Publications

Frank Kammer

This is a survey of my publications arranged by topics. The ten particularly significant publications are highlighted blue in the list of references. Journal articles are marked with a star. They are long versions of previously published conference papers.

h-index: 10   (Google Scholar)
Average number of authors of my publications: ≈ 2.5 authors.

Space-efficient Graph Algorithms

Succinct Choice Dictionaries [11]

The *choice dictionary* is introduced as a data structure that can be initialized with a parameter $n \in \mathbb{N} = \{1, 2, \dots\}$ and subsequently maintains an initially empty subset S of $\{1, \dots, n\}$ under insertion, deletion, membership queries and an operation *choice* that returns an arbitrary element of S. The choice dictionary appears to be fundamental in space-efficient computing. We show that there is a choice dictionary that can be initialized with n and an additional parameter $t \in \mathbb{N}$ and subsequently occupies $n + O(n(t/w)^t + \log n)$ bits of memory and executes each of the four operations *insert*, *delete*, *contains* (i.e., a membership query) and *choice* in $O(t)$ time on a word RAM with a word length of $w = \Omega(\log n)$ bits. In particular, with $w = \Theta(\log n)$, we can support *insert*, *delete*, *contains* and *choice* in constant time using $n + O(n/(\log n)^t)$ bits for arbitrary fixed t. We extend our results to maintaining several pairwise disjoint subsets of $\{1, \dots, n\}$.

A static representation of a subset S of $\{1, \dots, n\}$ that consists of $n + s$ bits $b_1, \dots, b_{n+s}$ is called *systematic* if $b_\ell = 1 \Leftrightarrow \ell \in S$ for $\ell = 1, \dots, n$ and is said to have *redundancy* s. We extend the former definition to dynamic data structures and prove that the minimum redundancy of a systematic choice dictionary with parameter n that executes every operation in $O(t)$ time on a w-bit word RAM is $\Theta(n/(tw))$, provided that $tw = O(n/\log n)$. Allowing a redundancy of $\Theta(n \log(t \log n)/(t \log n) + n^\epsilon)$ for arbitrary fixed $\epsilon > 0$, we can support additional $O(t)$-time operations *p-rank* and *p-select* that realize a bijection from S to $\{1, \dots, |S|\}$ and its inverse. The bijection may be chosen arbitrarily by the data structure, but must remain fixed as long as S is not changed. In particular, an element of S can be drawn uniformly at random in constant time with a redundancy of $O(n \log \log n/\log n)$.

We study additional space-efficient data structures for subsets S of $\{1, \dots, n\}$, including one that supports only insertion and an operation *extract-choice* that returns and deletes an arbitrary element of S. All our main data structures can be initialized in constant time and support efficient iteration over the set S, and we can allow changes to S while an iteration over S is in progress. We use these abilities crucially in designing the most space-efficient algorithms known for solving a number of graph and other combinatorial problems in linear time. In particular, given an undirected graph G with n vertices and m edges, we can output a spanning forest of G in $O(n+m)$ time with at most $(1 + \epsilon)n$ bits of working memory for arbitrary fixed $\epsilon > 0$, and if G is connected,

we can output a shortest-path spanning tree of G rooted at a designated vertex in $O(n+m)$ time with $n \log_2 3 + O(n/(\log n)^t)$ bits of working memory for arbitrary fixed $t \in \mathbb{N}$.

Space-efficient Euler partition and bipartite edge coloring [12]

We describe space-efficient algorithms for two problems on undirected multigraphs: Euler partition (partitioning the edges into a minimum number of trails); and bipartite edge coloring (coloring the edges of a bipartite multigraph with the minimum number of colors). Let n, m and Δ be the numbers of vertices and of edges and the maximum degree, respectively, of the input multigraph. For Euler partition we reduce the amount of working memory needed by a logarithmic factor, to $O(n+m)$ bits, while preserving a running time of $O(n+m)$. For bipartite edge coloring, still using $O(n+m)$ bits of working memory, we achieve a running time of $O(n+m\min\{\Delta, \log\Delta(\log^*\Delta + (\log m \log\Delta)/\Delta)\})$. This is $O(m\log\Delta\log^*\Delta)$ if $m = \Omega(n\log n \log\log n/\log^* n)$, to be compared with $O(m\log\Delta)$ for the fastest known algorithm.

