Parameterized Complexity-News

The Newsletter of the Parameterized Complexity Community Volume 3, May 2008

Welcome

Frances Rosamond, Editor
Welcome to the latest issue of the Parameterized Complexity Newsletter. We begin with celebration of two long open problems resolved! This leads us to ask what are the next challenges. Our aim is to be provocative and informative, suggesting new problems while keeping the community abreast of the rapidly expanding list of applications and techniques. The world records of FPT races (as we know them)are summarized. The newsletter has a Problem Corner and a section of research ideas. There are sections for recent papers and manuscripts, for conferences, and one to keep us up-to-date on new positions and occasions. Over a million euros! Congratulations J.A. Telle. Grant successes are mentioned for inspiration. We extend congratulations to new graduates.

Contributions, suggestions or requests to add or delete a name from my mailing list may be sent to the email address: (`fptnews@yahoo.com`). Suggestions for a logo for the newsletter are welcome. Copies of the newsletter are archived at the IWPEC website which is (`http://www.scs.carleton.ca/~dehne/iwpec`).

New Results

by Moritz Mueller, Igor Razgon, Fran Rosamond and Saket Saurabh

These results are so new that they don't fit into the 'FPT Race' table–many are the very first results of long open problems. The race starts now. It was difficult to choose from among so many outstanding new results and directions. The Newsletter does not contain *all* the news.

A. Directed Problems cracked!

The long-outstanding parameterized Directed Feedback Vertex Set has been solved with an $O^*(k! * 4^k)$ algorithm. The paper by Chen, Liu, Lu, O'Sullivan, and Razgon will appear at STOC'08. Directed "Spanning Tree with Constraints" problems, such as Directed Maximum Leaf or Directed Spanning Tree, have solutions based on the methodology: reduce to bounded treewidth. Results include an $O(2^k * k)$ kernel for 'Minimum-Leaf Outbranching', parameter the number of non-leaf vertices. The paper by Gutin, Razgon, Kim will appear at AAIM'08 and can be found at CoRR abs/0801.1979(2008), and "Parameterized Algorithms for Directed Maximum Leaf Problems" by Alon, Fomin, Gutin, Krivelevich and Saurabh was presented at ICALP'07.

B. Almost 2-SAT

Given a 2-CNF formula, is it possible to remove at most k clauses so that the resulting 2-CNF formula is satisfiable? This problem known as 'Almost-2-SAT', 'All-but-k-2-SAT', 'Minimum 2-CNF-Deletion', or '2-SAT-Deletion', now has an $O^*(15^k)$ algorithm due to Razgon and O'Sullivan. The extended abstract will appear at ICALP'08. The full version of the algorithm is available at http://arxiv.org/abs/0801.1300.

The '2-SAT Deletion' problem is equivalent to '$n/2+k$-Vertex Cover', which is equivalent to 'Within-k-vertices-of-König-in-Perfect-Graphs', equivalent to 'Removeable Horn'.

Graphs where the size of a minimum vertex cover equals that of a maximum matching are known as König-Egervry. In "The Complexity of Finding Subgraphs

Contents of this issue:

Welcome . . . 1
New Results . . . 1
Established FPT Races . . . 3
Treewidth: History, Applications, Algorithms, and Programs . . . 4
Local Search . . . 7
Resources and Publications . . . 8
Humboldt Research Award . . . 9
Conferences . . . 9
Grant Success . . . 10
Prizes and Awards . . . 10
Appointments and Positions . . . 10
Congratulations! . . . 10

Whose Matching Number Equals the Vertex Cover Number”, ISAAC’07, Mishra, Raman, Saurabh, Sikdar and Subramanian investigate finding a minimum number of vertices (edges) to delete to make the resulting graph König-Egervry. They show ‘Above-Guarantee-Vertex-Cover’ (Vertex Cover parameterized by the additional number of vertices needed beyond the matching size) is FPT ; e.g., ‘König Deletion’ is FPT applying the ‘Almost-2-SAT’ result of Razgon et al.

C. Theoretical Progress

Parameterized Approximation The question of FPT approximation: “... as inspired from various issues coming from the Robertson-Seymour theorems we might ask for an algorithm for DOMINATING SET, which, when given an instance (G, k) with parameter k, either says that there is no dominating set of G of size k or gives a k-approximate one. (e.g., one of size $2k$.) Does the existence of such a parametrized algorithm imply something like [W2] = FPT?” was raised as early as 1993 by Karl Abrahamson, Rodney Downey and Michael Fellows: Fixed-Parameter Tractability and Completeness IV: On Completeness for W[P] and PSPACE Analogues. Ann. Pure Appl. Logic 73(3): 235-276 (1995). Recent results in this area include the positive result for the ‘Parameterized Approximability of the Disjoint Cycle Problem’, ICALP’07. Grohe and Grüber give a polynomial-time, and possibly the first, FPT approximation algorithm for a natural W[1]-hard problem. Negative results are shown in the CCC’08 paper by Kord Eickmeyer, Martin Grohe, and Magdalena Grüber: ‘Approximisation of natural W[P]-complete minimisation problems is hard’, and by a recent paper of Downey, Fellows, McCartin and Rosamond showing that Independent Dominating Set is completely FPT inapproximable.

