An Improved Parameterized Algorithm for Treewidth

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UNIVERSITY OF BERGEN

joint work with
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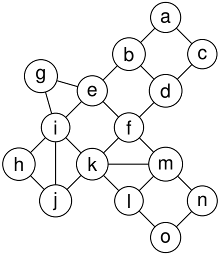
Jagiellonian TCS seminar

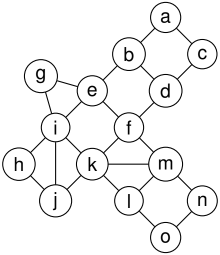
18 January 2023

Treewidth



Graph G

Treewidth



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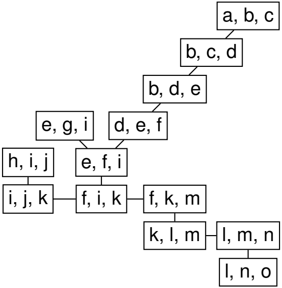
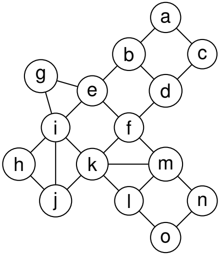


A tree decomposition of G

Treewidth



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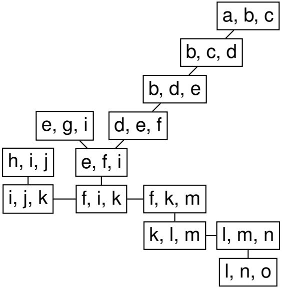

A tree decomposition of G

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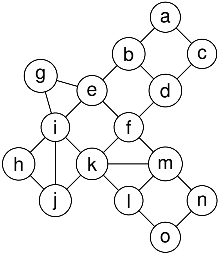

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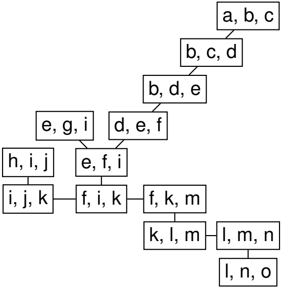

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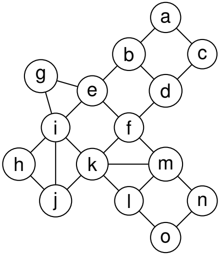

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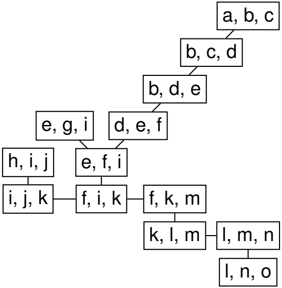

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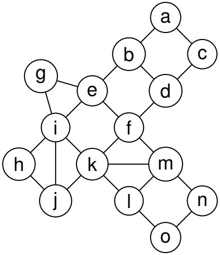

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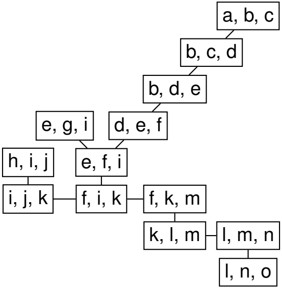

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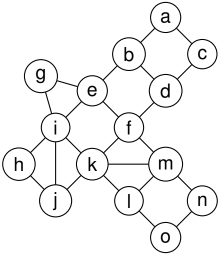

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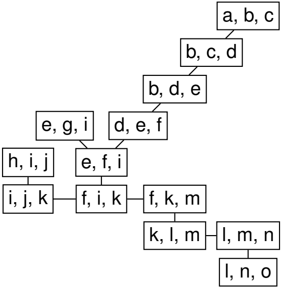

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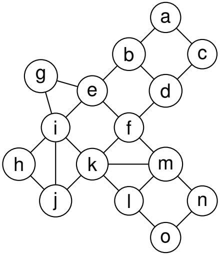

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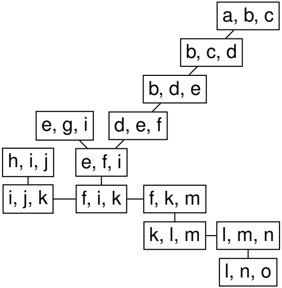

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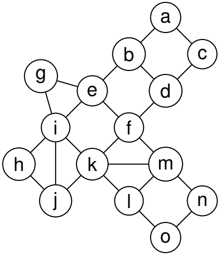

