Graph modification of bounded size to minor-closed classes as fast as vertex deletion

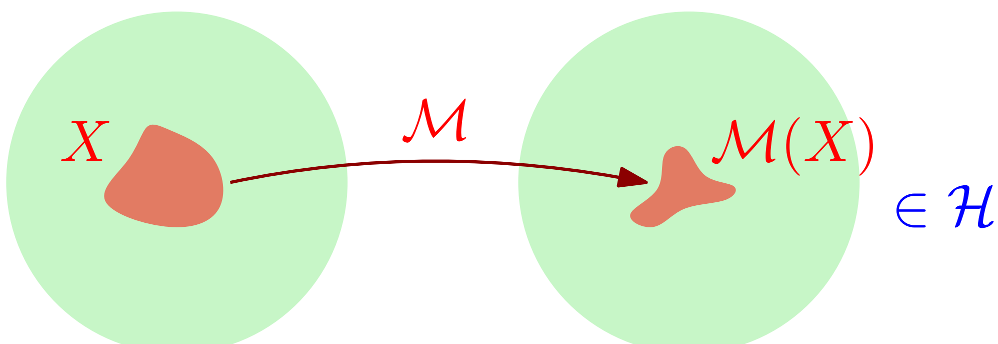
Laure Morelle, Ignasi Sau, Dimitrios M. Thilikos

LIRMM, CNRS, Université de Montpellier, France

ESA 2025, Warsaw, Poland

Modification $\mathcal{M}$, graph class $\mathcal{H}$

Graph modification problem:
Input: Graph G, integer k.
Question: Can we do $\leq k$ modifications to G s.t. the modified graph belongs to the target class $\mathcal{H}$?



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Modification +	Target class =	Problem
vertex deletion	edgeless graphs	VERTEX COVER
	forests	FEEDBACK VERTEX SET
	bipartite graphs	ODD CYCLE TRANSVERSAL
edge addition + deletion	union of cliques	CLUSTER EDITING
edge contraction	planar graphs	CONTRACTION TO PLANAR

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Highly prolific field:
299 papers mentionned just for edge-modifications in
[A survey of parameterized algorithms and the complexity of edge-modification, Crespelle, Drange, Fomin, Golovach, 2023]

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Holy grail:
Instead of solving modification problems one by one, can we provide a meta-algorithm solving as many problems as possible at once?

Meta-algorithm on target classes

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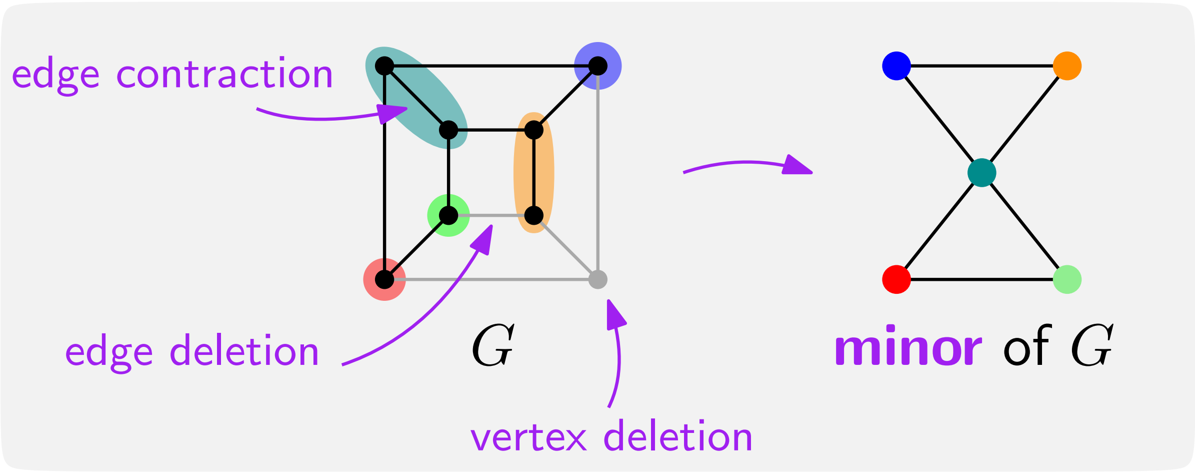

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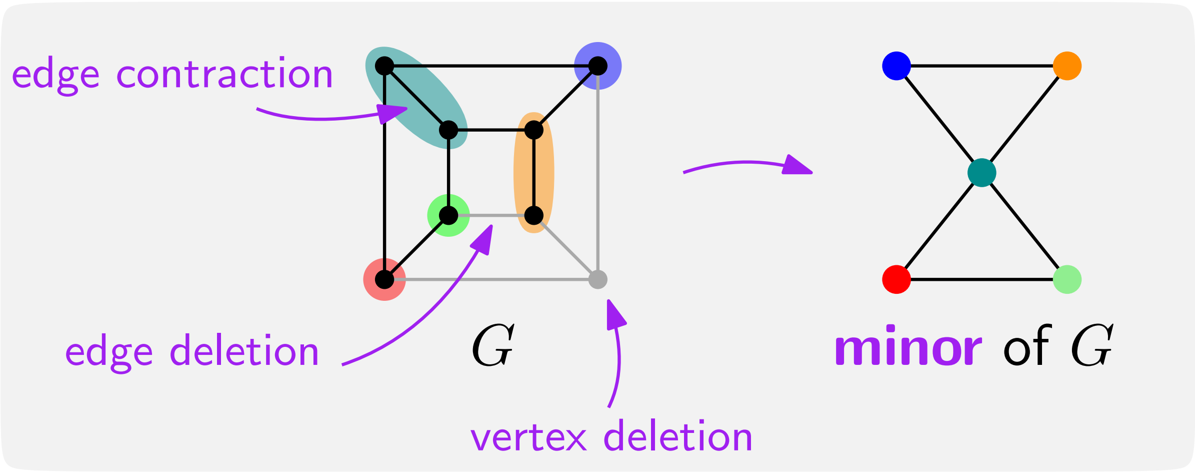

Minor-closed graph class $\mathcal{H}$

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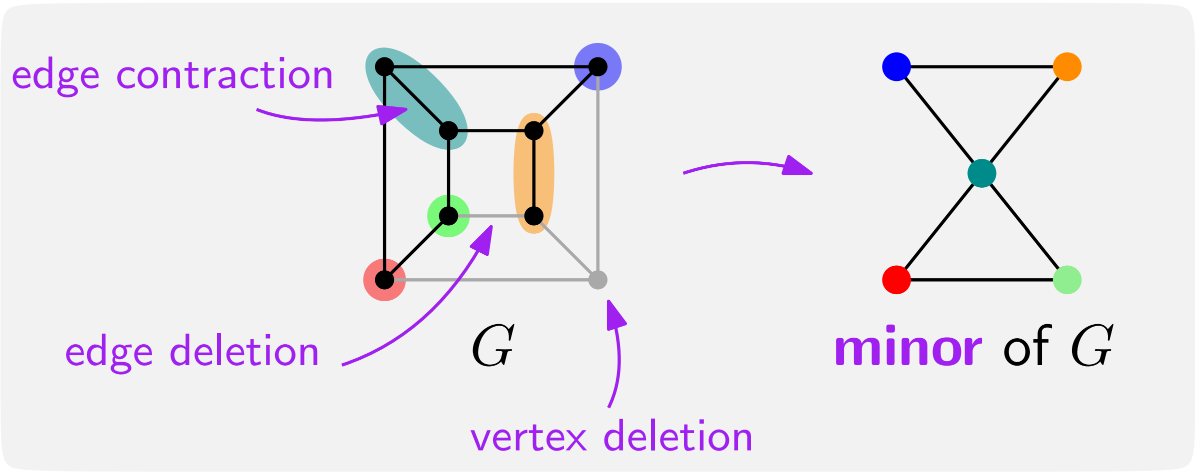

Minor-closed graph class $\mathcal{H}$ ← If $G \in \mathcal{H}$, then minors of G in $\mathcal{H}$.

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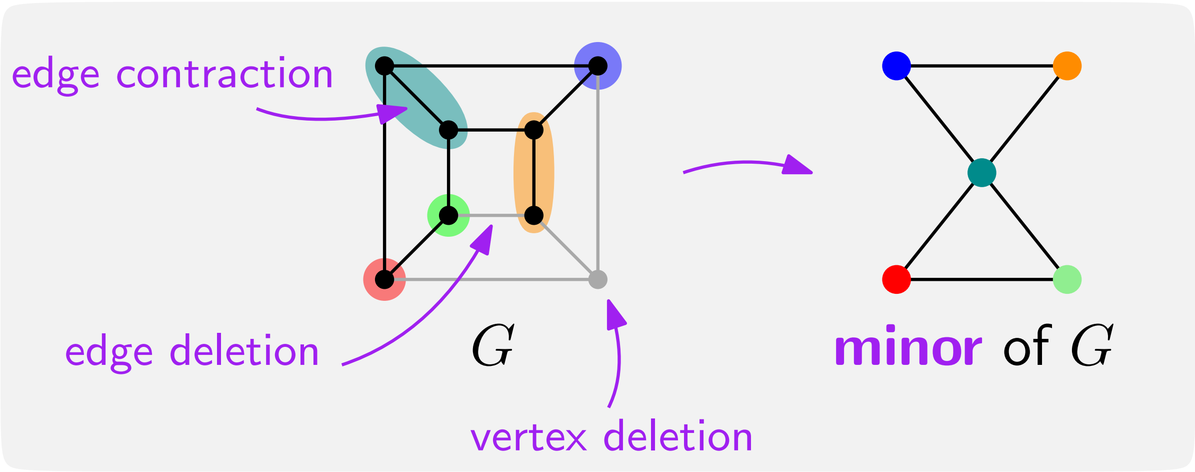

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edgeless graphs, forests, planar graphs, graphs embeddable on a surface, . . .

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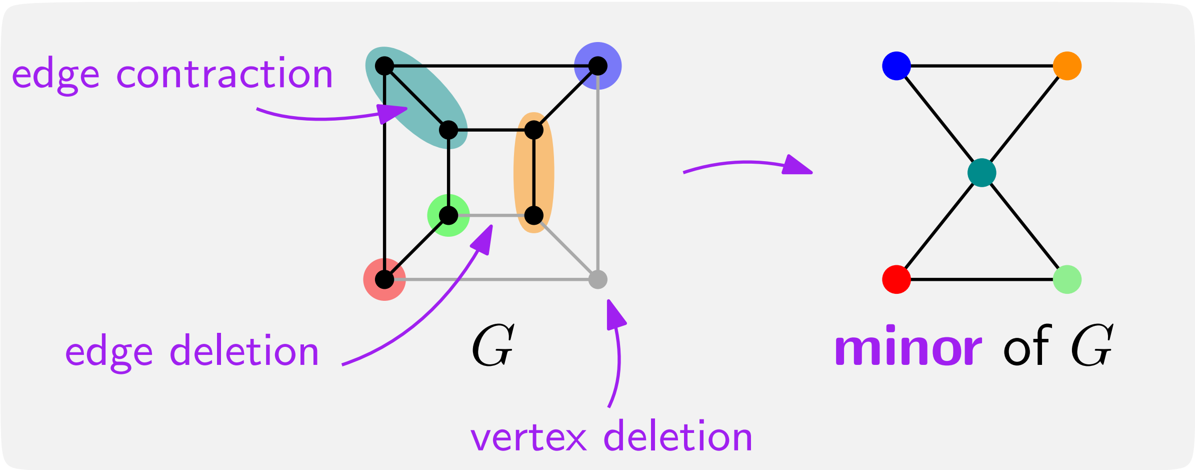

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$\mathcal{H}$ has a finite number of minor-obstructions.

