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Effiziente Algorithmen

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The meeting was devoted to new developments in the field of combinatorial algorithms and the quest to make such algorithms as efficient as possible, in terms of running time, space consumption or other measures. Whereas some participants reported on research on classical topics in computational geometry, data structures, average-case analysis and parallel computing, we also saw a number of presentations situated in more recent areas such as approximation, online and dynamic algorithms, cache-obliviousness and nonstandard flow problems. A recurring theme was the internet and algorithms for its analysis and use.

Susanne Albers
Torben Hagerup
Kurt Mehlhorn
David P. Williamson

Abstracts

Dynamic TCP Acknowledgement: Penalizing Long Delays

Susanne Albers

(joint work with Helge Bals)

We study the problem of acknowledging dynamically a sequence of data packets that are sent across a TCP connection. We investigate objective functions that aim at keeping the maximum acknowledgement delay of any data packet as short as possible and hence are particularly useful when TCP is used for interactive data transfer. We present tight upper and lower bounds on the best competitive performance of deterministic online algorithms. Additionally we show lower bounds on the competitiveness of randomized strategies.

On the Complexity of (Un-)Folding

Helmut Alt

We consider the problem of 'folding' a linkage of rigid straight segments from a given start to a given target position with a continuous non-intersecting motion. The problem is nontrivial even for trees in two dimensions since it is known that not all configurations can be unfolded to a straight position. We show that deciding foldability for trees in two dimensions and chains in three dimensions is PSPACE-complete.

Cache-Oblivious Data Structures for Orthogonal Range Searching

Lars Arge

(joint work with Pankaj Agarwal, Andrew Danner, and Bryan Holland-Minkley)

We describe cache-oblivious data structures for orthogonal range searching, the problem of finding all T points in a set of N points in $\mathbb{R}^d$ lying in a query hyper-rectangle. Cache-oblivious data structures are designed to be efficient in arbitrary memory hierarchies.

We first describe a dynamic linear-size data structure that answers d-dimensional queries in $O((N/B)^{1-1/d} + T/B)$ memory transfers, where B is the block size of any two levels of a multilevel memory hierarchy. A point can be inserted into or deleted from this data structure in $O(\log 2_B N)$ memory transfers. We also describe a static structure for the two-dimensional case that answers queries in $O(\log_B N + T/B)$ memory transfers using $O(N \log_2 2N)$ space. The analysis of the latter structure requires that $B = 2^{2^c}$ for some non-negative integer constant c.

Management of Multi-Queue Switches in QoS Networks

Yossi Azar

(joint work with Yossi Richter)

The concept of Quality of Service (QoS) networks has gained growing attention recently, as the traffic volume in the Internet constantly increases, and QoS guarantees are essential to ensure proper operation of most communication based applications. A QoS switch serves m incoming queues by transmitting packets arriving at these queues through one output port, one packet per time unit. Each packet is marked with a value indicating its guaranteed quality of service. Since the queues have bounded capacity and the rate of arriving packets can be much higher than the transmission rate, packets can be lost due to insufficient queue space. The goal is to maximize the total value of transmitted packets. This problem encapsulates two dependent questions: admission control, namely which packets to discard in case of queue overflow, and scheduling, i.e. which queue to use for transmission in each time unit. We use competitive analysis to study online switch performance in QoS based networks. Specifically, we provide a novel generic technique that decouples the admission control and scheduling problems. Our technique transforms any single queue admission control strategy (preemptive or non-preemptive) to a scheduling and admission control algorithm for our general m queues model, whose competitive ratio is at most twice the competitive ratio of the given admission control strategy. We use our technique to derive concrete algorithms for the general preemptive and non-preemptive cases, as well as for the interesting special cases of the 2-value model and the unit-value model. To the best of our knowledge this is the first result combining both scheduling and admission control decisions for arbitrary packets sequences in multi-queue switches. We also provide a 1.58-competitive randomized algorithm for the unit-value case. This case is interesting by itself since most current networks (e.g. IP networks) only support a best-effort service in which all packets streams are treated equally.