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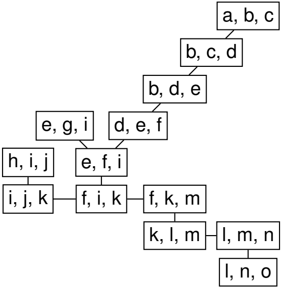

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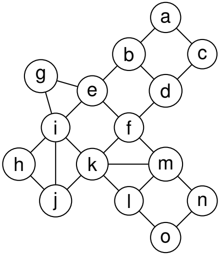

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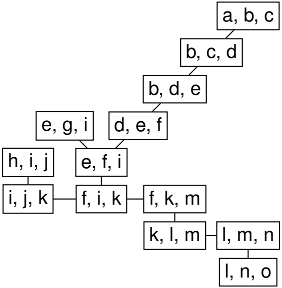

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[Bertele & Brioschi'72, Halin'76, Robertson & Seymour'84]

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Theorem (This work)

There is a $2^{\mathcal{O}(k^2)} n^4$ time algorithm for treewidth.

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Theorem (This work)

There is a $k^{\mathcal{O}(k/\varepsilon)} n^4$ time $(1+\varepsilon)$-approximation algorithm for treewidth.

Outline

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1. How to improve a tree decomposition

Suffices to solve the *Subset treewidth* problem

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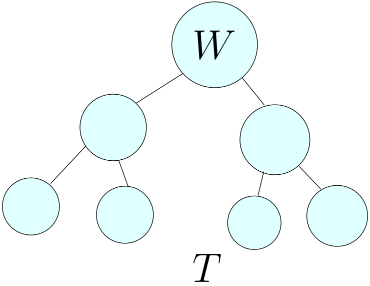
2. Solving the subset treewidth problem

Algorithms for subset treewidth that then imply algorithms for treewidth

How to improve a tree decomposition

Setting

Suppose we have a tree decomposition T whose largest bag is W



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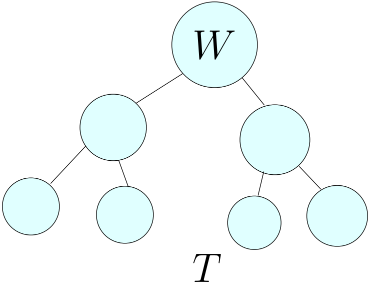

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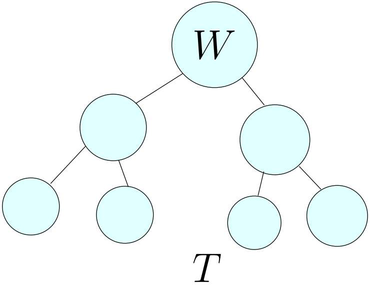

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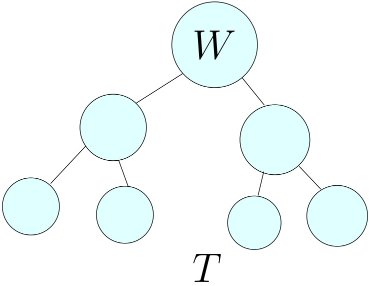

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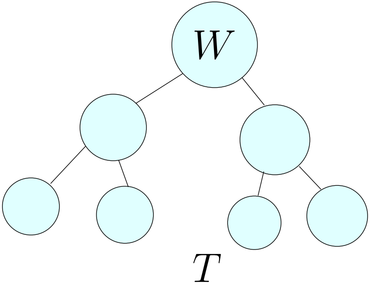

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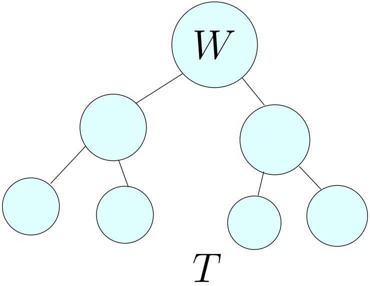
(assume to start with width $\mathcal{O}(\text{tw}(G))$ decomposition)



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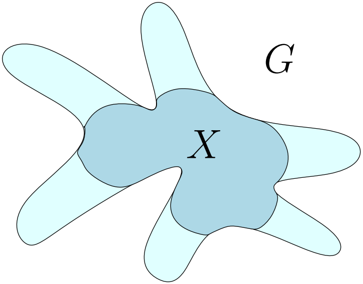

