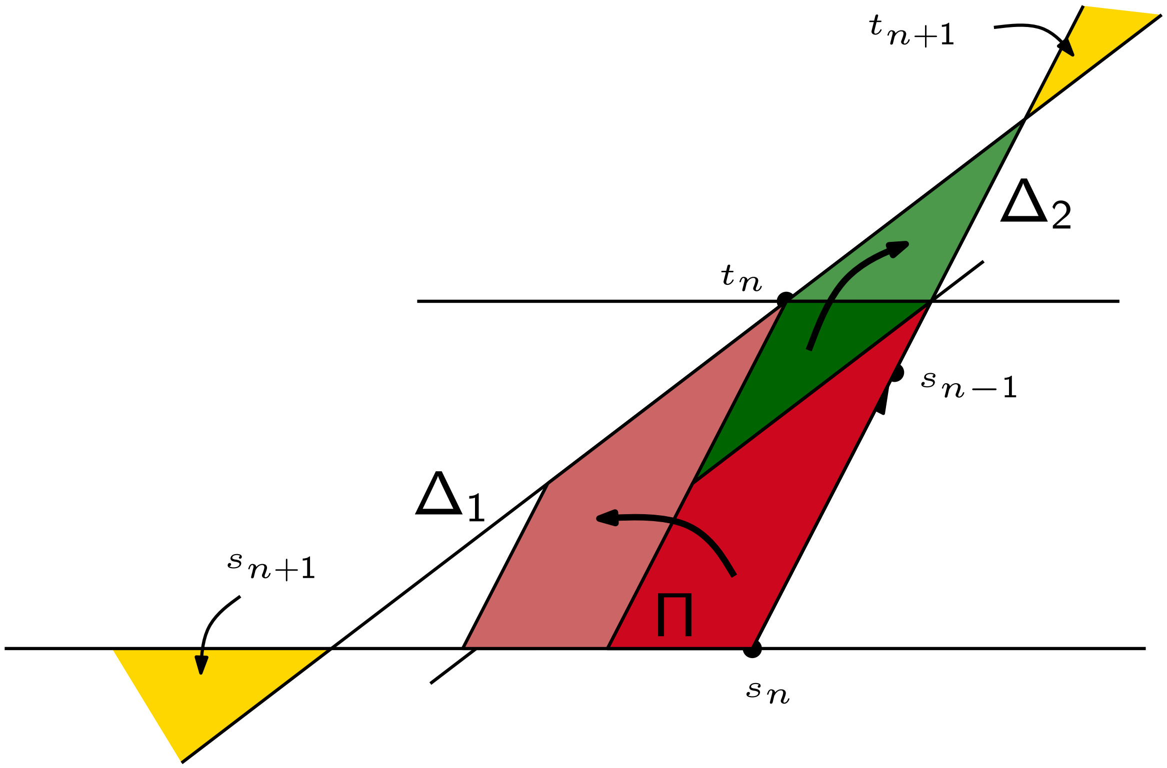

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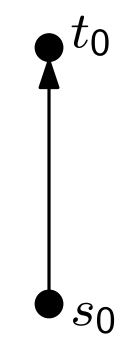

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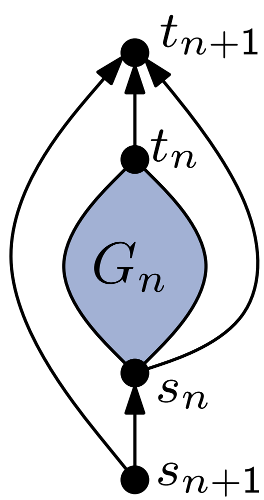

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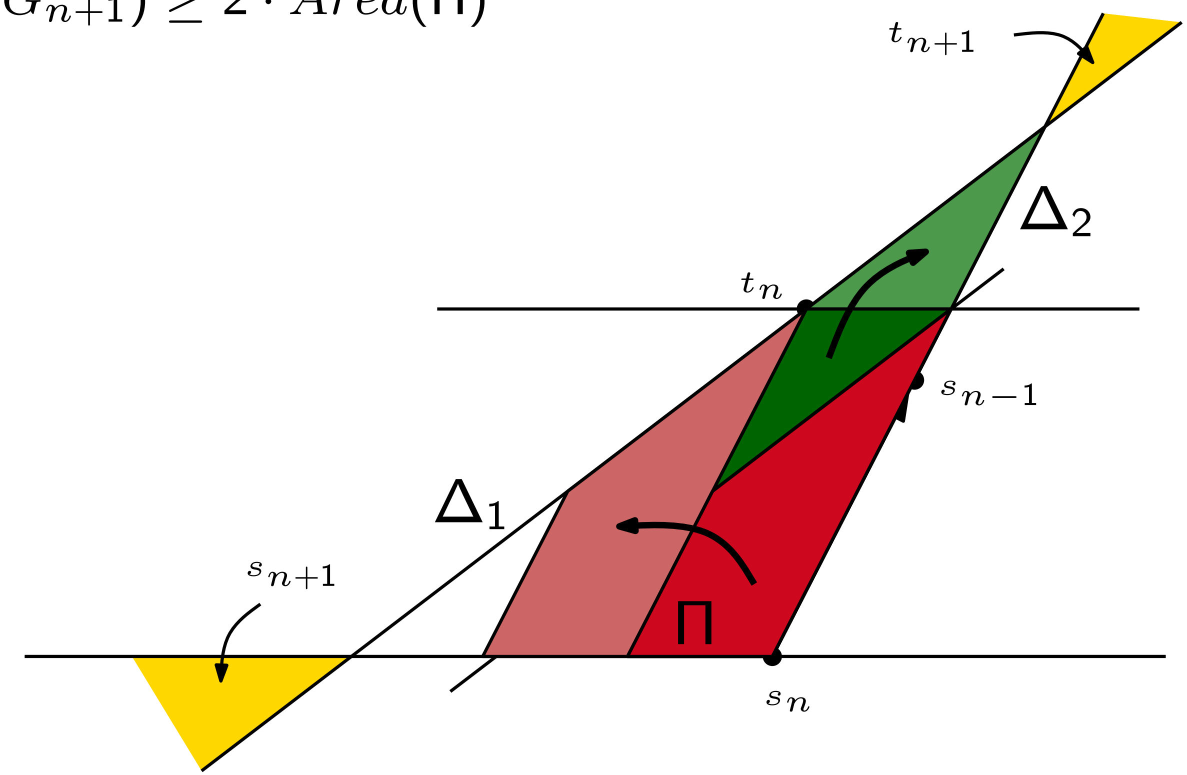

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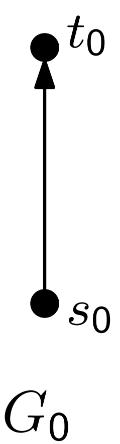
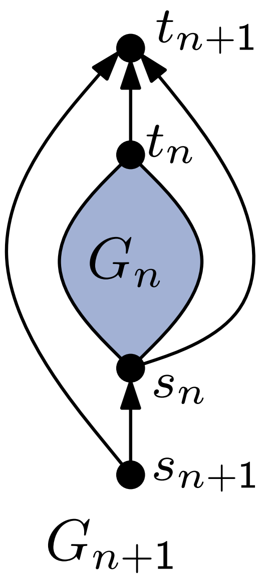
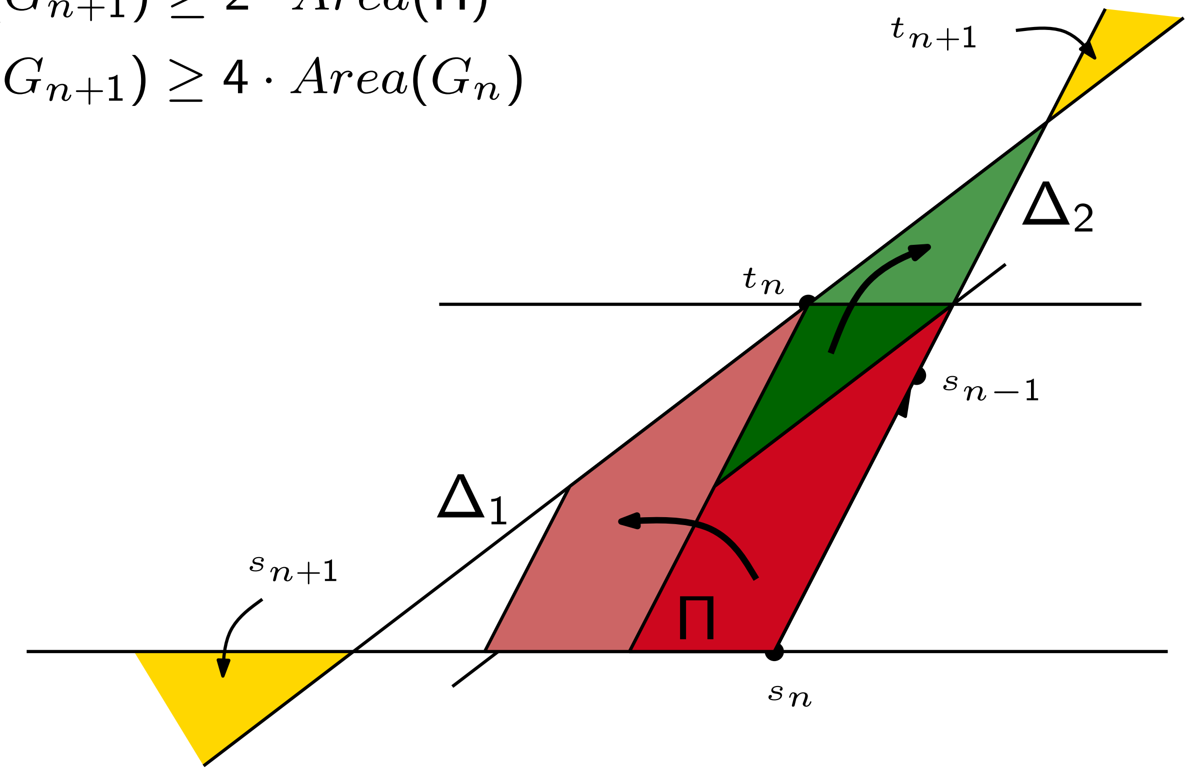
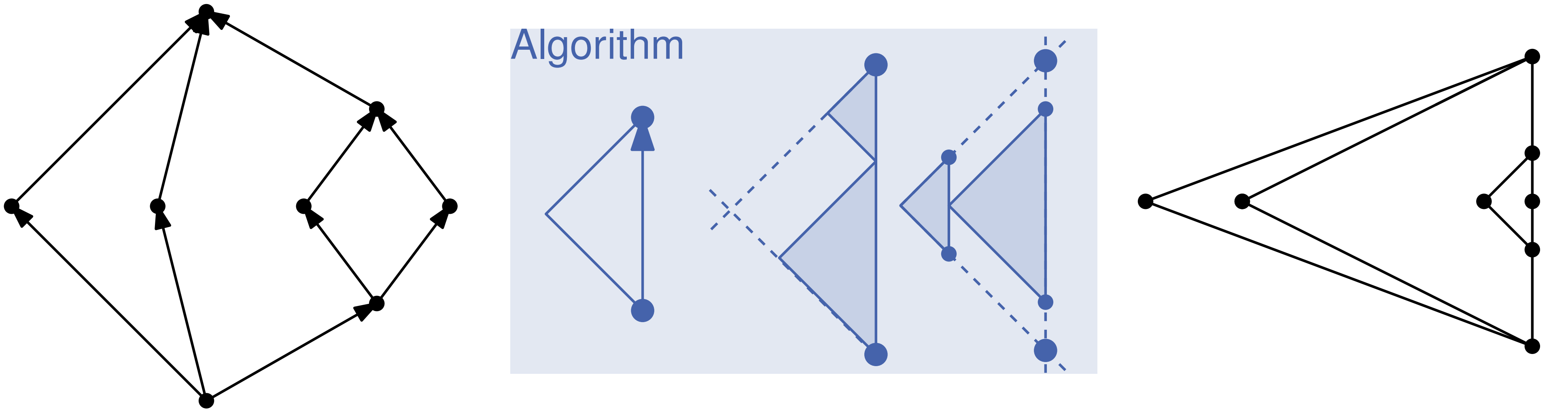
- $Area(G_{n+1}) \geq 4 \cdot Area(G_n)$







Property of the Algorithm



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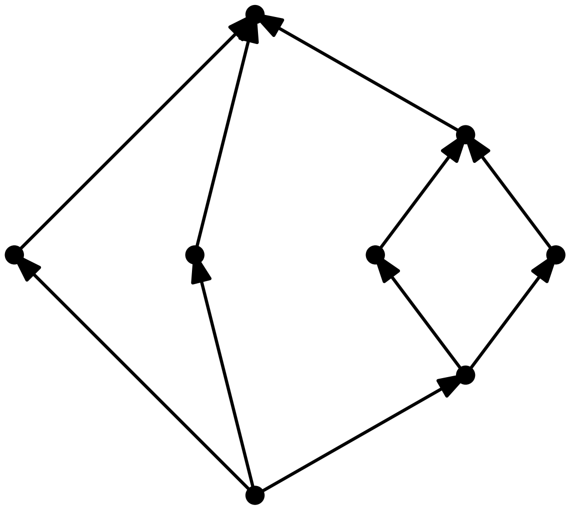

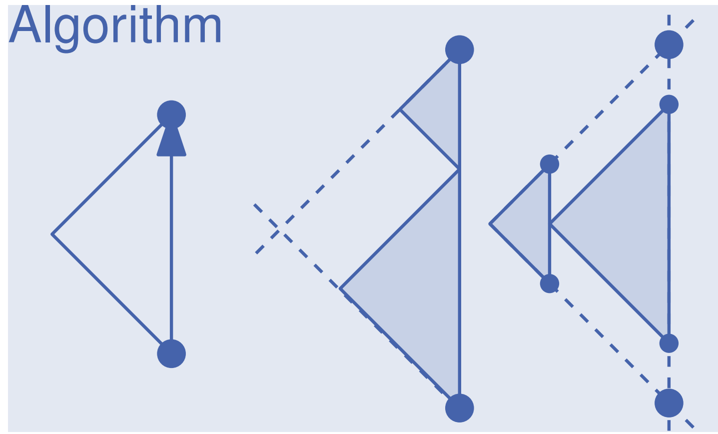

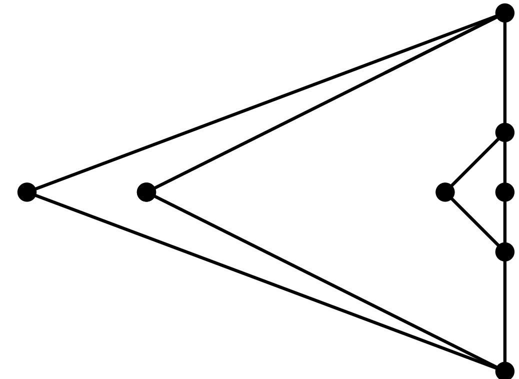

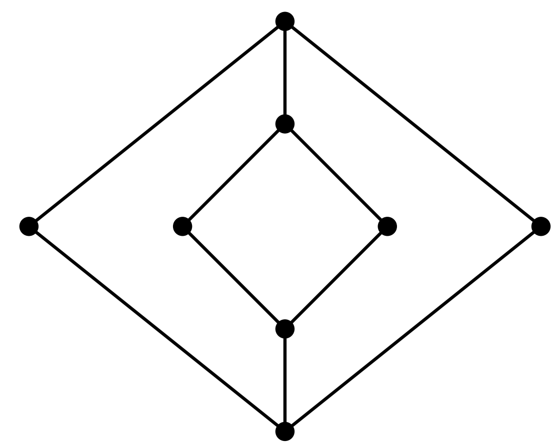

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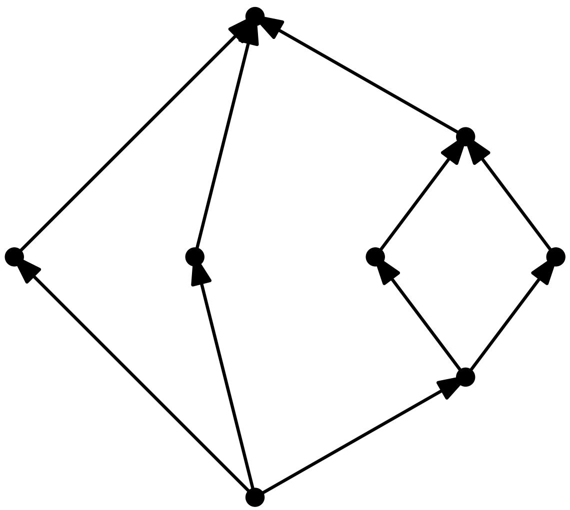

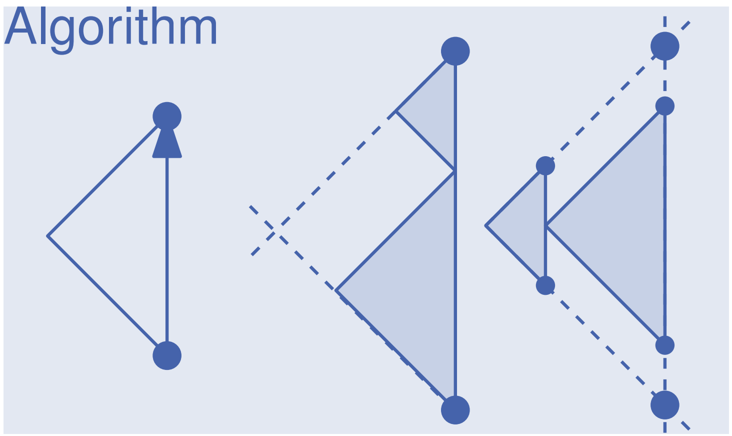

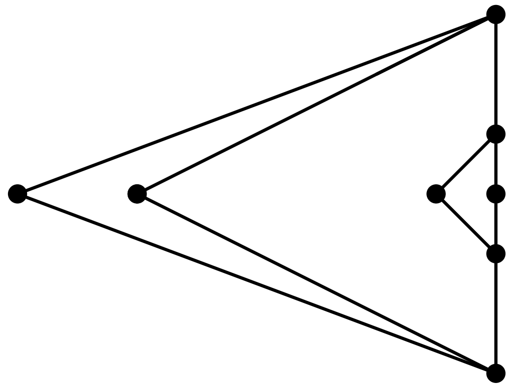

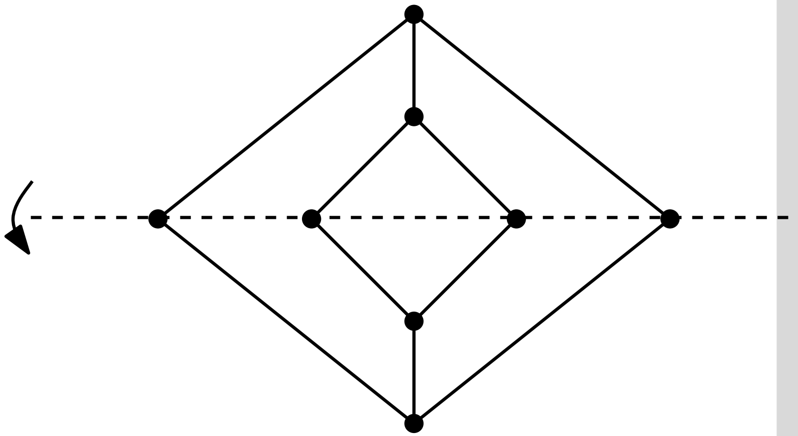

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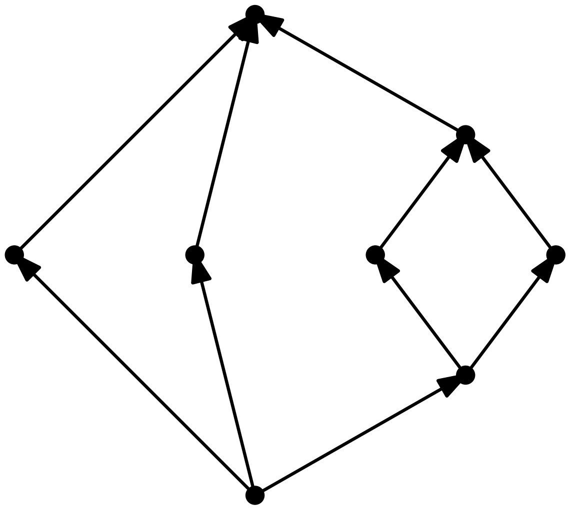

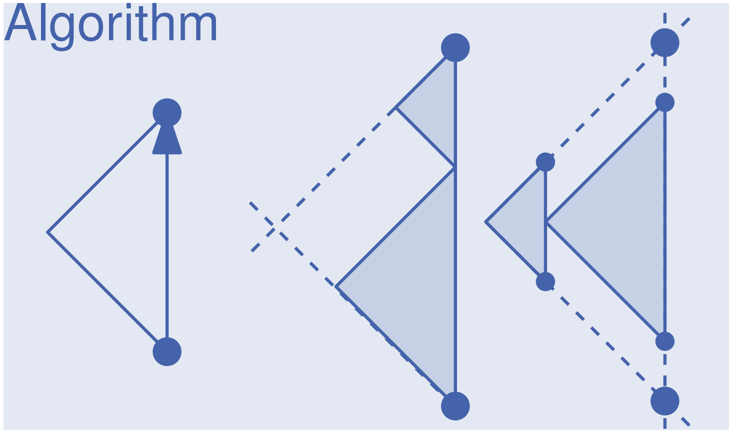

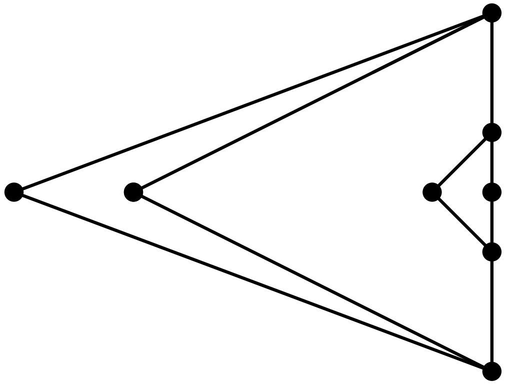

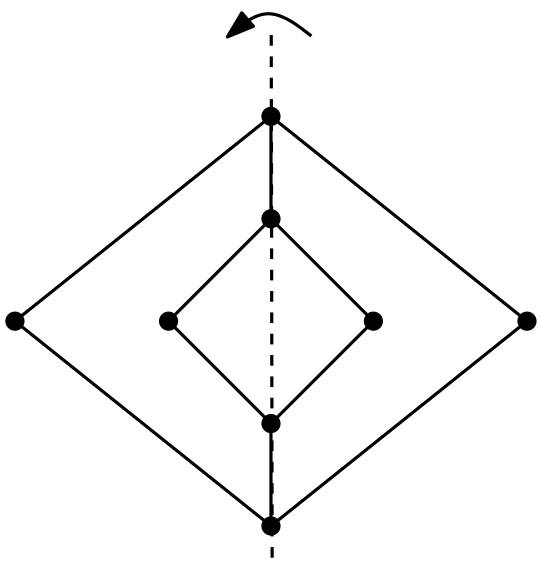

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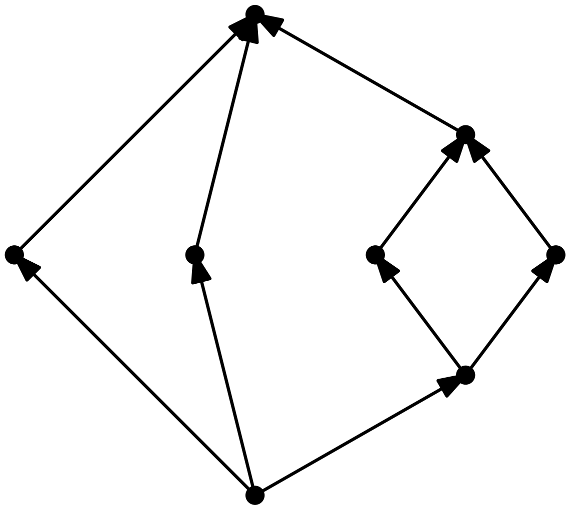