A preliminary version of this paper appears in the proceedings of the 35th Annual ACM Symposium on Theory of Computing (STOC), 2003, pp. 82-89.

Finding a Guard that Sees Most and a Shop that Sells Most

Otfried Cheong

(joint work with Alon Efrat and Sariel Har-Peled)

We present a near-quadratic time algorithm that computes a point inside a simple polygon P having approximately the largest visibility polygon inside P, and near-linear time algorithm for finding the point that will have approximately the largest Voronoi region when added to an n-point set.

A New Approach to Dynamic All-Pairs Shortest Paths

Camil Demetrescu

(joint work with Giuseppe F. Italian)

We discuss novel combinatorial properties of graphs that allow us to devise a completely new approach to dynamic shortest path problems. In particular, we present a new all-pairs shortest paths algorithm that supports any edge weight update in $O\ (n^2)$ amortized time and any distance query in constant time. Our algorithm is deterministic and works on directed graphs with nonnegative real-valued edge weights. We finally show that, according to an extensive computational study on synthetic and real-world instances, our new techniques can be very efficient in practice.

Almost Random Graphs with Simple Hash Functions

Martin Dietzfelbinger
(joint work with Philipp Wölfel)

We describe a simple randomized construction for generating pairs of hash functions h_1, h_2 from a universe U to ranges $V = [m] = \{0, 1, \ldots, m-1\}$ and $W = [m]$ so that for every key set $S \subseteq U$ with $n = |S| \leq m/(1+\epsilon)$ the (random) bipartite (multi)graph with node set $V \uplus W$ and edge set $\{(h_1(x), h_2(x)) \mid x \in S\}$ exhibits a structure that is essentially random. The construction combines d-wise independent classes for d a relatively small constant with the well-known technique of random offsets. While keeping the space needed to store the description of h_1 and h_2 at $O(n^\zeta)$, for $\zeta < 1$ fixed arbitrarily, we obtain a much smaller (constant) evaluation time than previous constructions of this kind, which involved Siegel's high-performance hash classes. The main new technique is the combined analysis of the graph structure and the inner structure of the hash functions, as well as a new way of looking at the cycle structure of random (multi)graphs. The construction may be applied to improve on Pagh and Rodler's 'cuckoo hashing' (2001), to obtain a simpler and faster alternative to a recent construction of Östlin and Pagh (2002/03) for simulating uniform hashing on a key set S, and to the simulation of shared memory on distributed memory machines.

Cuts and Disjoint Paths in the Valley-Free Path Model

Thomas Erlebach
(joint work with Alexander Hall, Alessandro Panconesi and Danica Vukadinović)

In the valley-free path model, a path in a given directed graph is valid if it consists of a sequence of forward edges followed by a sequence of backward edges. This model is motivated by routing policies of autonomous systems in the Internet. We give a 2-approximation algorithm for the problem of computing a maximum number of edge- or vertex-disjoint valid paths between two given vertices s and t, and we show that no better approximation ratio is possible unless $P = NP$. Furthermore, we give a 2-approximation for the problem of computing a minimum vertex cut that separates s and t with respect to all valid paths and prove that the problem is APX-hard. The corresponding problem for edge cuts is shown to be polynomial-time solvable. We present additional results for acyclic graphs.

Some Issues on Peer to Peer Networks

Amos Fiat

In this talk we review certain recent results regarding peer to peer networks:

1. Use of Latent Semantics for Search, joint work with Edith Cohen and Haim Kaplan, suggests how one can utilize the idea of common interests so as to speed up search in unstructed peer to peer networks.

2. Censorship resistant peer to peer networks, joint work with Jared Saia, show that structured peer to peer networks can be created that allow most peers to access most data items, efficiently, even if an adversary deletes a constant fraction of carefully chosen pairs.