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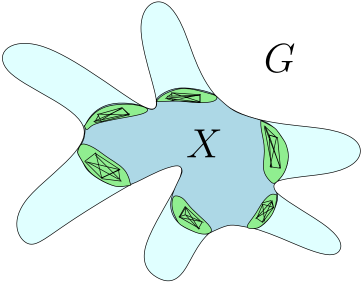

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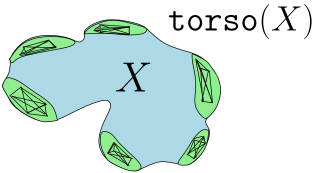

- Make neighborhoods of components of $G \setminus X$ into cliques
- Delete $V(G) \setminus X$

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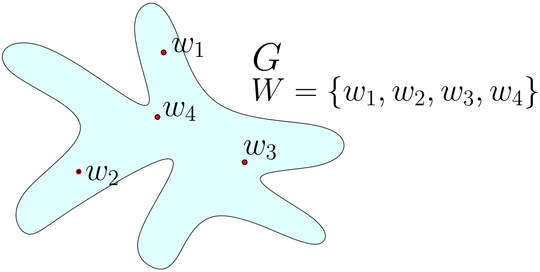

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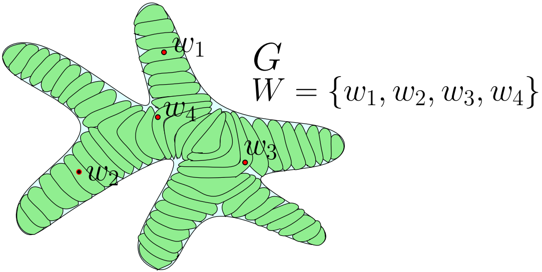

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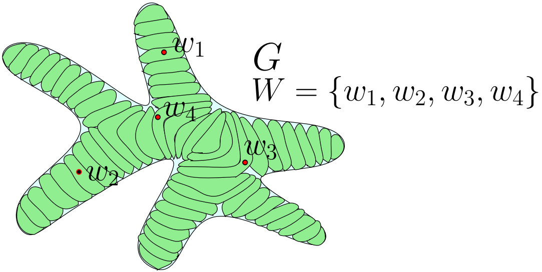

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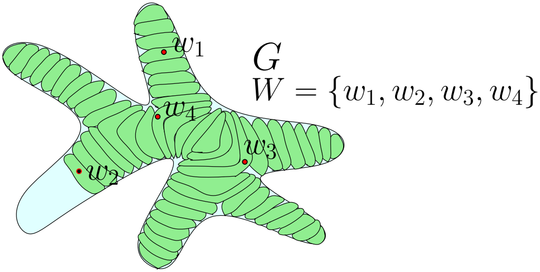

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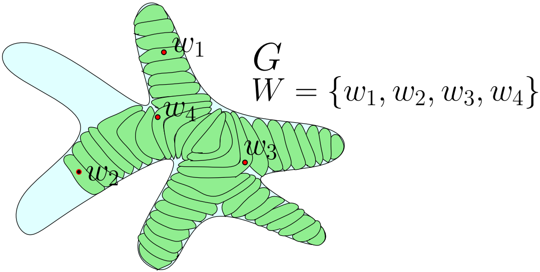

Improving a tree decomposition

Let W be a largest bag of T — SUBSET TREEWIDTH

Want to find:

- a set X with $W \subseteq X \subseteq V(G)$, and
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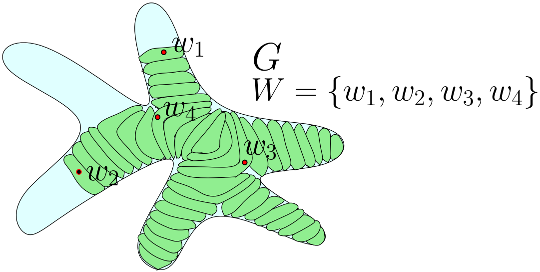

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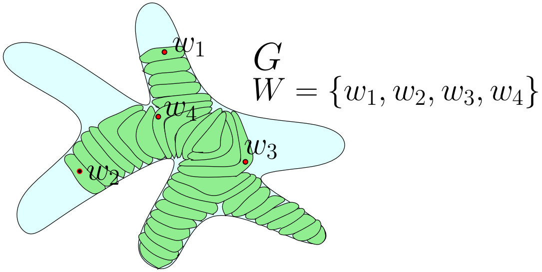