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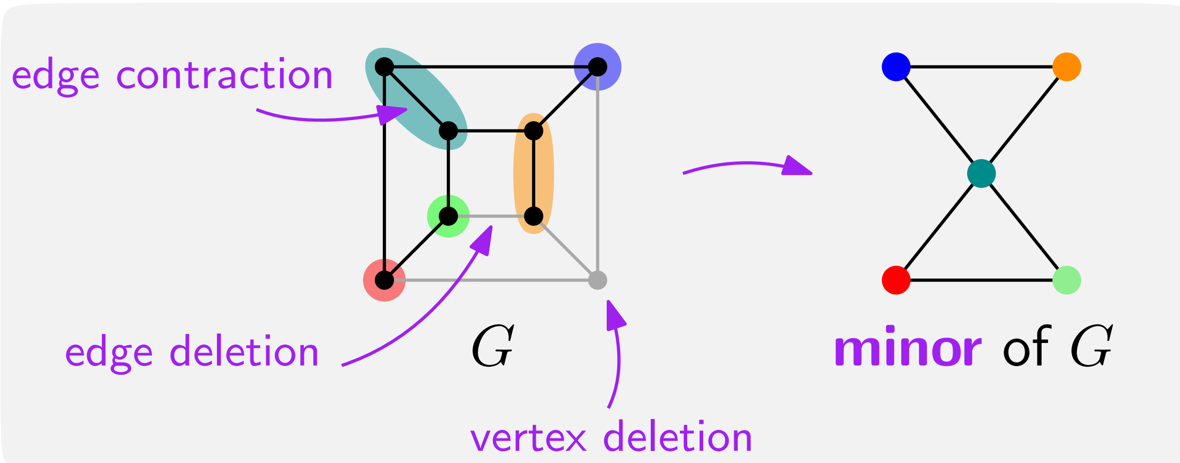

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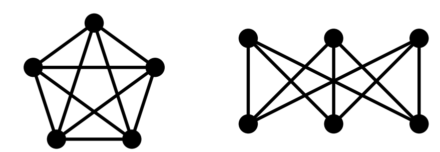

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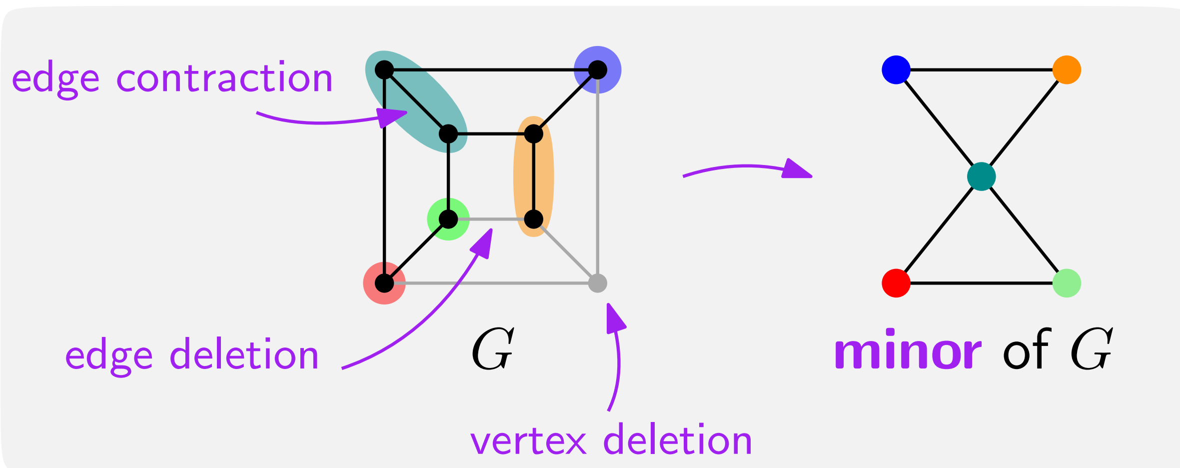

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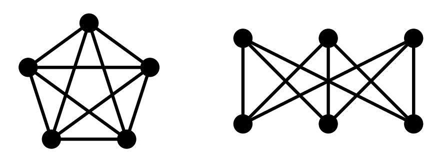

[Korhonen, Pilipczuk, Stamoulis, 2024]

Checking whether H is a minor of G can be done in time $\mathcal{O}_H(n^{1+o(1)})$.

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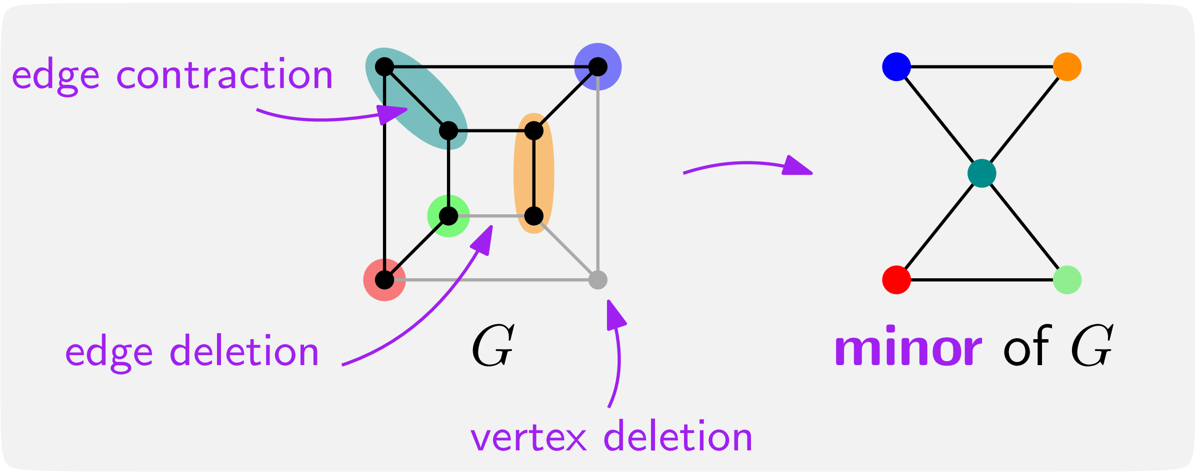

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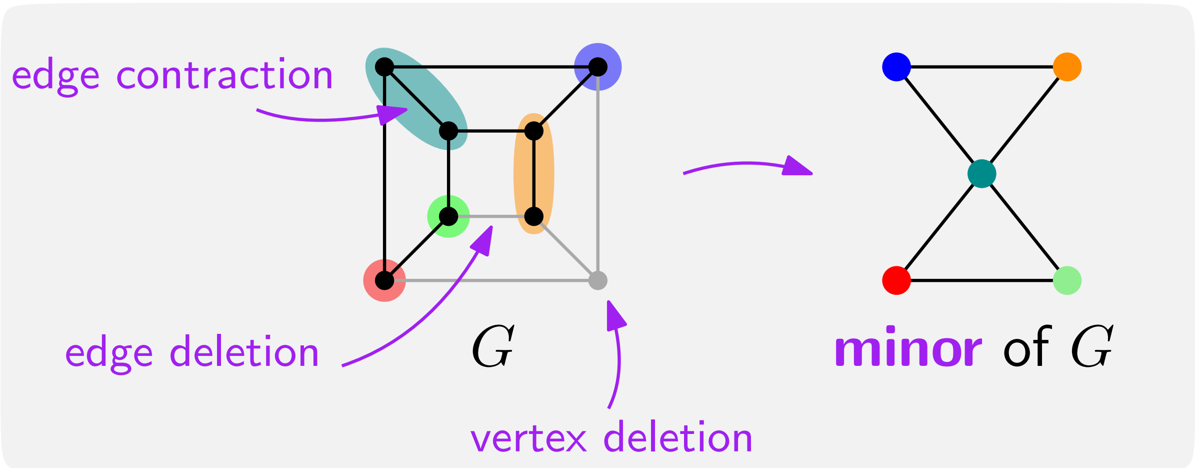

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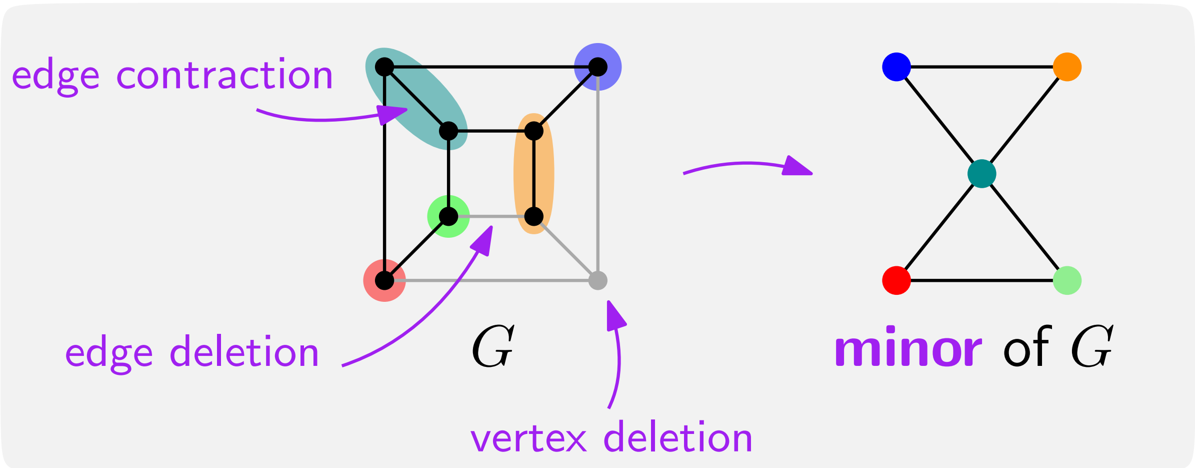

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because yes-instances of k-Vertex / Edge Deletion to $\mathcal{H}$ are minor-closed.

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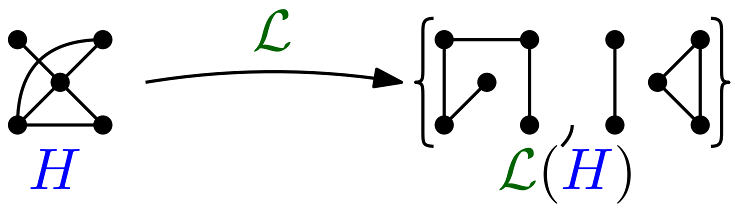

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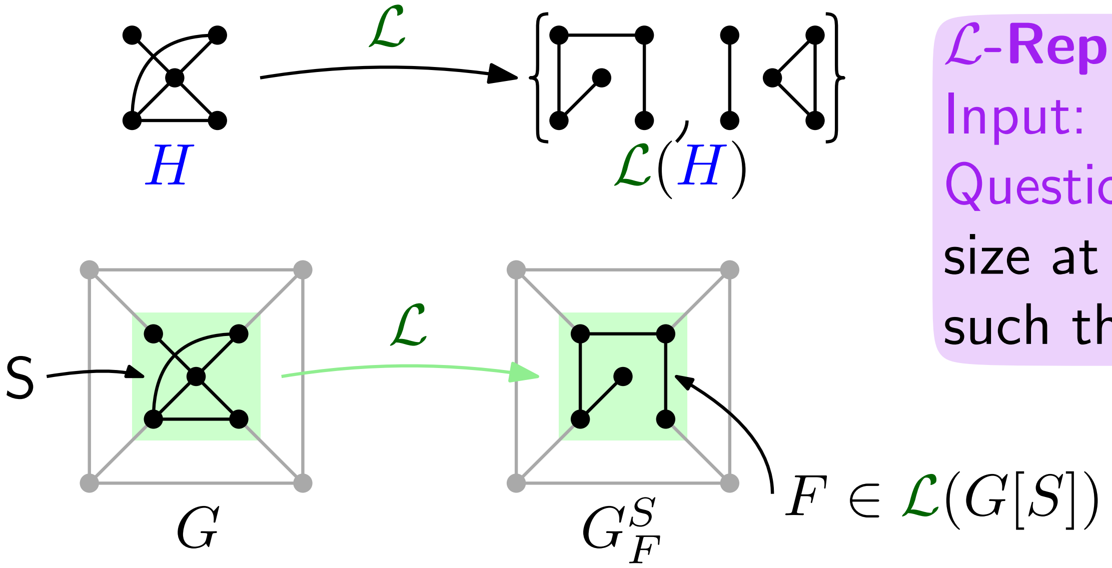