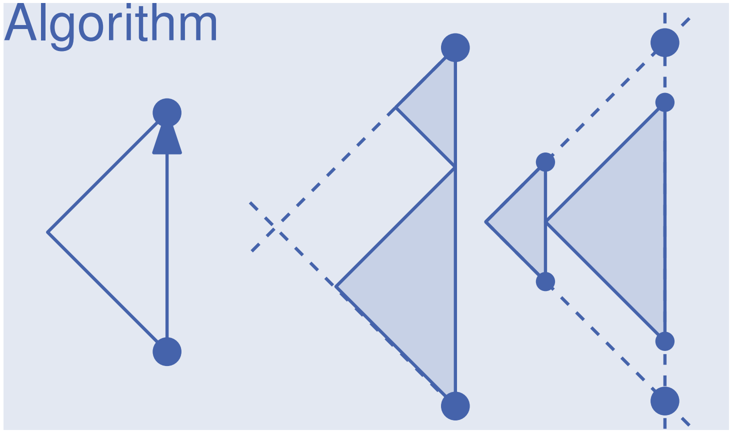

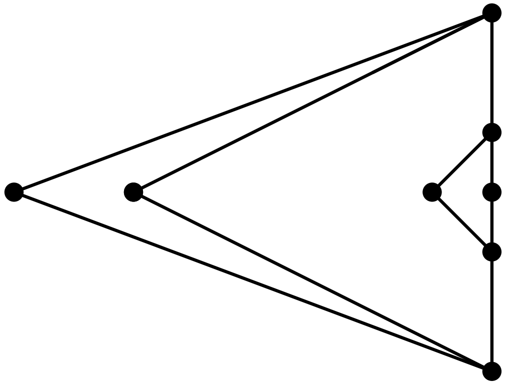

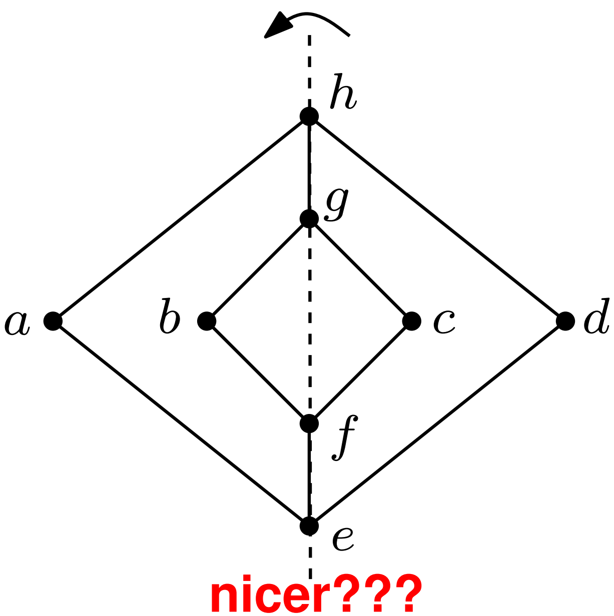

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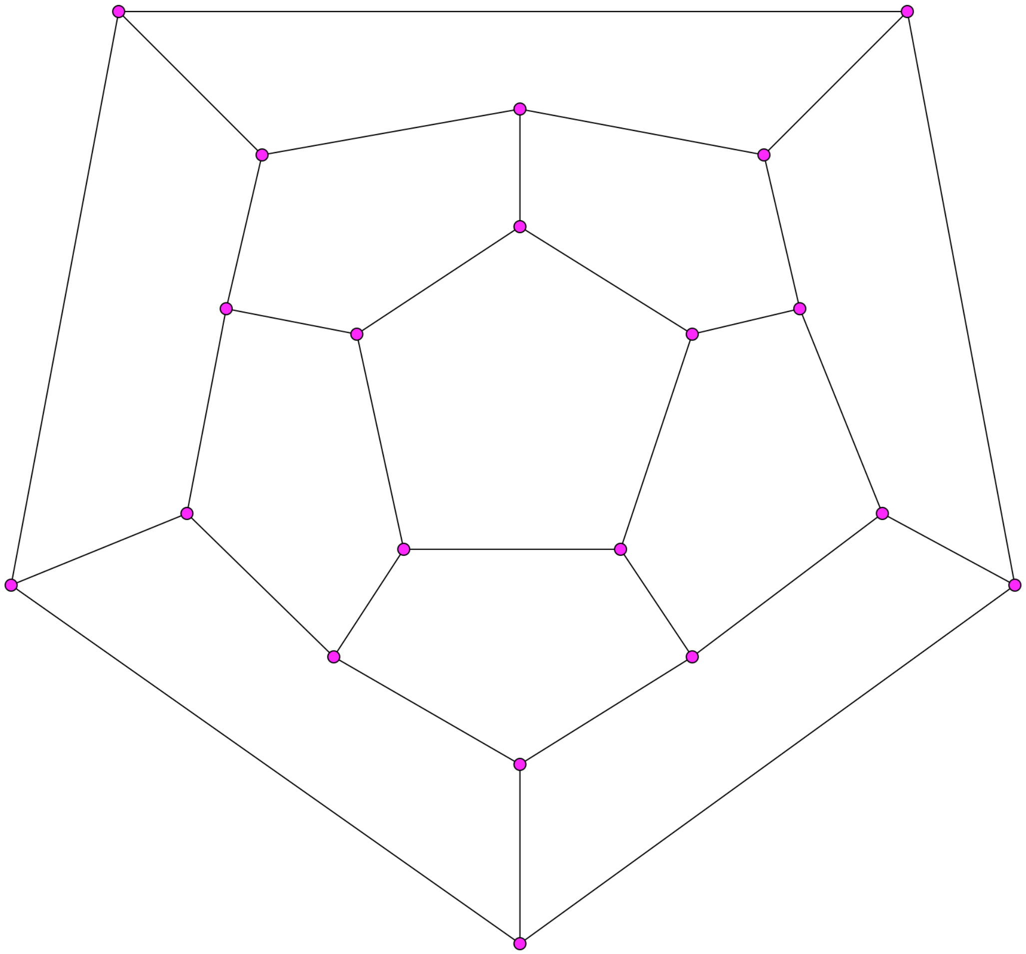

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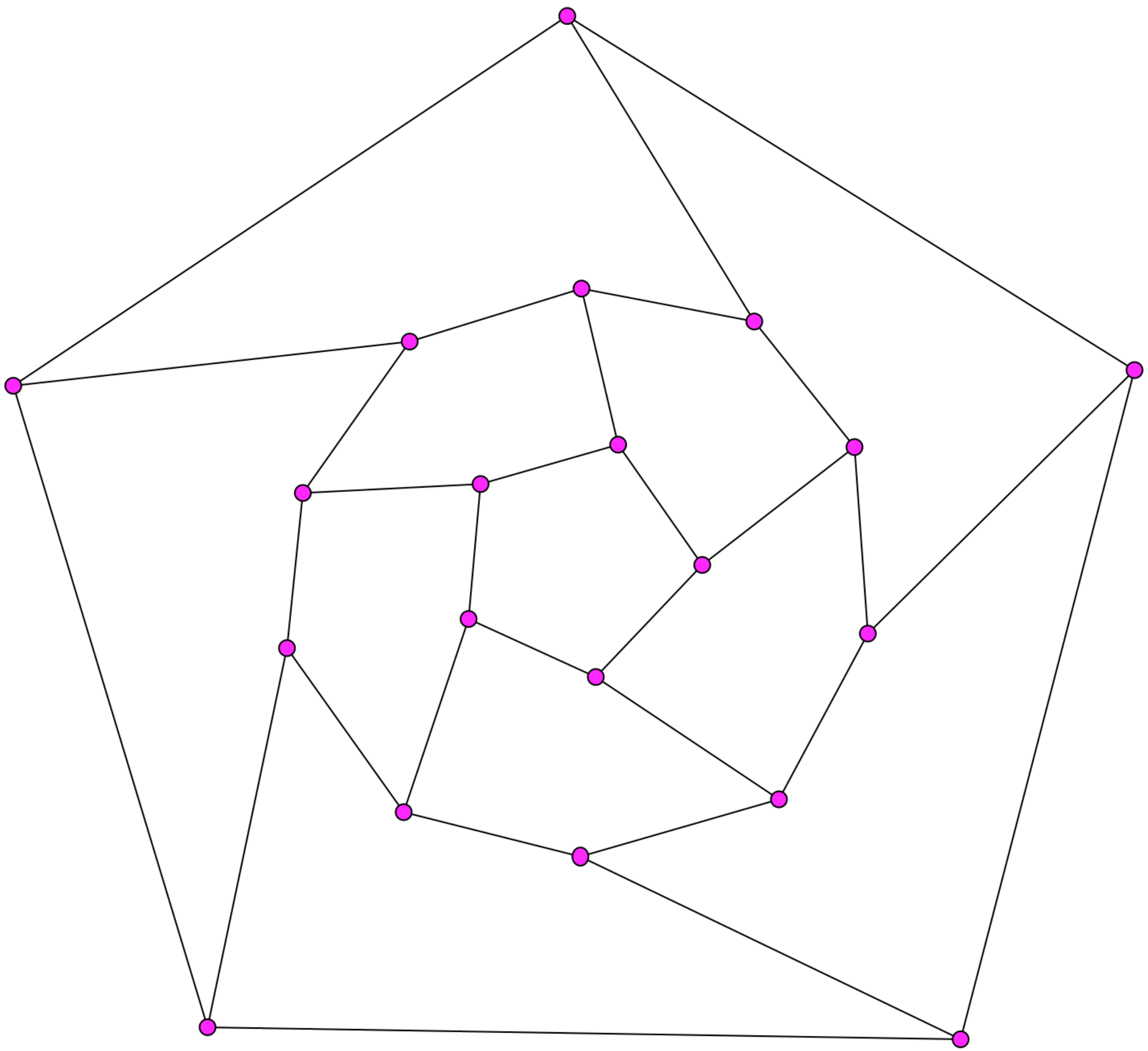

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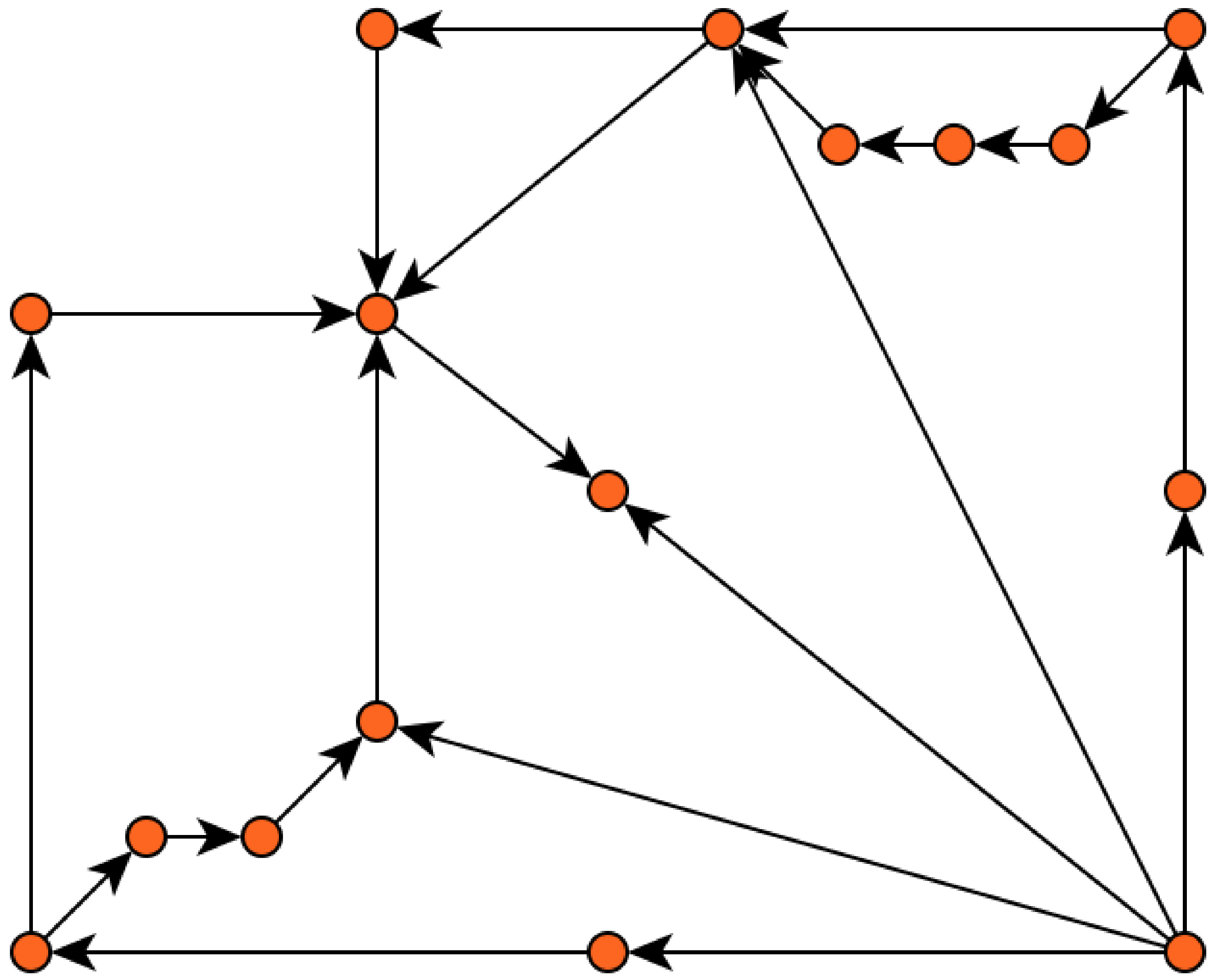

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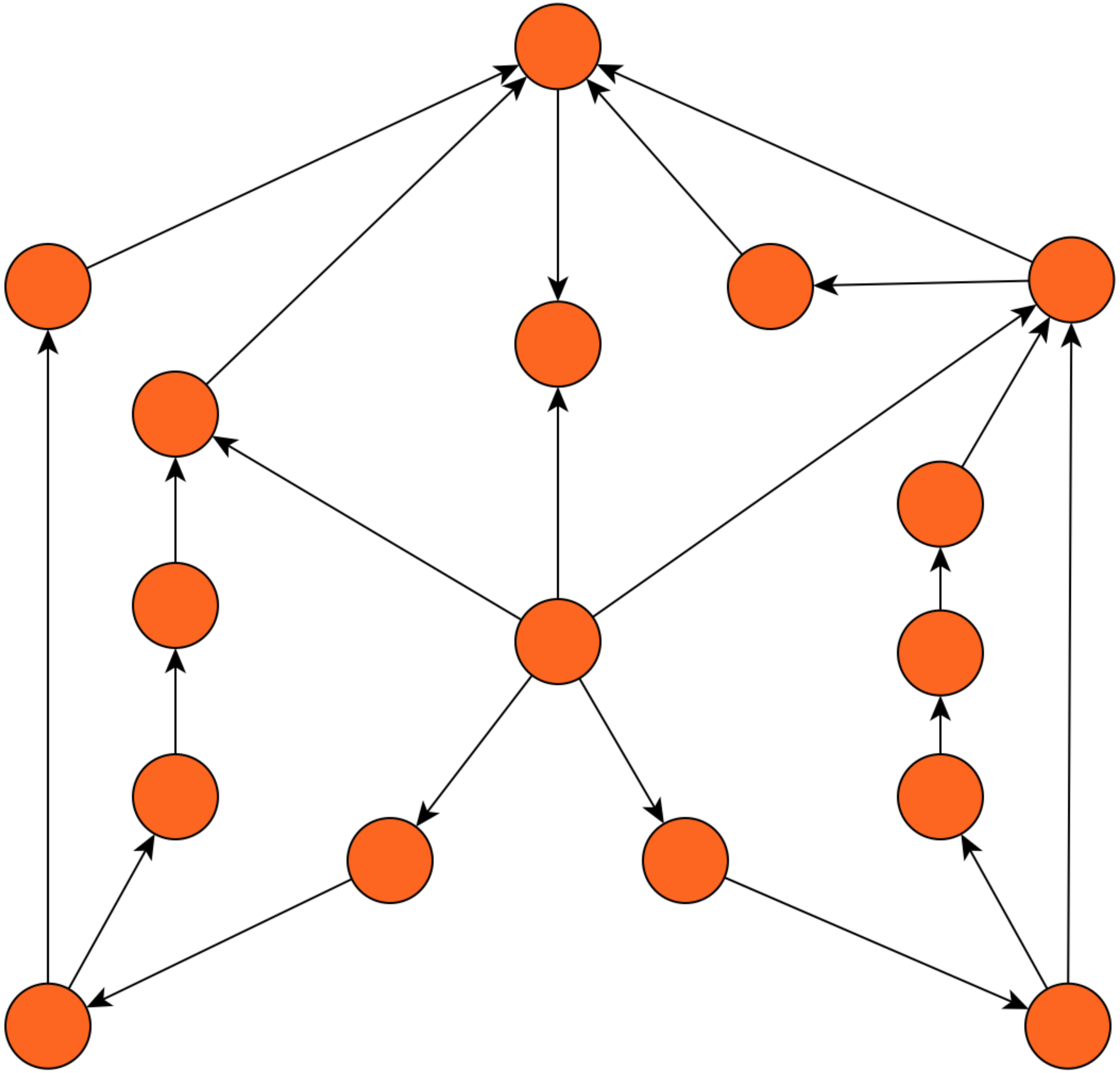

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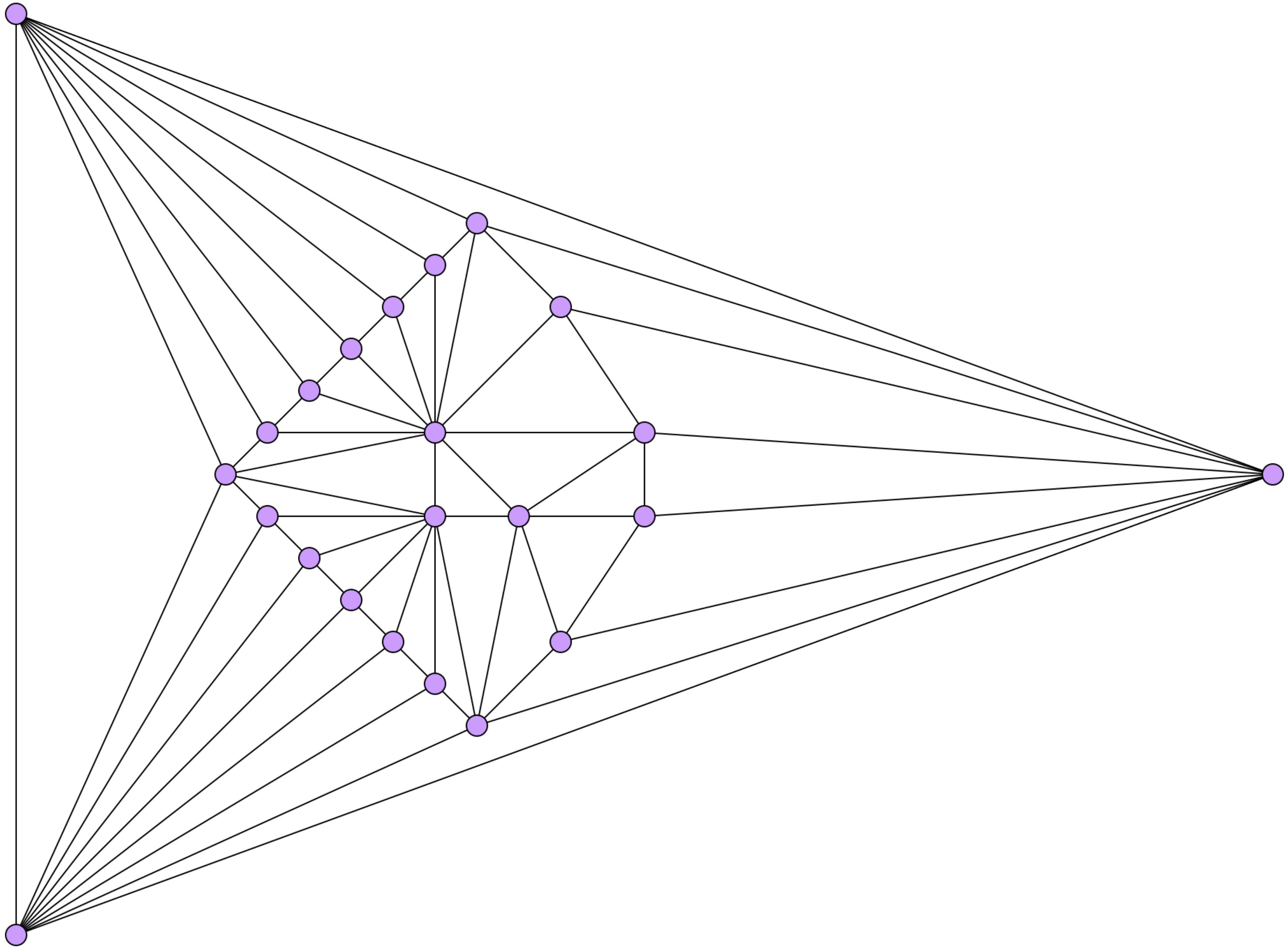