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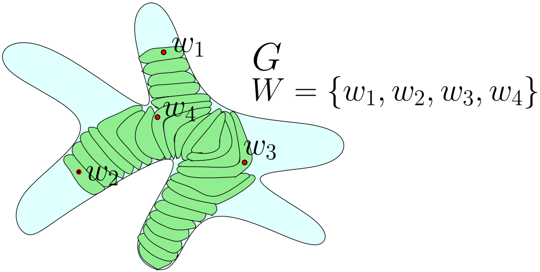

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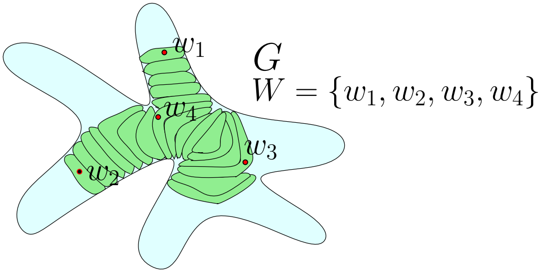

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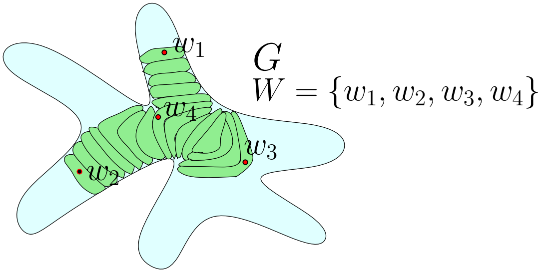

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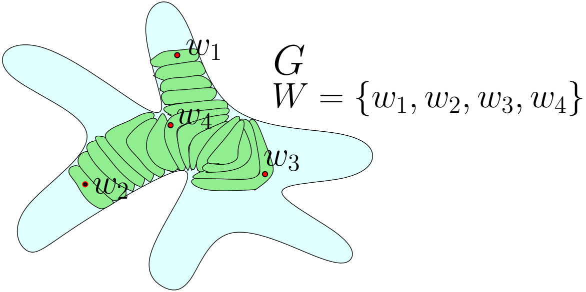

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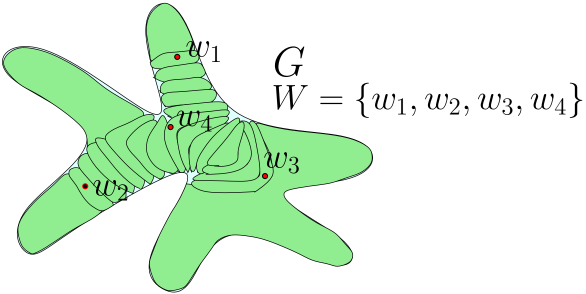
Big-leaf formulation:

- Find a tree decomposition of G whose internal bags have size $\leq |W| - 1$ and cover W, but leaf bags can be arbitrarily large



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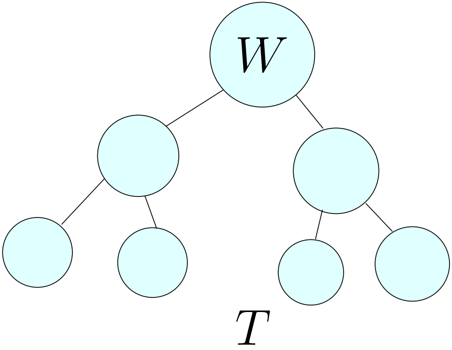

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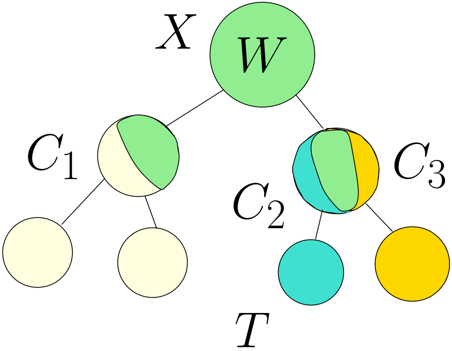

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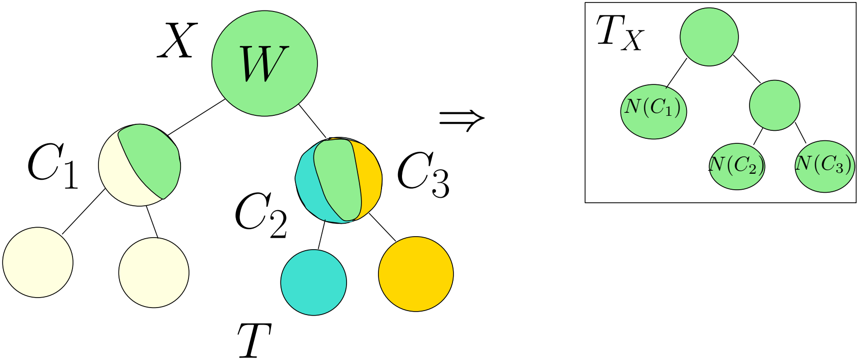