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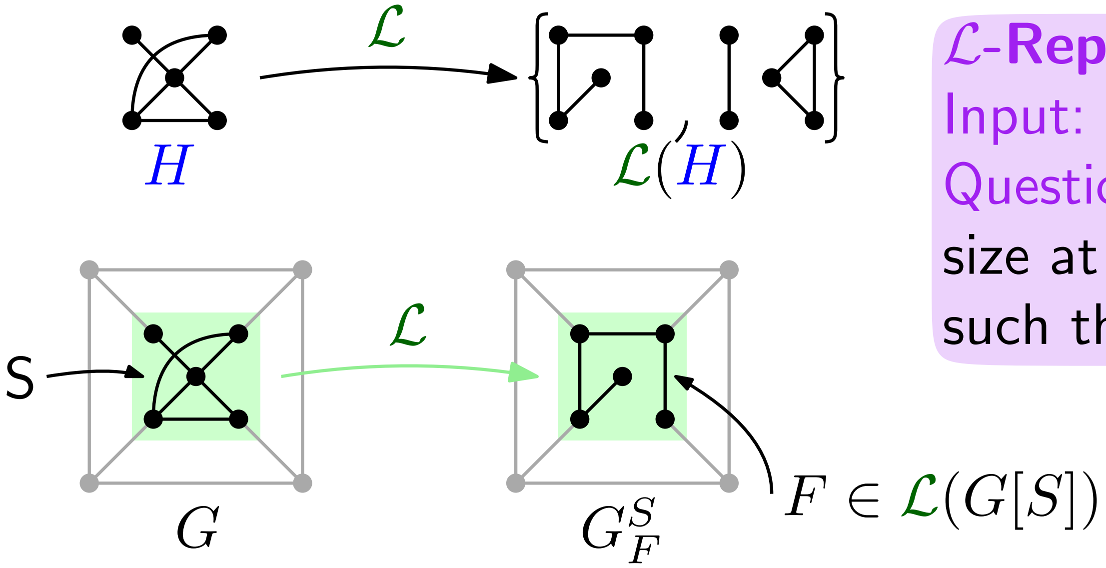

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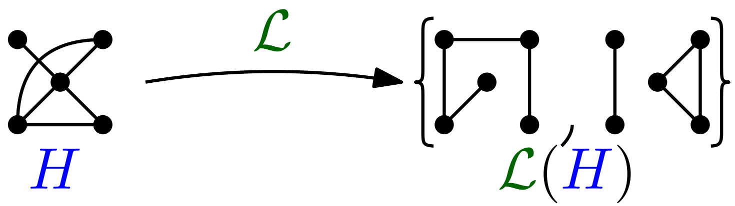

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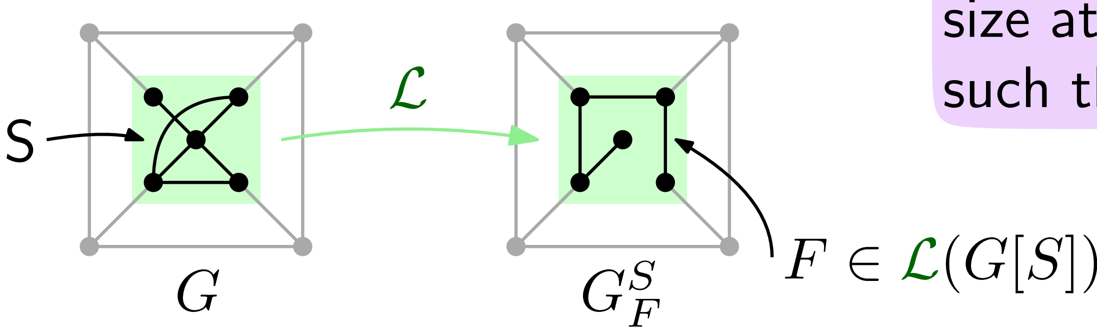

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$\mathcal{L}$-REPLACEMENT TO PLANAR in time $f(k) \cdot n^2$.

- EDGE DELETION TO PLANAR
- PLANAR COMPLETION TO A SUBGRAPH
- MATCHING DELETION TO PLANAR
- PLANAR SUBGRAPH ISOMORPHISM

Meta-algorithm on modifications and target classes

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[S., Stamoulis, Thilikos, 2025]

Given a formula $\varphi \in \mathsf{CMSO/tw + dp}$, and a graph G that is H-minor-free, one can check whether $G \models \varphi$ in time $f(|\varphi|, |H|) \cdot n^2$.

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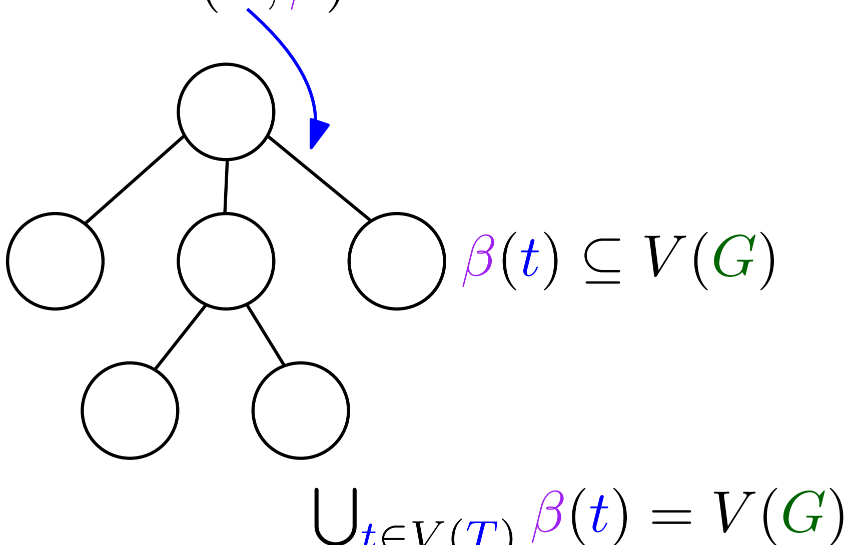

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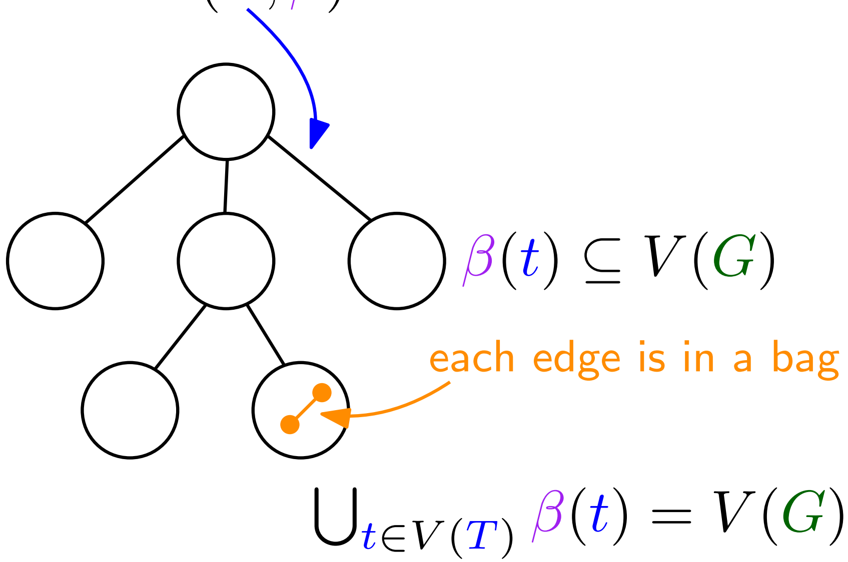

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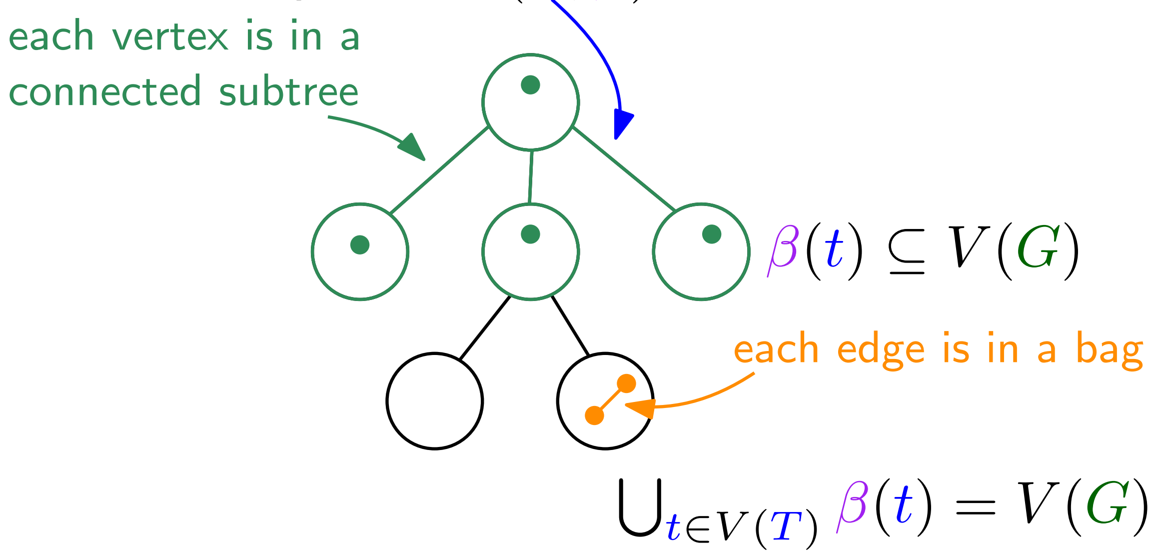

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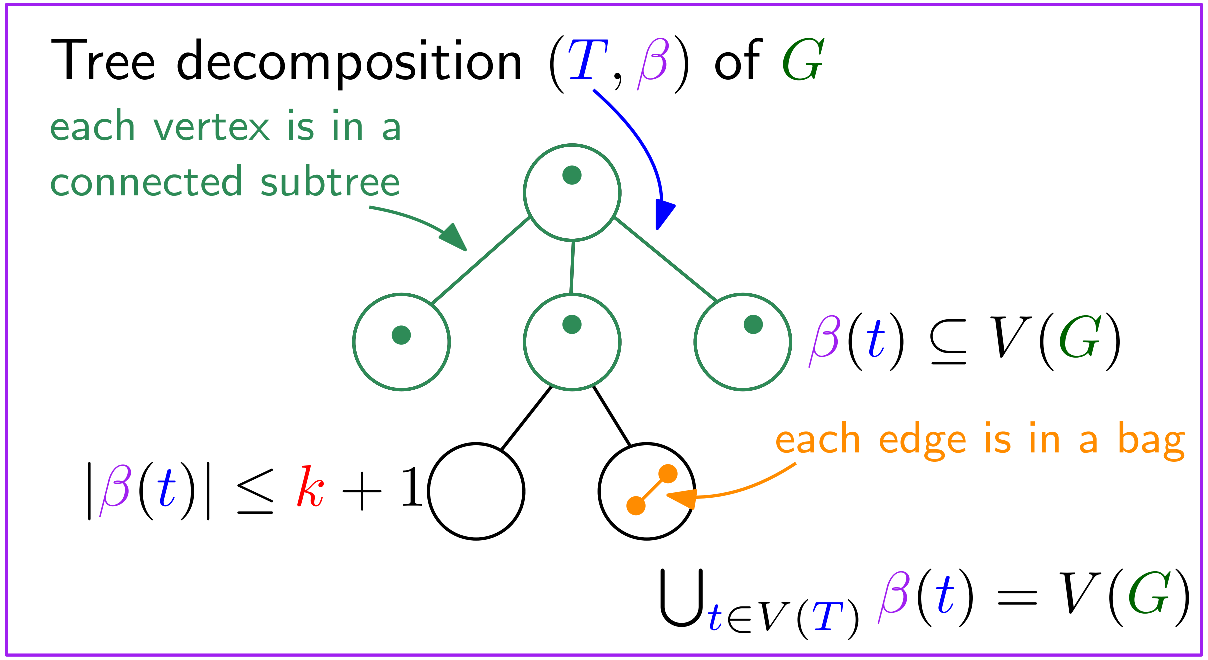