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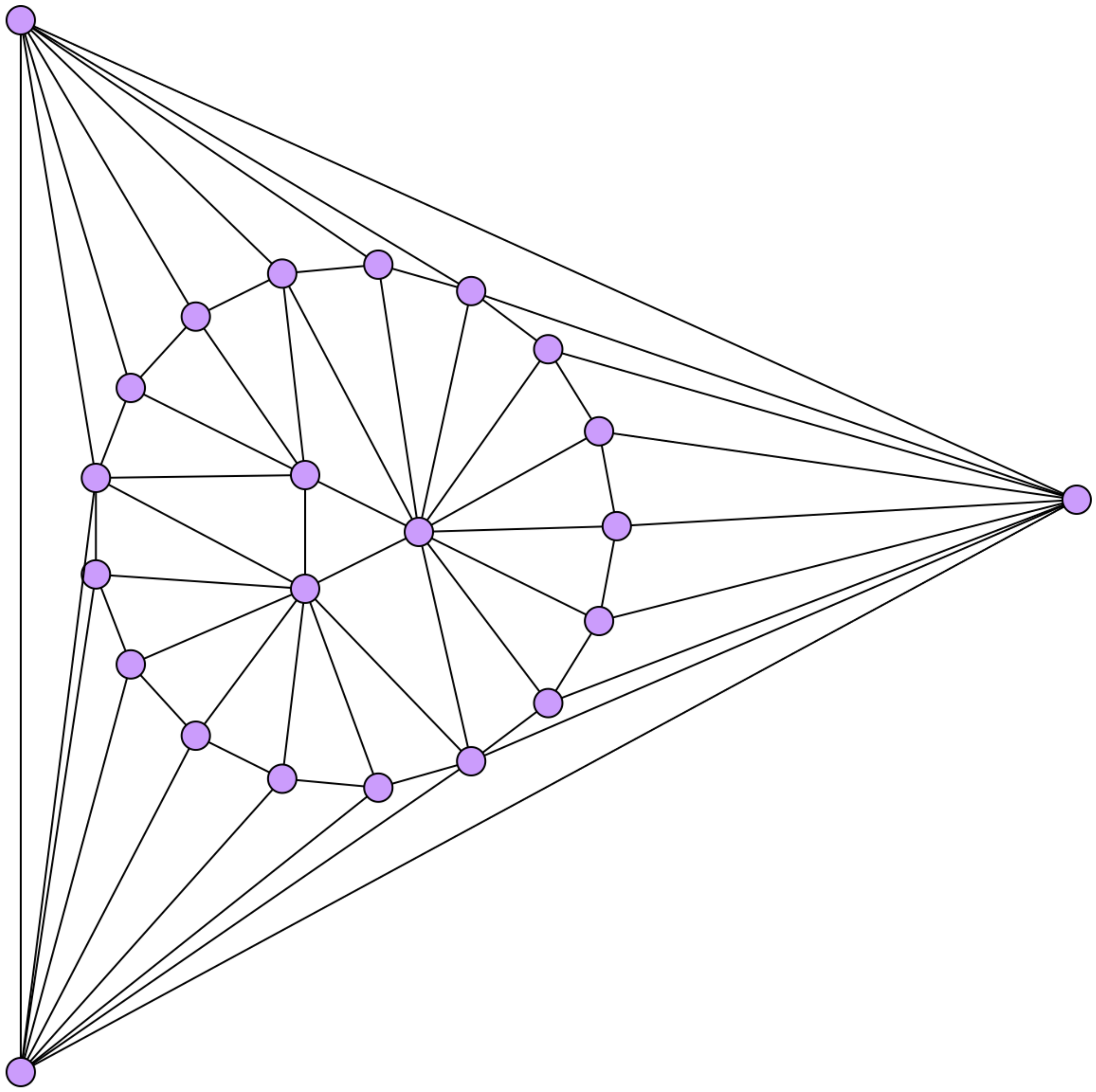

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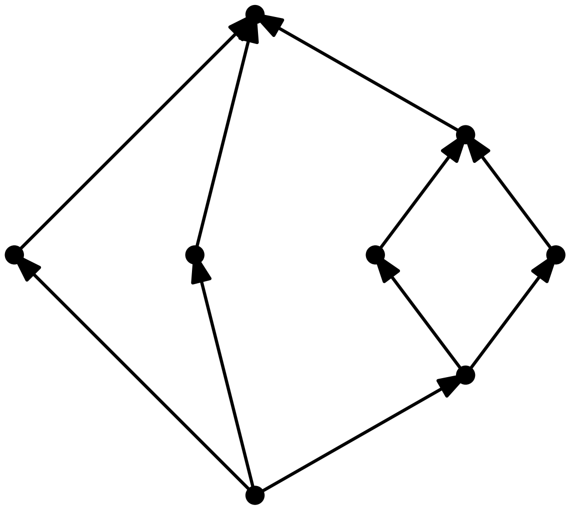

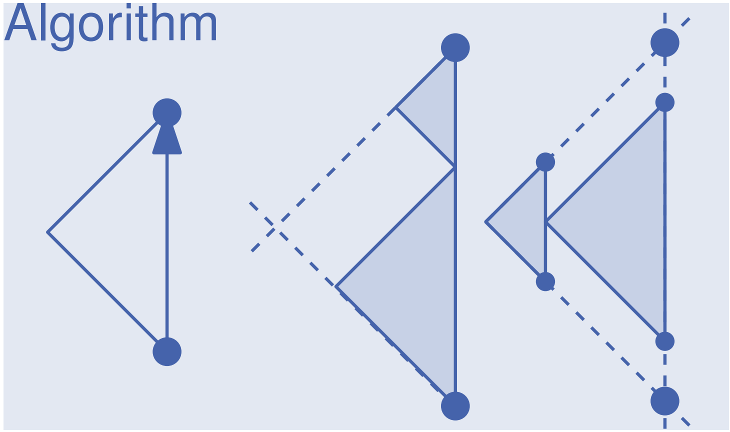

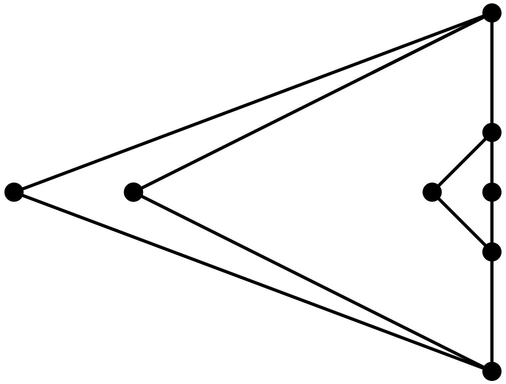

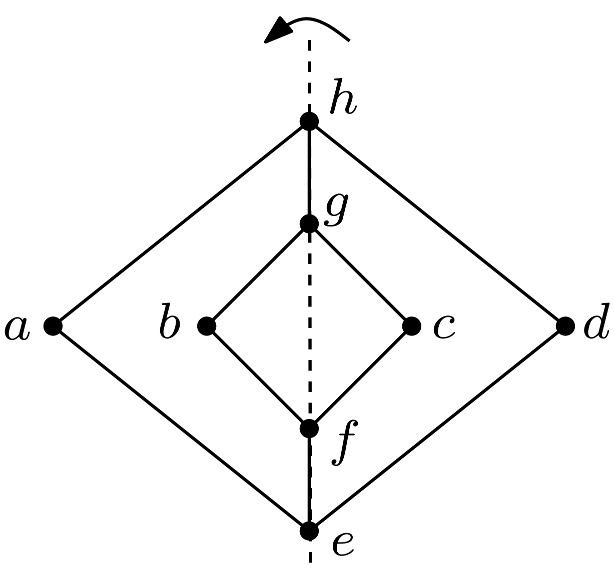

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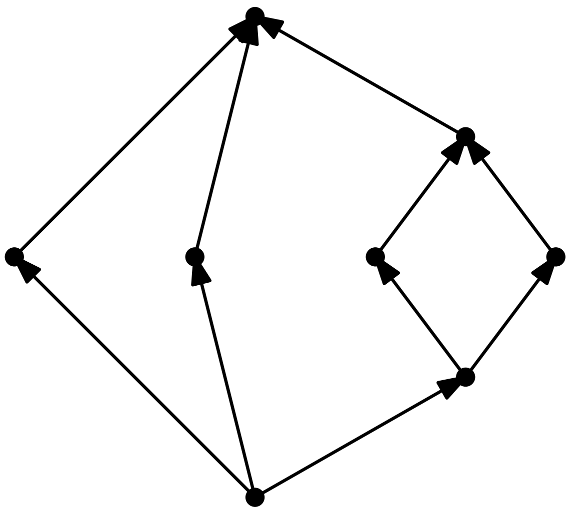

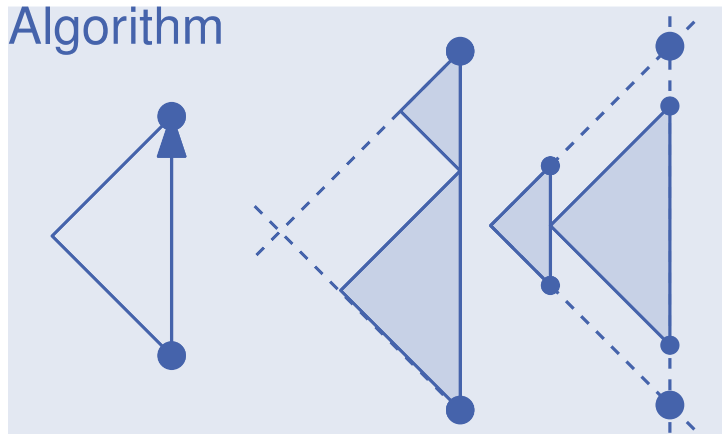

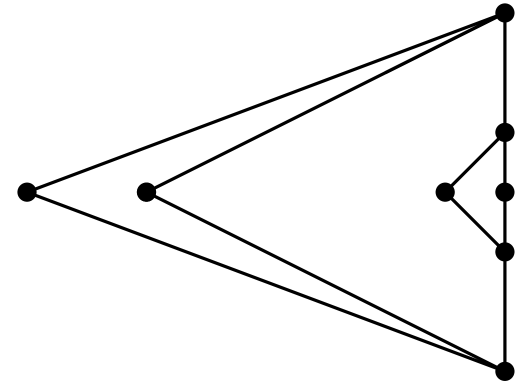

- Graph $G = (\{a, b, c, d, e, f, g, h\},$
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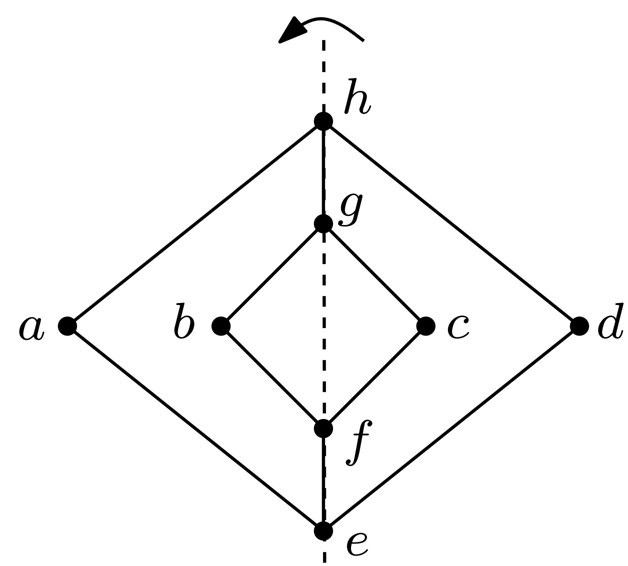

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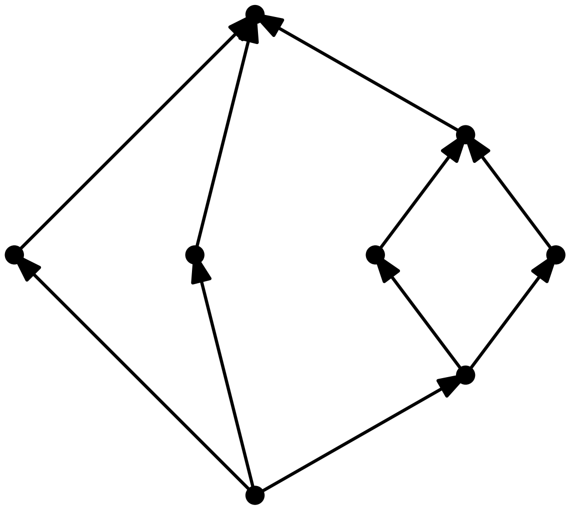

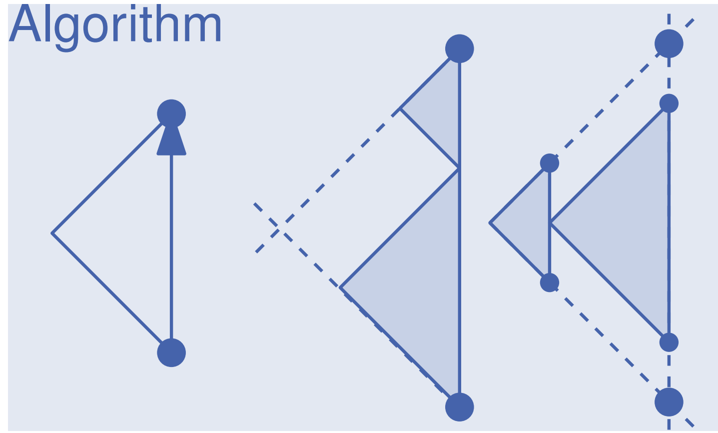

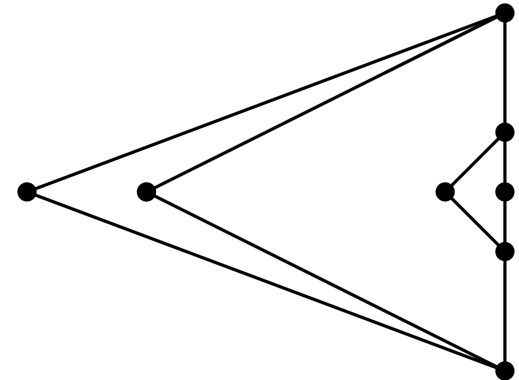

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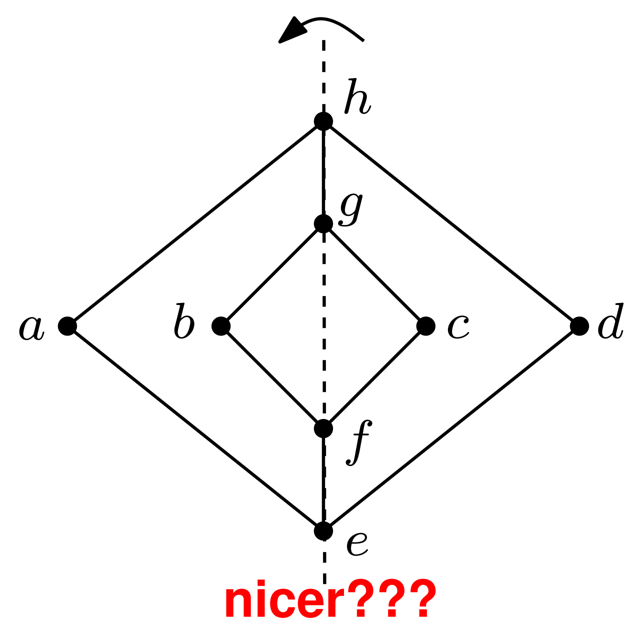
- Let G' be G where $b \to c \to b$, $a \to d \to a$.



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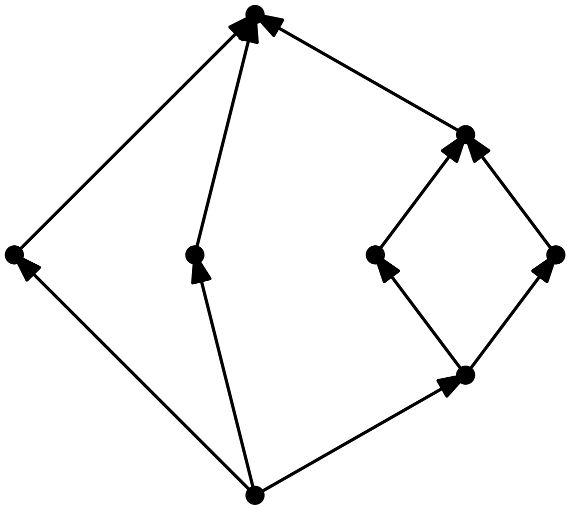

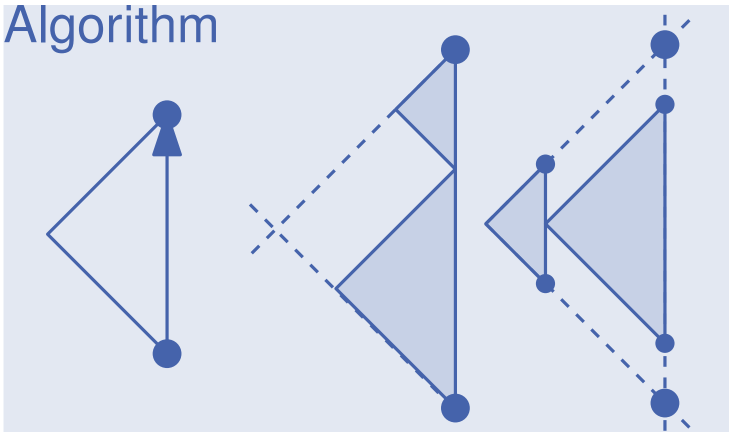

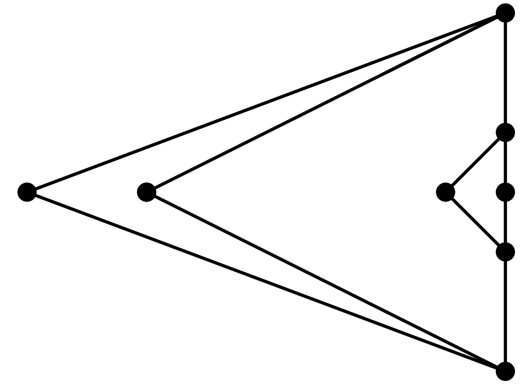

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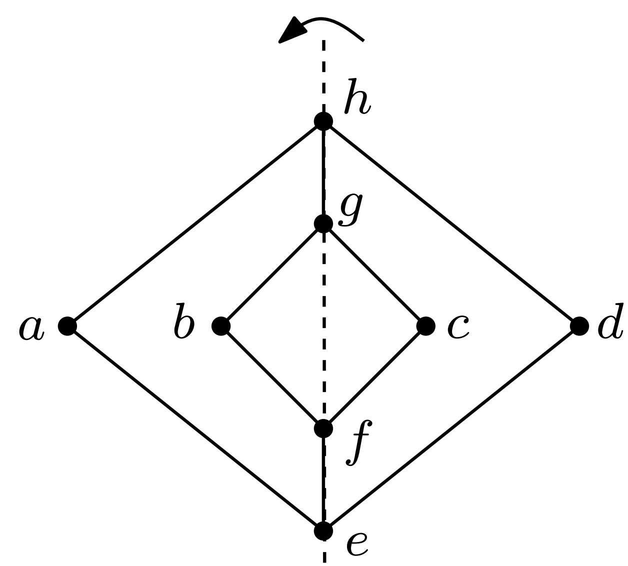
- Let G' be G where $b \to c \to b$, $a \to d \to a$.
- G and G' are isomorphic.



Graph Automorphism

Definition: Automorphism of a digraph

An **automorphism** of a directed graph $G = (V, E)$ is a permutation of the vertex set which preserves adjacency of the vertices and either preserves or reverses all the directions of the edges:

- $(u, v) \in E \Leftrightarrow (\pi(u), \pi(v)) \in E$, or
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- Finding an automorphism group of a graph is *isomorphism complete*, that is equivalent to testing whether two graphs are isomorphic.

Graph Automorphism

Definition: Automorphism of a digraph

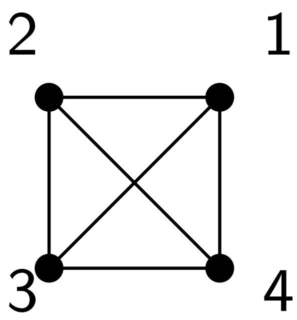
An **automorphism** of a directed graph $G = (V, E)$ is a permutation of the vertex set which preserves adjacency of the vertices and either preserves or reverses all the directions of the edges:

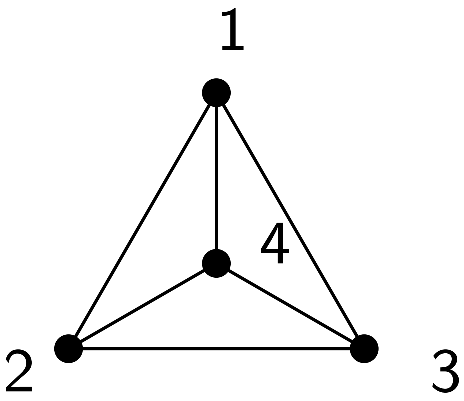
- $(u, v) \in E \Leftrightarrow (\pi(u), \pi(v)) \in E$, or
- $(u, v) \in E \Leftrightarrow (\pi(v), \pi(u)) \in E$

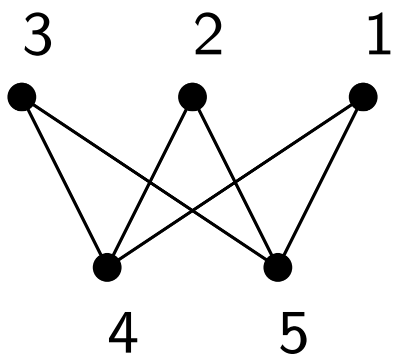
- The set of all automorphisms (direction preserving and reversing) forms the **automorphism group** of G.
- Finding an automorphism group of a graph is *isomorphism complete*, that is equivalent to testing whether two graphs are isomorphic.
- For planar graphs, graphs with bounded degree isomorphism problem has polynomial-time algorithms (for more see citations in [HEL00]).

