On the tree-width of even-hole-free graphs

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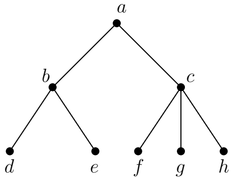
Motivation

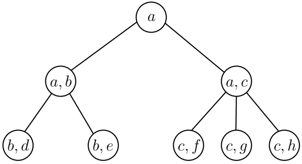
- A sort of dichotomy between "even-hole-free graphs" and "perfect graphs" (G is perfect if for every induced subgraph H of G, $\chi(H) = \omega(H)$)

	EHF graphs	Perfect graphs
Structure	"Simpler"	More complex
Polynomial α, χ	?	YES

- Better understanding of the structure of even-hole-free graphs

Tree decomposition



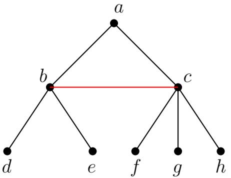


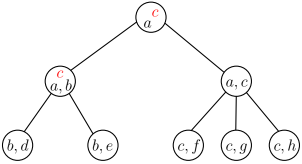
AXIOMS

1. Every vertex is in a bag
2. Every edge is in a bag
3. $\forall v \in V(G)$, the support of v forms a subtree

- Tree-width of G (or $tw(G)$) measures how close G from being a tree
- Tree decomposition of G: "gluing" the pieces of subgraphs of G in a tree-like fashion (a tree decomposition resembles "fat tree" with nodes represented as "bags" of vertices)
  - width of T = the size of the largest bag - 1
  - tree-width of G: width of the optimal tree decomposition of G
- $tw(G) \leq k$ if G can be recursively decomposed into subgraphs of size $\leq k + 1$

Tree decomposition





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Algorithmic use of tree-width

Many graph optimization problems that are NP-hard become tractable on bounded tree-width graphs

Theorem (Courcelle, 1990)

Every graph property definable in the monadic second-order logic (MSO) formulas can be decided in linear time on class of graphs of bounded tree-width.

Some graph problems expressible in MSO:

- maximum independent set, maximum clique, coloring

Even-hole-free graphs (or ehf graphs)

- H is an induced subgraph of G if H can be obtained from G by *deleting vertices*
- G is H-free if no induced subgraph of G is isomorphic to H
- When $\mathcal{H}$ is a family of graphs, $\mathcal{H}$-free means H-free, $\forall H \in \mathcal{H}$
- Even hole: induced cycle of even length (i.e. no chord in the cycle)
- G is even-hole-free means G does not *contain* an even hole
- Some examples: chordal graphs, complete graphs

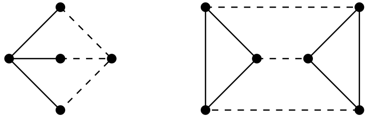


Figure: Theta and prism

Remark. (Theta, prism)-free is a superclass of even-hole-free

Tree-width of even-hole-free graphs

Observation: since complete graph is ehf, the tree-width of the class is unbounded

- When *planar* $\rightarrow tw \leq 49$ [Silva, da Siva, Sales, 2010]
- Pan-free $\rightarrow tw \leq 1.5\omega(G) - 1$ [Cameron, Chaplick, Hoàng, 2015]
- K_3-free $\rightarrow tw \leq 5$ [Cameron, da Silva, Huang, Vušković, 2018]★
- Cap-free $\rightarrow tw \leq 6\omega(G) - 1$ [same authors as ★]

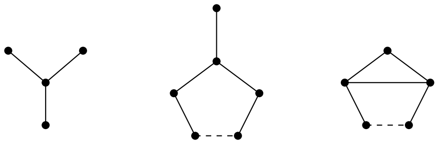


Figure: Claw, pan, and cap

Tree-width of even-hole-free graphs

Some even-hole-free graphs of unbounded width:

- Diamond-free [Adler, Le, Müller, Radovanović, Trotignon, Vušković, 2017]
  - It has unbounded *rank-width* (implies unbounded tree-width)
- K_4-free [S., Trotignon, 2019]
  - It has unbounded tree-width (and unbounded rank-width)