3. Unlinkability, joint work with Ron Berman and Amnon Ta-Shma, proves the correctness of a protocol similar to Chaum's onion routing and mixing, under an adversarial model where the adversary controls all but a small fraction of the links in the network.

Randomized Permutations in a Coarse Grained Parallel Environment

Jens Gustedt

We show how to uniformly distribute data at random (not to be confounded with permutation routing) in a coarse grained parallel environment with p processors. In contrast to previously known work, our method is able to fulfil the three goals of uniformity, work-optimality and balance among the processors simultaneously. To guarantee the uniformity we investigate the matrix of communication requests between the processors. We show that its distribution is a generalization of the multivariate hypergeometric distribution and we give algorithms to compute it efficiently.

Simpler Computation of Single-Source Shortest Paths in Linear Average Time

Torben Hagerup

Meyer as well as Goldberg recently described algorithms that solve the single-source shortest-paths problem in linear average time on graphs with random edge lengths drawn from the uniform distribution on $[0, 1]$. It is shown that the same result can be obtained through simple combinations of standard data structures and with a trivial probabilistic analysis.

Flows Over Time

Alexander Hall

(joint work with Steffen Hippler, Katharina Langkau, and Martin Skutella)

Flow variation over time is an important feature in network flow problems arising in various applications such as road or air traffic control, production systems, communication networks (e.g., the Internet), and financial flows. The common characteristic are networks with capacities and transit times on the arcs which specify the amount of time it takes for flow to travel through a particular arc. Moreover, in contrast to static flow problems, flow values on arcs may change with time in these networks.

While the 'maximum s-t-flow over time' problem can be solved efficiently and 'min-cost flows over time' are known to be NP-hard, the complexity of (fractional) 'Multicommodity flows over time' has been open for many years. We prove that this problem is NP-hard, even for series-parallel networks, and present new and efficient algorithms under certain assumptions on the transit times or on the network topology. As a result, we can draw a complete picture of the complexity landscape for flow over time problems.

Additionally we mention new results in a slightly different model, where the transit times depend on the rate at which flow enters the arcs.

A Lower Bound for Real-RAM Data Structures

Riko Jacob

Consider the problem of a data-structure on the real-RAM, that maintains a set of n real numbers under insertions, and allows membership queries. We show that such a data-structure needs to take amortized time $q(n) = \Omega(\log n)$ for queries, and amortized time $\Omega(\log(n/q(n))$ for insertions. This results also apply for predecessor and planar convex-hull data-structures.

Improved Approximation Algorithms for the General Max-Min Resource Sharing and Fractional Covering Problem

Klaus Jansen

We propose an improved approximation algorithm for the general max-min resource sharing (and fractional covering) problem with M nonnegative concave (linear) constraints on a convex set B. The algorithm (based on a Lagrangian decomposition method) uses an approximate block solver that solves a simpler maximization problem over the convex set B (called the block problem) approximately with ratio $c \geq 1$. We show that our algorithm achieves within $O(M\epsilon^{-2}\ln(M\epsilon^{-1}))$ iterations or calls to the approximate block solver a solution for the max-min resource sharing and fractional covering problem with approximation ratio $c/(1-\epsilon)$. Our algorithm is the first one for both problems where the number of iterations is independent of the width and the approximation ratio c.

Automated Generation of Runtime-Proofs for Certain NP-Complete Problems

Frank Kammer

Many proofs of an upper bound for the runtime of NP-complete problems have something in common: They determine a good choice of some smaller instances whose solutions allow to solve the examined input instance in polynomial time. It is interesting that these smaller instances can be found using only a few rules, which are mainly problem-independent. My presentation shows, how a computer can use these rules to prove an upper bound.