Geometric Automorphism

- Geometric realizability of automorphisms:







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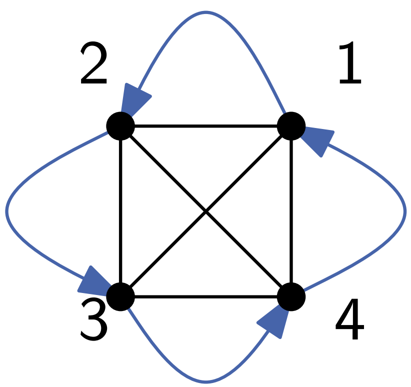
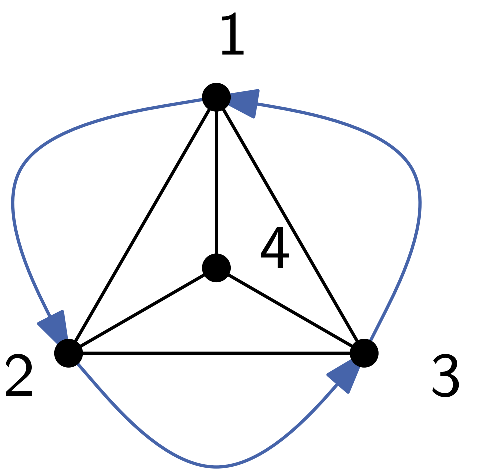


This drawing displays the automorphism $1 \to 2 \to 3 \to 4 \to 1$ as rotational symmetry. But does not shows the $1 \to 2 \to 3 \to 1$



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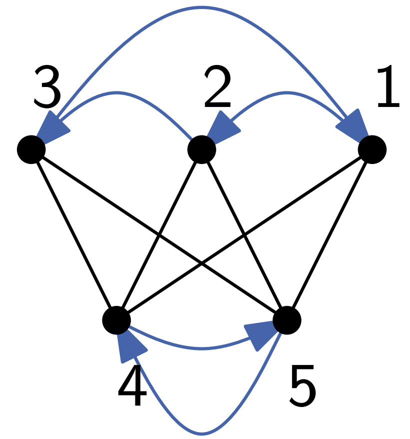

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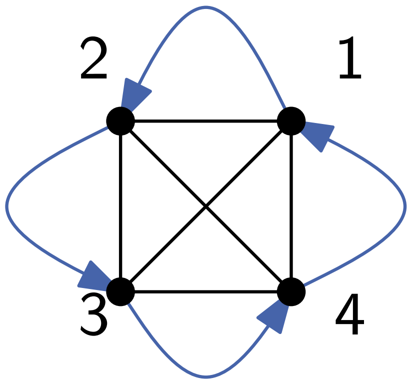

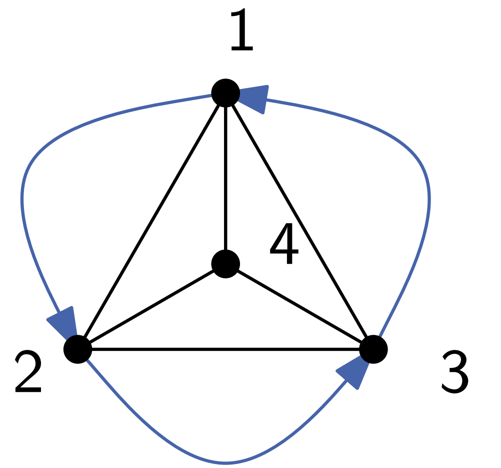

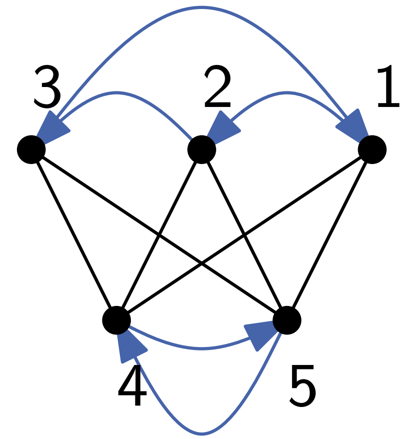

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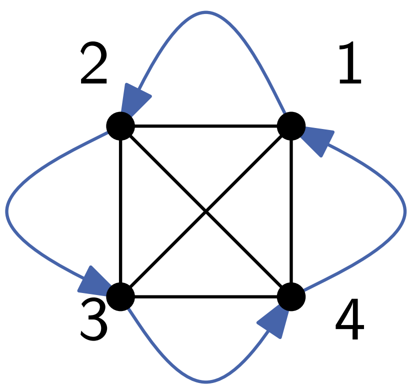

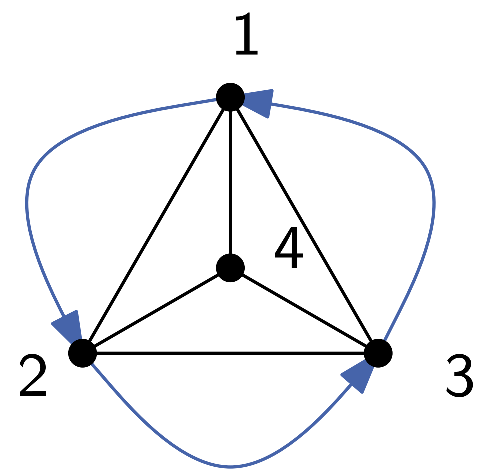

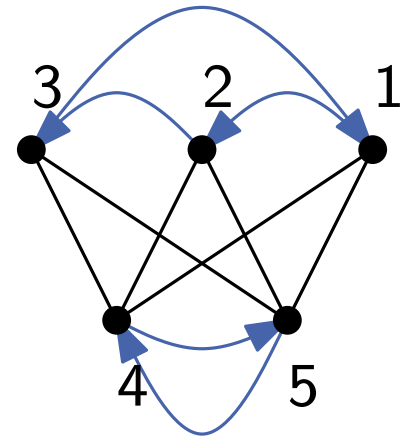

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Automorphism $1 \to 2 \to 3 \to 1$, $4 \to 5 \to 4$ is not geometrically representable. But $1 \to 3 \to 1$, $4 \to 5 \to 4$ is representable as vertical symmetry.

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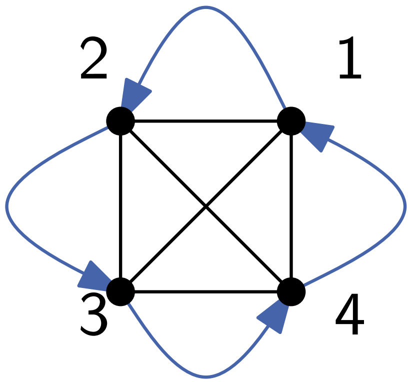

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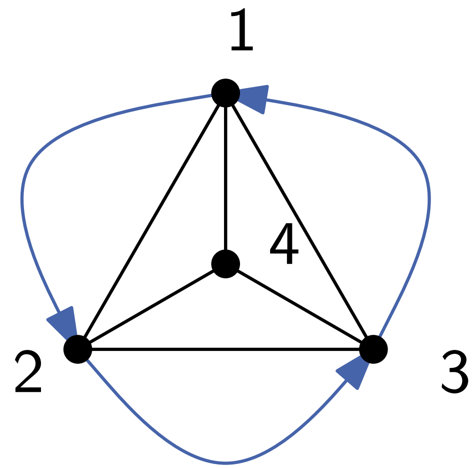

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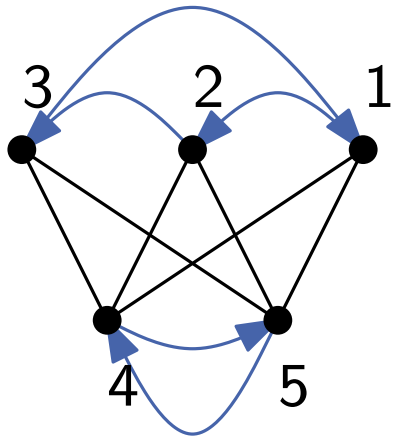

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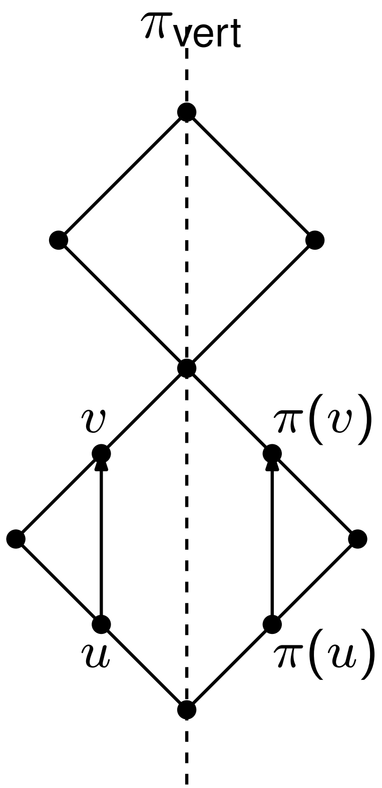
- An automorphism group P of a graph is geometric, if there exists a drawing of G that displays each element of P as a symmetry.
- For general graphs it is $\mathcal{NP}$-hard to find a geometric automorphism of a graph.
- For planar graphs, planar geometric automorphisms can be found in polynomial time. For outerplanar graphs and trees in linear time.

Symmetries in SP-Graphs



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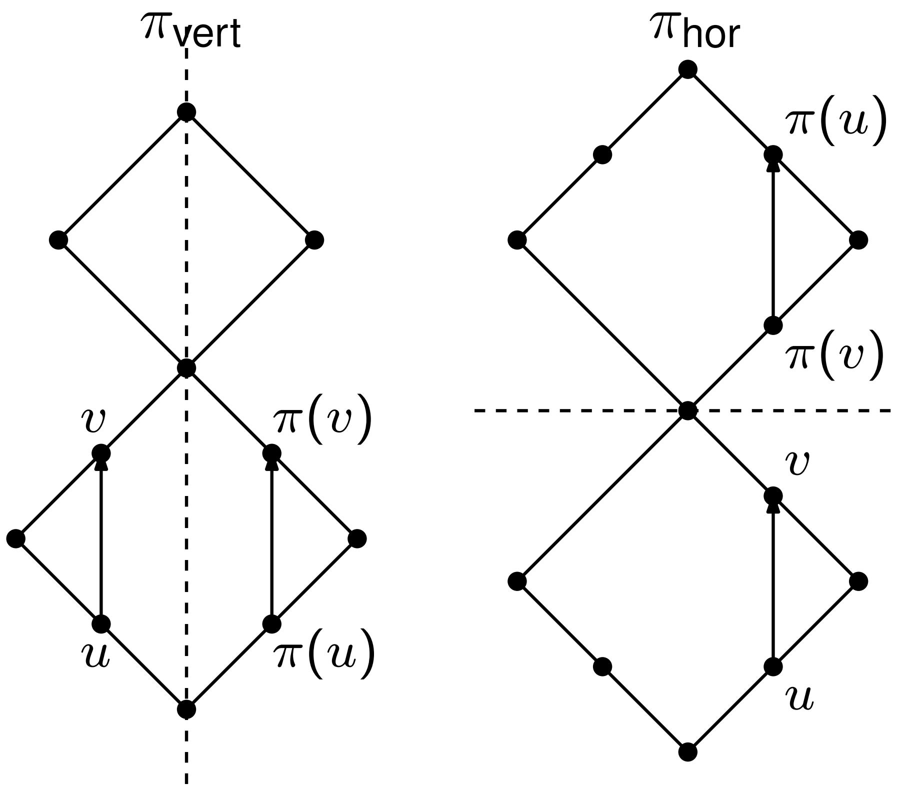

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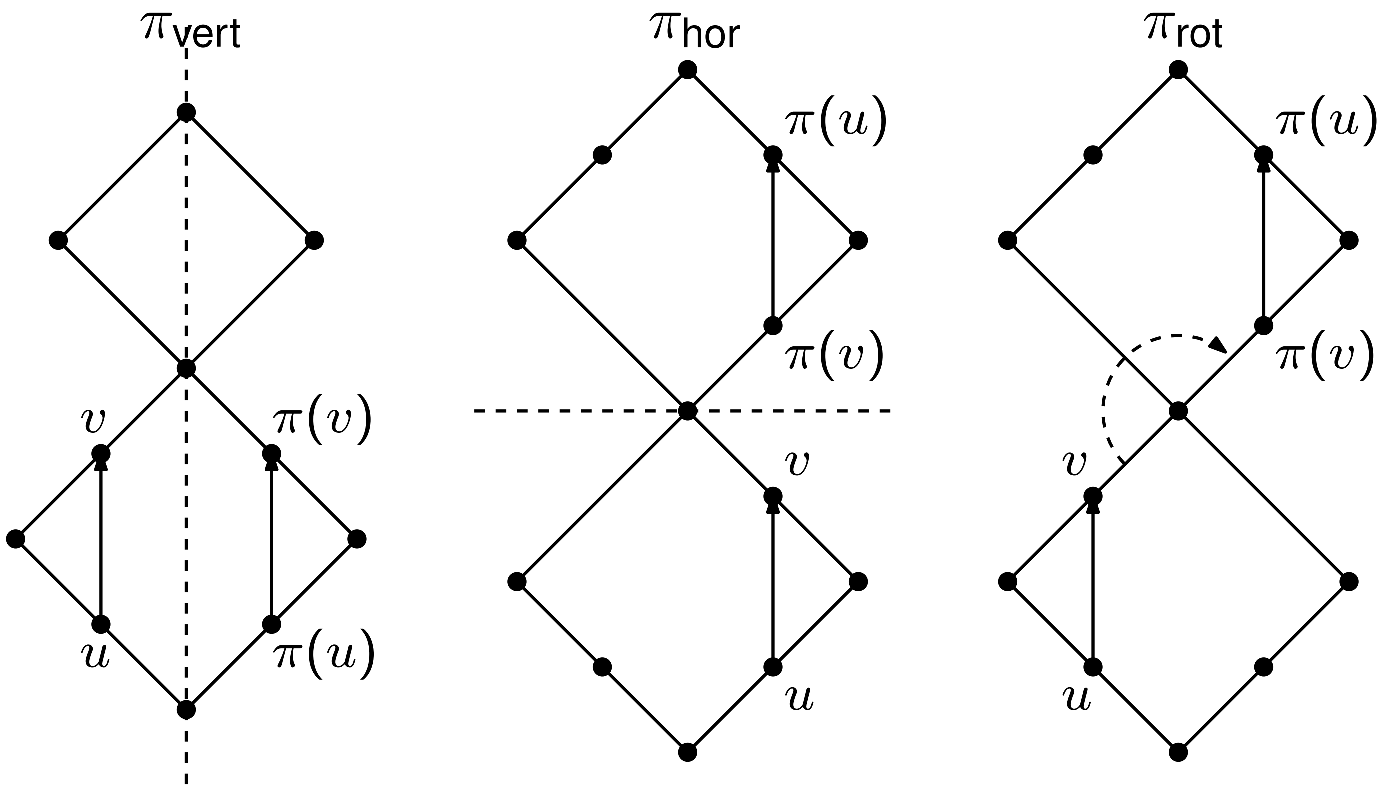

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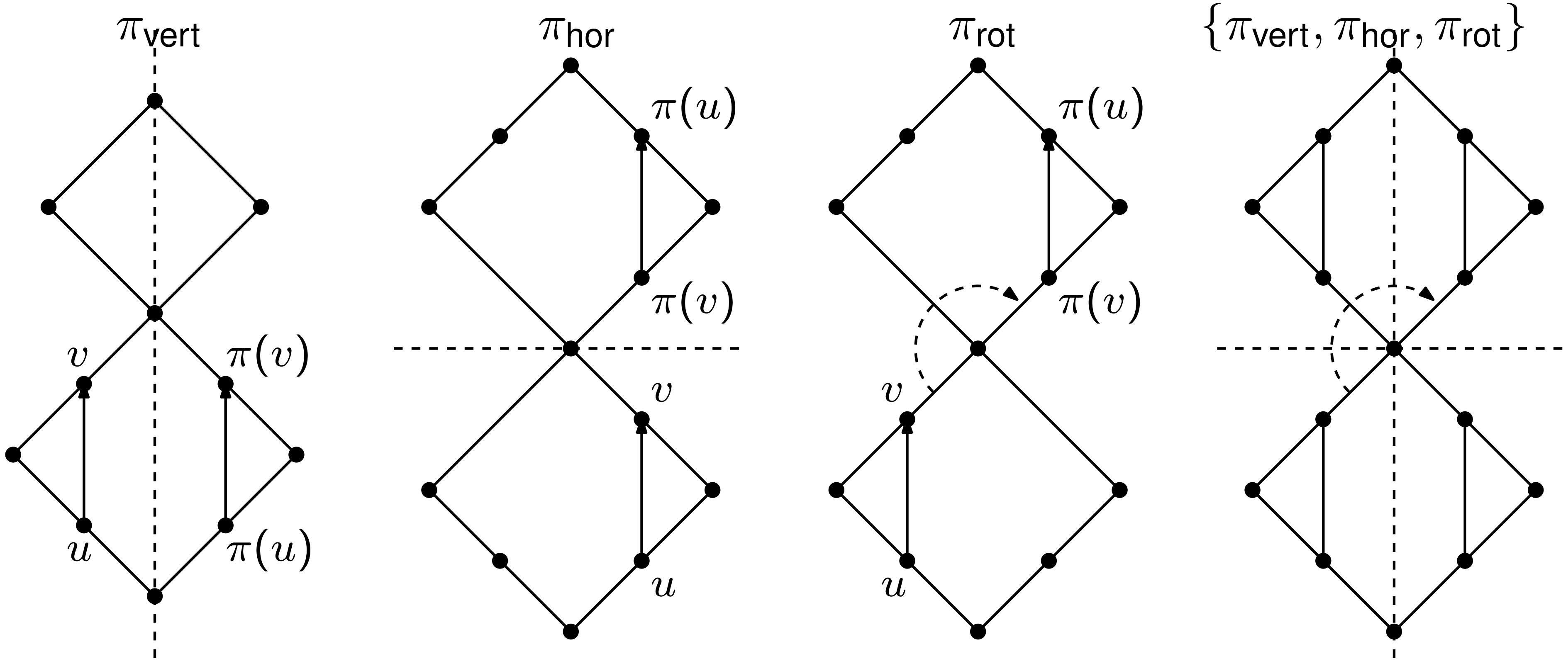

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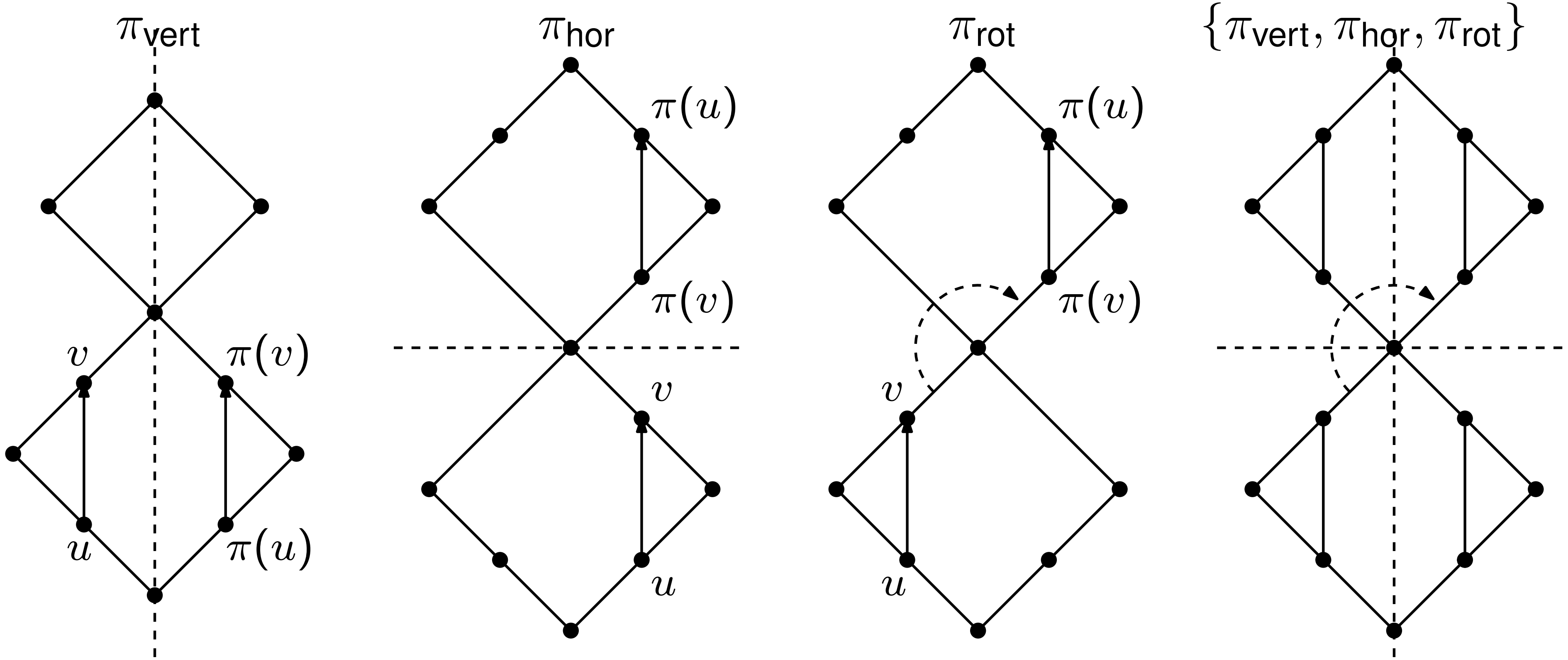
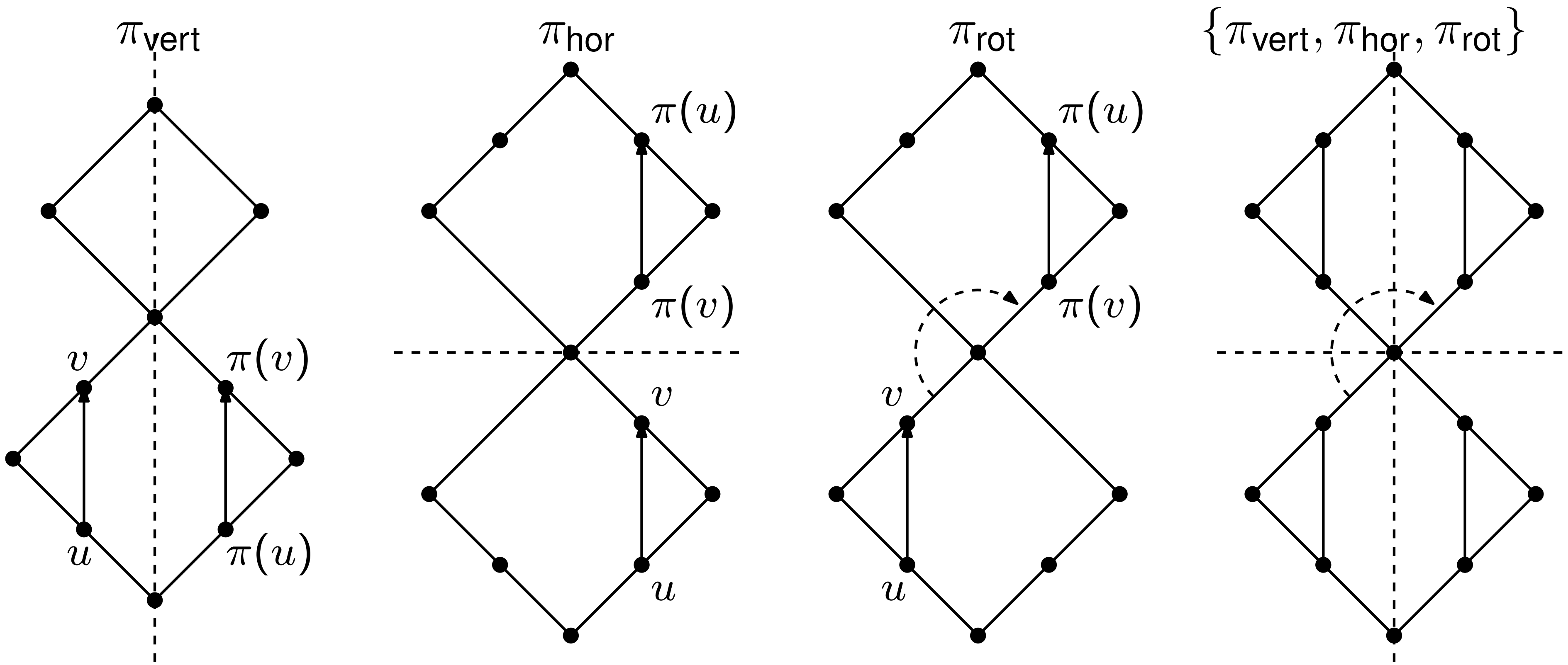


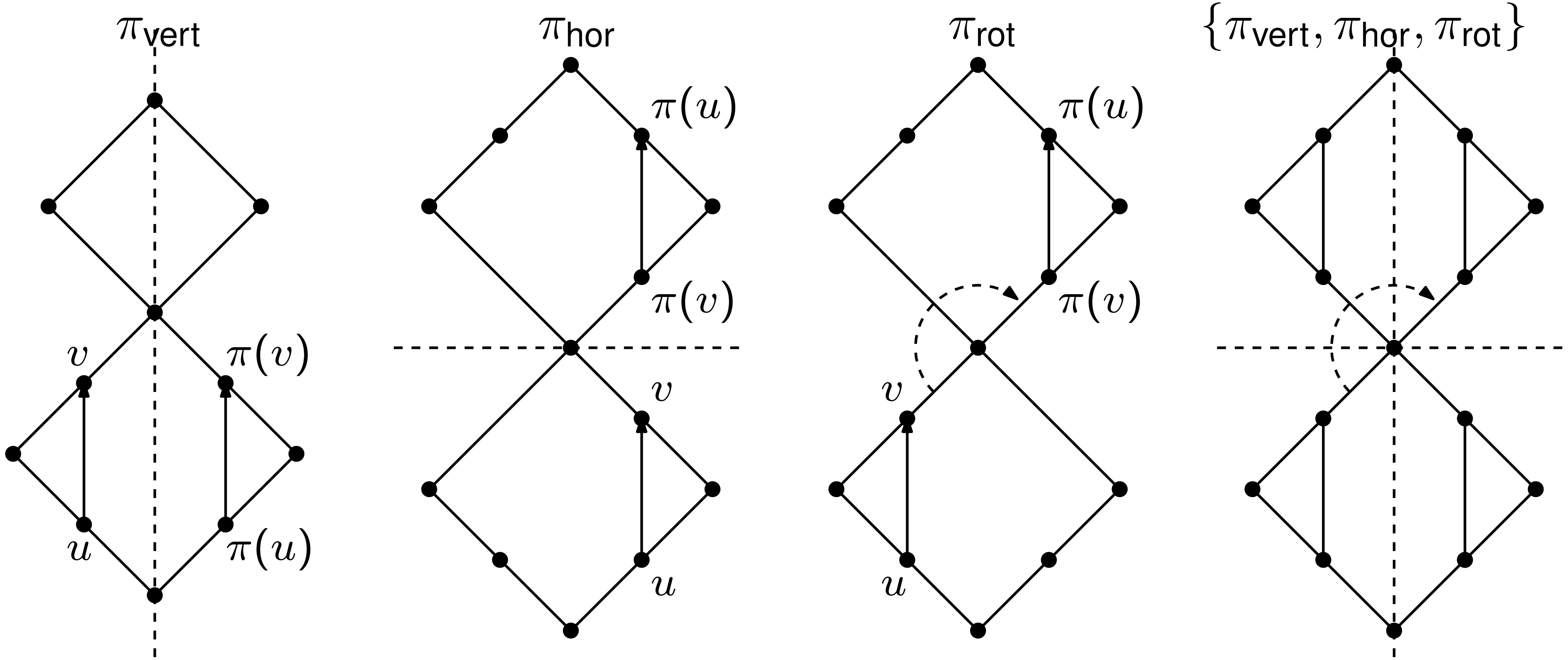
- A geometric automorphism group P of a graph G is upward planar, if there exists an upward planar drawing of G that displays each element of P as a symmetry.

