

Dieter Kratsch (Ed.)

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Graph-Theoretic Concepts in Computer Science

31st International Workshop, WG 2005

Metz, France, June 2005

Revised Selected Papers



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Volume Editor

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Preface

The 31st International Workshop on Graph-Theoretic Concepts in Computer Science (WG 2005) was held on the campus “Île du Saulcy” of the University Paul Verlaine-Metz in France. The workshop was organized by the Laboratoire d’Informatique Théorique et Appliquée (LITA) and it took place June 23 – 25 2005. The 94 participants of WG 2005 came from universities and research institutes of 18 different countries.

The WG 2005 workshop continues the series of 30 previous WG workshops. Since 1975, WG has taken place 20 times in Germany, four times in The Netherlands, two times in Austria as well as once in Italy, in Slovakia, in Switzerland and in Czech Republic, and has now been held for the first time in France. The workshop aims at uniting theory and practice by demonstrating how graph-theoretic concepts can be applied to various areas in computer science, or by extracting new problems from applications. The goal is to present recent research results and to identify and explore directions of future research. The talks were given in the “Petit Théâtre”. They showed how recent research results from algorithmic graph theory can be used in computer science and which graph-theoretic questions arise from new developments in computer science. There were two fascinating invited lectures by Georg Gottlob (Vienna, Austria) and Gregory Kucherov (Nancy, France).

The number of submitted papers was an all-time record of 125. In a careful reviewing process with four reports per submission, the Program Committee selected 38 papers for presentation at the workshop. The Program Committee decided to accept more papers than usual due to the quality of the submissions. Nevertheless, a number of good submissions had to be rejected.

With much pleasure, I thank all those who contributed to the great success of WG 2005: the authors who submitted their work to the workshop, the speakers, the Program Committee members and the referees. I am indebted to the members of the Local Organization Committee: Michaël Rao, Mathieu Liedloff and Damien Aignel. Without their engagement and the help of various students during the meeting, WG 2005 could not have been such a great success.

Special thanks go to the sponsoring organizations: GDR du CNRS: Algorithmique, Langage et Programmation, GDR du CNRS: Architecture, Réseaux et Systèmes, Parallélisme, Laboratoire d’Informatique Théorique et Appliquée de l’Université Paul Verlaine-Metz, UFR MIM de l’Université Paul Verlaine-Metz, Université Paul Verlaine-Metz, Conseil Général de la Moselle, Conseil Régional de Lorraine, Communauté d’Agglomération Metz Métropole (CA2M).

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Hypertree Decompositions: Structure, Algorithms, and Applications*

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Abstract. We review the concepts of hypertree decomposition and hypertree width from a graph theoretical perspective and report on a number of recent results related to these concepts. We also show – as a new result – that computing hypertree decompositions is fixed-parameter intractable.

1 Hypertree Decompositions: Definition and Basics

This paper reports about the recently introduced concept of *hypertree decomposition* and the associated notion of *hypertree-width*. The latter is a cyclicity measure for hypergraphs, and constitutes a hypergraph invariant as it is preserved under hypergraph isomorphisms. Many interesting NP-hard problems are polynomially solvable for classes of instances associated with hypergraphs of bounded width. This is also true for other hypergraph invariants such as treewidth, cutset-width, and so on. However, the advantage of hypertree-width with respect to other known hypergraph invariants is that it is more general and covers larger classes of instances of bounded width. The main concepts of hypertree decomposition and hypertree-width are introduced in the present section. A normal form for hypertree decompositions is described in Section 2. Section 3 describes the Robbers and Marshals game which characterizes hypertree-width. In Section 4 we use this game to explain why the problem of checking whether the hypertree-width of a hypergraph is $\leq k$ is feasible in polynomial time for each constant k . However, in Section 5 we show that this problem is fixed-parameter intractable with respect to k . In Section 6 we compare hypertree-width to other relevant hypergraph invariants. In Section 7 we discuss heuristics for computing hypertree decompositions. In Section 8 we show how hypertree decompositions can be beneficially applied for solving constraint satisfaction problems (CSPs). Finally, in Section 9 we list some open problems left for future research. Due to space limitations this paper is rather short, and most proofs are missing. A more thorough treatment can be found in [13,16,2,1,15,17], most of which are available at the Hypertree Decomposition Homepage at <http://si.deis.unical.it/~frank/Hypertrees>.

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A *hypergraph* is a pair $H = (V(H), E(H))$, consisting of a nonempty set $V(H)$ of *vertices*, and a set $E(H)$ of subsets of $V(H)$, the *hyperedges* of H . We only consider finite hypergraphs. *Graphs* are hypergraphs in which all hyperedges have two elements.

For a hypergraph H and a set $X \subseteq V(H)$, the *subhypergraph induced by X* is the hypergraph $H[X] = (X, \{e \cap X \mid e \in E(H)\})$. We let $H \setminus X := H[V(H) \setminus X]$. The *primal graph* of a hypergraph H is the graph

$$\underline{H} = (V(H), \{\{v, w\} \mid v \neq w, \text{ there exists an } e \in E(H) \text{ such that } \{v, w\} \subseteq e\}).$$

A hypergraph H is *connected* if $\underline{H}$ is connected. A set $C \subseteq V(H)$ is *connected (in H)* if the induced subhypergraph $H[C]$ is connected, and a *connected component* of H is a maximal connected subset of $V(H)$. A sequence of nodes of $V(H)$ is a *path* of H if it is a path of $\underline{H}$.