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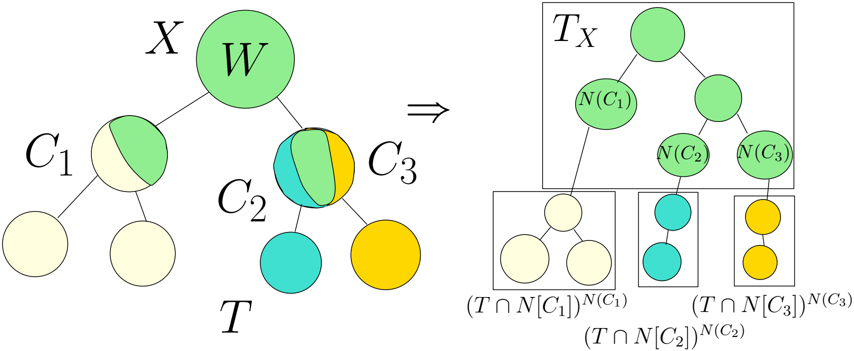
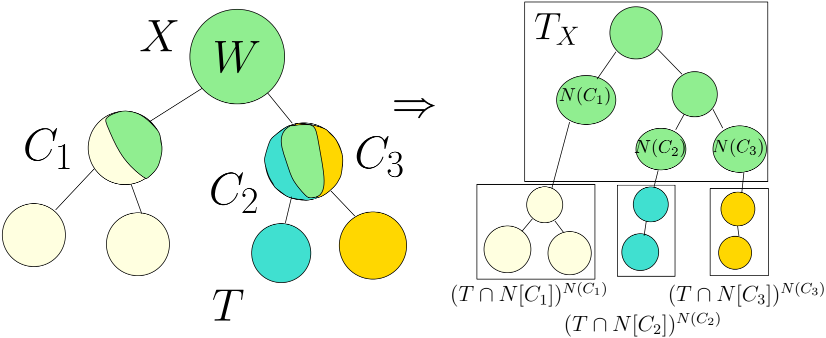


Does T improve?



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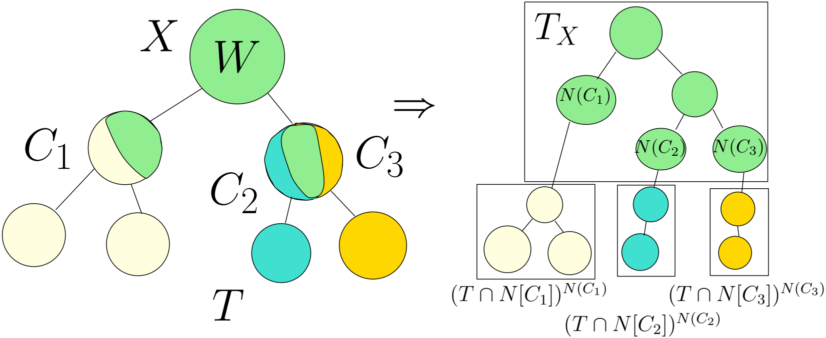

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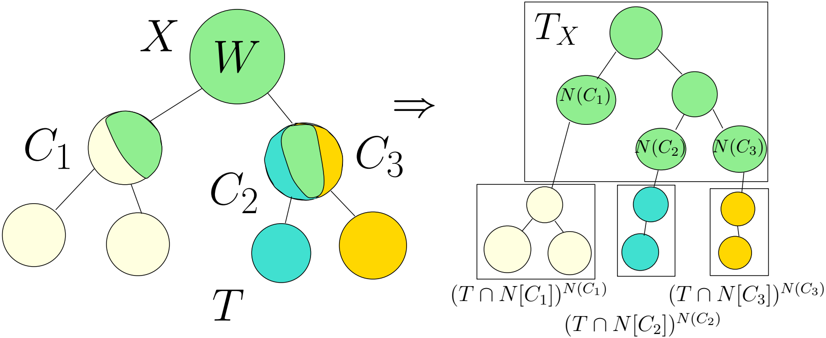