Symmetries in SP-Graphs



- A geometric automorphism group P of a graph G is upward planar, if there exists an upward planar drawing of G that displays each element of P as a symmetry.
- How does a geometric automorphism group for a series-parallel graph look like?

Symmetries in SP-Graphs

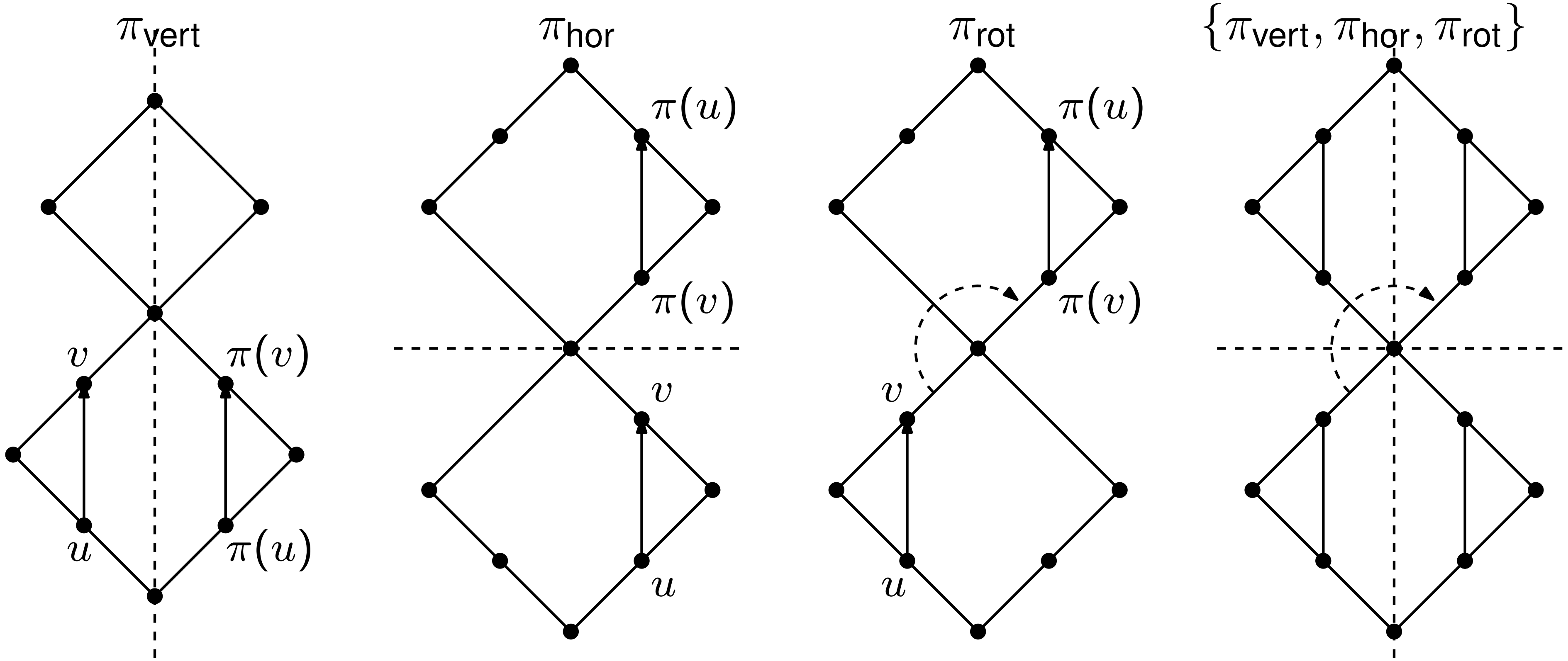


Theorem (Hong, Eades, Lee '00) [HEL00]

An upward planar automorphism group of a series-parallel digraph is either

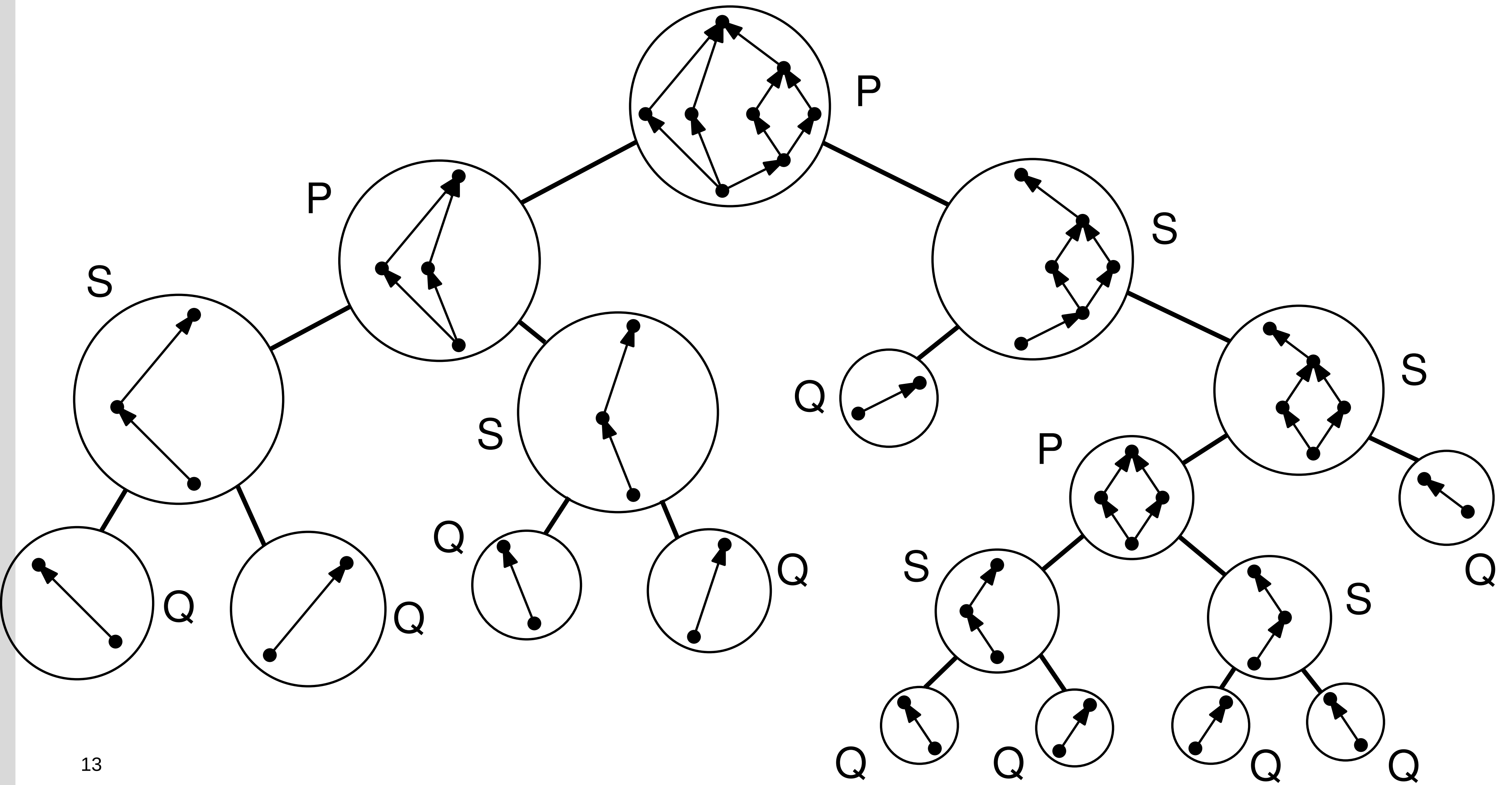
- $\{\text{id}\}$
- $\{\text{id}, \pi\}$ with $\pi \in \{\pi_{\text{vert}}, \pi_{\text{hor}}, \pi_{\text{rot}}\}$
- $\{\text{id}, \pi_{\text{vert}}, \pi_{\text{hor}}, \pi_{\text{rot}}\}$.

Symmetries in SP-Graphs



- The automorphism group of maximum size can be found in linear time.
- Given a maximum size automorphism group of a series-parallel graph, a polyline upward planar drawing that displays this automorphism can be constructed in linear time as well.

Vertical Automorphism



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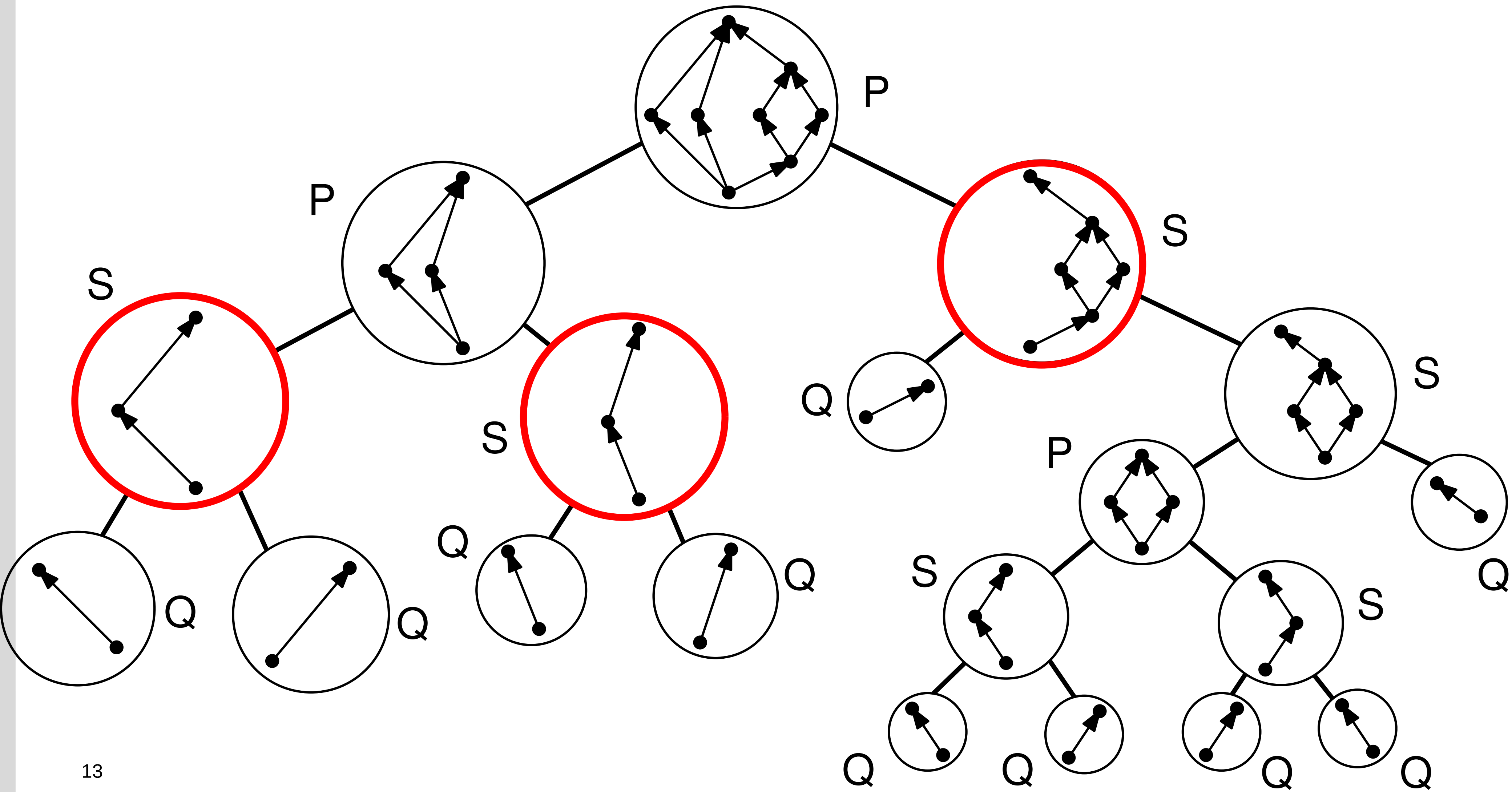

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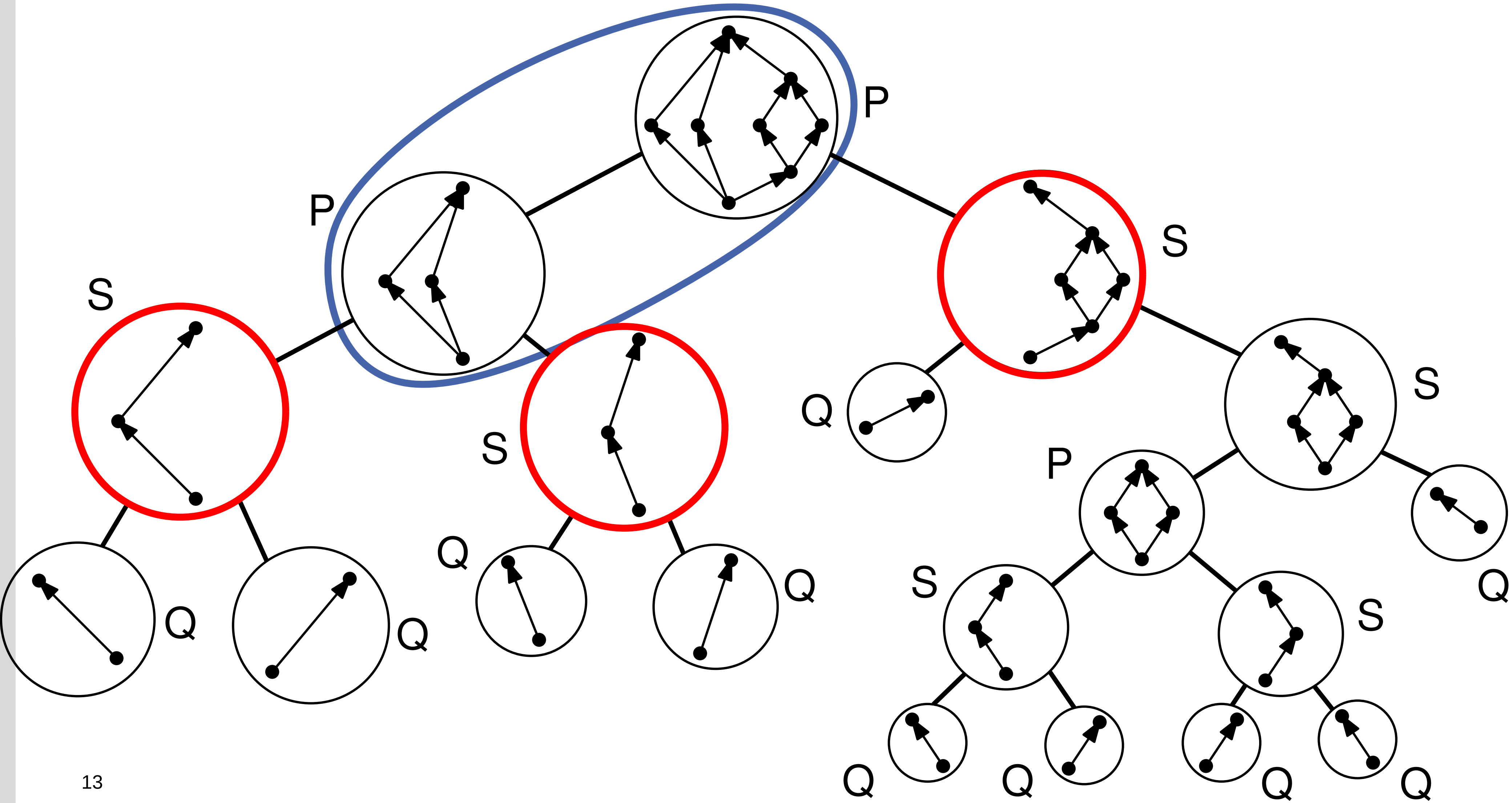

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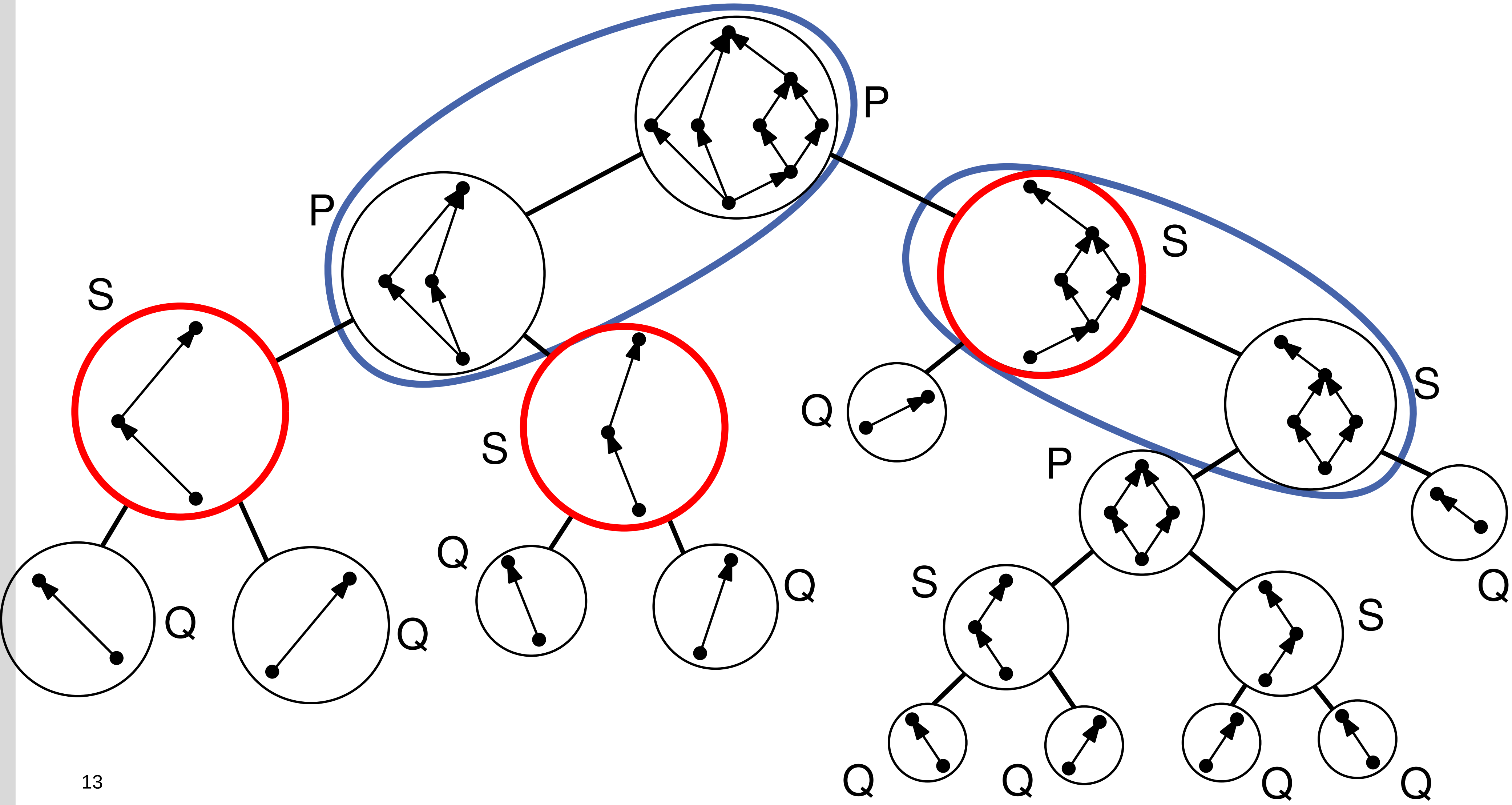

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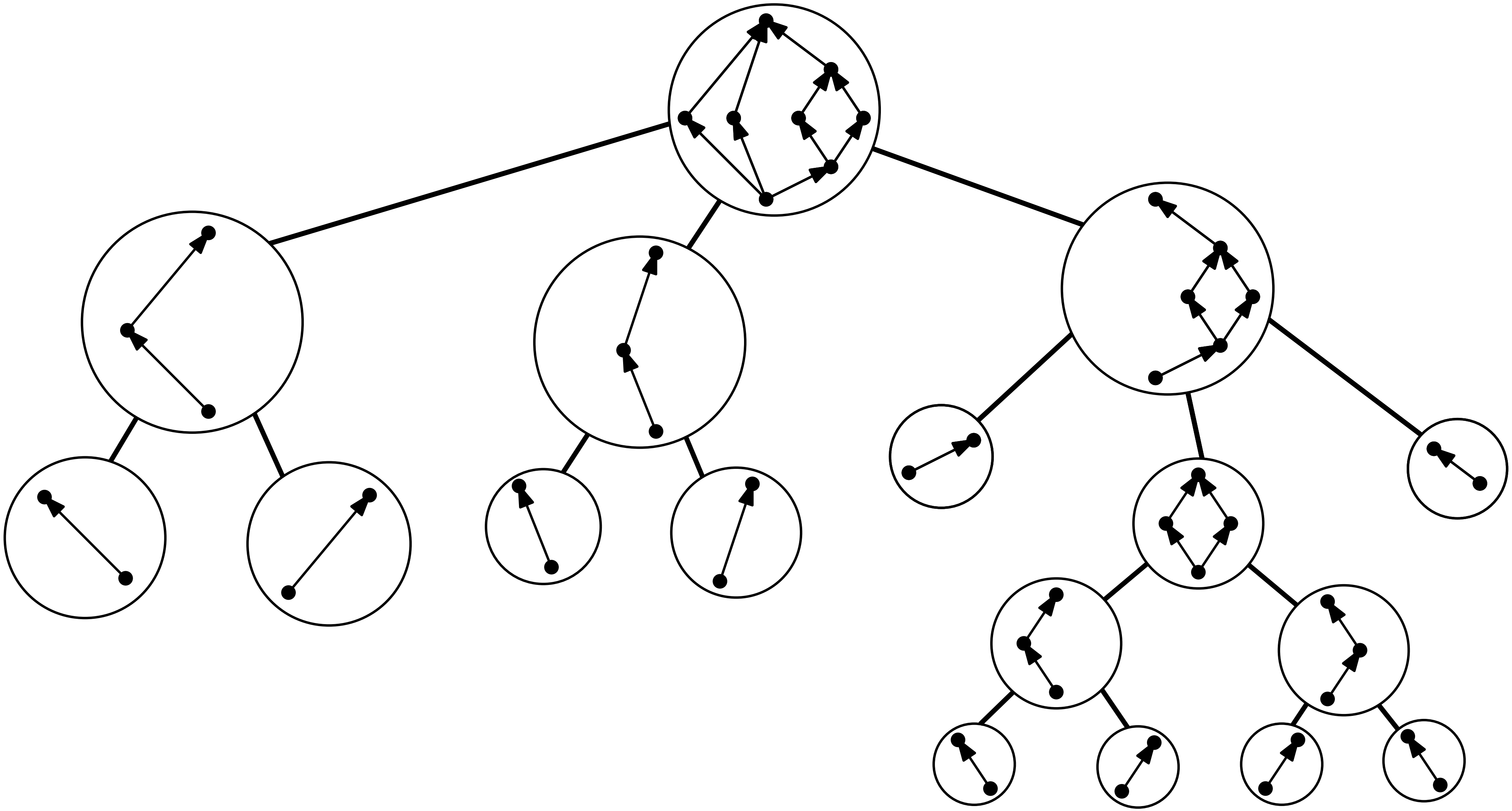