Lower Bounds for Kernels A parameterized problem is in FPT if and only if there is a P-time algorithm that reduces the input (x, k) to *kernelized* input (x', k') where $k' \leq k$, $|x'| \leq g(k)$ and (x, k) is a yes-instance if and only if (x', k') is a yes-instance. The big surprise is that so many problems in FPT admit fairly small kernels. Sometimes the best kernelizations are achieved by fairly sophisticated (polynomial-time) algorithms, and this can lead to practical applications. Some problems in FPT (k-CLIQUE COVER is one), however, have only known exponential-in-k kernelization. This makes it natural to search for lower bound methods. Bodlaender, Downey, Fellows and Hermelin recently developed techniques for arguing that some FPT problems do not admit poly(k) kernelization, unless reasonable complexity hypotheses fail. This work will be presented by Hermelin at ICALP’08. LONG PATH is an example of a problem the new techniques apply to.

Miniaturization Isomorphism FPT is often seen as a practical necessity. In ‘An Isomorphism between Subexponential and Parameterized Complexity Theory,’ (CCC’06), Yijia Chen and Martin Grohe show how parameterization offers theoretical help for classical problems, transporting structure to subexponential complexity. They show a close connection between subexponential time complexity and parameterized complexity by proving that the miniaturization mapping is a reduction-preserving isomorphism between the two theories.

‘Randomized’ can be deleted! Alekhnovich and Razborov posed that any result establishing non-automatizability of tree-like Resolution needs to be formulated within a complexity framework in which the asymptotics $n^{O(1)}$ and n^{logn} are essentially different; i.e., parameterized complexity. The derandomization of their FOCS’01 result that resolution is not automatizable unless W[P] is in randomized FPT has been shown now (over 10 years later) by Eickmeyer, Grohe and Grueber in ‘Approximation of Natural W[P]-complete Minimisation Problems is Hard’ (CCC’08). The paper contains also many non-approximability results on W[P]-minimization.

Induced Subgraph Isomorphisms Yijia Chen, Marc Thurley and Mark Weyer: Understanding the Complexity of Induced Subgraph Isomorphisms (ICALP’08) give a full complexity classification of Induced Substructure Isomorphism. The upper part of their dichotomy uses parameterized hardness and the lower part uses classical tractability, and they proved that this has to be so: one cannot classify this problem with classical theory alone. Another example of how parameterization can be useful (even necessary) for answering theoretical questions.

Hypergraph Transversal Duality Khaled Elbassion, Matthias Hagen, Imran Rau: Some fixed-parameter tractable classes of hypergraph duality and related problems, accepted to IWPEC’08. They present FPT algorithms for the problem Dual: Given two hypergraphs, decide if one is the transversal hypergraph of the other, with the number of edges of the hypergraphs, the maximum degree of a vertex, and a vertex complementary degree as parameters. They use an Apriori approach to obtain FPT for generating all maximal independent sets of a hypergraph, all minimal transversals of a hypergraph, and all maximal frequent sets where parameters bound the intersections or unions of edges.

Multicolor-Clique A new very powerful and useful technique for proving W[1]-hardness: reduction from Multicolor-Clique (MCC), either the *vertex representation* or the *edge representation* has been introduced by Mike Fellows, Hermelin and Rosamond (2007) in "On the Fixed-Parameter Intractability and Tractability of Multiple-Interval Graph Problems," (unpublished). Given a k-colored graph G, MCC asks if there exists a k-clique consisting of one vertex of each color. The technique is used by Michael Dom and Somnath Sikdar in "The Parameterized Complexity of the Rectangle Stabbing Problem and its Variants", COCOA'08 and by Stefan Szeider and Luke Mathieson in "The Parameterized Complexity of Regular Subgraph Problems and Generalizations", CATS'08.

D. Other Areas using Parameterized

Artificial Intelligence *The Parameterized Complexity of Global Constraints* by C. Bessiere, E. Hebrard, B. Hnich, Z. Kiziltan, C. G. Quimper and T.Walsh has been accepted at AAAI 2008, the top AI conference and according to its citation impact, a few times higher than that of STOC. AAAI can be considered as a top conference of all of Computer Science.

Cognitive Science and Psychology Iris vonRooij will give a plenary, *Dealing with Intractability in Cognitive Models* to the European Mathematical Psychology Group (EMPG'08)in Graz. The lecture will discuss how parameterized complexity techniques can help cognitive scientists identify sources of intractability in their cognitive models.

Computational Biology Clustering is being used in experiments and implementations by several research groups: Moscato (Newcastle, AU), Langston (Tenn, USA), Niedermeier (Jena), among others. Recent results include Sebastian Böcker, Sebastian Briesemeister and Quang Bao Anh Bui and Anke Truß: Going Weighted: Parameterized Algorithms for Cluster Editing, COCOA'08.

Social Science and Voting New results include: A Protocol for Achieving a Consensus Based on the Generalised Dodgson's Rule and Its Complexity by Fellows, Rosamond, Slinko. On Complexity of Lobbying in Multiple Referenda by Christian, Fellows, Rosamond and Slinko in Review of Economic Design, 2007. Fixed-Parameter Algorithms for Kemeny Scores by Betzler, Fellows, Guo, Niedermeier, and Rosamond has been accepted for AAIM'08.

Established FPT Races

The results gradually keep improving, and the latest best results are summarized here. The table is not complete and we are awaiting information on your favorite problem for the next issue.