A *tree decomposition* of a hypergraph H is a tuple (T, χ) , where $T = (V(T), E(T))$ is a tree and $\chi : V(T) \rightarrow 2^{V(H)}$ is a function associating a set of vertices $\chi(t) \subseteq V(H)$ to each vertex t of the decomposition tree T , such that for each $e \in E(H)$ there is a node $t \in V(T)$ such that $e \subseteq \chi(t)$, and for each $v \in V(H)$ the set $\{t \in V(T) \mid v \in \chi(t)\}$ is connected in T .

We assume the tree T in a tree decomposition to be rooted. For every node t , T_t denotes the rooted subtree of T with root t . For each such subtree T_t , let $\chi(T_t) = \bigcup_{v \in V(T_t)} \chi(v)$.

The *width* of a tree decomposition (T, χ) is $\max \{ |\chi(t)| - 1 \mid t \in V(T) \}$, and the *tree-width* of H is the minimum of the widths of all tree decompositions of H .

Observe that (T, χ) is a tree decomposition of H if and only if it is a tree decomposition of $\underline{H}$. Thus a hypergraph has the same tree-width as its primal graph.

Let H be a hypergraph. A *generalized hypertree decomposition* of H is a triple (T, χ, λ) , where (T, χ) is a tree decomposition of H and $\lambda : V(T) \rightarrow 2^{E(H)}$ is a function associating a set of hyperedges $\lambda(t) \subseteq E(H)$ to each vertex t of the decomposition tree T , such that for every $t \in V(T)$ we have $\chi(t) \subseteq \bigcup \lambda(t)$. The *width* of a generalized hypertree decomposition (T, χ, λ) is $\min \{ |\lambda(t)| \mid t \in V(T) \}$, and the *generalized hypertree-width* $\text{ghw}(H)$ of H is the minimum of the widths of all generalized hypertree decompositions of H .

A *hypertree decomposition* of H is a generalized hypertree decomposition (T, χ, λ) that satisfies the following *special condition*: $(\bigcup \lambda(t)) \cap \chi(T_t) \subseteq \chi(t)$ for all $t \in V(T)$. The *hypertree-width* $\text{hw}(H)$ of H is the minimum of the widths of all hypertree decompositions of H .

Example 1. Figure 1 shows a hypergraph H (consisting of 15 hyperedges and 19 vertices) and a tree decomposition of H . A generalized hypertree decomposition and a hypertree decomposition of H are illustrated in Figure 2. The left set within each rectangle represents the λ -labels and the right set represents the χ -labels. The generalized hypertree decomposition violates the special condition, because vertex 13 disappears from node with λ -label $\{h_{10}, h_{14}\}$ and it appears again in a subtree rooted at this node. The generalized hypertree-width of H is 2, whereas its hypertree-width is 3.

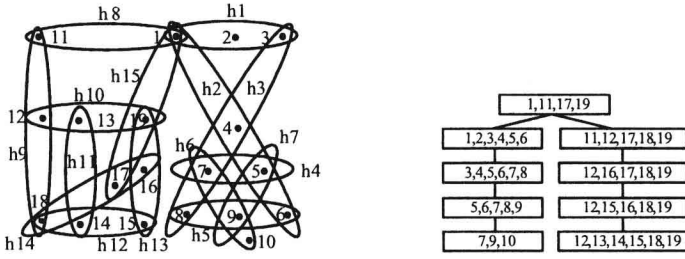


Fig. 1. A hypergraph H (left) and a tree decomposition of H (right)

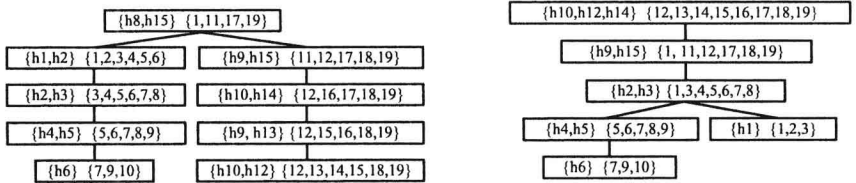


Fig. 2. Generalized hypertree decomposition (left) and hypertree decomposition (right) of H

Example 2. Let H be a the hypergraph with $V(H) = \{1, \dots, n\}$ and

$$E(H) = \{\{v, w\} \mid v, w \in V(H) \text{ with } v \neq w\} \cup \{V(H)\}.$$

Hence H is the hypergraph obtained from a complete graph with n vertices by adding a hyperedge that contains all vertices. It is easy to see that $\text{hw}(H) = 1$ and $\text{tw}(H) = n - 1$. Moreover, even the treewidth of the bipartite incidence graph of H is $n - 1$.

The structure of many problems can be described by hypergraphs (see also Section 8). Let us informally define a *hypertree decomposition* as a method of dividing hypergraphs into different parts so that the solution of certain problems whose structure is best described by hypergraphs can be obtained by a polynomial divide-and-conquer algorithm that suitably exploits this division. The *width* of such a decomposition is the size of the largest indecomposable part of this division.

The importance of hypergraph decompositions (be it tree decompositions, hypertree decompositions, or several others) lies in the fact that many problems can be polynomially solved if their associated hypergraph has a low width for the chosen decomposition (see Section 8). The problem is thus to find decompositions that have the following properties:

1. They should be as *general* as possible, i.e., so that the classes of hypergraphs of bounded width are as large as possible. A criterion for comparing the generality of decomposition methods will be given in Section 6.
2. They should be *polynomially computable*. More precisely, for each fixed constant k , we want to be able to check in polynomial time whether a decomposition of width k of an input hypergraph exists.