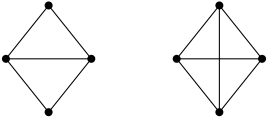


Figure: Diamond and K_4

Ehf graphs of unbounded tree-width

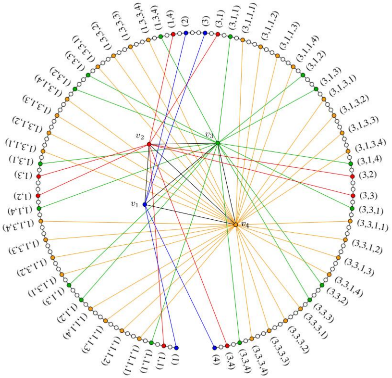


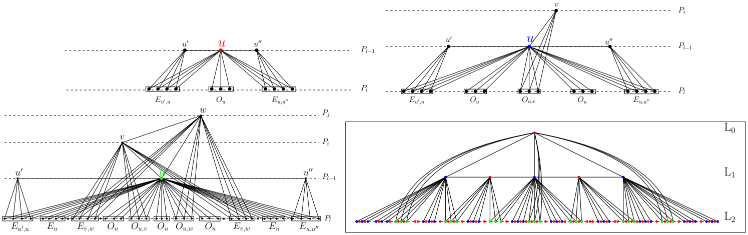
Figure: A diamond-free ehf graph of large *rank-width*; it contains large clique

Question: **What if the clique size is bounded?**

Ehf graphs of unbounded tree-width

Bounded clique size does not imply bounded tree-width

- The following: A family of K_4-free graphs with arbitrarily large tw



- The graphs have large degree and contains large clique minor
  clique minor: pairwise adjacent connected subgraphs

<u>Question:</u> **Are these two conditions necessary?**

Main questions

Even-hole-free graphs with no K_4 have unbounded tree-width

- Our construction which certifies this contains large clique minor
- It also contains vertices of high degree

Are these two conditions necessary? YES!

- Even-hole-free graphs with no clique minor have bounded tree-width [Aboulker, Adler, Kim, S., Trotignon, 2020]
- Even-hole-free graphs of bounded degree have bounded tree-width [Abrishami, Chudnovsky, Vušković, 2020]

1st contribution: even-hole-free graphs with no H-minor

Theorem (Aboulker, Adler, Kim, S., Trotignon, 2020)

Even-hole-free graphs with no H-minor for some graph H have bounded tree-width. (This is actually proven for (theta, prism)-free graphs.)

- This provides another proof that planar ehf graphs have bounded tree-width.
- For the proof, we develop an "induced wall theorem" for graphs excluding fixed minor.
- From this, we derive that ehf graphs excluding fixed minor have bounded tree-width.

Even-hole-free graphs with no H-minor

Theorem (Induced wall minor theorem for graphs excluding H-minor)

If G is H-minor-free with $tw(G) \geq f_H(k)$, then G contains a $(k \times k)$-wall or the line graph of a chordless $k \times k$-wall as an induced subgraph.

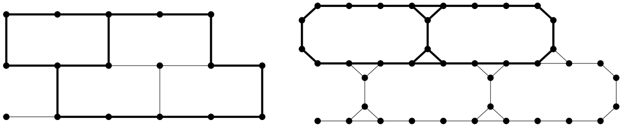


Figure: A (3×3)-wall and the line graph of chordless (3×3)-wall

Even-hole-free graphs with no H-minor

Theorem (Fomin, Golovach, Thilikos, 2011)

For every H, there exists a constant $c_H > 0$ and an integer k s.t. for every connected H-minor free graph G with $tw(G) \geq c_H \cdot k^2$, G contains either Γ_k or Π_k as a contraction.