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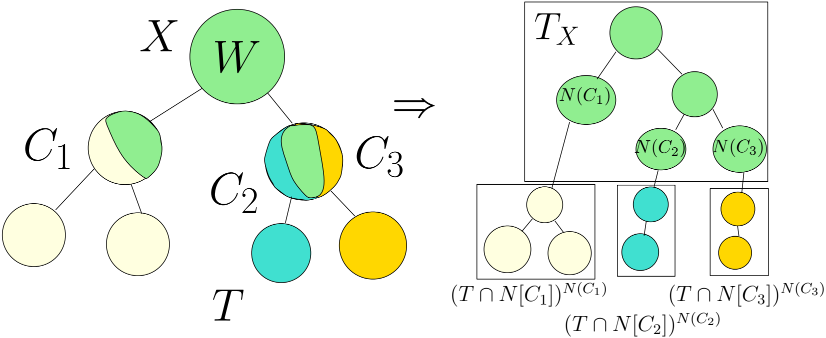

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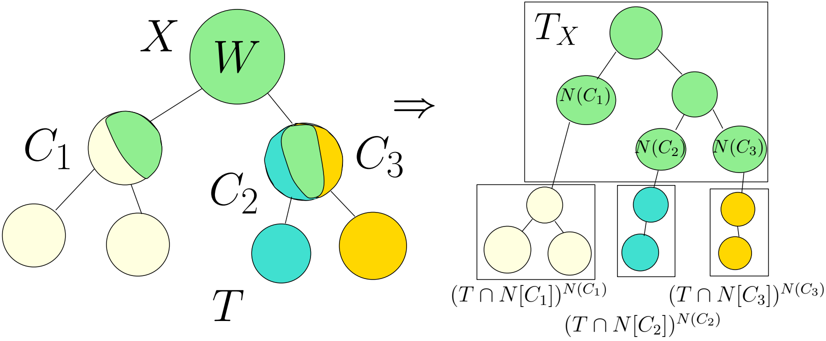

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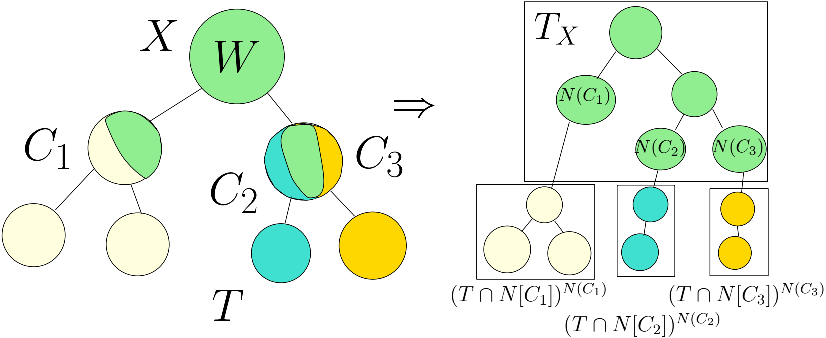

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- (actually need a bit stronger condition than linkedness for improvement)

Subset treewidth for exact algorithms

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SUBSET TREEWIDTH

Input: Graph G, integer k, set of vertices $W \subseteq V(G)$ with $|W| = k + 2$

Output: Set $X \subseteq V(G)$ with $W \subseteq X$ and tree decomposition of $\texttt{torso}(X)$ of width $\leq k$ or that the treewidth of G is $> k$

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If there is an $f(k) \cdot n^{\mathcal{O}(1)}$ time algorithm for subset treewidth, then there is an $f(k) \cdot n^{\mathcal{O}(1)}$ time algorithm for treewidth with the same function f.

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$2^{\mathcal{O}(k^2)} n^2$ time algorithm for subset treewidth $\rightarrow$ $2^{\mathcal{O}(k^2)} n^4$ time algorithm for treewidth

Subset treewidth for approximation schemes

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If there is an $f(k,t) \cdot n^{\mathcal{O}(1)}$ time algorithm for partitioned subset treewidth, then there is a $f(\mathcal{O}(k), \mathcal{O}(1/\varepsilon)) \cdot k^{\mathcal{O}(k)} n^{\mathcal{O}(1)}$ time $(1+\varepsilon)$-approximation algorithm for treewidth with the same function f.