Space-Efficient Plane-Sweep Algorithms [3]

We introduce space-efficient plane-sweep algorithms for basic planar geometric problems. It is assumed that the input is in a read-only array of n items and that the available workspace is $\Theta(s)$ bits, where $\lg n \leq s \leq n \cdot \lg n$. Three techniques that can be used as general tools in different space-efficient algorithms are introduced and employed within our algorithms. In particular, we give an almost-optimal algorithm for finding the closest pair among a set of n points that runs in $O(n^2/s + n \cdot \lg s)$ time. We also give a simple algorithm to enumerate the intersections of n line segments that runs in $O((n^2/s^{2/3}) \cdot \lg s + k)$ time, where k is the number of intersections. The counting version can be solved in $O((n^2/s^{2/3}) \cdot \lg s)$ time. When the segments are axis-parallel, we give an $O((n^2/s) \cdot \lg^{4/3} s + n^{4/3} \cdot \lg^{1/3} n)$-time algorithm for counting the intersections, and an algorithm for enumerating the intersections that runs in $O((n^2/s) \cdot \lg s \cdot \lg\lg s + n \cdot \lg s + k)$ time, where k is the number of intersections. We finally present an algorithm that runs in $O((n^2/s + n \cdot \lg s) \cdot \sqrt{(n/s) \cdot \lg n})$ time to calculate Klee's measure of axis-parallel rectangles.

Space-Efficient Biconnected Components and Recognition of Outerplanar Graphs [19]

We present space-efficient algorithms for computing cut vertices in a given graph with n vertices and m edges in linear time using $O(n + \min\{m, n\log\log n\})$ bits. With the same time and using $O(n+m)$ bits, we can compute the biconnected components of a graph. We use this result to show an algorithm for the recognition of (maximal) outerplanar graphs in $O(n\log\log n)$ time using $O(n)$ bits.

Space-Efficient Basic Graph Algorithms [2]

We reconsider basic algorithmic graph problems in a setting where an n-vertex input graph is read-only and the computation must take place in a working memory of $O(n)$

bits or little more than that. For computing connected components and performing breadth-first search, we match the running times of standard algorithms that have no memory restrictions, for depth-first search and related problems we come within a factor of $\Theta(\log\log n)$, and for computing minimum spanning forests and single-source shortest-paths trees we come close for sparse input graphs.

Tree Decompositions, FPT and Kernelizations

Approximate Tree Decompositions of Planar Graphs in Linear Time [24, 27]

Many algorithms have been developed for NP-hard problems on graphs with small treewidth k. For example, all problems that are expressible in linear extended monadic second order can be solved in linear time on graphs of bounded treewidth. It turns out that the bottleneck of many algorithms for NP-hard problems is the computation of a tree decomposition of width $O(k)$. In particular, by the bidimensional theory, there are many linear extended monadic second order problems that can be solved on n-vertex planar graphs with treewidth k in a time linear in n and subexponential in k if a tree decomposition of width $O(k)$ can be found in such a time.

We present the first algorithm that, on n-vertex planar graphs with treewidth k, finds a tree decomposition of width $O(k)$ in such a time. In more detail, our algorithm has a running time of $O(nk^2 \log k)$. We show the result as a special case of a result concerning so-called weighted treewidth of weighted graphs.

Linear-Time Kernelization for the Rooted k-Leaf Outbranching Problem [17, 18]

In the ROOTED k-LEAF OUTBRANCHING PROBLEM, a digraph $G = (V, E)$, a vertex r of G, and an integer k are given, and the goal is to find an r-rooted spanning outtree of G with $\geq k$ leaves (a subtree of G with vertex set V, all edges directed away from r, and $\geq k$ leaves). We present a linear-time algorithm that computes a problem kernel with $O(k^6)$ vertices and $O(k^7)$ edges for the ROOTED k-LEAF OUTBRANCHING PROBLEM. By combining the new result with a result of Daligault and Thomassé [IWPEC 2009], a kernel with a quadratic number of vertices and edges can be found on n-vertex m-edge digraphs in time $O(n + m + k^{14})$.

The Complexity of Minimum Convex Coloring [13, 25]

A coloring of the vertices of a graph is called convex if each subgraph induced by all vertices of the same color is connected. We consider three variants of recoloring a colored graph with minimal cost such that the resulting coloring is convex. Two variants of the problem are shown to be $\mathcal{NP}$-hard on trees even if in the initial coloring each color is used to color only a bounded number of vertices. For graphs of bounded treewidth, we present a polynomial-time $(2 + \epsilon)$-approximation algorithm for these two variants and a polynomial-time algorithm for the third variant. Our results also show that, unless $\mathcal{NP} \subseteq DTIME(n^{O(\log\log n)})$, there is no polynomial-time approximation

algorithm with a ratio of size $(1-o(1)) \ln \ln N$ for the following problem: Given pairs of vertices in an undirected N-vertex graph of bounded treewidth, determine the minimal possible number l for which all except l pairs can be connected by disjoint paths.