Problem	*f(k)*	**kernel**	**Ref**
Vertex Cover	1.2738^k	$2k$	1
Feedback Vertex Set	5^k	k^3	2
Planar DS	$2^{15.13\sqrt{k}}$	$67k$	3
1-Sided Crossing Min	1.4656^k		4
Max Leaf	6.75^k	$4k$	5
Directed Max Leaf	$2^{O(k \log k)}$	?	6
Set Splitting	2^k	$2k$	7
Nonblocker	2.5154^k	$5k/3$	8
3-D Matching	2.77^{3k}		9
Edge Dominating Set	2.4181^k	$8k^2$	10
k-Path*	4^k	no $k^{O(1)}$	11
Convex Recolouring	4^k	$O(k^2)$	12
VC-max degree 3	1.1899^k		13
Clique Cover	$2^{\Delta k}$	2^k	14
Clique Partition		2^k	15
Cluster Editing	1.83^k	$4k$	16
Steiner Tree	2^k		17
3-Hitting Set	2.076^k	$O(k^2)$	18
Minimum Fill/ Interval Completion	$O(k^{2k}n^3m)$		19

1) J. Chen, I. Kanj and G. Xia. Improved Parameterized Upper Bounds for Vertex Cover. *MFCS 2006.*
2) J. Chen, F. Fomin, Y. Liu, S. Lu and Y. Villanger. Improved Algorithms for the Feedback Vertex Set Problems. *WADS 2007.*
H. L. Bodlaender. A Cubic Kernel for Feedback Vertex Set. *STACS 2007.*
3) F. Fomin and D. Thilikos. Dominating sets in planar

graphs: Branch-width and exponential speed-up. *SODA 2003*, for the running time.
H. Fernau. Parameterized Algorithmics: A Graph Theoretic Approach. *HabSchrift. Wilhelm-Schickard Institut für Informatik, Universität Tübingen, 2005*, for the kernel.
4) V. Dujmovic, H. Fernau and M. Kaufmann. Fixed parameter algorithms for one-sided crossing minimization revisited. *GD 2003*.
5) P. Bonsma and Florian Zickfeld. Spanning Trees with Many Leaves in Graphs without Diamonds and Blossoms. *LATIN 2008*, for the running time.
V. Estivill-Castro, M. Fellows, M. Langston and F. Rosamond. Fixed-Parameter Tractability is Polynomial-Time Extremal Structure Theory I: The Case of Max Leaf. *ACiD 2004*, for the kernel.
6) Paul Bonsma and Frederic Dorn. Tight Bounds and Faster Algorithms for Directed Max-Leaf Problems. http://arxiv.org/abs/0804.2032
7)D. Lokshtanov and C. Sloper. *ACiD 2005*.
Chen & Lu. Improved Algorithms for Weighted and Unweighted Set Splitting Problems. *COCOON 2007*, randomized $O(2^k)$ algorithm.
8) F. Dehne, M. Fellows, H. Fernau, E. Prieto, and F. Rosamond. Nonblocker: Parameterized Algorithms for Minimum Dominating Set. *SOFSEM 2006*.
9) Y. Liu, S. Lu, J. Chen and S-H. Sze. Greedy Localization and Color-Coding: Improved Matching and Packing Algorithms. They also have a randomized result of 2.32^{3k}. *IWPEC 2006*.
10) Fedor V. Fomin, Serge Gaspers, Saket Saurabh and Alexey A. Stepanov. On Two Techniques of Combining Branching and Treewidth. *To appear in Algorithmica*, for the running time.
H. Fernau. EDGE DOMINATING SET: Efficient Enumeration-Based Exact Algorithms. *IWPEC 2006*, for the kernel.
11) J. Chen, S. Lu, S-H. Sze, F. Zhang. Improved Algorithms for Path, Matching, and Packing Problems. *SODA 2007*.
J. Kneis, D. Mölle, S. Richter and P. Rossmanith. Divide-and-Color. *WG 2006* (independently found the same algorithm).
H. Bodlaender, R. Downey, M. Fellows and D. Hermelin. On Problems Without Polynomial Kernels. *ICALP 2008*.
* From Moritz Mueller: Pointed Path (the starting point of the length k path is given) has no strong subexponential kernelization ('strong' means that it doesn't increase the parameter) unless ETH fails. Or: Path has no poly kernel even when restricted to planar and connected graphs. An open problem is the subexponential kernelizability for Path, and finding methods for excluding subexponential kernelizations.
12) O. Ponta, F. Hüffner and R. Niedermeier. Speeding up Dynamic Programming for Some NP-hard Graph Recoloring Problems. *TAMC 2008*.
H. Bodlaender, M. Fellows, M. Langston, M. Ragan, F. Rosamond and M. Weyer. Kernelization for Convex Recoloring. *ACiD 2006*.
13) I. Razgon. Personal Communication.
14) J. Gramm, J. Guo, F. Hüffner, and R. Niedermeier. Data reduction, exact, and heuristic algorithms for clique cover. *ALENEX 2006*.
15) E. Mujuni and F. Rosamond. Parameterized Complexity of the Clique Partition Problem. *CATS 2008*.
16) S. Böcker, S. Briesemeister, Q. Bui and Anke Truß. PEACE: Parameterized and Exact Algorithms for Cluster Editing. Manuscript, Lehrstuhl für Bioinformatik, Friedrich-Schiller-Universität Jena, 2007
J. Guo. A More Effective Linear Kernelization for Cluster Editing. *ESCAPE 2007*.
17) A. Björklund, T. Husfeldt, P. Kaski and M. Koivisto. Fourier meets Möbius: Fast Subset Convolution. *STOC 2007*.
18) M. Wahlström. Algorithms, Measures and Upper Bounds for Satisfiability and Related Problems. PhD Thesis, Department of Computer and Information Science, Linköpings universitet, Sweden, 2007.
F. Abu-Khzam. Kernelization Algorithms for d-hitting Set Problems. *WADS 2007*.
19) P. Heggernes, C. Paul, J. A. Telle, and Y. Villanger. Interval completion with few edges. *STOC 2007*.