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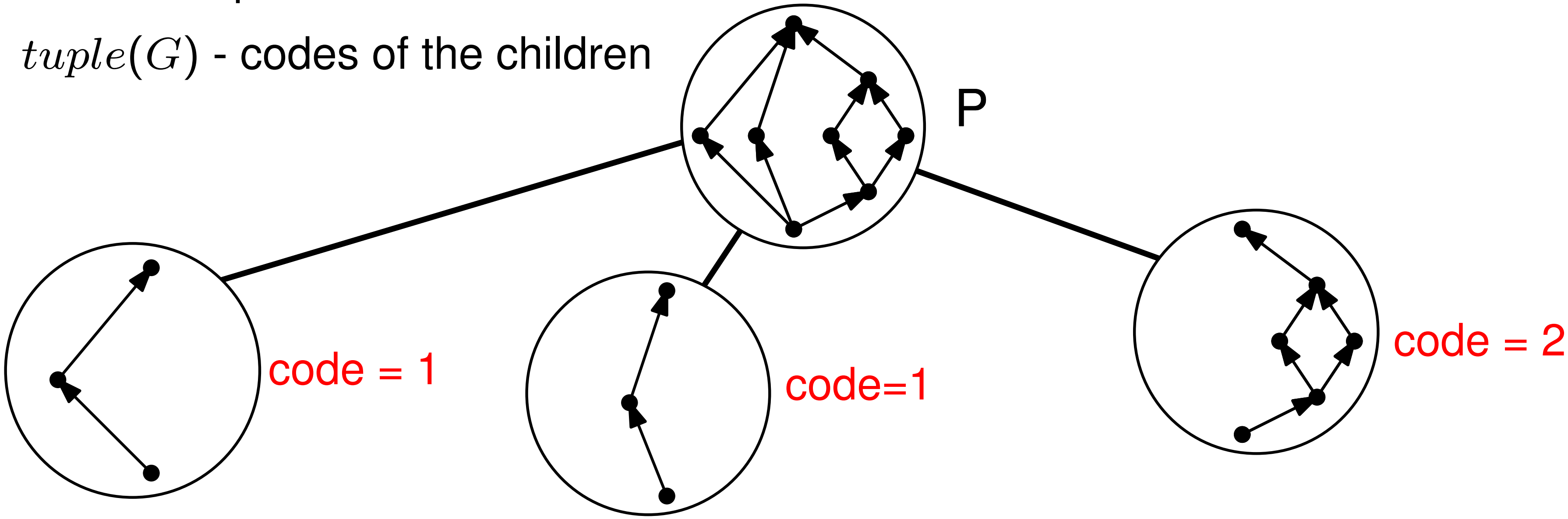
- $code(G)$ - two graphs at the same level have the same code iff they are isomorphic
- $tuple(G)$ - codes of the children



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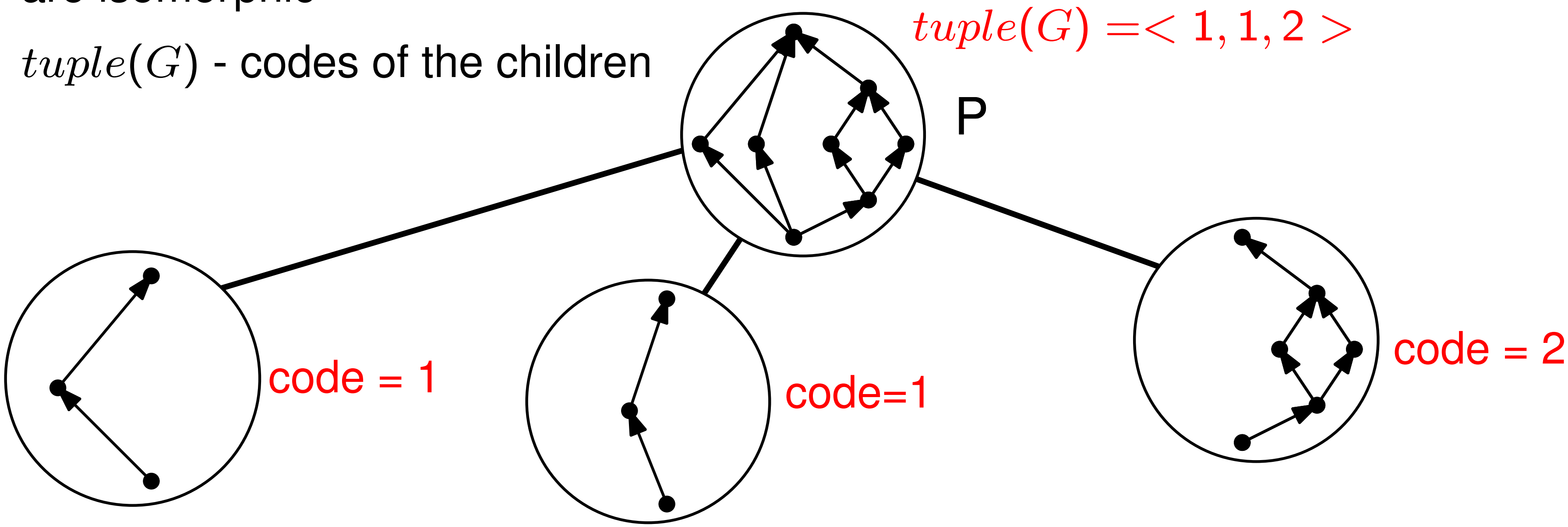

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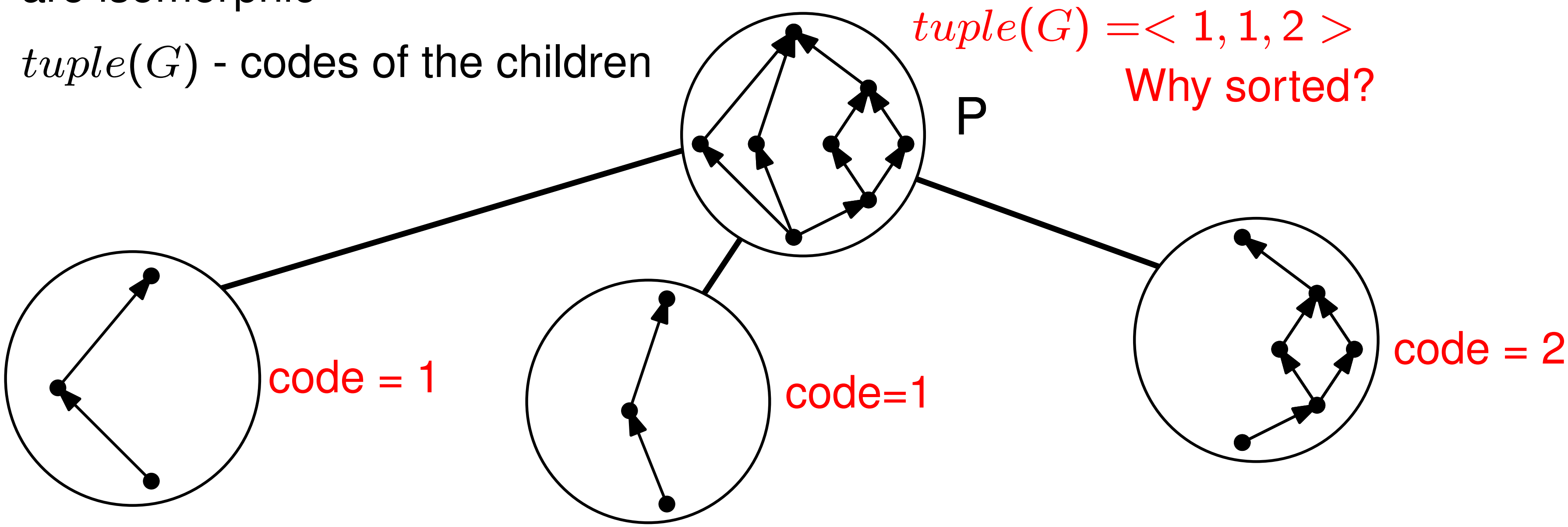

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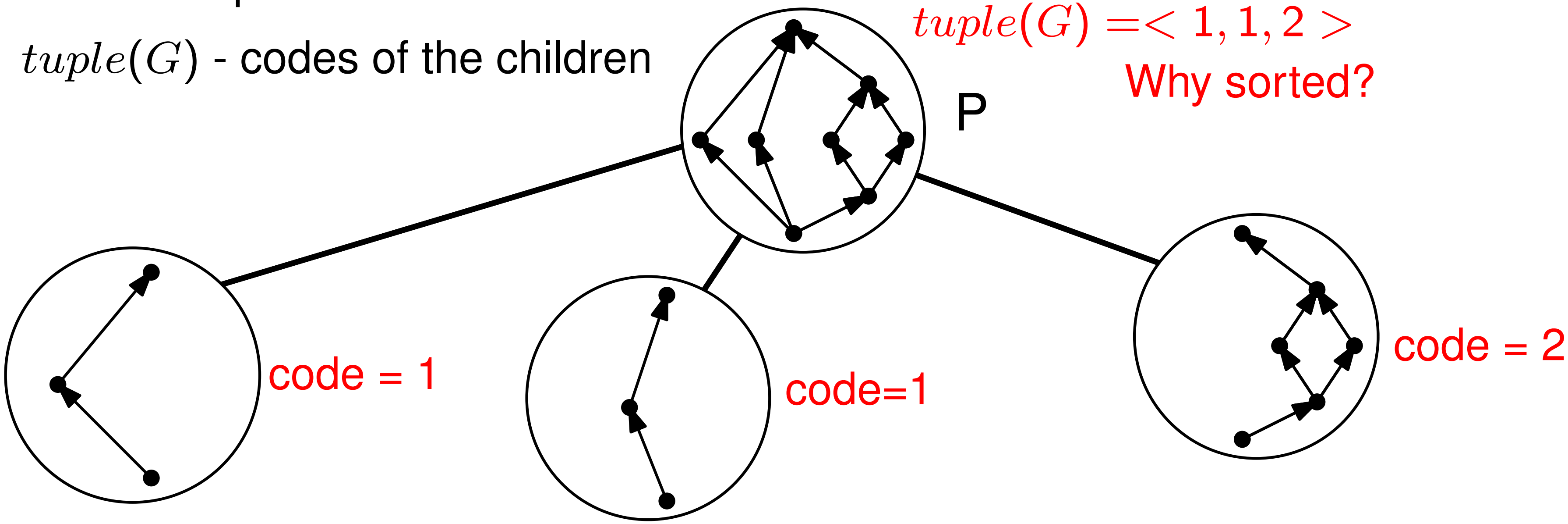

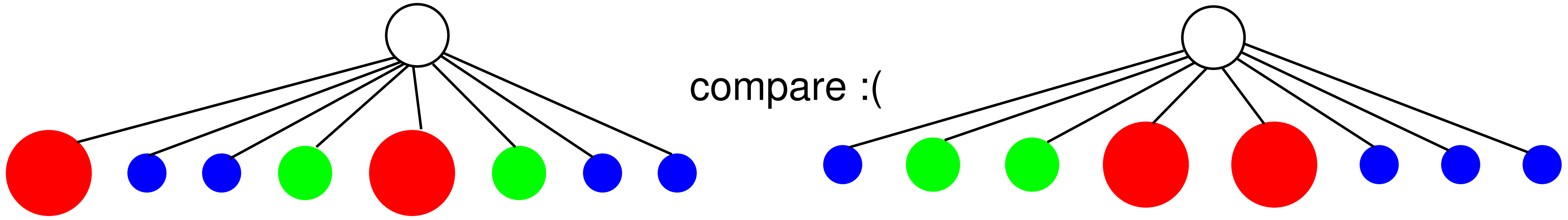

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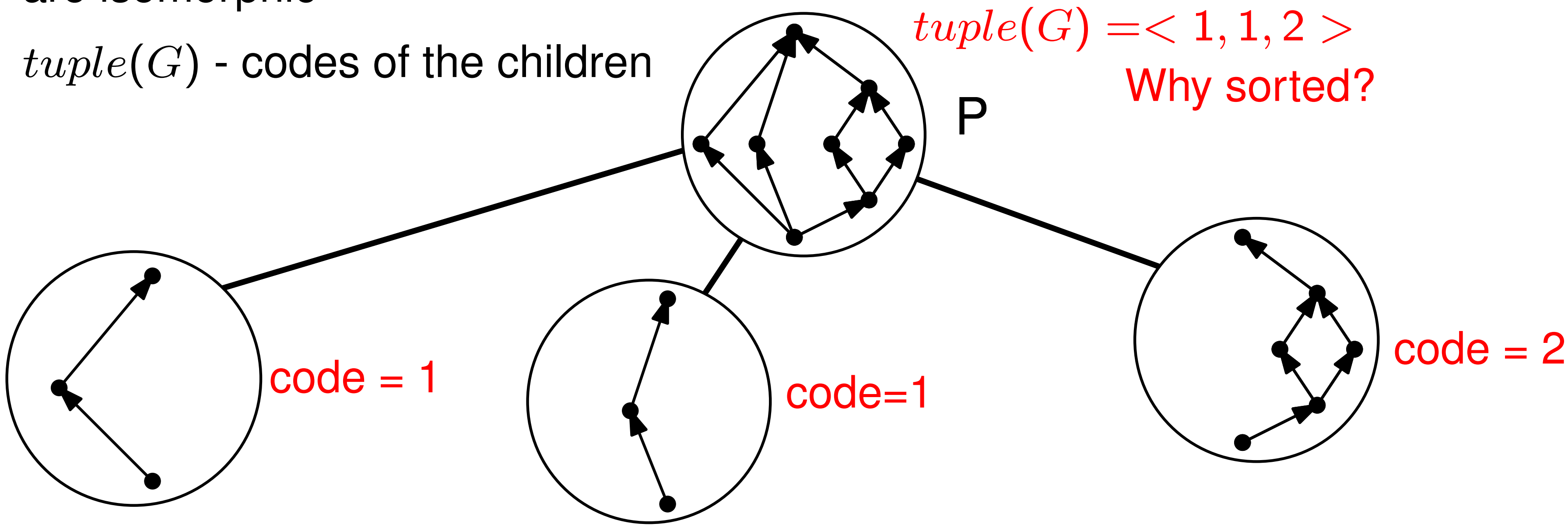

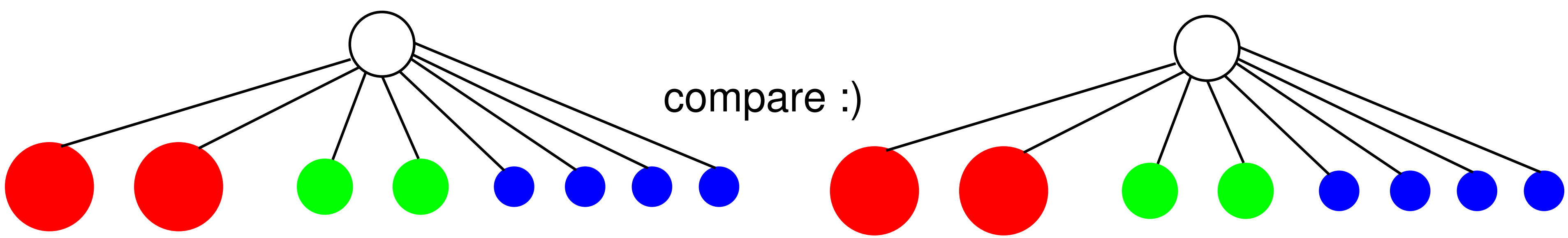

Vertical Automorphism

Algorithm constructing a Canonical Labeling

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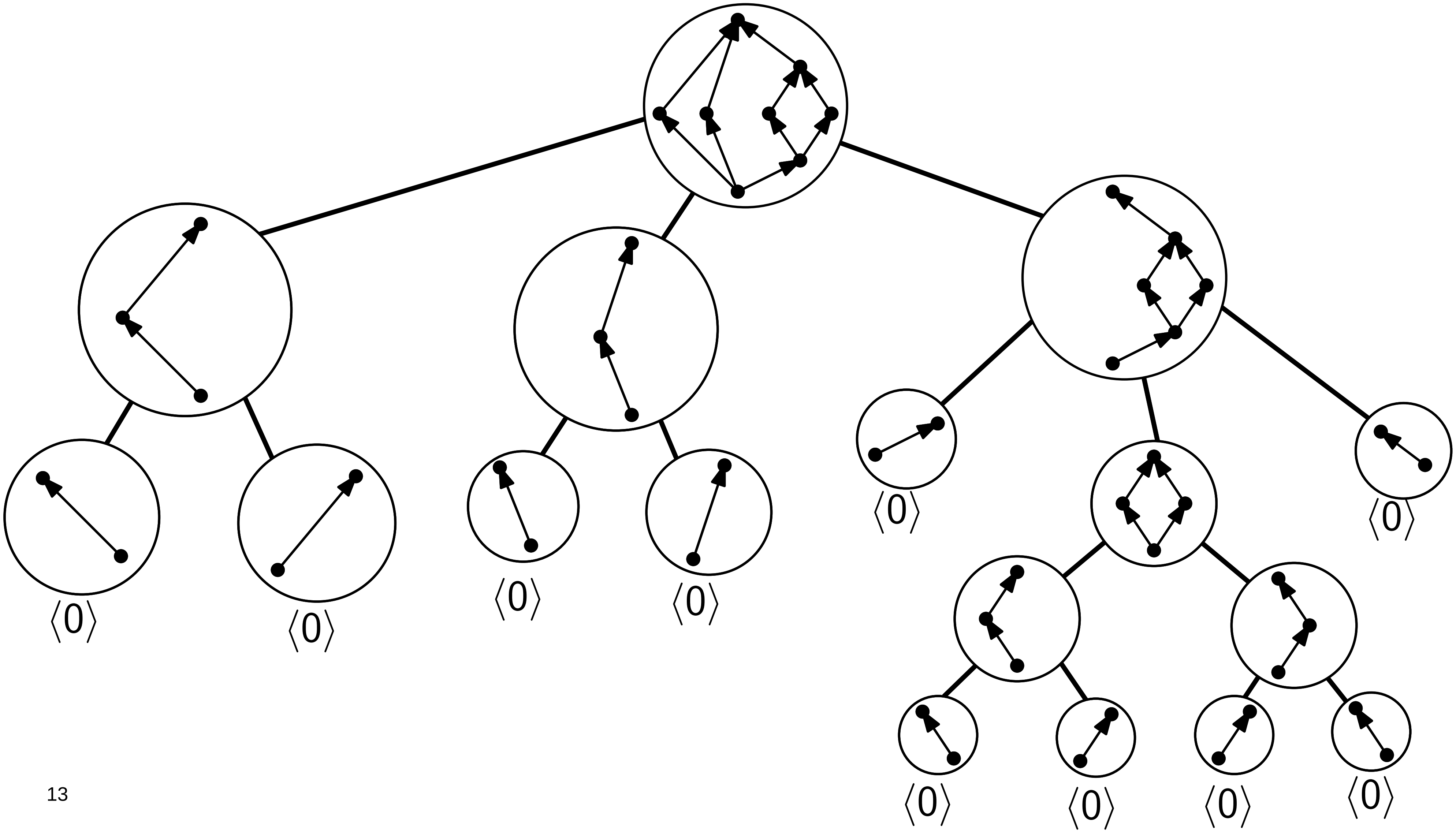
Lemma

Two nodes u and v at the same depth of the decomposition tree of G represent isomorphic subgraphs of G iff $code(u) = code(v)$.