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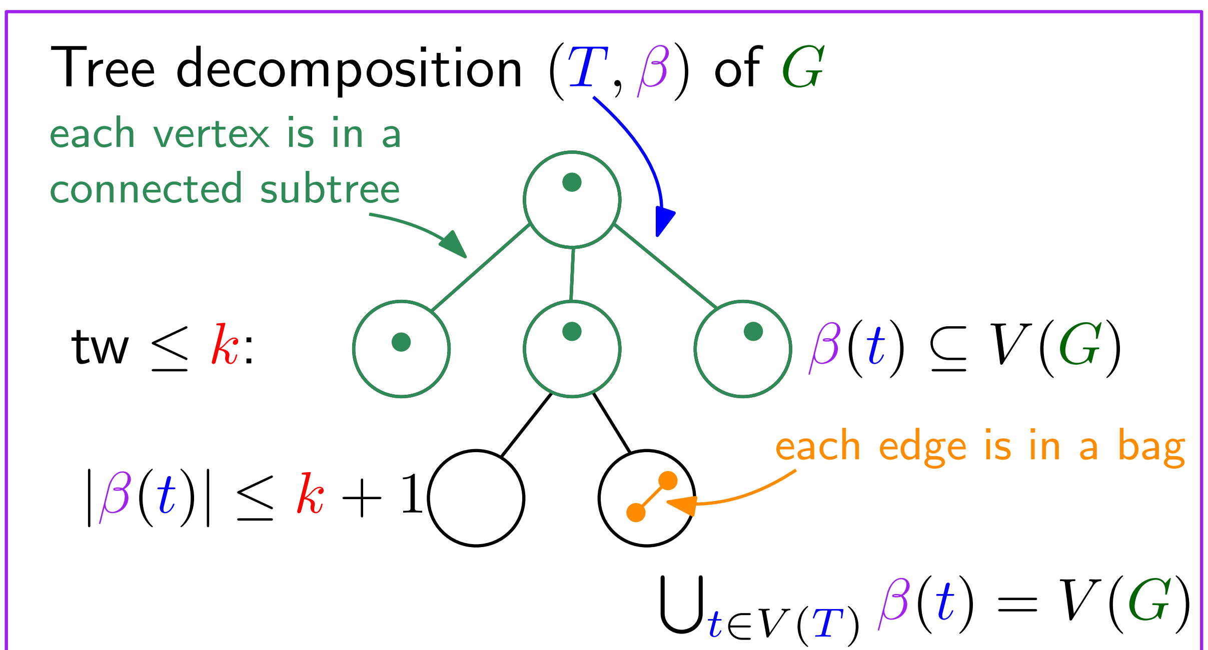

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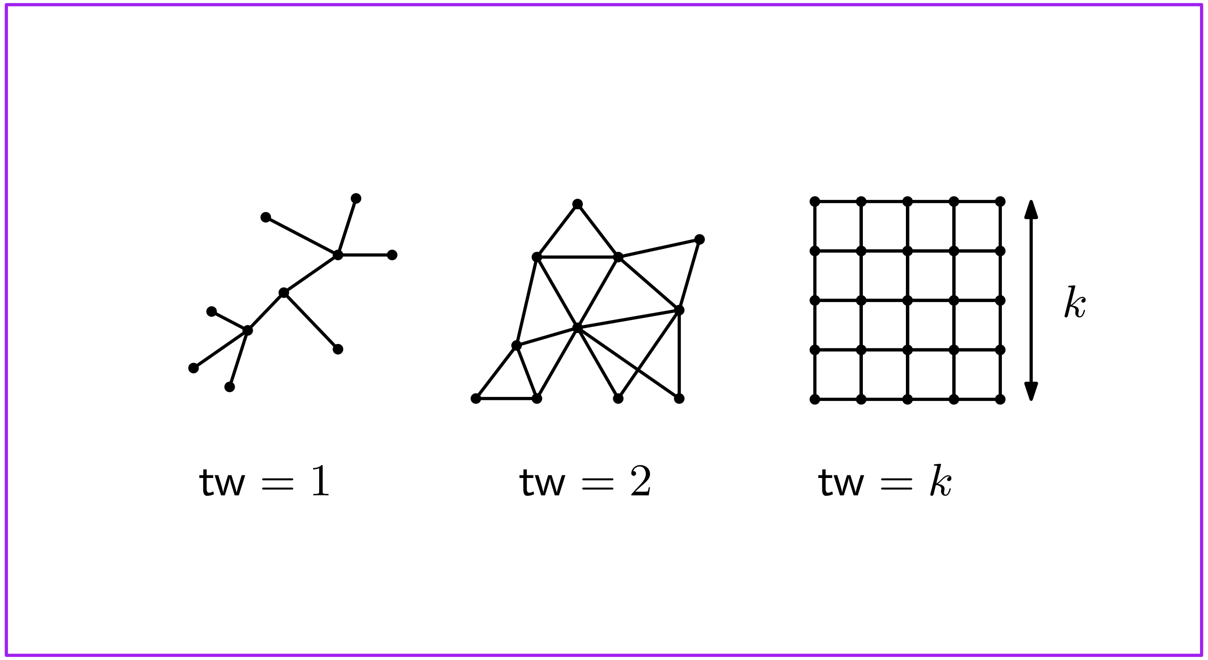

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Natural goal: efficient parametric dependence on k, for particular (still relevant) cases of the modification operation.

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[Baste, S., Thilikos, 2018-2020]
[S., Stamoulis, Thilikos, 2020-2021]
[Morelle, S., Stamoulis, Thilikos, 2023]
[Morelle, S., Thilikos, ESA 2025]

$\mathcal{H}$ minor-closed

Vertex Deletion to $\mathcal{H}$ in time $2^{O_{\mathcal{H}}(\mathsf{tw} \log \mathsf{tw})} \cdot n$

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The result of this paper

"MODIFICATION OF BOUNDED SIZE TO $\mathcal{H}$" in time $2^{\mathsf{poly}_{\mathcal{H}}(k)} \cdot n^2$

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The result of this paper

$\mathcal{L}$-REPLACEMENT TO $\mathcal{H}$ in time $2^{\mathsf{poly}_{\mathcal{H}}(k)} \cdot n^2$

Our result can be seen as a rare example of an efficient meta-algorithm for graph modification problems to minor-closed graph classes.

Our result: if $\mathcal{H}$ minor-closed

One can solve $\mathcal{L}$-Replacement to $\mathcal{H}$ in time $2^{\mathsf{poly}_{\mathcal{H}}(k)} \cdot n^2$.

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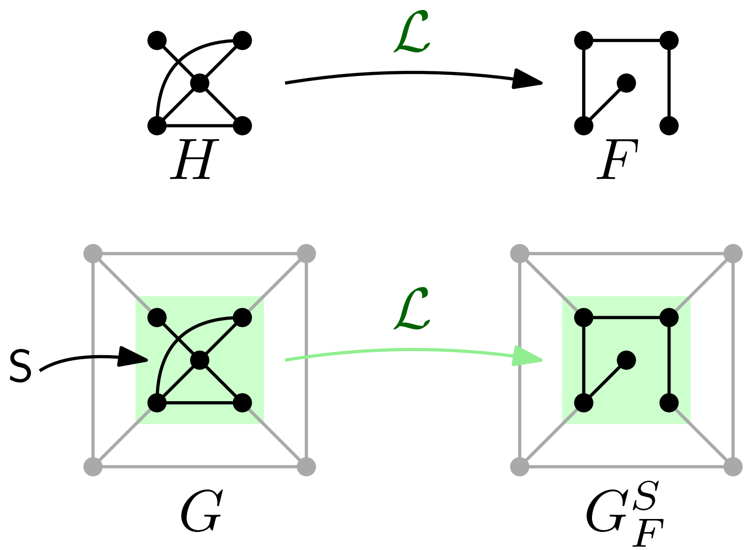

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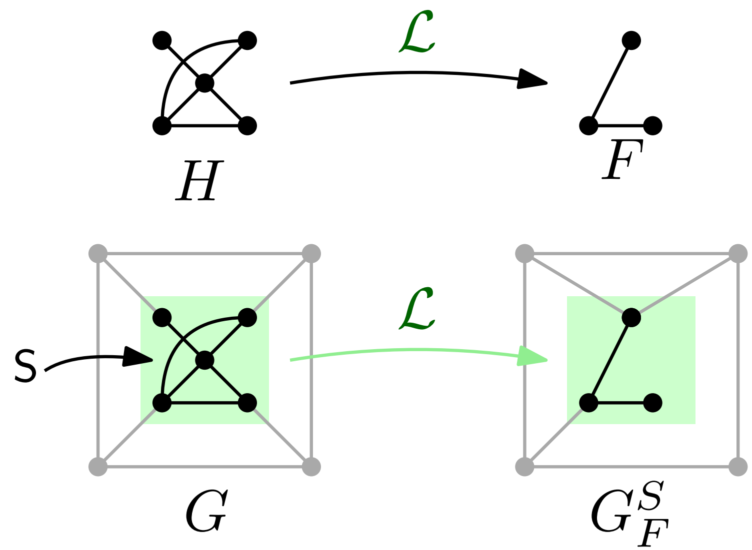
R-action: function $\mathcal{L}$ mapping each graph H to a collection $\mathcal{L}(H)$ of graphs of smaller size.



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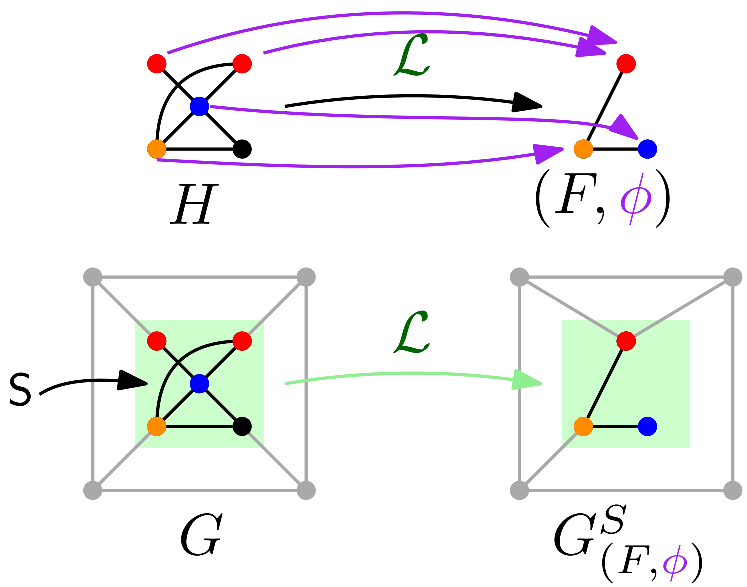
Our result: if $\mathcal{H}$ minor-closed

One can solve $\mathcal{L}$-Replacement to $\mathcal{H}$ in time $2^{\mathsf{poly}_{\mathcal{H}}(k)} \cdot n^2$.