On the Fractal Behaviour of TCP

Howard Karloff

(joint work with Anna Gilbert)

We propose a natural, mathematically tractable model of TCP which captures both its additive-increase, multiplicative-decrease behaviour and its feedback mechanism. Neither a fluid nor a mean-field model, our model does not explicitly model the loss process; the losses are entirely determined by the rates of the sources at the time of buffer overflow. The system involves two sources competing to send packets into one recipient buffer of size B, from which bytes are drained at the rate of d per step. We prove that for many choices of the pairs (B,d), the long term behaviour of the system is fractal. We conjecture that this fact continues to hold for all $B > d$ and $d > 2$.

Nearest Neighbour Search in Geometric Pattern Spaces

Christian Knauer

One of the central problems of geometric pattern matching is the so-called matching problem. The task is to determine, given two shapes Q and P, how to transform Q according to a class of admissible transformations, so as to minimize a specific distance measure between the image of Q and P. This problem has various incarnations, depending on which shapes are considered (e.g., point sets, polygonal curves), what the admissible transformations are (e.g., translations, rigid motions) and which distance measure is used (e.g. Hausdorff distance, Frchet distance). In many applications one is faced with the problem of preprocessing a set of shapes $\{P_1, ..., P_n\}$ into a search structure, in order to be able to quickly solve the matching problem for query shapes. We consider the special case where the size of the shapes in the search structure, as well as the size of the queries is constant. We show that for many combinations of shapes, distance measures, and admissible transformations it is possible to build a search structure with sublinear query time of slightly subquadratic space in the same amount of preprocessing time that allows nearest neighbor queries to a set of shapes with respect to the distance measure and the set of transformations. The technique is based on point-location in a sign-invariant decomposition of the configuration space of the patterns used in combination with quantifier elimination to incorporate the transformations.

Smoothed Competitive Analysis of the Multi-Level Feedback Algorithm

Stefano Leonardi

(joint work with L. Becchetti, A. Marchetti-Spaccamela, G. Schaefer, and T. Vredeveld)

Spielman and Teng invented the concept of smoothed analysis to explain the success of algorithms that are known to work well in practice while presenting poor worst case performance. Spielman and Teng [STOC 01] proved that the simplex algorithm runs in expected polynomial time if the input instance is smoothened with a normal distribution.

We extend this notion to analyze online algorithms. In particular we introduce smoothed competitive analysis to study the Multi-Level Feedback (MLF) algorithm, at the basis of the scheduling policies of Unix and Windows NT, when the processing times of jobs released over time are only known at time of completion.

We show that, if the k least significant of K bits describing the processing time of a job are randomly changed, MLF achieves a tight smoothed competitive ratio of O(2K-k) to minimize the average flow time. A direct consequence is a first constant approximation for this problem in the average case under a quite general class of probability distributions.

Matching Algorithms Are Fast on Sparse Random Graphs

Kurt Mehlhorn

(joint work with Holger Bast, Guido Schäfer and Hisao Tamaki)

We consider random (bipartite or general) graphs in the $G_{n,p}$ model: potential edges are chosen independently with probability p. We show that every non-maximum matching in such a graph has a logarithmic length augmenting path with high probability provided that $p \geq c/n$ for some constant c. Our proof works for $c \approx 8.5$ in the bipartite case and for $c \approx 27$ in the general case. We leave it open whether the result holds for all p. As a consequence, the expected running time of the matching algorithms of Hopcroft/Karp and Micali/Vazirani is $O(m \log n)$. Previously, the result was only known for $p \geq (\ln n)/n$ (Motwani, JACM).

Data Reduction for Domination in Networks

Rolf Niedermeier
(joint work with Jochen Alber, Nadja Betzler, Britta Dorn)

We present theoretical and some empirical results towards computing optimal dominating sets in graphs by means of data reduction. The data reduction rules are based on considering the local neighborhood of vertices and vertex pairs. If the problem cannot be fully solved by the (polynomial time) reduction rules, at least they may serve as efficient preprocessing which can be followed by any other exact, heuristic, or approximation algorithm to cope with this NP-complete problem.