Vertical Automorphism



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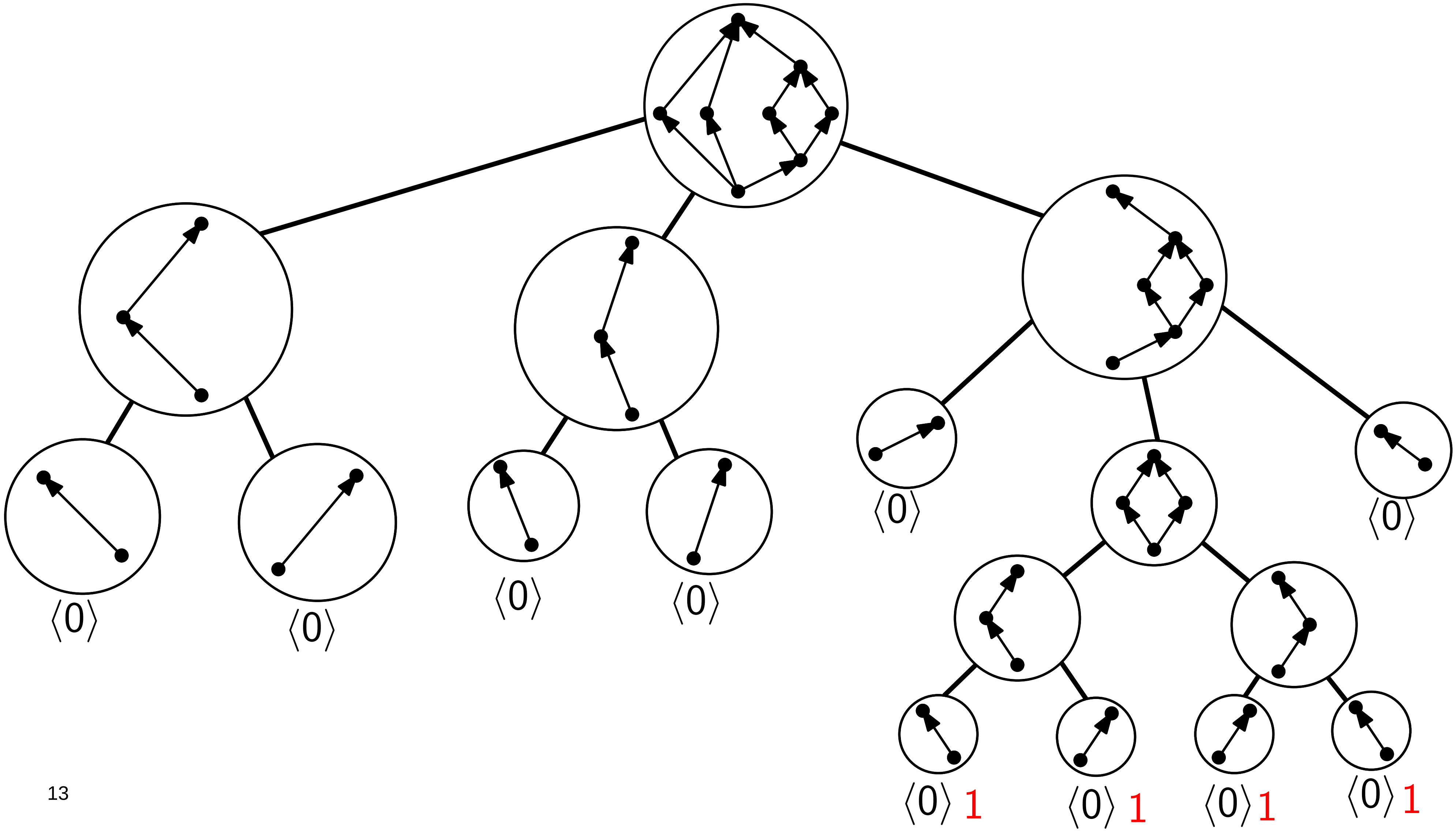

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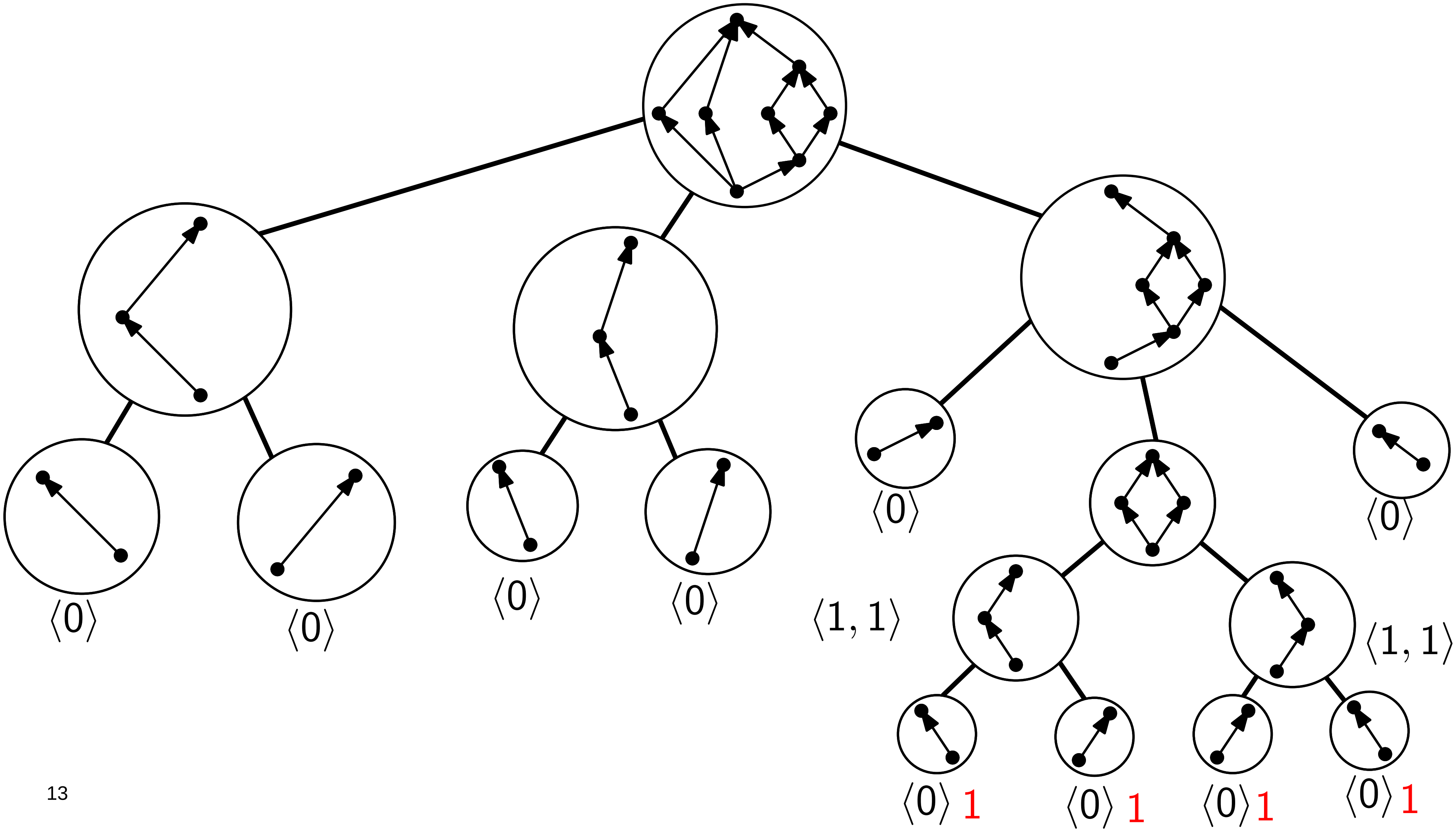

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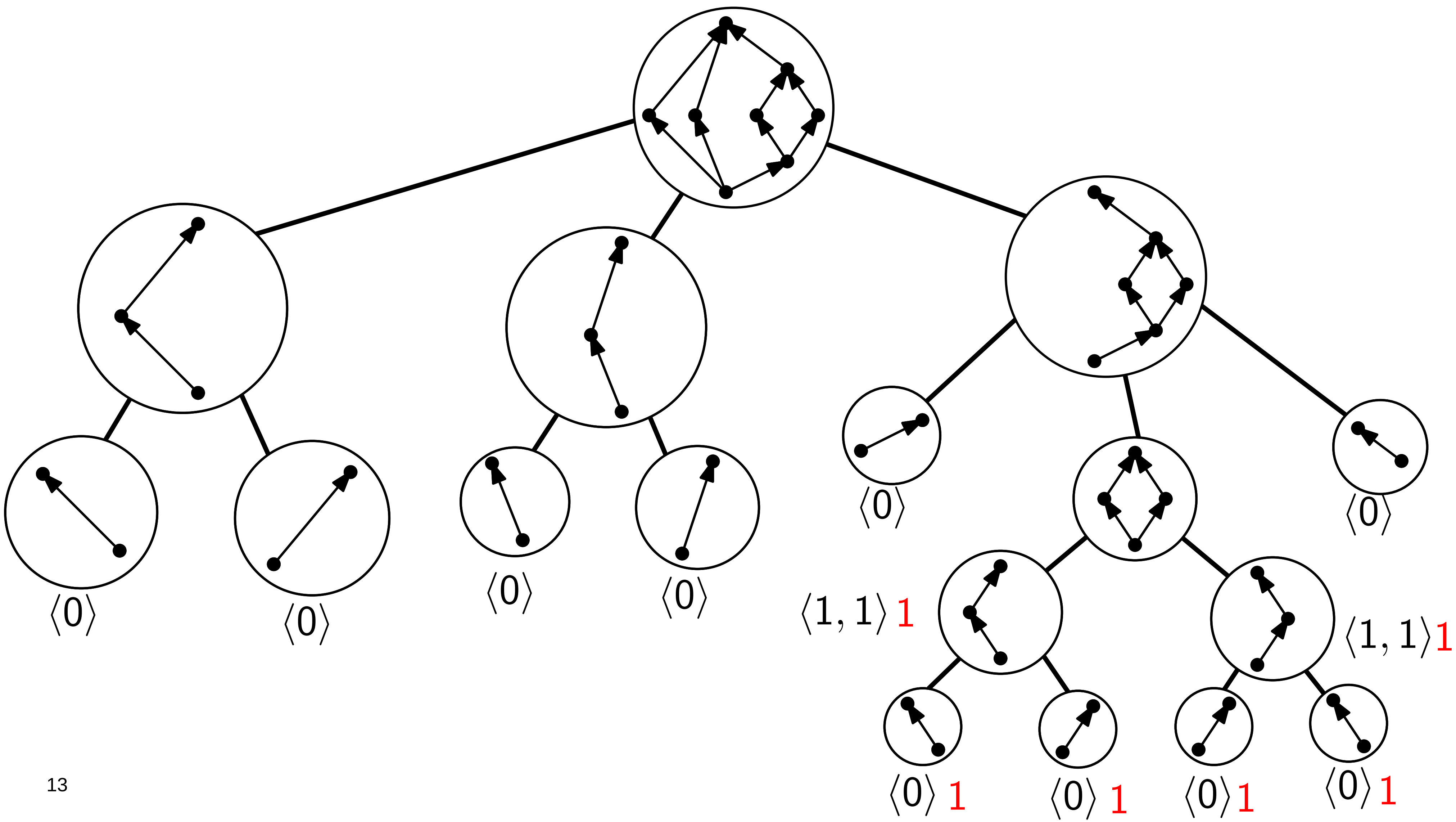

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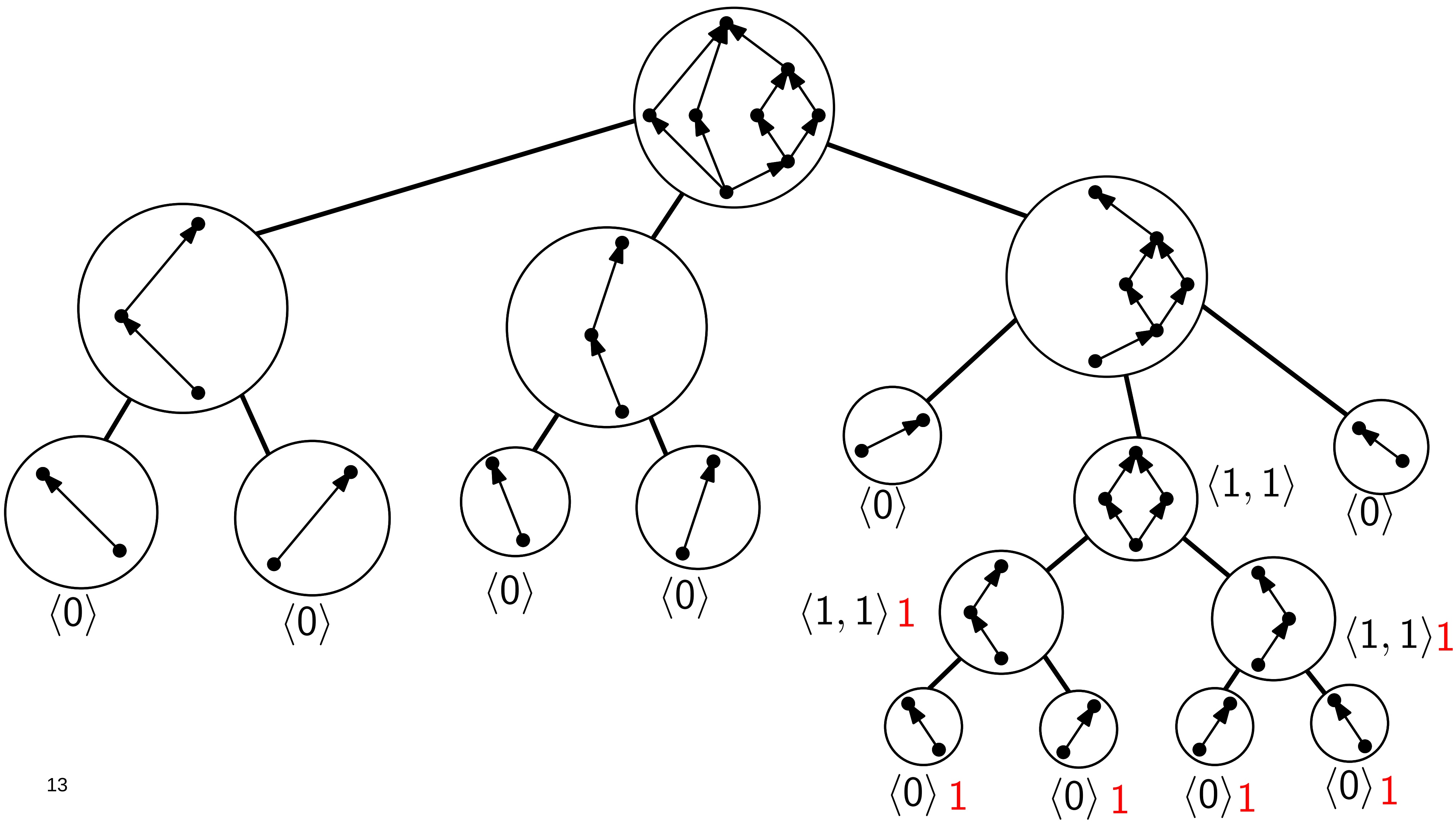

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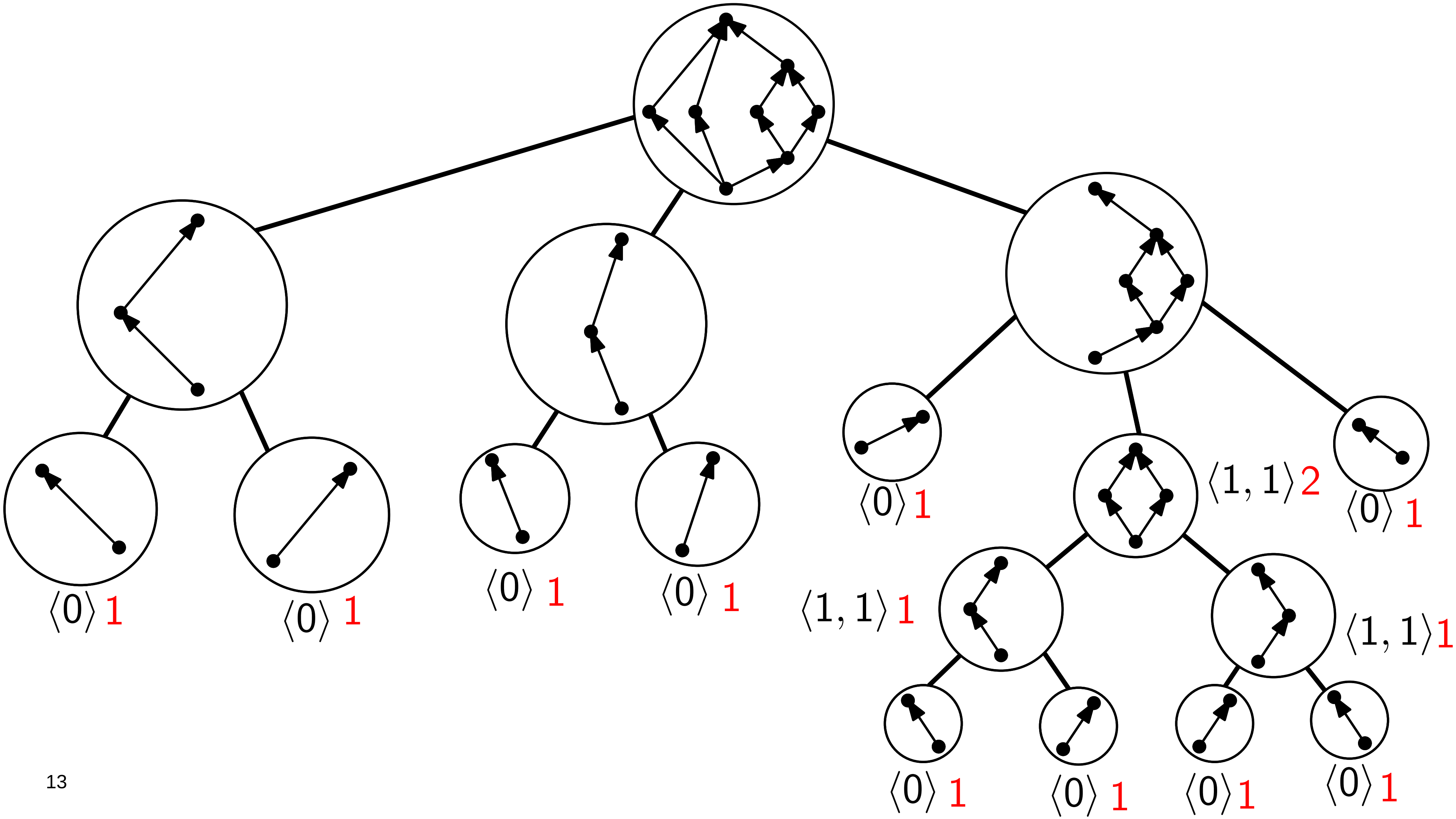

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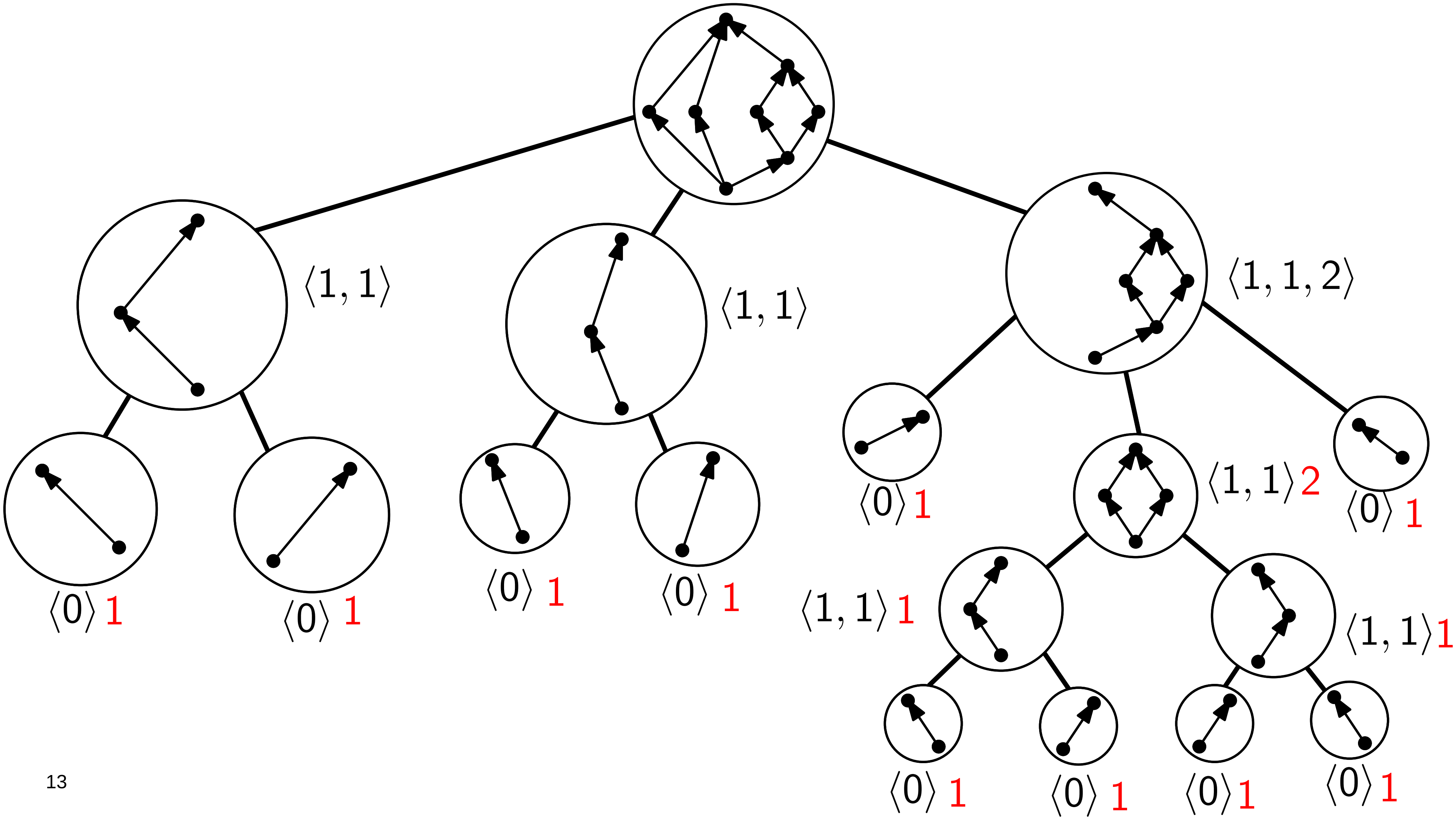

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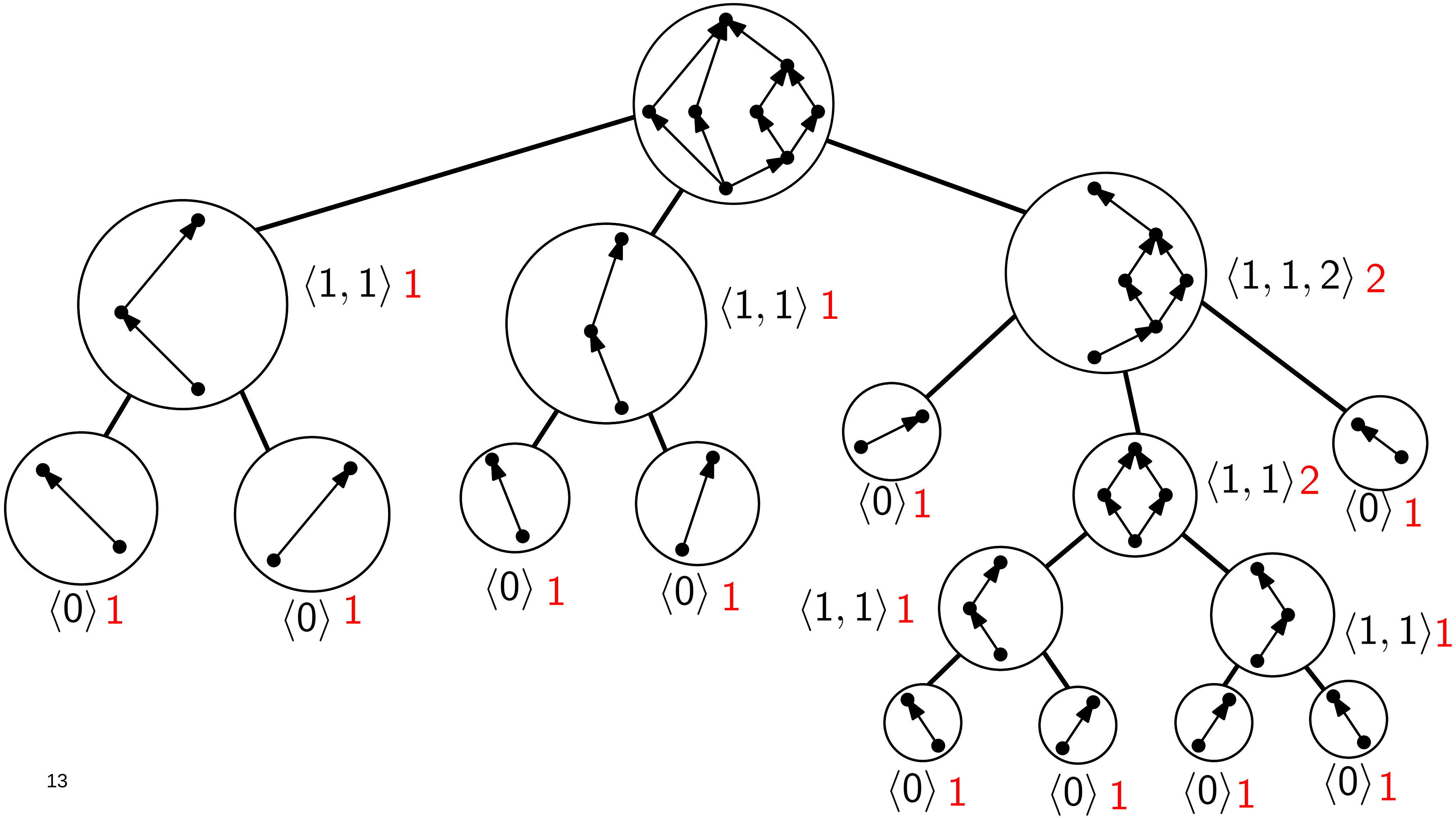