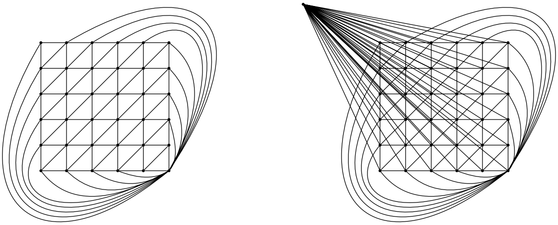


Figure: Γ_6 and Π_6

2nd contribution: even-hole-free graphs of bounded degree

Conjecture (Aboulker, Adler, Kim, S., Trotignon, 2020)

Even-hole-free graphs with bounded degree have bounded tree-width.

We prove the following cases:

- **Subcubic ehf graphs** have tree-width at most 3
  - Approach: a full structure theorem for subcubic (theta, prism)-free graphs (every graph is either simple or it has a "nice" separator which yields boundedness on the tree-width).
- **Pyramid-free ehf graphs of degree** ≤ 4
  - Approach: a combination of structural properties to show K_6-minor-freeness.
  - $tw(G) \leq f_{K_6}(3)$, with f as in the induced grid theorem.

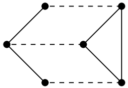


Figure: Pyramid

Structure theorem of subcubic even-hole-free graphs

Theorem (Aboulker, Adler, Kim, S., Trotignon, 2020)

Let G be a (theta, prism)-free subcubic graph. Then either:

- *G is a basic graph; or*
- *G has a clique separator of size at most 2; or*
- *G has a proper separator.*

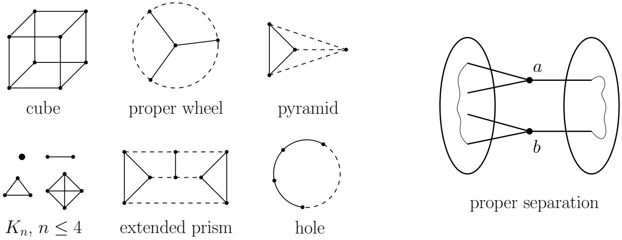


Figure: Basic graphs and proper separator

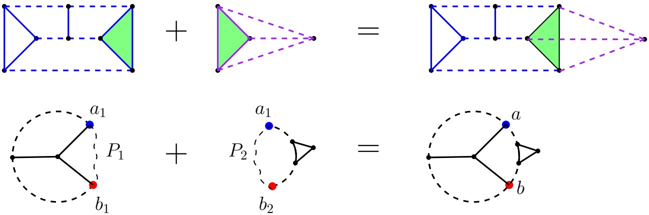
Tree-width of even-hole-free graphs (a proof)

Theorem (Aboulker, Adler, Kim, S., Trotignon, 2020)

Subcubic even-hole-free graphs have tree-width ≤ 3.

Sketch of proof.

- Every basic graph has tree-width at most 3.
- "Gluing" along a clique and proper gluing preserve tree-width to be ≤ 3.



Tree-width of ehf graphs (+pyramid-free) of max degree 4

(*skipped for now...*)

Theorem (Aboulker, Adler, E. Kim, S., Trotignon, 2020)

Every (even hole, pyramid)-free graph of maximum degree 4 has tree-width $< f_{K_6}(3)$.

Sketch of proof.

- f is the bound given in the 'induced grid theorem'
- The core of the proof: If G is (even hole, pyramid)-free graph of maximum degree at most 4, then G contains no K_6-minor.
- The K_6-minor freeness follows from the structure theorem for graphs in the class: for every graph in the class, it is either *basic* or it has a clique separator.

Even-hole-free graphs of bounded degree

The "bounded degree $\Rightarrow$ bounded tree-width" conjecture has been proven! (using another technique: balanced separator)

Theorem (Abrishami, Chudnovsky, Vušković, 2020)

Ehf graphs of bounded degree have bounded tree-width. (This is actually proven for a superclass of ehf graphs.)

Open problems

There is a function f such that if $tw(G) > f(k)$, then G contains (as an induced subgraph) one of the following:

- a subdivision of a $(k \times k)$-wall
- line graph of a subdivision of a $(k \times k)$-wall
- a vertex of degree at least k

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The End