Treewidth: History, Applications, Algorithms, and Programs

by Hans Bodlaender and Fran Rosamond

This text is based on a talk given by Hans Bodlaender at the Workshop on Graph Decompositions: Theoretical, Algorithmic and Logical Aspects, CIRM'08. Much more can be said that is not written here. Treewidth is of great practical and theoretical importance.

Many problems belong to FPT when the treewidth (TW) is a parameter. Applications are found in probabilistic networks, a technology that underlies many modern decision support systems. Vertices of a graph represent statistical variables, and the (in)dependencies are modeled by the edges, and tables with conditional probabilities. The central problem, inference, is #P-complete;

however, Lauritzen and Spiegelhalter showed that it is linear time solvable when the TW (of the moralized graph) is bounded. TW often appears to be small for actual probabilistic networks, and many modern commercial and freeware systems use the Lauritzen-Spiegelhalter algorithm as the main method for solving inference. TW is also used in resistance of electrical networks and graph minor theory. Many NP-hard (and some PSPACE-hard, or #P-hard) graph problems become polynomial or linear time solvable when restricted to graphs of bounded TW (or pathwidth or branchwidth), including independent set, Hamiltonian circuit, and graph coloring. In minor testing, for fixed H, and k, testing if H is a minor of a given graph of treewidth at most k can be done in $O(n)$ time. Treewidth and the related notion of branchwidth differ at most by a factor 1.5. Amongst others, Dorn et al., and Pönitz and Tittmann performed experiments that show that treewidth, pathwidth, or branchwidth can be used well to solve problems on practical instances.

Courcelle's linear time algorithm for problems expressible in Monadic Second-Order Logic (quantification over vertices, sets of vertices, edges, sets of edges, adjacency and incidence checks, or, and, not) provides a theoretical method to quickly derive linear time algorithms for many problems on graphs of small treewidth.

Cook and Seymour use treewidth (or branchwidth) as follows for an excellent heuristic for TSP: Run the iterative Lin-Kernighan algorithm a number of times (e.g., five times). Take the union of these five tours. Find a minimum length Hamiltonian circuit in this graph using tree (or branch) decomposition. The graph appears in practice to have small TW.

While computing the treewidth of a graph is NP-hard, (Arnborg et al, 1987), and the linear time algorithm by Bodlaender (1996) has such a large constant hidden in the O-notation that it is not practical, even for treewidth four (Röhrig, 1998), there are several methods to compute the treewidth exactly or approximately (upper *and* lower bounds) that work well in practice.

Different representations The usual definition of treewidth is in terms of tree decompositions. However, several other equivalent definitions exist. The most well known, and one that historically predates the tree decomposition definition is the one by partial k-trees by Arnborg and Proskurowski. In the 1980's, several researchers independently invented similar notions: Partial k-trees (Arnborg, Proskurowski), Treewidth and tree decompositions (Robertson, Seymour), Clique trees (Lauritzen, Spiegelhalter), Recursive graph classes (Borie), k-Terminal recursive graph families (Wimer), Decomposition trees (Lautemann), Contex-free graph grammars (Lengauer, Wanke).

Treewidth also has a representation as a search problem. The TW of a graph can be expressed as minimum number of searchers to capture a fugitive in a certain search game. The fugitive is on a vertex of a graph. Searchers move with helicopters and see the fugitive. The fugitive sees the helicopter land and can move with infinite speed, but not through vertices with a searcher. The TW equals the number of searchers needed to capture the fugitive minus one.

Other representations, useful for algorithms are: the treewidth of a graph G is the minimum over all chordal graphs H containing G as subgraph of the maximum clique size of H, and a representation in terms of permutations of the vertices (see below). The equivalence of these representations follows from classic results from chordal graph theory.

Preprocessing Before employing a relatively slow exact algorithm for an NP-hard problem, one usually would start by preprocessing the graph: using reduction rules, we simplify the graph into a smaller equivalent graph while maintaining optimality. By a recent result by Bodlaender et al. (ICALP'08), it follows that it is 'unlikely' that treewidth has a polynomial kernel. Still, there are several preprocessing/reduction methods that work well in practice and use polynomial time.

Arnborg, Proskurowski, 1986 showed that a graph has TW at most 3, iff it is reduced to the empty graph using only 6 reduction rules. These rules were generalized by Bodlaender, Koster, van den Eijkhof, van der Gaag (2001, WG'02 and UAI'01) to work on graphs with treewidth more than three. Bodlaender and Koster also investigated the preprocessing technique of using *Safe Separators*, which splits the graph into smaller parts. The treewidth of the original instance equals the maximum of the TW of the parts.

Combination of the techniques often leads to good results: often, quite quickly (polynomial time and a matter of seconds or minutes), much smaller instances are obtained. These then can be used as input to a slower exact algorithm, e.g., dynamic programming or branch and bound. The following table shows some recent results when the method was applied to probabilistic networks. The first column lists networks, the second lists network vertices before preprocessing and the third lists the number of vertices after preprocessing. Notice that in some cases we have been able to reduce to the empty graph.