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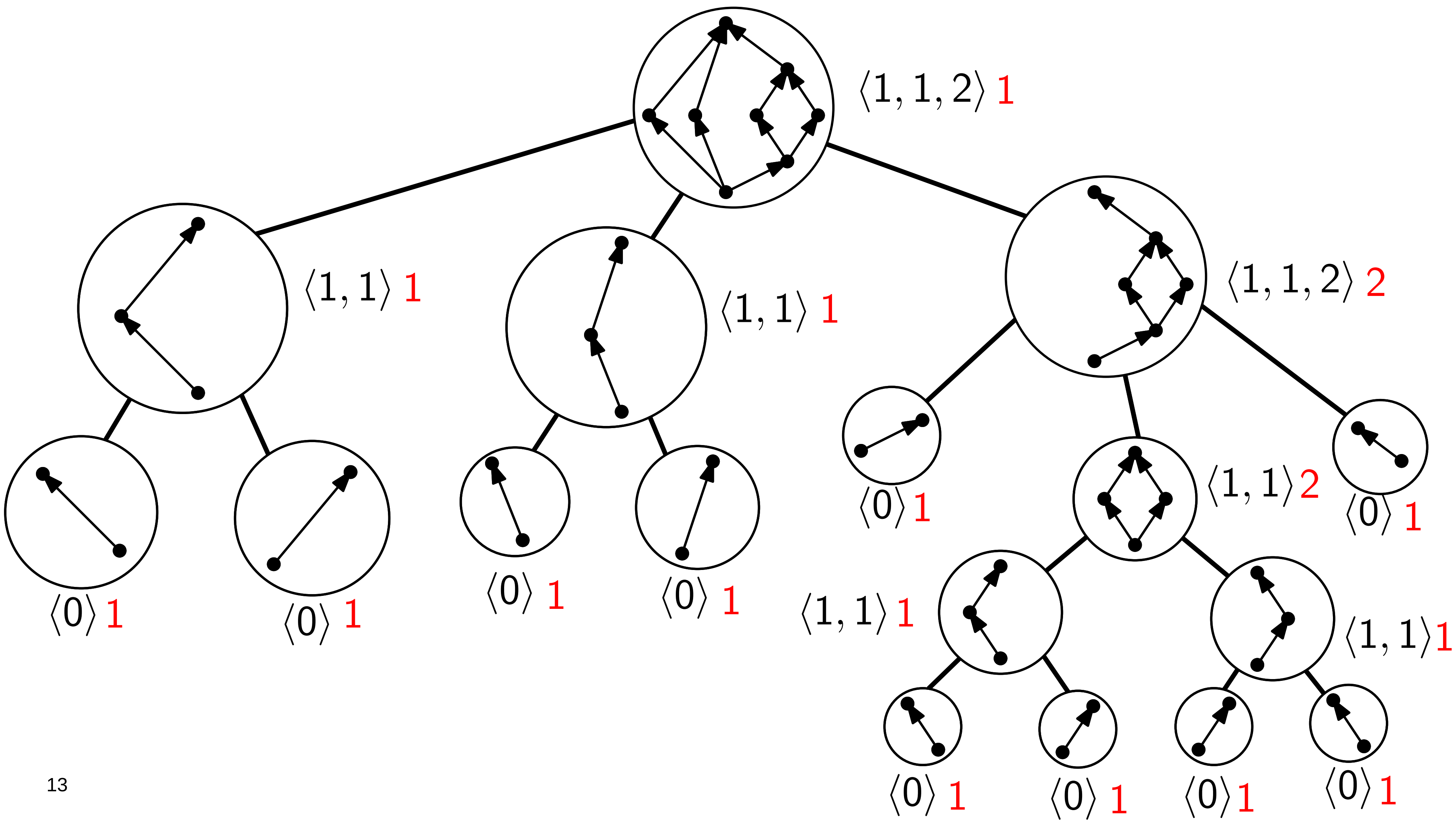
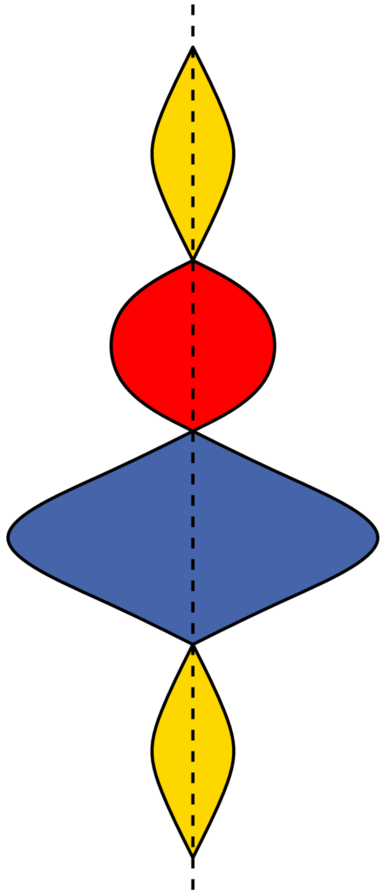


Vertical Automorphism

- Let G be composed out of $G_1 \dots G_n$ through series or parallel composition, $tuple(G)$ contains the codes of $G_1, \dots, G_n$.
- How can we use $tuple(G)$ do decide whether G has a vertical automorphism?



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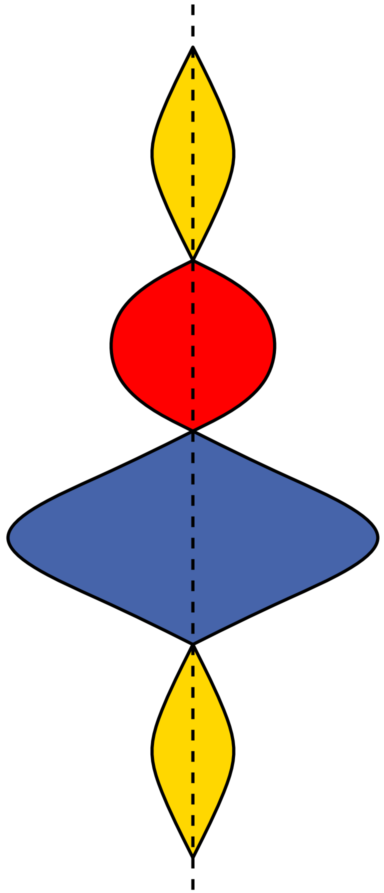

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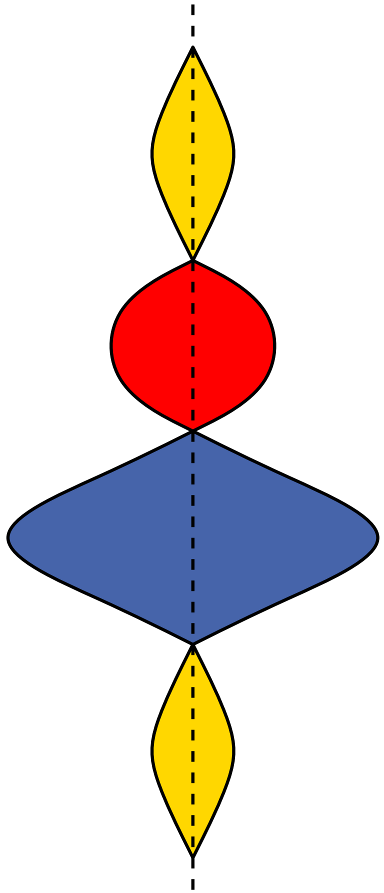

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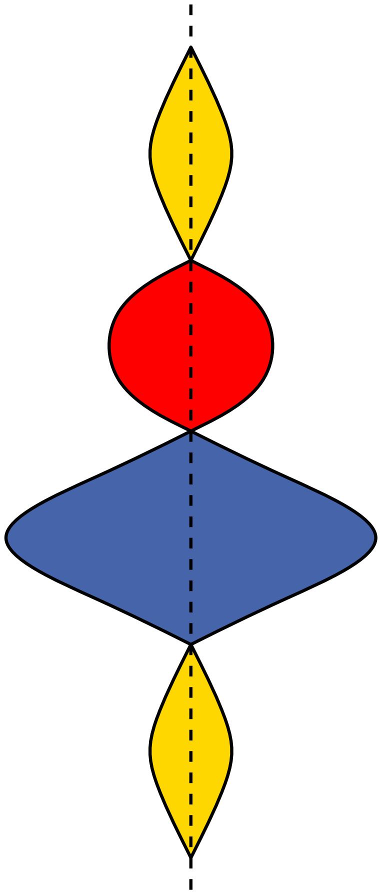

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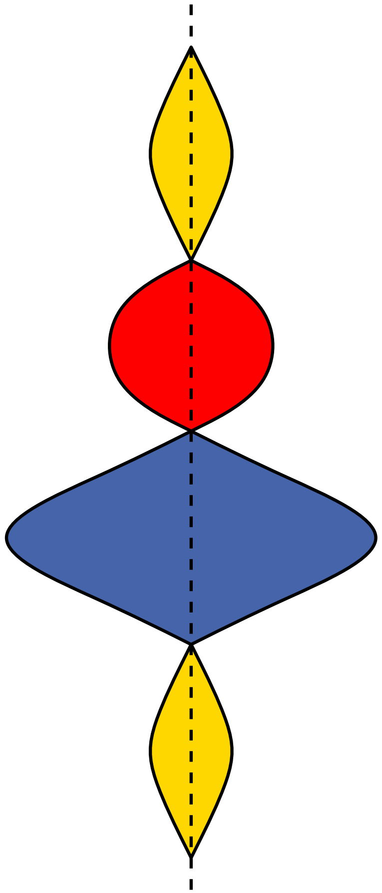

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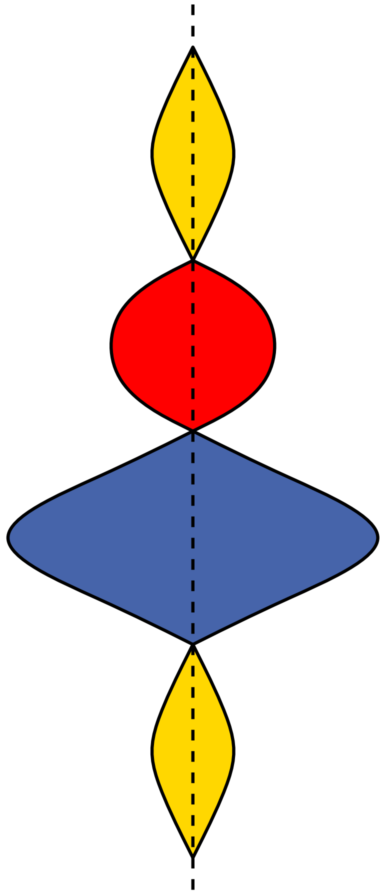
- Therefore each of the series components has a vertical automorhism

G is an S-node

Vertical Automorphism

- Let G be composed out of $G_1 \ldots G_n$ through series or parallel composition, $tuple(G)$ contains the codes of $G_1, \ldots, G_n$.
- How can we use $tuple(G)$ do decide whether G has a vertical automorphism?



G is an S-node

Lemma (Hong, Eades, Lee '00) [HEL00]

If G is an S-node, then G has a vertical automorphism iff each of $G_1, \ldots, G_k$ has a vertical automorphism.

Proof:

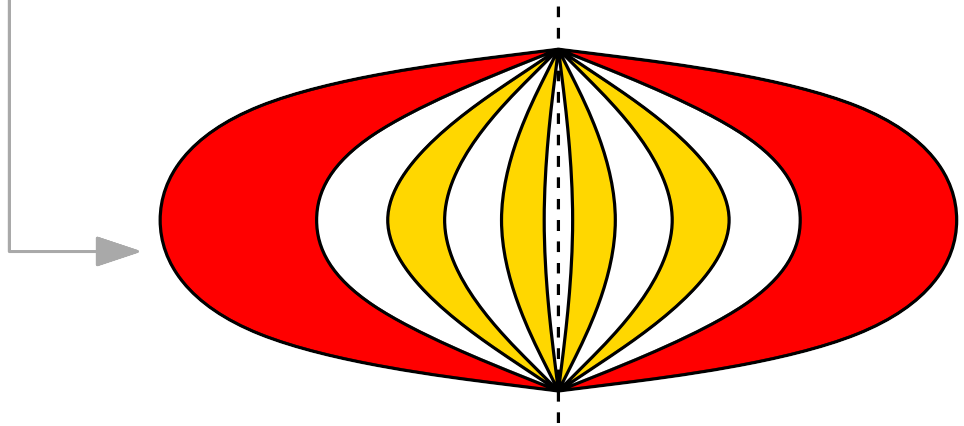
- Assume G has a vertical automorphism α
- Then α "fixes" all the components
- Therefore each of the series components has a vertical automorhism
- If each of $G_1, \ldots, G_n$ has a vertical isomorphism, arrange them as in Figure.

Vertical Automorphism

Lemma (Hong, Eades, Lee '00) [HEL00]

If G is a P-node, consider a partition of $\mathcal{C}_j = \{G_i : 1 \leq i \leq k, code(G_i) = j\}$, $j = 1, \ldots, k$ into classes of isomorphic graphs.

- If $\forall j$, $|\mathcal{C}_j|$ are even $\Rightarrow$ has a vertical automorphism.
- If there exists a unique j, such that $|\mathcal{C}_j|$ is odd $\Rightarrow$ G has a vertical automorphism iff graphs of $\mathcal{C}_j$ have a vertical automorphism.
- If there exists $|\mathcal{C}_i|, |\mathcal{C}_j|$ with $i \neq j$, both odd $\Rightarrow$ G does not have a vertical automorphism.



Proof:

- Arrange components as in Figure.

G is P-node, $tuple(G) =< \underbrace{1 \ldots 1}_{even}, \underbrace{2 \ldots 2}_{even}, \cdots >$

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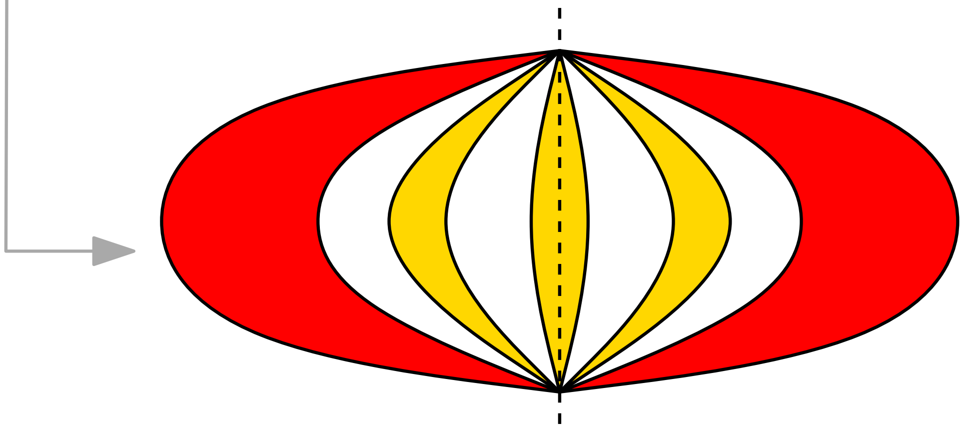

$$tuple(G) = < \underbrace{1 \ldots 1}_{odd}, \underbrace{2 \ldots 2}_{even}, \underbrace{3 \ldots 3}_{even}, \cdots >$$

Proof:

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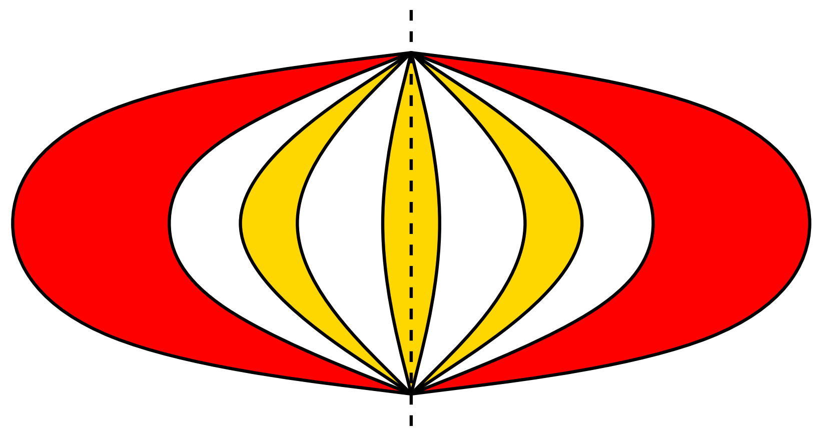

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Proof:

- Any vertical automorphism “fixes” a member of $\mathcal{C}_j$, therefore it has a vertical automorphism.

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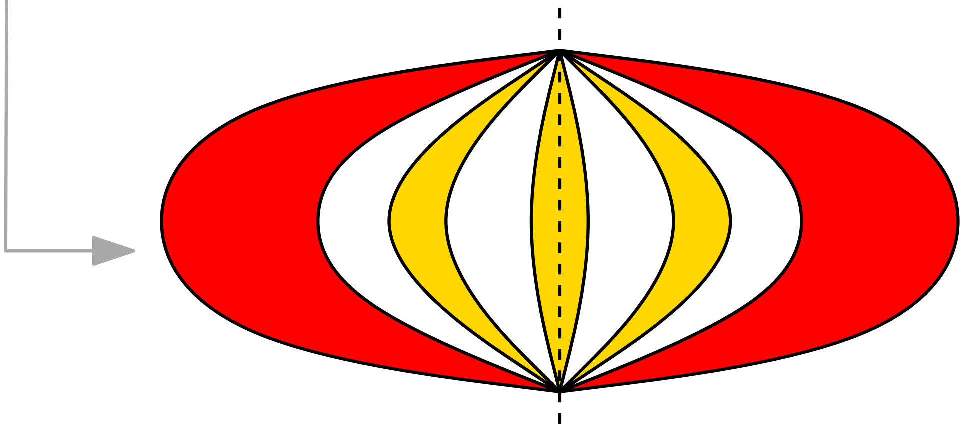

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- Any vertical automorphism "fixes" a member of $\mathcal{C}_j$, therefore it has a vertical automorphism.
- Conversly, arrange as in figure.

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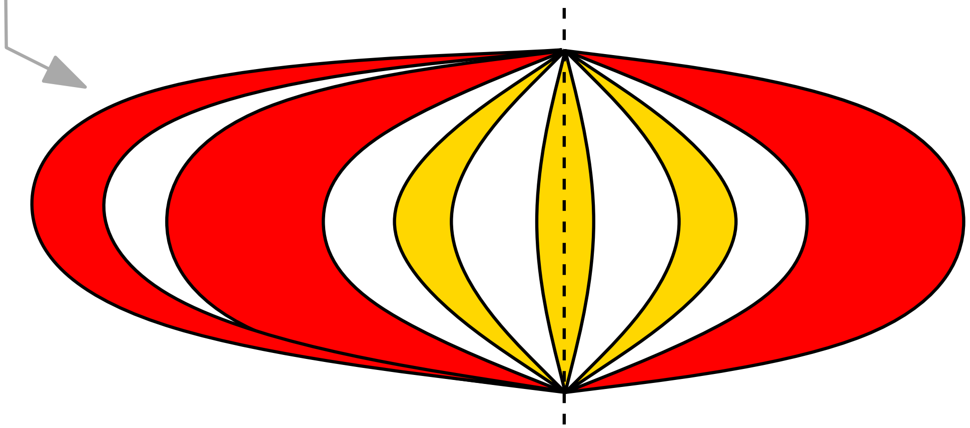

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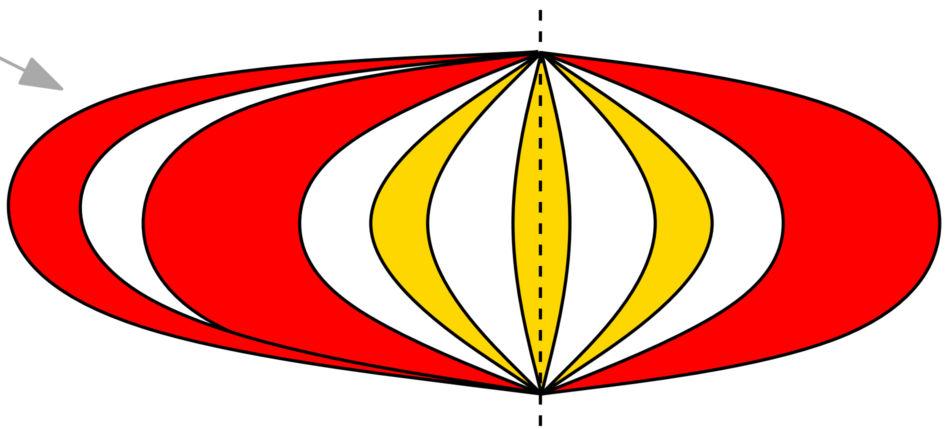

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Proof:

- Any vertical automorphism has to "fix" two distinct components.

Vertical Automorphism

Karlsruhe Institute of Technology

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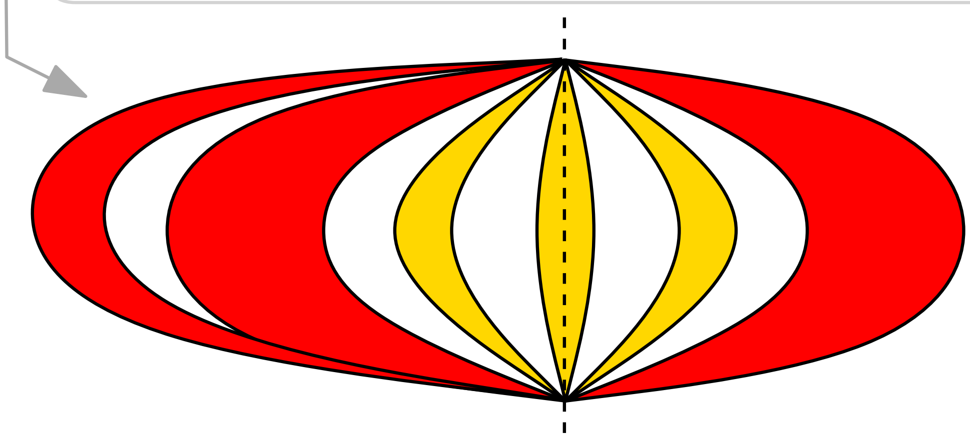

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Proof:

- Any vertical automorphism has to "fix" two distinct components.
- In both components we can find a path on which some vertices are aligned on the axis. Contradicts planarity.

Vertical Automorphism

Theorem (Hong, Eades, Lee '00)

Given a decomposition tree of a series-parallel graph and its canonical labeling. Let G be a component which consists from $G_1, \ldots, G_k$ through series or parallel composition.

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