For planar graphs with a dominating set of size k, we can prove that after the data reduction a reduced graph with at most $335k$ vertices remains as a 'problem kernel'.

Analysis of a Simple Fair Scheduling Algorithm

Mike Paterson
(joint work with Micah Adler, Petra Berenbrink, Tom Friedetzky, Leslie Ann Goldberg and Paul Goldberg)

A set of n jobs is being run concurrently. Each job has an associated weight which gives the proportion of processor time which should ideally be allocated to it. In each time quantum, p of the jobs receive one unit of service, and we need a rule to select the p jobs at each quantum. Proportionate fairness means that, over time, each job should receive service proportional to its weight. Since the units are discrete, this ideal cannot always be achieved, and in addition any practical rule must be very fast to evaluate.

We consider a very simple variant of Surplus Fair Scheduling (Chandra, Adler, Goyal and Shenoy) and give tight bounds on its worst-case deviation from fairness. We show that this deviation is approximately $\log n + O(p)$.

Dynamic Dictionaries and Binary Trees in Near-Minimum Space

Rajeev Raman

We consider space-efficient solutions to two dynamic data structuring problems. We first give a representation of a set $S \subseteq U = \{0, \ldots, m-1\}$, $|S| = n$ that supports membership queries in $O(1)$ worst case time and insertions/deletions in $O(1)$ expected amortised time. The representation uses $\alpha + o(\alpha)$ bits, where $\alpha = \lceil \lg \binom{m}{n} \rceil$ is the information-theoretic minimum space to represent S. This improves upon the $O(\alpha)$-bit solutions of Brodnik and Munro and Pagh, and uses up to a log-factor less space than search trees or hash tables. The representation can associate s-bit *satellite* data with elements of S, which can be retrieved in response to a successful membership query; the space bound increases to $\alpha + ns + o(\alpha + ns)$.

We also give a representation of a binary tree on n nodes, where $b = O(\lg n)$-bit satellite data may be associated with each node. The representation supports traversal of the tree, starting and ending at the root. During the traversal, one can move to the parent or left/right child of the current node in $O(1)$ time, inspect the satellite datum (if any) associated with it, determine the size of the subtree rooted at it or its pre-order number. One can modify the tree by adding or deleting nodes adjacent to the current node, in $O(1)$ amortised time. The space used by this representation is either $(b+2)n + o(bn)$ bits or $(2b+2)n + o(bn)$ bits, depending on whether satellite data are associated with internal or external nodes only, or both. An even more space-efficient version reduces the lower-order term to $o(n)$ bits, but updates now take $O((\lg\lg n)^{1+\epsilon})$ time, for any constant $\epsilon > 0$; this improves upon the equally space-efficient structure of Munro et al., in which updates take $O(\lg^c n)$ time, for some $c \geq 1$.

An Efficient Automata Approach to Some Problems on Context-Free Grammars

Peter Rossmanith

An automata-based approach to a number of elementary problems on context-free grammars is presented by computing the predecessors of a given regular language represented by a finite automaton, i.e., all strings from which exists a derivation to a string in the regular language.

This approach is of pedagogical interest since it provides a uniform solution to decision procedures usually solved by independent algorithms in textbooks. A closer inspection reveals that the new algorithm is competitive to well-known solutions for most standard problems.

The challenge is to make the computation of predecessors as fast as possible while also not using too much space.

On the k-Splittable Flow Problem

Martin Skutella

In traditional multi-commodity flow theory, the task is to send a certain amount of each commodity from its start to its target node, subject to capacity constraints on the edges. However, no restriction is imposed on the number of paths used for delivering each commodity; it is thus feasible to spread the flow over a large number of different paths. Motivated by routing problems arising in real-life applications, such as, e.g., telecommunication, unsplittable flows have moved into the focus of research. Here, the demand of each commodity may not be split but has to be sent along a single path.