Network	Before	After
Alarm	37	0
Munin(1)	189	48
Munin(2)	1003	79
Oesoca+	67	0
Pignet2	3032	746
Wilson	27	0

Upper bound heuristics There are fast and easy heuristics for computing treewidth that use a definition of tree decomposition quite different from the familiar *bags*. This definition is related to Gauss elimination. In graph elimination, the neighborhood of a vertex is made into a clique and the vertex removed. Different vertex orderings (elimination schemes) are possible. The *fill-in graph* is the minimum over all elimination schemes of the number of added edges (new non-zeros). For chordal graphs, the fill-in is zero. Given a permutation π (elimination order) of the vertices, the fill-in graph is made as follows: For $i = 1$ to n: add an edge between each pair of higher numbered neighbors of the ith vertex. Given such a permutation, the $TW(G)$ is the minimum over all permutations of vertices of the maximum number of higher numbered neighbors of a vertex in the fill-in graph. TW is the minimum over all elimination schemes of maximum degree of a vertex when eliminated (min max number of non-zeros in a row when eliminating row).

There are relationships between TW and chordal graphs. A graph G is chordal, if and only if:
G has a tree decomposition with each bag a clique (the intersection graph of subtrees of a tree),
G has an elimination order and for each v, its higher numbered neighbors form a clique (perfect elimination scheme)
A graph G has TW $\leq k$, if and only if:
G is a subgraph of a chordal graph (triangulation) with maximum clique size $\leq k$,
G has an elimination order with each vertex $\leq k$ higher numbered neighbors in the fill-in graph.

Any heuristic that creates a permutation of the vertices thus can be used as a heuristic for TW. Some are based upon chordal graph graph recognition algorithms (Max Cardinality Search, LexBFS, ...). Often used, very fast, and usually quite good are the Minimum Degree and Minimum Fill-in heuristics. Other variants are known (Bachoore, B, 2004), and various improvements using the useful idea that if H is a subgraph of G then TW(G) is at least the treewidth of H. Stepwise improvement of trivial tree decomposition was provided by Koster (1999). Other heuristics use a principle known as nested dissection, Amir (2001).

Much slower, but better results are obtained using local search based algorithms. A tabu search algorithm by Clautiaux et al. (2004) modifies elimination orderings by inserting vertices on a different positions, such that the fill-in graph changes. Koster, Marchal, van Hoesel (2006) use *flipping* of edges in triangulation.

Lower bounds Lower bounds are useful: they help speed up a branch-and-bound algorithm, tell how good an upper bound is, and a large lower bound tells us that a dynamic programming algorithm using tree decompositions is not a good idea for this particular instance. The minimum degree of a graph is a trivial lower bound on TW. This can be improved to *degeneracy*: repeatedly remove the vertex of minimum degree; TW is at least the largest minimum degree seen. Using the fact that contraction of an edge of the graph does not increase TW, Koster, Wolle, Bodlaender (2004) provided TW lower bounds using the notion of *contraction degeneracy*: contract the vertex of minimum degree to a neighbor instead of deleting it. Further lower bound heuristics Ramachandramurthi (WG'94), Lucena (2003) and Bodlaender and Koster, (WG'04) use Maximum Cardinality Search. More lower bounds were found by using an alternative TW characterisation called *brambles*, Bodlaender, Grigoriev and Koster (ESA'05).

A nice technique to improve lower bound methods was obtained by Clautiaux *et al.* (2003) using the fact that if v and w have $k+1$ vertex disjoint paths and $TW(G) \leq k$, then the treewidth of $G + \{v, w\}$ is at most k. Take a conjectured bound on the TW, add the edges that are safe by the fact, and then run a lower bound method on the graph with added edges. These LBN and LBP methods can be further improved by adding contractions: LBN+ and LBP+ (Bodlaender, Koster, Wolle ESA'04).

Exact algorithms Exact algorithms have been found using branch-and-bound, dynamic programming and ILP. Elimination orderings have been used by Gogate, Dechter (2004), Bachoore, B (2005) and by B, Fomin, Koster, Kratsch, Thilikos (ESA'06) with DP in Held-Karp style.

Gogate and Dechter's Branch-and-Bound algorithm builds a permutation of the vertices. For each vertex v: Choose v as first vertex and add fill-in edges for v. Run a lower bound heuristic on the new graph and possibly stop at this branch. Otherwise recurse (next time finding 2nd vertex, etc.)

A nice technique to limit the number of branches, by Bodlaender et al. (ESA'06) is to find a clique W in G. In practice, one can find a maximum clique. This is fast enough for the instances on which we can hope to solve TW exactly! There is always an elimination ordering that gives the optimal TW and that ends on W. Thus, we limit our search for elimination orderings with W at the end, and this saves a lot of time. The technique can be used for branch-and-bound and for dynamic programming algorithms for TW. Current investigations include the use of a *sentinel technique* to quickly check simpliciality for a branch-and-bound algorithm.

Building the decomposition has been accomplished by Shoikhet, Geiger (1997) implementing an algorithm of Arnborg, Corneil and Proskurowski (1987). Exact algorithms for TW 1, 2, 3 has been done by Arnborg, Proskurowski (1986) using reduction. Koster et al. (2006) use ILP-methods. Bodlaender et al. (ESA'06) give a Dynamic Programming algorithm for TW that uses $O^*(2^n)$ time and works on up to 60 vertices. Berry and Bodlaender (2007) speed up DP or branching algorithms using the notion of *moplex*.