Treelike and Chordal Graphs: Algorithms and Generalizations [16]

We present algorithms to compute tree decompositions on planar and chordal graphs. Using these algorithms and other algorithms to find a tree decomposition we solve the k-disjoint paths problem on chordal graphs and minimum convex coloring in graphs of small treewitdh. Finally, we show several algorithms on intersection graphs.

Linear-Time Computation of a Linear Problem Kernel for Dominating Set on Planar Graphs [1]

We present a linear-time data reduction algorithm that transforms a given planar graph G with domination number $\gamma(G)$ into a planar graph G' of size $O(\gamma(G))$ with $\gamma(G) = \gamma(G')$. In addition, a minimum dominating set for G can be inferred from a minimum dominating set for G'. In terms of parameterized algorithmics, this implies a linear-size problem kernel for the NP-hard DOMINATING SET problem on planar graphs, where the kernelization takes linear time. This improves on previous kernelization algorithms that provide linear-size kernels in cubic time.

The k-Disjoint Paths Problem on Chordal Graphs [22]

Algorithms based on a bottom-up traversal of a tree decomposition are used in literature to develop very efficient algorithms for graphs of bounded treewidth. However, such algorithms can also be used to efficiently solve problems on chordal graphs, which in general do not have a bounded treewidth. By combining this approach with a sparsification technique we obtain the first linear-time algorithm for chordal graphs that solves the k-disjoint paths problem. In this problem k pairs of vertices are to be connected by pairwise vertex-disjoint paths. We also present the first polynomial-time algorithm for chordal graphs capable of finding disjoint paths solving the k-disjoint paths problem with minimal total length. Finally we prove that the version of the disjoint paths problem, where k is part of the input, is NP-hard on chordal graphs.

Determining the smallest k such that G is k-outerplanar [15]

The outerplanarity index of a planar graph G is the smallest k such that G has a k-outerplanar embedding. We show how to compute the outerplanarity index of an n-vertex planar graph in $O(n^2)$ time, improving the previous best bound of $O(k^3 n^2)$. Using simple variations of the computation we can determine the radius of a planar graph in $O(n^2)$ time and its width in $O(n^3)$ time.

We also give a linear-time 4-approximation algorithm for the outerplanarity index and show how it can be used to solve maximum independent set and several other NP-hard problems faster on planar graphs with outerplanarity index within a constant factor of their treewidth.

Connectivity [21]

We are mainly concerned with the strength of connections between vertices with respect to the number of vertex- or edge-disjoint paths. As we shall see, this is equivalent to the question of how many nodes or edges must be removed from a graph to destroy all paths between two (arbitrary or specified) vertices.

We present algorithms which check k-vertex (k-edge) connectivity, compute the vertex (edge) connectivity, and compute the maximal k-connected components of a given graph.

A Lower Bound for the Treewidth of k-Outerplanar Graphs [23]

Many optimization problems can be solved efficiently if a tree-decomposition of small width is given. Unfortunately, all known algorithms computing, for general graphs, a tree decomposition of width k, if one exists, have a running time exponential in k. However, Bodlaender observed that each k-outerplanar graph has a tree decomposition of width at most $3k - 1$ and his analysis implicitly leads to an $O(kn)$-time algorithm for computing such a tree-decomposition. In this paper we show that the bound $3k - 1$ is tight, i.e., for every $k \in I\!N$, there are k-outerplanar graphs having treewidth $3k - 1$.

Temporal Graphs

On Temporal Graph Exploration [7]

A temporal graph is a graph in which the edge set can change from step to step. The temporal graph exploration problem TEXP is the problem of computing a foremost exploration schedule for a temporal graph, i.e., a temporal walk that starts at a given start node, visits all nodes of the graph, and has the smallest arrival time. We consider only temporal graphs that are connected at each step. For such temporal graphs with n nodes, we show that it is **NP**-hard to approximate TEXP with ratio $O(n^{1-\varepsilon})$ for any $\varepsilon > 0$. We also provide an explicit construction of temporal graphs that require $\Theta(n^2)$ steps to be explored. We then consider TEXP under the assumption that the underlying graph (i.e. the graph that contains all edges that are present in the temporal graph in at least one step) belongs to a specific class of graphs. Among other results, we show that temporal graphs can be explored in $O(n^{1.5}k^2 \log n)$ steps if the underlying graph has treewidth k and in $O(n \log^3 n)$ steps if the underlying graph is a $2 \times n$ grid. We also show that sparse temporal graphs with regularly present edges can always be explored in $O(n)$ steps.