We study a generalization of this problem. In the considered flow model, a commodity can be split into a bounded number of chunks which can then be routed on different (not necessarily disjoint) paths. In contrast to classical (splittable) flows and unsplittable flows, we can show that already the single-commodity case of this problem is NP-hard and even hard to approximate. We present approximation algorithms for the single- and multi-commodity case. The single-commodity results rely on an efficient algorithm for the restricted problem where all k paths must carry the same amount of flow. For this case, we also give a MaxFlow-MinCut type theorem in spirit of the classical result of Ford and Fulkerson.

Approximating Geometric Bottleneck Shortest Paths

Michiel Smid

(joint work with Prosenjit Bose, Anil Maheshwari, Giri Narasimhan, and Norbert Zeh)

In a geometric bottleneck shortest path problem, we are given a set S of n points in the plane, and want to answer queries of the following type: Given two points p and q of S and a real number L, compute (or approximate) a shortest path between p and q in the subgraph of the complete graph on S consisting of all edges whose lengths are less than or equal to L. We present efficient algorithms for answering several query problems of this type. Our solutions are based on Euclidean minimum spanning trees, spanners, the Delaunay triangulation, and separators in planar graphs. A result of independent interest is the following. For any two points p and q of S, there is a path between p and q in the Delaunay triangulation, whose length is less than or equal to $2\pi/(3\cos(\pi/6))$ times the Euclidean distance $|pq|$ between p and q, and all of whose edges have length at most $|pq|$.

Random Knapsack in Expected Polynomial Time

Berthold Vöcking

(joint work with Rene Beier)

In this paper, we present the first average-case analysis proving an expected polynomial running time for an exact algorithm for the 0/1 knapsack problem. In particular, we prove, for various input distributions, that the number of dominating solutions (i.e., Pareto-optimal knapsack fillings) to this problem is polynomially bounded in the number of available items. An algorithm by Nemhauser and Ullmann can enumerate these solutions very efficiently so that a polynomial upper bound on the number of dominating solutions implies an algorithm with expected polynomial running time. The random input model underlying our analysis is very general and not restricted to a particular input distribution. We assume adversarial weights and randomly drawn profits (or vice versa). Our analysis covers general probability distributions with finite mean, and, in its most general form, can even handle different probability distributions for the profits of different items. This feature enables us to study the effects of correlations between profits and weights. Our analysis confirms and explains practical studies showing that so-called strongly correlated instances are harder to solve than weakly correlated ones.

A Better, Faster Approximation Algorithm for the Minimum Latency Problem

David P. Williamson

(joint work with Aaron Archer and Asaf Levin)

We give a 7.18-approximation algorithm for the minimum latency problem that uses only $O(n \log n)$ calls to the prize-collecting Steiner tree (PCST) subroutine of Goemans and Williamson. This improves the previous best algorithms in both performance guarantee and running time. A previous algorithm of Goemans and Kleinberg for the minimum latency problem requires an approximation algorithm for the k-MST problem which is called as a black box for each value of k. Their algorithm can achieve a performance guarantee of 10.77 while making $O(n^2 \log n)$ PCST calls (via a k-MST algorithm of Garg), or a performance guarantee of $7.18 + \epsilon$ while using $n^{O(1/\epsilon)}$ PCST calls (via a k-MST algorithm of Arora and Karakostas). In all cases, the running time is dominated by the PCST calls.

Since the PCST subroutine can be implemented to run in $O(n^2)$ time, the overall running time of our algorithm is $O(n^3 \log n)$.

The basic idea for our improvement is that we do not treat the k-MST algorithm as a black box. This allows us to take advantage of some special situations in which the PCST subroutine delivers a k-MST with a performance guarantee of 2. We are able to obtain the same approximation ratio that would be given by Goemans and Kleinberg if we had access to 2-approximate k-MST's for all values of k, even though we have them only for some values of k that we are not able to specify in advance.

Edited by Frank Kammer

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