[Fomin, Golovach, Thilikos, 2019]

$\mathcal{L}$-Replacement to Planar in time $f(k) \cdot n^2$.

R-action: function $\mathcal{L}$ mapping each graph H to a collection $\mathcal{L}(H)$ of graphs of smaller size.



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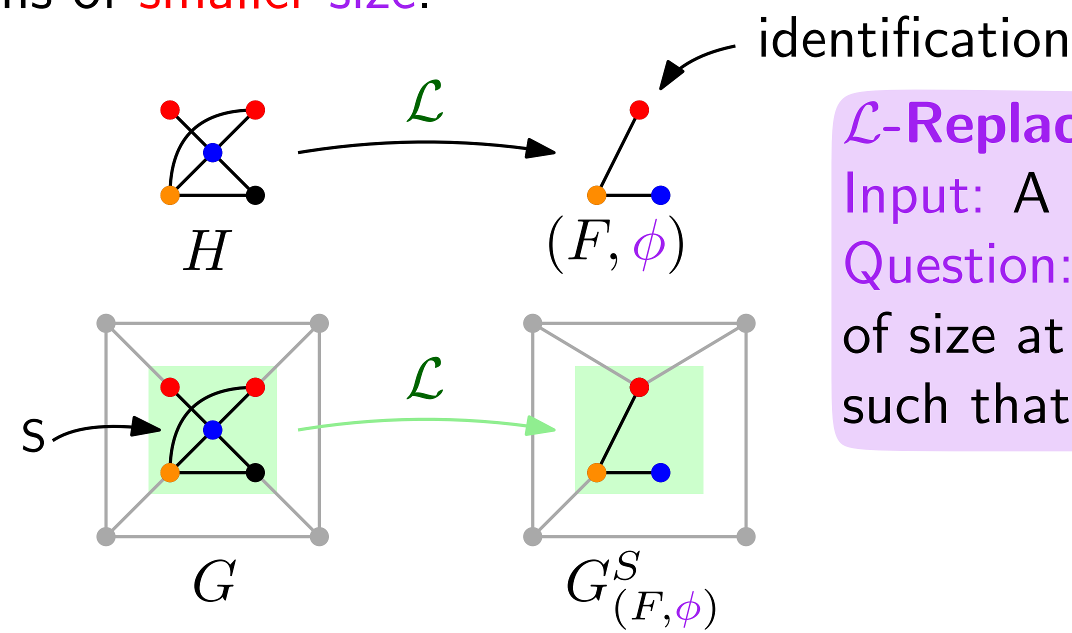

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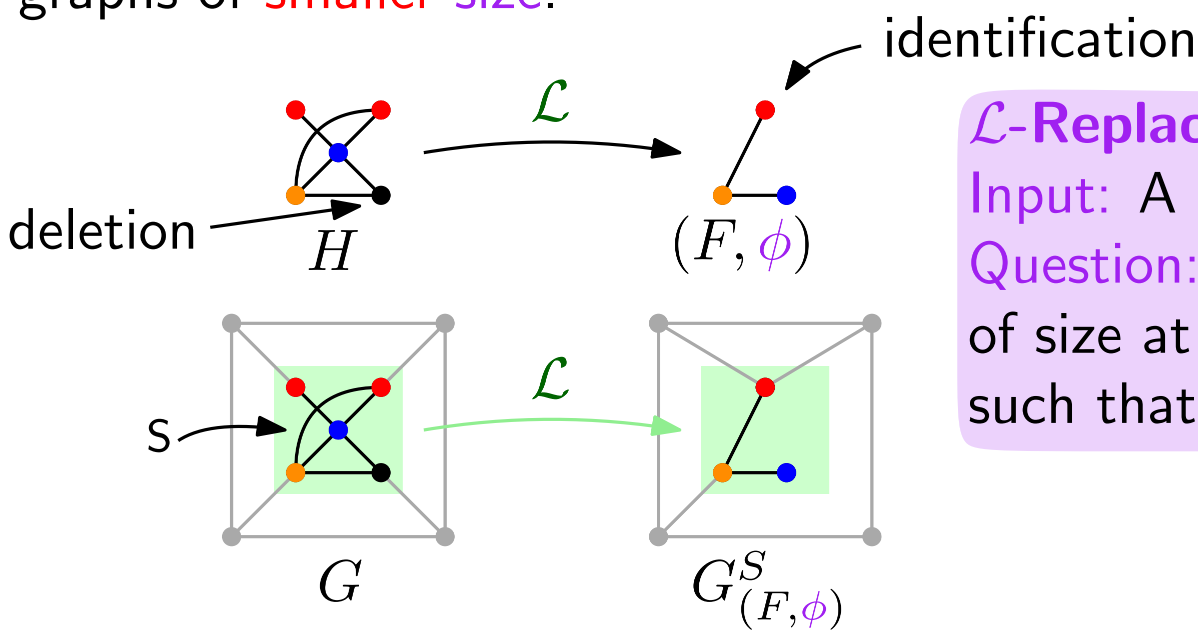

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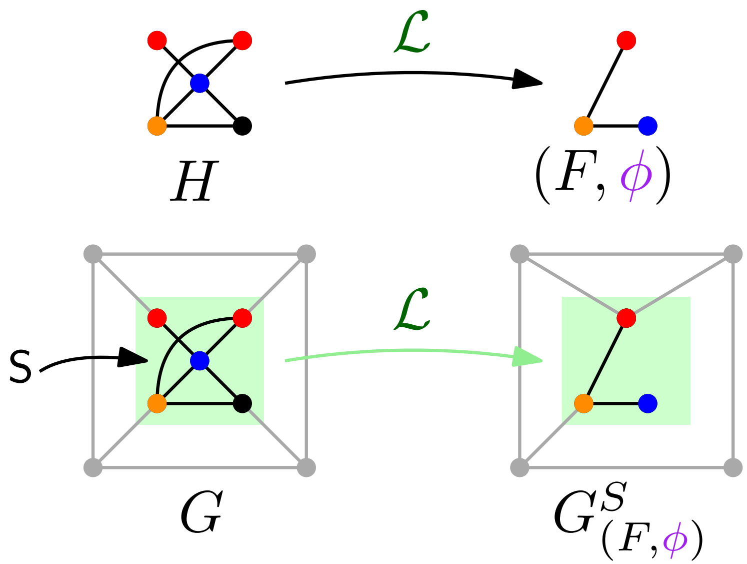

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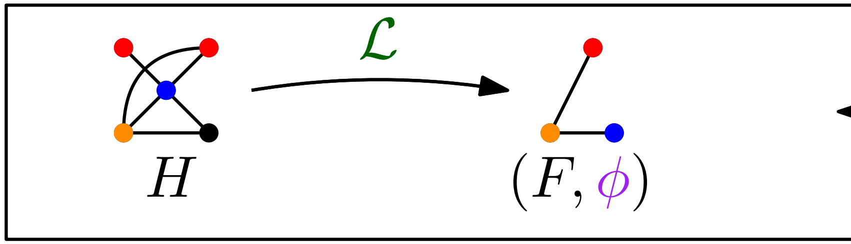

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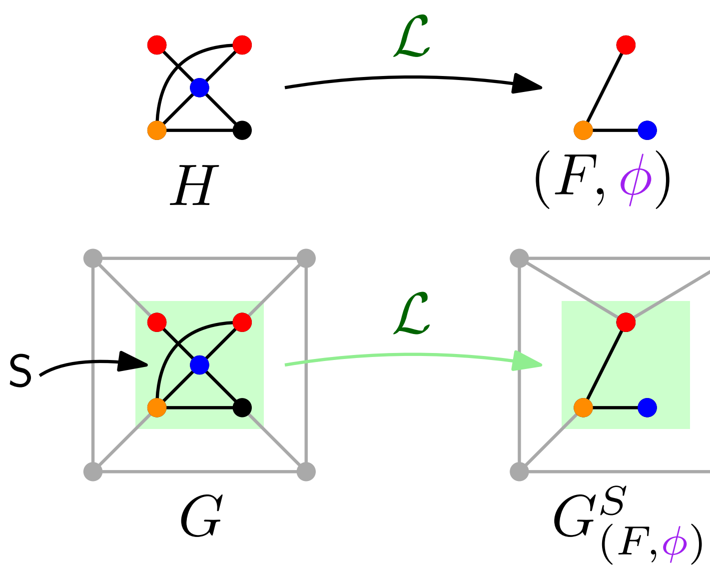

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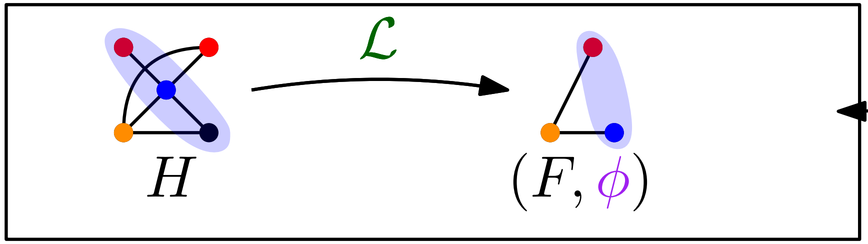

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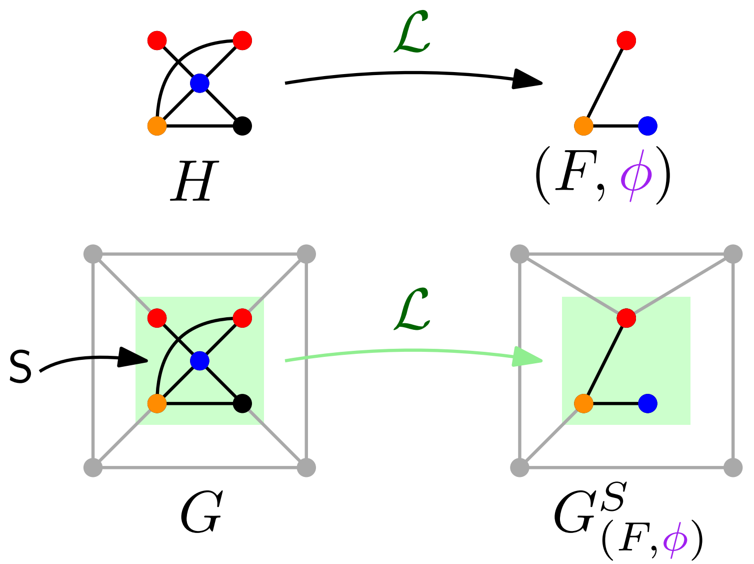

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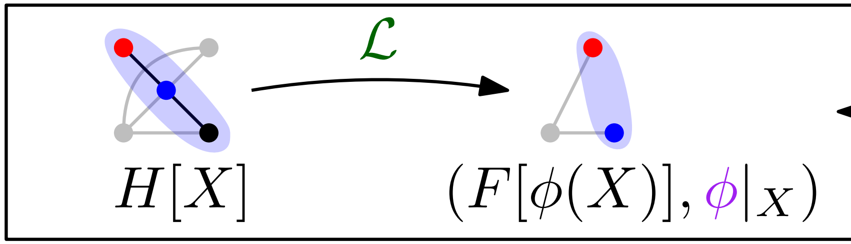