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Solving the subset treewidth problem

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Goal: Sketch $k^{\mathcal{O}(kt)} n^{\mathcal{O}(1)}$ time algorithm for partitioned subset treewidth

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(this is also a $k^{\mathcal{O}(k^2)} n^{\mathcal{O}(1)}$ time algorithm for subset treewidth)

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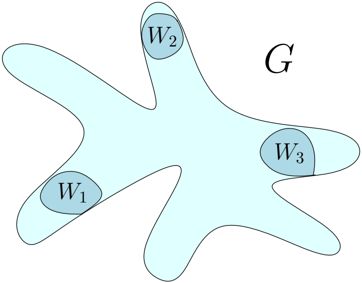

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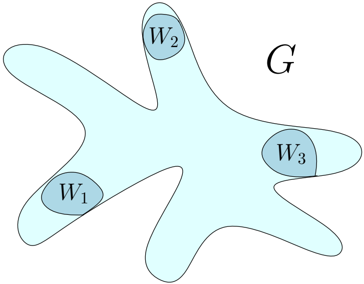

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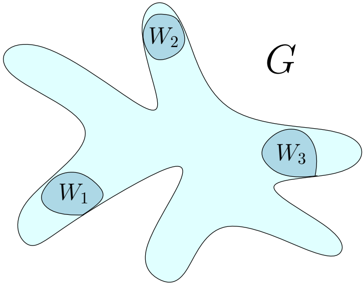

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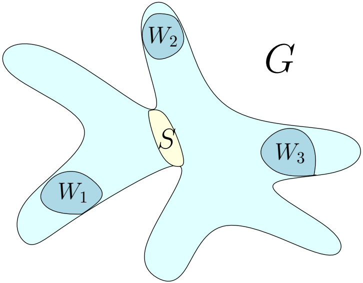

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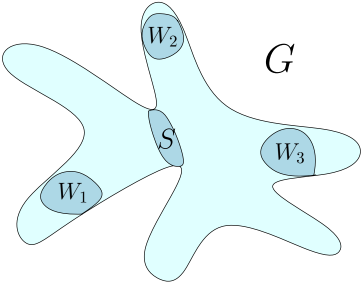

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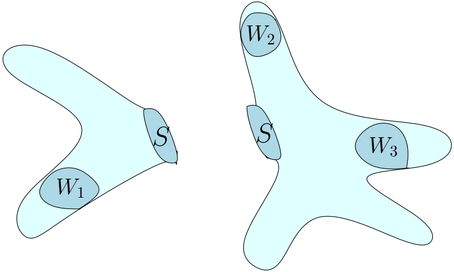
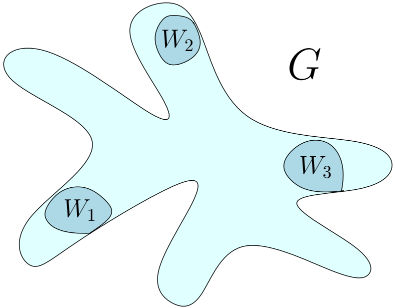


Branching for partitioned subset treewidth

- Now terminal cliques *strongly linked* into each other



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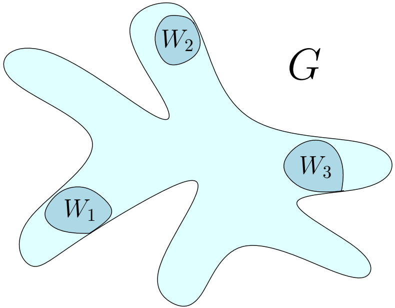

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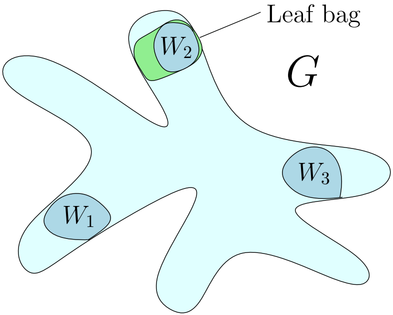

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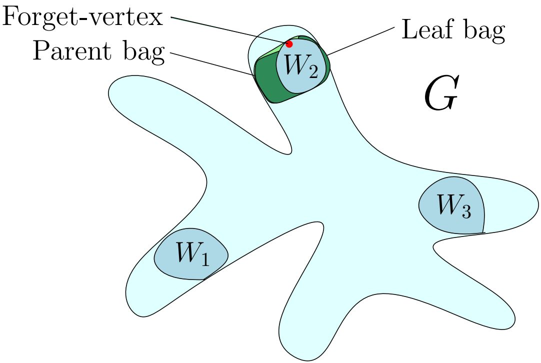