Closing remarks One interesting issue when doing experimental graph algorithms is how to test them. One could say: *Random graphs do not exist*: testing on random graphs only has clear dangers. As random graphs fulfill 0-1 laws, they have properties that may explain the behaviour of the algorithm in testing, while graphs from applications may not fulfill these properties.

Current investigations show that treewidth is useful in practice, and that we do not need to be scared away by the fact that treewidth is NP-hard. For many small instances, we can compute the treewidth exactly, especially when we first use preprocessing; for others, often upper and lower bound heuristics give reasonable results.

Local Search

by Daniel Marx

Local search is a technique that has been applied successfully in many areas of Operations Research and Combinatorial Optimization for more than 50 years. The basic idea is to find better and better solutions by improving the current solution. The improvement is local: the current solution is replaced by the best solution in its neighborhood, where the neighborhood is defined in a problem-specific way. For example, in the Traveling Salesperson Problem (TSP), we can define the neighbors of a tour to be those tours that can be obtained by replacing at most 2 arcs in the tour (this is the well-known 2-change rule). In an optimization problem involving Boolean formulas, two assignments can be considered neighbors if they differ only on a single variable (or more generally, on at most k variables for a fixed constant k). Metaheuristic approaches such as simulated annealing and tabu search are variations on this theme.

The effectiveness of local search procedure largely depends on the set of allowed operations that is used to define the neighborhood. Presumably, having a larger set of operations increases our chances of finding a better tour, i.e., it is less likely that the algorithm gets stuck in a local optimum. So in the TSP problem, it would be preferable to allow the replacement of at most k arcs (instead of 2) and for Boolean formulas, it would be preferable to allow the flipping of at most k variables for k as large as possible. However, the time required to find the best solution in the local neighborhood increases if we increase k. A simple brute-force search gives a running time of $n^{O(k)}$, which is prohibitive for large n even for, say, $k = 10$. Thus it is a very natural question whether there is a more effective approach for searching the neighborhood: is it fixed-parameter tractable, parameterized by k? Formally, let P be an optimization problem and suppose that we have defined a distance metric on the solutions. We define the following problem:

P-Local-Search	
Input:	An instance I of P, a solution x for I, and an integer k.
Parameter:	k
Question:	Is there a solution x' for I that is strictly better than x and the distance of x and x' is at most k?

If P-Local-Search is fixed-parameter tractable, then this means that the local neighborhood can be searched in a nontrivial way, i.e., there is an algorithm that can be used for larger values of k for which the $n^{O(k)}$ brute force algorithm is no longer feasible. Therefore, local search algorithms for the problem P can be improved by searching a larger neighborhood. It is worth pointing out that studying the complexity of P-Local-Search makes sense only in the parameterized setting. If problem P is NP-hard, then we do not expect P-Local-Search to be polynomial-time solvable: intuitively, being able to check whether a given solution is optimal seems almost as powerful as finding the optimum (although there are technicalities such as whether there is a feasible solution at all). So here parameterized complexity is not just a finer way of analyzing the running time, but an essential prerequisite for any meaningful treatment of the problem.

So far, there are only a handful of parameterized complexity results in the literature, but they show that this is a fruitful research direction. The fixed-parameter tractability results are somewhat unexpected and this suggests that there are many other such results waiting to be discovered. The W[1]-hardness results show that proving hardness is doable also in this setting.

- Khuller, Bhatia, and Pless [1] investigated the NP-hard problem of finding a feedback edge set that is incident to the minimum number of vertices. This problem is motivated by applications in meter placement in networks. They proved (among other results) that checking whether it is possible to obtain a better solution by replacing at most k edges of the feedback edge set can be done in time $O(n^2 + nf(k))$, i.e., it is fixed-parameter tractable parameterized by k.

- Marx [3] showed that the k-change local search problem for TSP (find a better tour by replacing at most k arcs in the tour) is W[1]-hard. The result holds even if the distance matrix is symmetric and satisfies the triangle inequality. However, it remains an interesting open question whether the problem is fixed-parameter tractable if the cities are points in the Euclidean plane.

- Krokhin and Marx [2] investigated the local search problem for finding a minimum weight assignment for a Boolean constraint satisfaction instance. That is, given a satisfying assignment for a CSP instance, the task is to find another satisfying assignment by flipping at most k variables such that the number of 1's is strictly less in the new assignment. In general, this problem is W[1]-hard, but it is investigated in a setting similar to Schaefer's Dichotomy Theorem [4]: for every finite set Γ of Boolean constraints, it is proved that the problem restricted to instances having constraints only from Γ is either FPT or W[1]-hard. In particular, the problem is FPT for 1-in-3 SAT and for affine constraints. Furthermore, it follows as a by product that local search for both Minimum Vertex Cover and Maximum Independent Set is W[1]-hard, even in bipartite graphs.

References

[1] S. Khuller, R. Bhatia, and R. Pless. On local search and placement of meters in networks. *SIAM J. Comput.*, 32(2):470–487, 2003.

[2] A. Krokhin and D. Marx. On the hardness of losing weight, 2008. Accepted for ICALP 2008.

[3] D. Marx. Searching the k-change neighborhood for TSP is W[1]-hard. *Oper. Res. Lett.*, 36(1):31–36, 2008.