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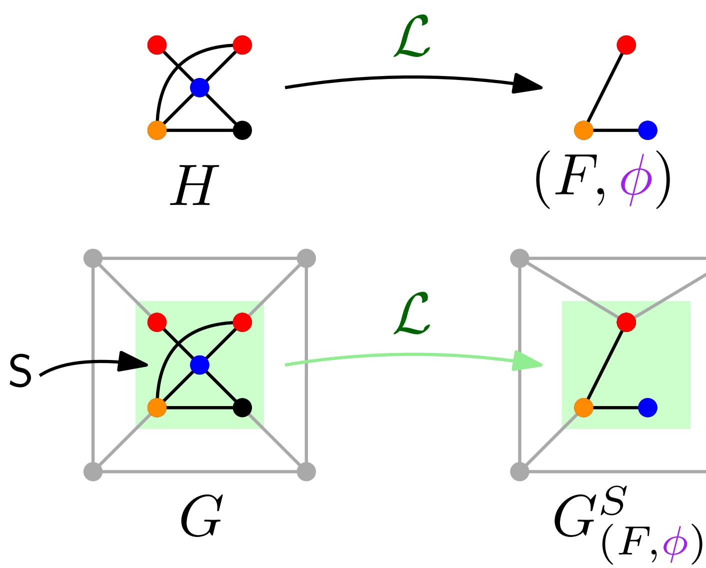

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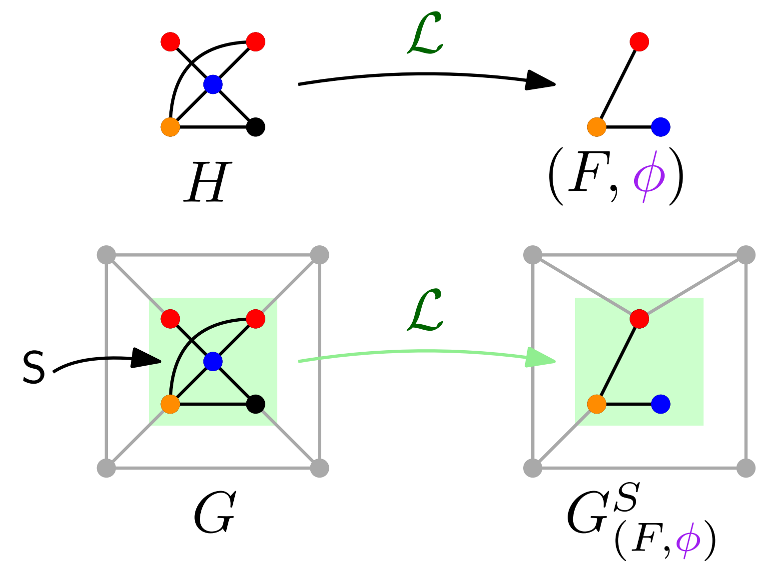
$\mathcal{L}$ hereditary:

- Vertex Deletion to $\mathcal{H}$
- Edge Deletion to $\mathcal{H}$
- Edge Contraction to $\mathcal{H}$
- Subgraph Complementation to $\mathcal{H}$
- Vertex Identification to $\mathcal{H}$
- Matching Contraction to $\mathcal{H}$
- Independent Set Deletion to $\mathcal{H}$



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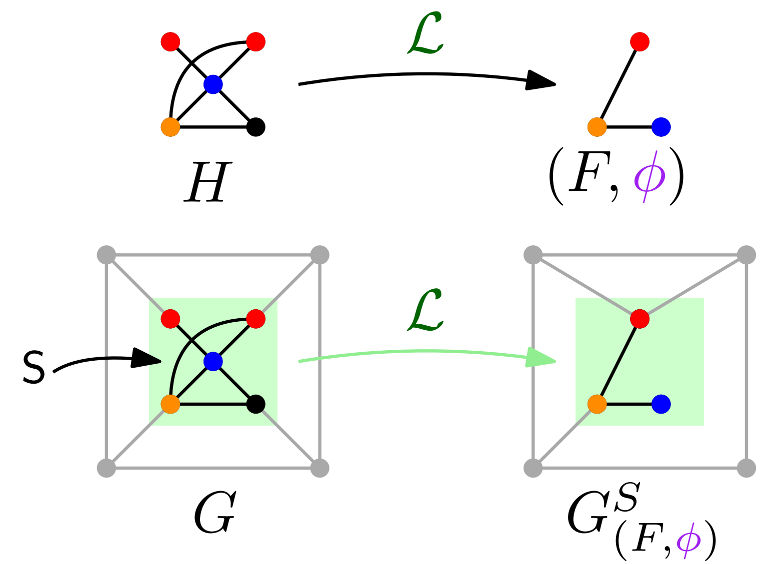

$\mathcal{L}$ non-hereditary:

- deleting exactly k vertices/edges
- Planar Subgraph Isomorphism

The Irrelevant Vertex technique

The Irrelevant Vertex technique ← originates from [Robertson, Seymour, 1995]

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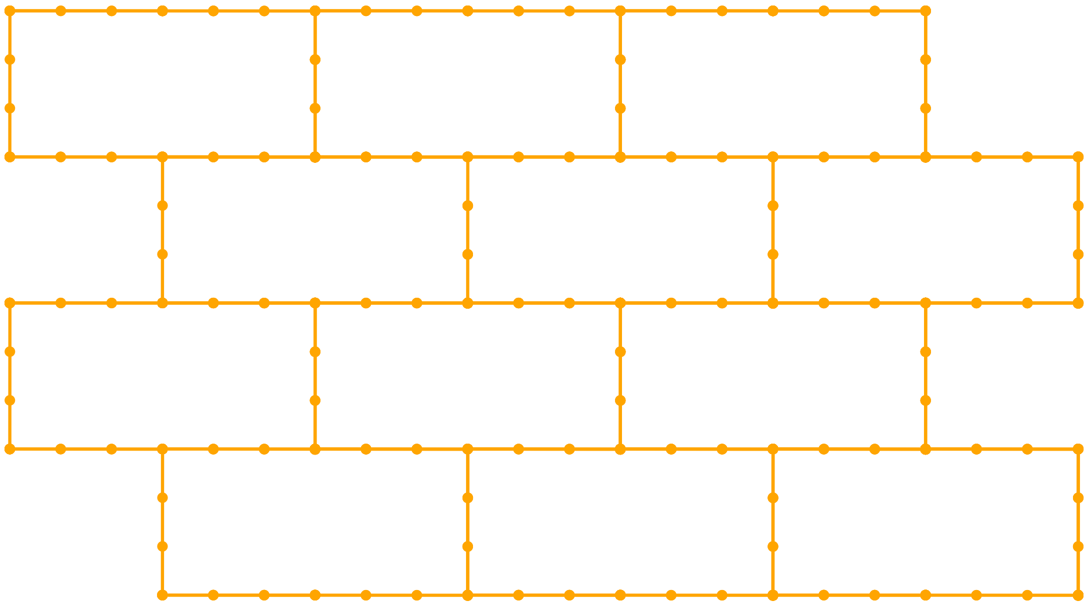
A **wall**:



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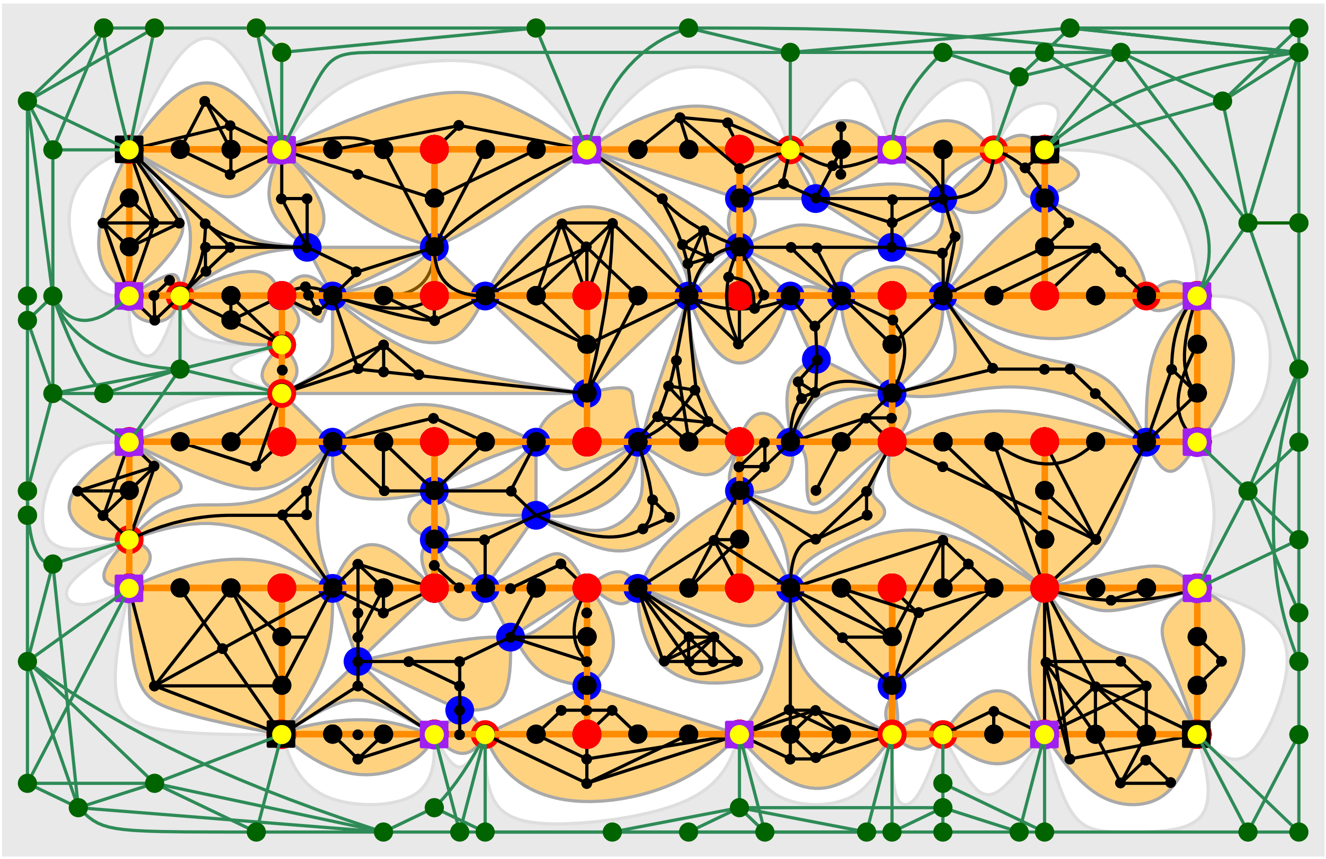
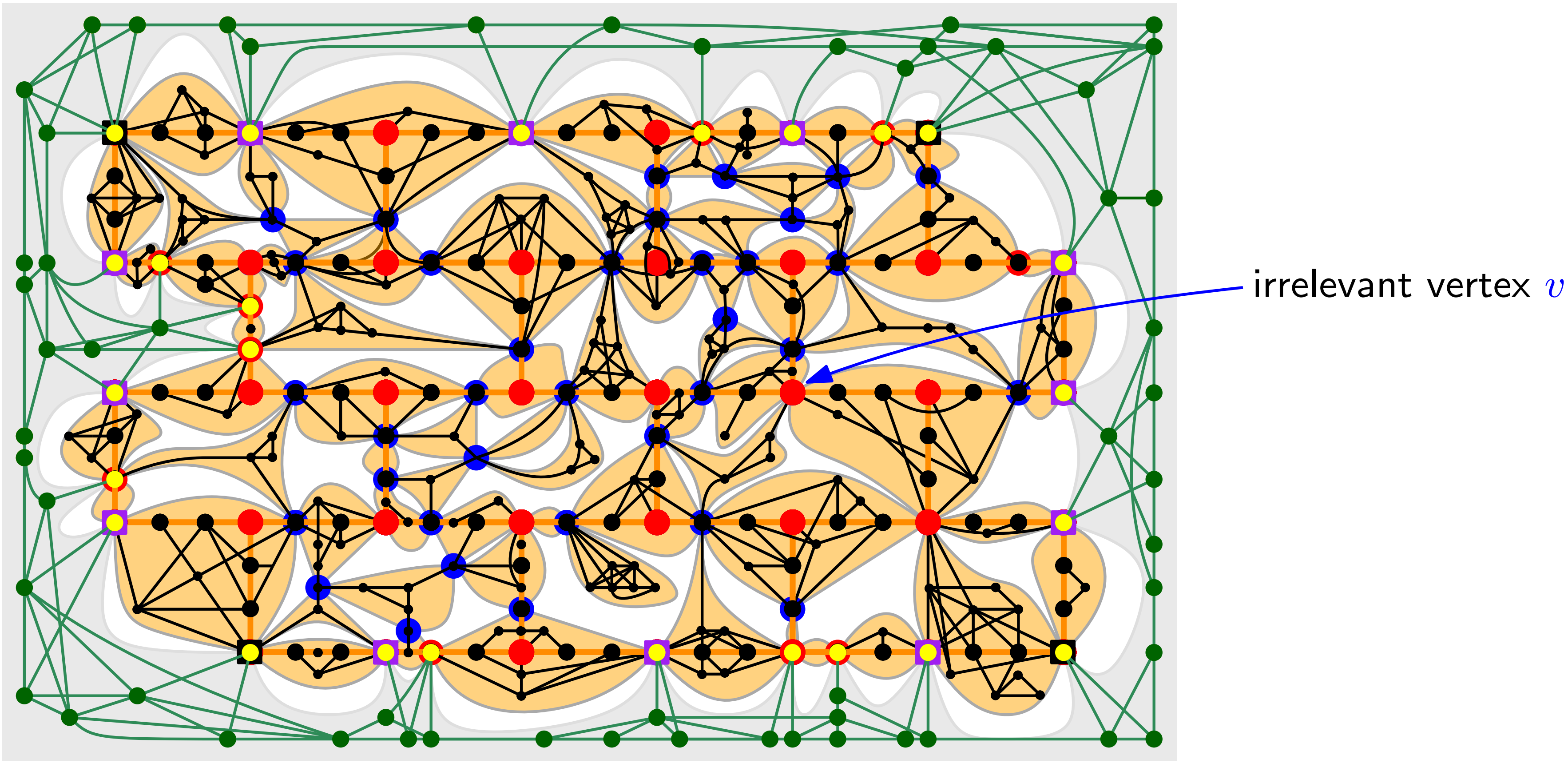
A **flat** wall:



The Irrelevant Vertex technique

Given a graph G and a big enough flat wall W in G, one can find a vertex v such that (G, k) and $(G - v, k)$ are equivalent instances of the problem.

A **flat** wall:



The Flat Wall theorem

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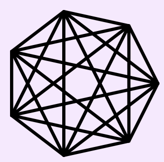
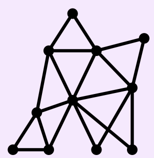
Given a graph G and integers t and r, one can find either:

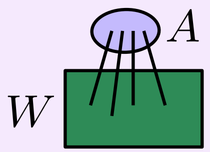
- a K_t-minor in G,



- a tree decomposition of G of width $f(t) \cdot r$, or



- a set $A \subseteq V(G)$ of size at most $f(t)$ and a flat wall W of $G - A$ of height r.



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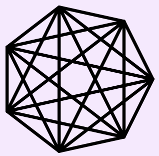

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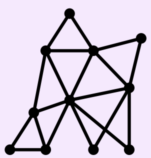

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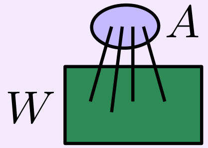

Irrelevant Vertex technique: find an irrelevant vertex v, or branch to identify some vertex v that is in the solution.

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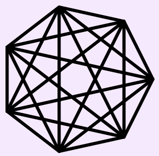

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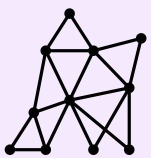

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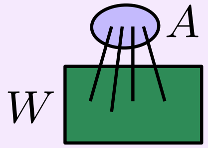

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Recurse on $(G - v, k)$

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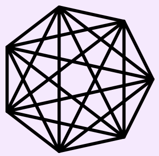

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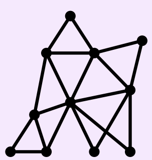

Courcelle's theorem: Every problem expressible in CMSO logic is solvable in time $f(\mathsf{tw}) \cdot n$.

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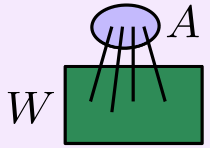

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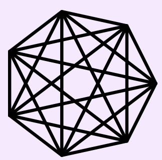

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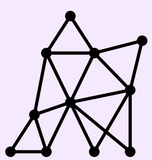

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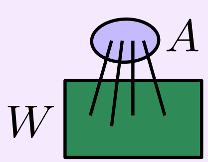

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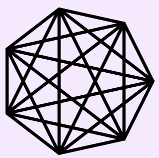
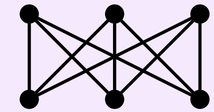


$s_{\mathcal{H}}$ = max size of an obstruction of $\mathcal{H}$



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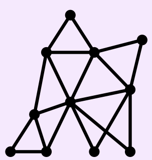

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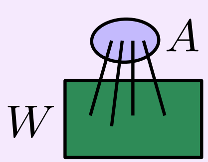

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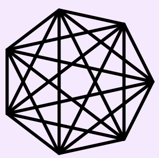

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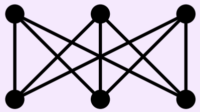

$t = s_{\mathcal{H}} + k$

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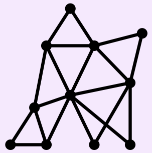

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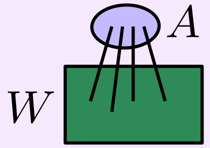

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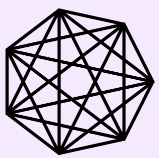

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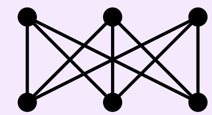

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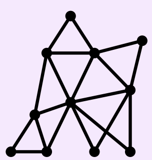

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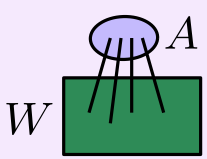

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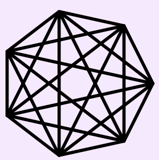

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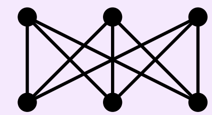

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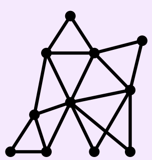

Courcelle's theorem: Every problem expressible in CMSO logic is solvable in time $f(\mathsf{tw}) \cdot n$.

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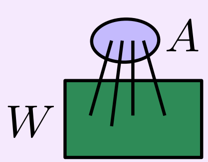


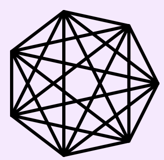
Irrelevant Vertex technique: find an irrelevant vertex v, or branch to identify some vertex v that is in the solution.

Recurse on $(G - v, k)$ ⟶ in time $2^{f_{\mathcal{H}}(k)} \cdot n$

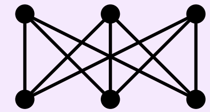
The Flat Wall theorem

Given a graph G and integers t and r, one can find either:

- a K_t-minor in G,



$s_{\mathcal{H}}$ = max size of an obstruction of $\mathcal{H}$



$t = s_{\mathcal{H}} + k$ ⟶ no-instance

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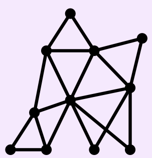
Conclude



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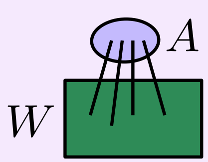

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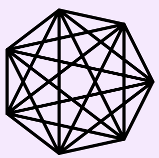

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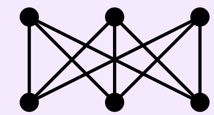

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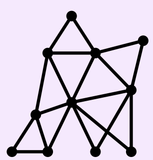

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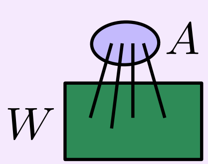

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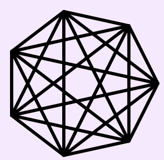

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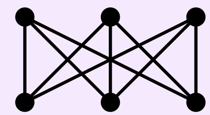

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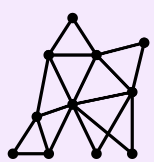

$\mathcal{L}$-Replacement to $\mathcal{H}$ in time $2^{O_{\mathcal{H}}(k^2+(k+\mathsf{tw})\log(k+\mathsf{tw}))} \cdot n$

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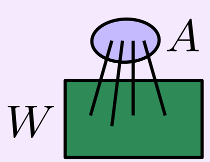

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bad!

$\mathcal{H}$ minor-closed

One can solve $\mathcal{L}$-Replacement to $\mathcal{H}$ in time $2^{\mathsf{poly}_{\mathcal{H}}(k)} \cdot n^2$ for $\mathcal{L}$ hereditary.

$\mathcal{H}$ minor-closed

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?

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$k^{2^{2^{s_{\mathcal{H}}}}{}^{24}} <$

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$$k^{2^{2^{s_{\mathcal{H}}^{24}}}} < \text{poly}_{\mathcal{H}}(k)$$

$\mathcal{H} = \mathcal{P}$ planar: $s_{\mathcal{H}} = 6 \rightarrow$ already very big!

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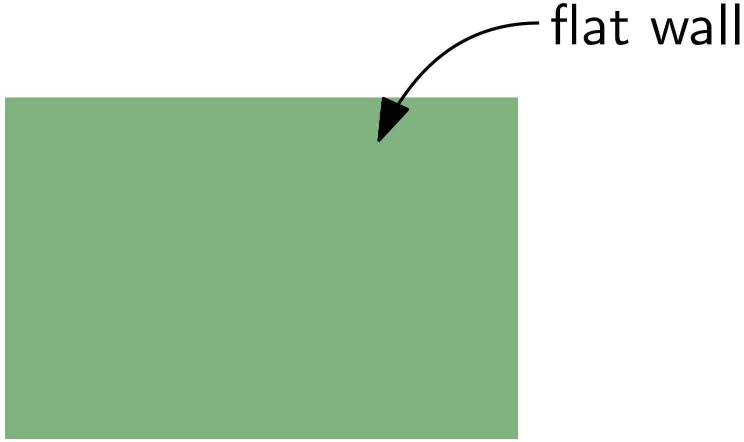
Irrelevant vertex technique

General case:



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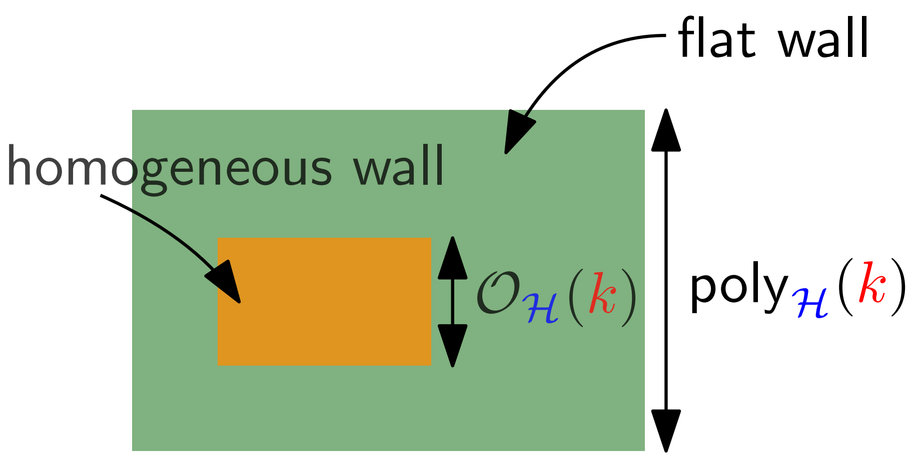