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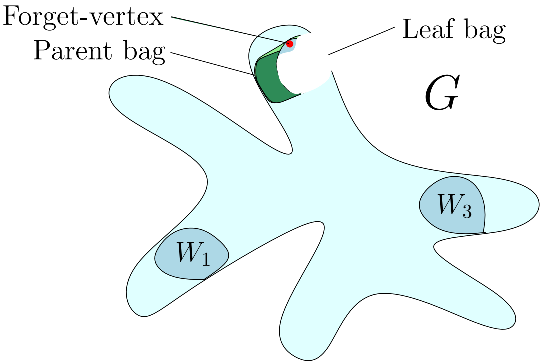

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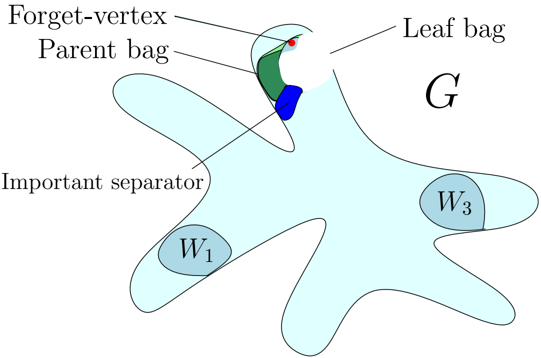

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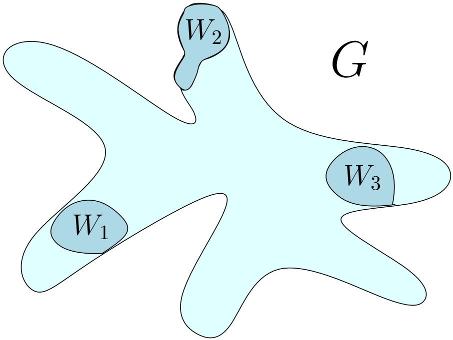
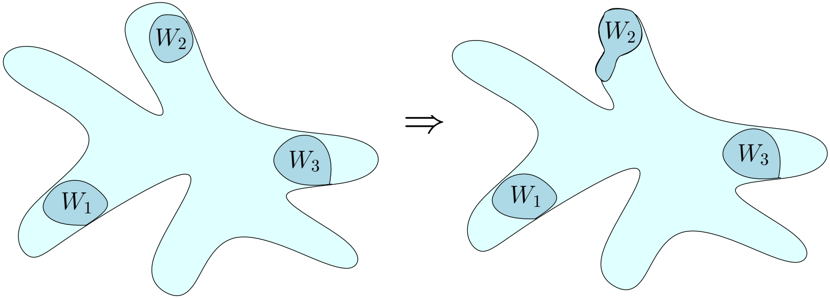


Analysis of branching



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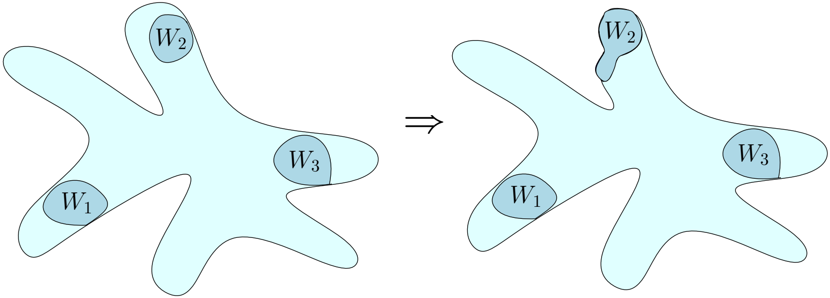

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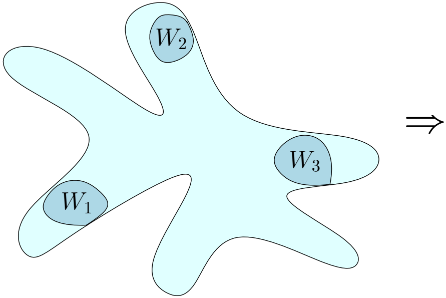

- Increased the size/flow of a leaf terminal clique by guessing a forget-vertex and an important separator
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- To get $k^{\mathcal{O}(kt)}n^{\mathcal{O}(1)}$ time, need also an important separator hitting set lemma

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- How much can the n^4 factor be optimized?
- Can we prove a $2^{\Omega(k)}$ lower bound assuming ETH?

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