Online- and Approximationalgorithms

Query-Competitive Algorithms for Cheapest Set Problems under Uncertainty [6, 8]

Considering the model of computing under uncertainty where element weights are uncertain but can be obtained at a cost by query operations, we study the problem of

identifying a cheapest (minimum-weight) set among a given collection of feasible sets using a minimum number of queries of element weights. For the general case we present an algorithm that makes at most $d \cdot OPT + d$ queries, where d is the maximum cardinality of any given set and OPT is the optimal number of queries needed to identify a cheapest set. For the minimum multi-cut problem in trees with d terminal pairs, we give an algorithm that makes at most $d \cdot OPT + 1$ queries. For the problem of computing a minimum-weight base of a given matroid, we give an algorithm that makes at most $2 \cdot OPT$ queries, generalizing a known result for the minimum spanning tree problem. For each of the above algorithms we give matching lower bounds. We also settle the complexity of the verification version of the general cheapest set problem and the minimum multi-cut problem in trees under uncertainty.

Approximation Algorithms for Intersection Graphs [26, 28]

We study three complexity parameters called *k-perfectly groupable*, *k-simplicial*, and *k-perfectly orientable*. These parameters measure in some sense how chordal-like a graph is. The similarity to chordal graphs is used to construct simple polynomial-time approximation algorithms with constant approximation ratio for many NP-hard problems, when restricted to graphs for which at least one of the three complexity parameters is bounded by a constant. As applications we present approximation algorithms with constant approximation ratio for maximum weighted independent set, minimum (independent) dominating set, minimum vertex coloring, maximum weighted clique, and minimum clique partition for large classes of intersection graphs.

Practical Approaches to Partially Guarding a Polyhedral Terrain [20]

We study the problem of placing guard towers on a terrain such that the terrain can be seen from at least one tower. This problem is important in many applications, and has an extensive history in the literature (known as, e.g. multiple observer siting). In this paper, we consider the problem on polyhedral terrains, and we allow the guards to see only a fixed fraction of the terrain, rather than everything. We experimentally evaluate how the number of required guards relates to the fraction of the terrain that can be covered. In addition, we introduce the concept of dominated guards, which can be used to preprocess the potential guard locations and speed up the subsequent computations.

Removing local extrema from imprecise terrains [9, 10]

In this paper we consider imprecise terrains, that is, triangulated terrains with a vertical error interval in the vertices. In particular, we study the problem of *removing* as many local extrema (minima and maxima) as possible from the terrain; that is, finding an assignment of one height to each vertex, within its error interval, so that the resulting terrain has minimum number of local extrema. We show that removing only minima or only maxima can be done optimally in $O(n \log n)$ time, for a terrain with n vertices. Interestingly, however, the problem of finding a height assignment that minimizes the total number of local extrema (minima as well as maxima) is NP-hard, and is even hard to approximate within a factor of $O(\log \log n)$ unless P = NP. Moreover, we show that even a simplified version of the problem where we can have only three different types of intervals for the vertices is already NP-hard, a result we obtain by proving hardness

of a special case of 2-Disjoint Connected Subgraphs, a problem that has lately received considerable attention from the graph-algorithms community.

Maximising Lifetime for Fault-Tolerant Target Coverage in Sensor Networks [4, 5]

We study the problem of maximising the lifetime of a sensor network for fault-tolerant target coverage in a setting with composite events. Here, a composite event is the simultaneous occurrence of a combination of atomic events, such as the detection of smoke and high temperature. We are given sensor nodes that have an initial battery level and can monitor certain event types, and a set of points at which composite events need to be detected. The points and sensor nodes are located in the Euclidean plane, and all nodes have the same sensing radius. The goal is to compute a longest activity schedule with the property that at any point in time, each event point is monitored by at least two active sensor nodes. We present a $(6 + \varepsilon)$-approximation algorithm for this problem by devising an approximation algorithm with the same ratio for the dual problem of minimising the weight of a fault-tolerant sensor cover. The algorithm generalises previous approximation algorithms for geometric set cover with weighted unit disks and is obtained by enumerating properties of the optimal solution that guide a dynamic programming approach.

Graph Drawing

Simultaneous Embedding of Two Planar Graphs with Two Bends per Edge [14]

The simultaneous embedding problem is, given two planar graphs $G_1 = (V, E_1)$ and $G_2 = (V, E_2)$, to find planar embeddings $\varphi(G_1)$ and $\varphi(G_2)$ such that each vertex $v \in V$ is mapped to the same point in $\varphi(G_1)$ and in $\varphi(G_2)$. This article presents a linear-time algorithm for the simultaneous embedding problem such that edges are drawn as polygonal chains with at most two bends and all vertices and all bends of the edges are placed on a grid of polynomial size. An extension of this problem with so-called fixed edges is also considered.

A further linear-time algorithm of this article solves the point-set-embedding problem: Given a planar graph G and a set of distinct points, find a planar embedding for G that maps each vertex to one of the given points. The solution presented also uses at most two bends per edge and a grid whose size is polynomial in the size of the grid that includes all given points.

An example shows two bends per edge to be optimal for both problems.

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