[4] T. J. Schaefer. The complexity of satisfiability problems. In *Conference Record of the Tenth Annual ACM Symposium on Theory of Computing (San Diego, Calif., 1978)*, pages 216–226. ACM, New York, 1978.

Resources and Publications

Open problems from Dagstuhl Seminar 07281 Structure Theory and FPT Algorithmics for Graphs, Digraphs and Hypergraphs, compiled by Erik Demaine, Gregory Gutin, Daniel Marx and Ulrike Stege.

Open Problems in Parameterized and Exact Computation from IWPEC 2006 by Hans L. Bodlaender, Leizhen Cai, Jianer Chen, Michael R. Fellows, Jan Arne Telle, Dniel Marx. Located on Bodlaender's Technical Reports page (http://www.cs.uu.nl/research/techreps/aut/hansb.html).

The survey: 'Invitation to data reduction and problem kernelization' by Jiong Guo and Rolf Niedermeier, *ACM SIGACT News*, 38(2):31-45, 2007.

The "Handbook of Satisfiability" IOS Press, expected 2008. Eds: Armin Biere, Hans van Maaren and Toby Walsh, will contain the chapter 'Fixed-Parameter Tractability' by Marko Samer and Stefan Szeider.

EATCS Feb'08 contains an informative interview with Rod Downey provided by C.S. Calude.

Textbooks mentioning Parameterized Complexity
(1) Richard Johnsonbaugh and Marcus Schaefer, *Algorithms*, Prentice-Hall, 2004.
(2) J. Kleinberg and E. Tardos, *Algorithm Design*, Addison-Wesley, 2005.

Compendium of Parameterized Problems collected by Marco Cesati can be found at `http://bravo.ce.uniroma2.it/home/cesati/research/compendium/`. The core set of problems can also be found in lists of Michael Hallett and H. Tod Wareham.

Jena Group of Rolf Neidermeier puts their publications and many other helpful items on their web page `http://www.minet.uni-jena.de/www/fakultaet/theinf1/publications`.

Journal of Problem Solving Iris vonRooij reports that the new online open access multi-disciplinary journal *Journal of Problem Solving (JPS)*(http://docs.lib.purdue.edu/jps/) publishes empirical and theoretical papers on mental mechanisms involved in problem solving. JPS welcomes research in all areas of human problem solving, with special interest in optimization and combinatorics, mathematics and physics, knowledge discovery, theorem proving, games and puzzles, insight problems and problems arising in applied settings. The journal turn around is quite fast with a policy of finalizing reviews within 6-8 weeks.

The Computer Journal The Special Issue on Parameterized Complexity will be the first and third issues of *The Computer Journal* for 2008, Chief Editor is Fionn Murtagh. Guest Editors R. Downey, M. Fellows and M. Langston have written a visionary Foreword.

1. *Combinatorial Optimization on Graphs of Bounded Treewidth* by Hans Bodlaender and Arie Koster.
2. *Parameterized Complexity of Cardinality Constrained Optimization Problems* by Leizhen Cai.
3. *Parameterized Complexity and Biopolymer Sequence Comparison* by Liming Cai, Xiuzhen Huang, Chunmei Liu, Frances Rosamond, and Yinglei Song.
4. *On Parameterized Intractability: Hardness and Completeness* by Jianer Chen and Jie Meng.
5. *The Bidimensionality Theory and its Algorithmic Applications* by Erik Demaine and Mohammad Taghi Hajiaghayi.
6. *Parameterized Complexity of Geometric Problems* by Panos Giannopoulos, Christian Knauer and Sue Whitesides.
7. *Width Parameters Beyond Treewidth and Their Applications* by Georg Gottlob, Petr Hlineny, Sang-il Oum and Detlef Seese.
8. *Fixed-Parameter Algorithms for Artificial Intelligence, Constraint Satisfaction and Database Problems* by Georg Gottlob and Stefan Szeider.
9. *Fixed-Parameter Algorithms in Phylogenetics* by Jens Gramm, Arfst Nickelsen and Till Tantau.
10. *Some Parameterized Problems on Digraphs* by Gregory Gutin and Anders Yeo.
11. *Techniques for Practical Fixed-Parameter Algorithms* by Falk Huffner, Rolf Niedermeier and Sabastian Wernicke.
12. *Innovative Computational Methods for Transcriptomic Data Analysis: A Case Study in the Use of FPT for Practical Algorithm Design and Implementation* by Michael Langston, Andy Perkins, Arnold Saxton, Jon Scharff and Brynn Voy.
13. *Parameterized Complexity and Approximation Algorithms* by Daniel Marx.
14. *An Overview of Techniques for Designing Parameterized Algorithms* by Christian Sloper and Jan Arne Telle.
15. *Parameterized Complexity in Cognitive Modeling: Foundations, Applications and Opportunities* by Iris van Rooij and Todd Wareham.

Humboldt Research Award

Mike Fellows received a von Humboldt Research Award and he and Fran are spending most of 2008 with Rolf Niedermeier's group in Jena, Germany. Mike is available to visit research teams in Germany during 2008 (Contact Rolf or Mike).

Conferences

The IWPEC website is hosted by Carleton University at `www.scs.carleton.ca/~dehne/iwpec`.

IWPEC'08: International Workshop on Parameterized and Exact Computation May, Victoria, Canada. Special thanks to Ulrike Stege (IWPEC Local Arrangements) and Valerie King (STOC Local Arrangements) for cross-referencing IWPEC and STOC on the respective websites. IWPEC Proceedings are published by Springer.