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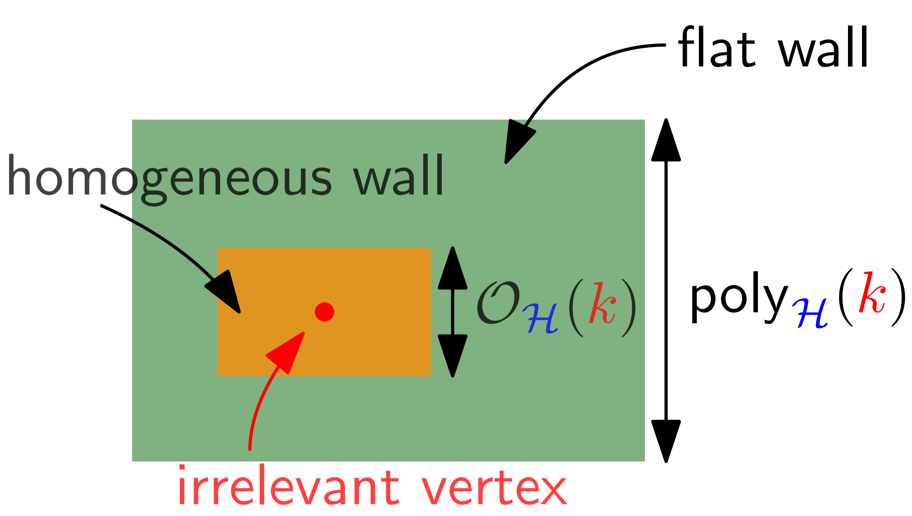

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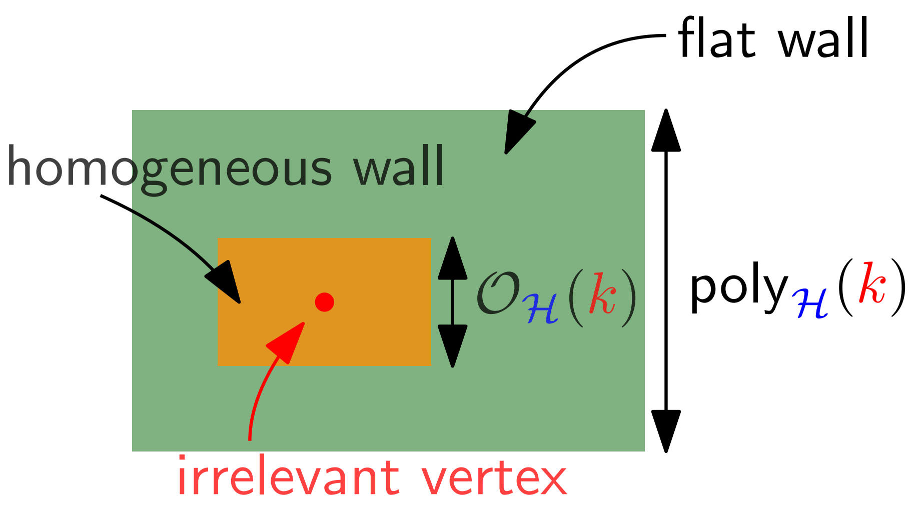
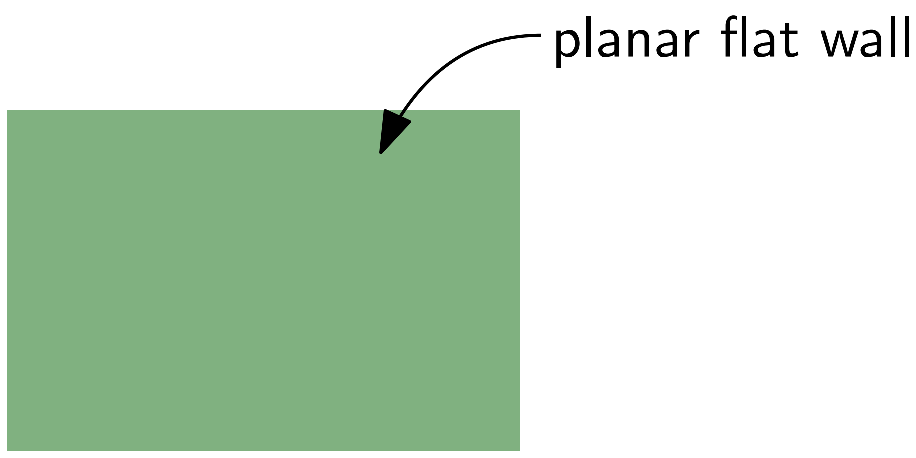


Planar case:



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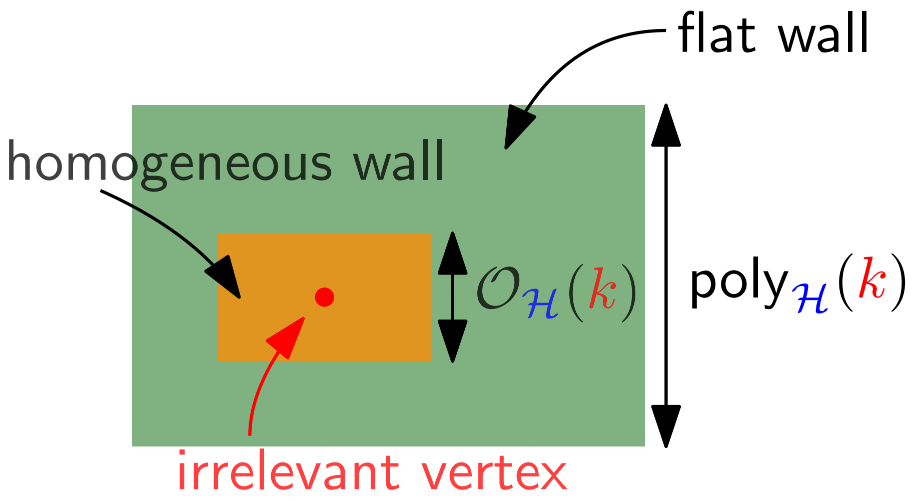

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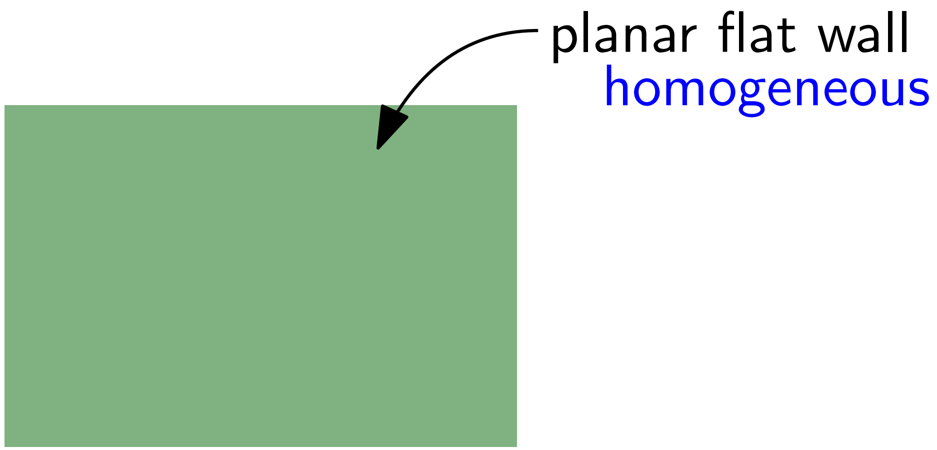

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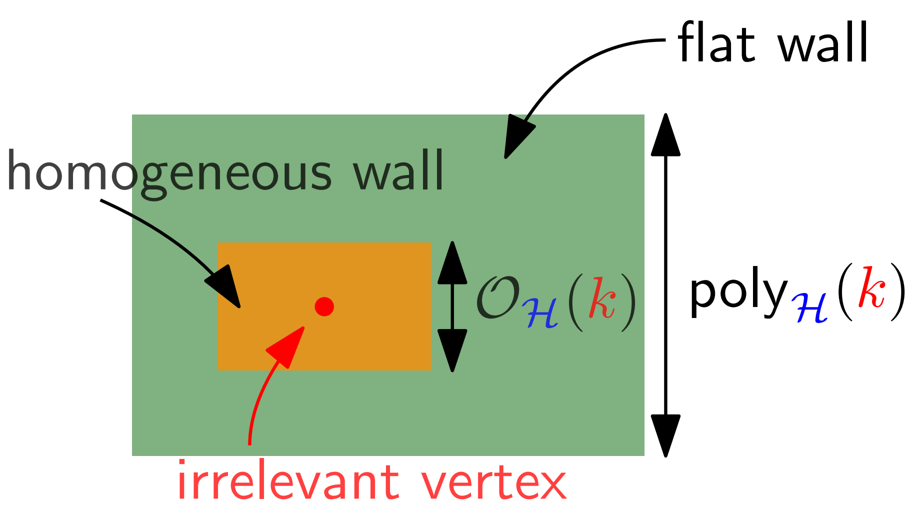

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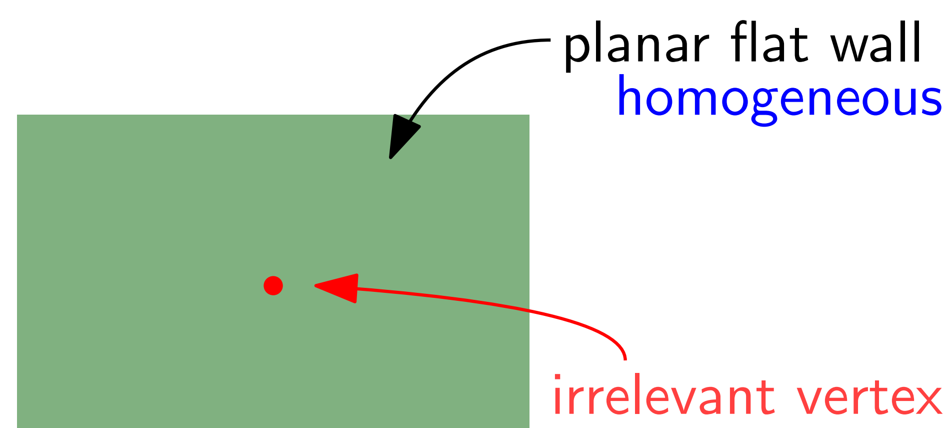

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→ works also for the class of graphs embeddable on a surface Σ

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One can solve $\mathcal{L}$-Replacement to $\mathcal{H}$ in time $2^{\mathsf{poly}_{\mathcal{H}}(k)} \cdot n^2$ for $\mathcal{L}$ hereditary.

Can we improve?

One can solve $\mathcal{L}$-Replacement to $\mathcal{P}$ in time $2^{\mathcal{O}(k^9)} \cdot n^2$ for $\mathcal{L}$ hereditary.

Can we go further?

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Can we remove?

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k: bound on the size of the vertex set involved in the modification

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treewidth instead?

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Elimination Distance to $\mathcal{H}$

$\mathcal{H}$-Treewidth

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Elimination Distance to $\mathcal{H}$

$\mathcal{H}$-Treewidth

Thanks!