AAIM'08 & Summer-School Student-Week on Parameterized Algorithmics July, Shanghai, China. Organizing Chair Prof. Rudolf Fleischer, Fudan Univ.

Grant Successes

Jan Arne Telle and Fedor Fomin Of only five Norwegian Research Awards to applied mathematics and computer science, the Algorithms Group at U. Bergen scored two! Jan Arne Telle receives about a million Euros for Parameterized Complexity. Fedor Fomin's award was partly for Parameterized Complexity. Congratulations.

Gregory Gutin Congratulations to Gregory Gutin, Royal Holloway who was awarded an EPSRC Grant for 2007/2010 of over 400,000 GBP.

Vladimir Estivill-Castro, Michael Langston and Mike Fellows Received an ARC Discovery Grant for 'Efficient Pre-Processing of Hard Problems: New Approaches, Basic Theory and Applications'.

Rolf Niedermeier and Vankatesh Raman Their DAAD-DST Project Based Personnel Exchange Programme grant: Provably Efficient Exact Algorithms for Computationally Hard Problems, provides collaboration support between Jena and India.

Rolf Niedermeier and Rudolph Fleischer Exchange program between Jena and Shanghai has been granted by the Bosch Stiftung. There are three new DFG projects in the Jena group ("DARE", "PABI" and "AREG), see http://theinf1.informatik.uni-jena.de/research/ for details.

Prizes and Awards

Congratulations **Jiong Guo** and **Falk Hueffner**. For two consecutive years, the Univ. Jena has nominated a student from Rolf Niedermeier's group for the dissertation prize of the "Gesellschaft für Informatik", the largest German-language computer science society. Each university in Germany, Austria and Switzerland can nominate only one computer science PhD candidate per year. In 2007, Dr. Guo received the dissertation award of the Universitaet Jena for the best PhD thesis in the Faculty of Mathematics and Computer Science of the university. Dr. Hueffner received the prize in 2008.

Congratulations **Danny Hermelin**, Ph.D. student at Haifa University, for being awarded the Adams Fellowship of the Israel Academy of Sciences and Humanities. The Adams Award is given in all areas and is highly competitive.

Congratulations **Frederic Dorn** for winning the ESA 2006 Best student paper award, Proceedings of 14th Annual European Symposium, with *Dynamic Programming and Fast Matrix Multiplication.*

Appointments and Positions

Iris van Rooij is now Assistant Professor in the Artificial Intelligence department at Radboud University Nijmegen and researcher in the CAI division of the Nijmegen Institute for Cognition and Information.

Daniel Marx has accepted a postdoc position at the Budapest University of Technology and Economics (Budapest, Hungary); previously Daniel was a postdoc at Humboldt-Universitt zu Berlin (Berlin, Germany) with Martin Grohe.

Barnaby Martin is working with Stefan Dantchev in the area of Proof Complexity at Durham Univ, UK.

Saket Saurabh has accepted a postdoctoral position with Fedor Fomin's group in Bergen.

CONGRATULATIONS!

Please contact our new graduates or their advisors if you know of post-doc or other opportunities for them.

Frederic Dorn. *Designing Subexponential Algorithms: Problems, Techniques and Structures.* University of Bergen, 2007. Advisor: Fedor Fomin. Dissertation supported by Norges forskningsrad project Exact Algorithms. Dr. Frederic Dorn is now a postdoctoral fellow Martin Grohe's group in Berlin.

Apichat Heednacram. *Practical FPT algorithmic methods for solving intractable problems.* Successful presentation at his Research Confirmation Seminar, School of Information and Communication Technology, 2007. Heednacram is now eligible to continue a PhD program at Griffith University. Supervisors Francis Suraweera and Vladimir Estivill-Castro.

Stephen Gilmour. *Meshing Structural Knowledge And Heuristics: Improving Ant Colony Optimization Via Kernelization-Based Templates.* Macquarie University, Sydney. Advisors: Mark Dras and Bernard Mans.

Falk Hüffner. *Algorithms and Experiments for Parameterized Approaches to Hard Graph Problems.* Friedrich Schiller University, Jena 2008. Advisor: Rolf Niedermeier. Dr. Hüffner has accepted a postdoctoral position with Ron Shamir in Tel Aviv. His dissertation includes many examples of Iterative Compression and Color Coding as well as implementations and experiments for many problems.

John C. McCabe-Dansted. *Feasibility and approximability of Dodgsons rule.* Master's Thesis, Auckland University. Supervisor: Arkadii Slinko. http://dansted.org/thesis06.

Zoltan Miklos. *Understanding tractable decompositions for constraint satisfaction.* St Anne's College, University of Oxford, 2008. Advisor: Georg Gottlob. Dr. Miklos has joined the Laboratoire de Systèmes d'Information Répartis (LSIR), Distributed Information Systems Laboratory, School of Computer and Communication Sciences as a post-doc.

Egbert Mujuni. *Fixed Parameter Tractability of Graph Coloring and Related Problems.* Mujuni defends in June at the University of Dar es Salaam. Advisors are Herbert Fleischner, Vienna Technical Univ, Austria; Stefan Szeidar, Durham Univ, UK; and Allen Mushi and B. Alphonc, both of Univ of Dar es Salaam, Tanzania.

Mark Weyer. *Modifizierte parametrische Komplexitätstheorie.* Univ. Freiburg. Advisor Jorg Flum. Dr. Weyer has a post-doc position with Martin Grohe's group.