# Parameterized Complexity-News

The Newsletter of the Parameterized Complexity Community Volume 2, November 2006

## Welcome

Frances Rosamond, Editor

Welcome to the second issue of the Parameterized Complexity Newsletter. 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, for which Mike Fellows has made many contributions. There are sections for recent papers and manuscripts, for conferences, and one to keep us up-to-date on new positions and occasions. Grant successes are mentioned for inspiration. We extend congratulations to new graduates.

This issue highlights several interesting applications. The research group led by Liming Cai at the University of Georgia is using $FPT$ algorithms for structure-sequence alignment, including protein threading with pseudoknotted structures. The group led by Michael Langston at the University of Tennessee is using the Crown Rule to investigate the complex ecosystem of the North Sea. The research team led by R. Ravi at Carnegie Mellon University has shown that the problem of constructing near-perfect phylogenetic trees is $FPT$, with parameter the *imperfectness* of a phylogeny. Finally, we report on some vertex-colored graph problems that have been investigated by several different groups.

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 (`http://www.geocities.com/retreat4artscience/`) and at the IWPEC website which is (`http://www.scs.carleton.ca/~dehne/iwpec`).

## Applications

### Protein Threading and Treewidth

A long stretch of complementary matching nucleotide residues in an RNA sequence is called a *stem.* A stretch of contiguous unpaired residues is called a *loop.* The structure which most often causes diffulty in dynamic programming is the *pseudoknot*, formed when one of the unpaired bases in a loop interacts with a complementary base somewhere else in the sequence, possibly quite remote. Song *et al.* have introduced a new method for efficient structure-sequence alignment (and thus, fast search programs) for RNA structure that includes pseudoknots. With their method, the optimal structure-sequence alignment corresponds to a *generalized* subgraph isomorphism problem in which the guest graph is the structure graph. A tree decomposition of the graph can be found for structures that include pseudoknots by considering them as the combination of a maximal pseudoknot-free structure with some additional *crossing* stems. A dynamic programming algorithm over the tree decomposition of the structure graph allows an optimal alignment to be found.

They introduce *structure graphs* for biopolymer sequences: mixed graphs $H = (V, E, A)$, in which each vertex represents a structural unit, each edge (non-directed) represents a stem that is profiled with a simplified covariance model, and each arc represents a loop (5' to 3') that is profiled with a hidden markov model.

The structure graphs for biopolymer structures are usually of small treewidth. For example, the treewidth is 2 for the structure graph of any pseudoknot-free RNA and the treewidth can only increase slightly for all known

### Contents of this issue:

pseudoknot structures. An experiment conducted by Song *et al.* shows that among 3890 protein tertiary structure templates compiled using PISCES, only 0.8% of them have tree width $t > 10$ and 92% have $t < 6$, when using a 7.5 $\mathring{A}$ $C_\beta$-$C_\beta$ distance cutoff for defining pair-wise interactions among amino acids. The search results on RNA genes with and without pseudoknots can be as good as the other best known approaches but requiring significantly less time (e.g., with speed up of 1 to 2 magnitudes–days instead of months).

Their algorithm constructs an optimal alignment by finding in the sequence graph the maximum valued subgraph isomorphic to the structure graph. It has the computational time complexity $O(k^t N^2)$ for each structure template containing $N$ residues given a tree decomposition of treewidth $t$ for the structure graph. The parameter $k$, small in nature, is determined by a statistical cutoff for the correspondence between the structure and the sequence. The algorithm has been successfully applied to RNA structure search for non-coding RNA identification.

Y. Song, C. Liu, X. Huang, R. L. Malmberg, Y. Xu, and L. Cai. Efficient Parameterized Algorithms for Biopolymer Structure-Sequence Alignment. In *Proc. Workshop on Algorithms for Bioinformatics*(2005).

Y. Song, C. Liu, R. L. Malmberg, F. Pan, and L. Cai. Tree Decomposition Based Fast Search of RNA Structures Including Pseudoknots in Genomes. In *Proc. IEEE Computer Society Computational Systems Biology Conference*(2005).

## North Sea Fisheries and Crown Rule

"Who eats whom and by how much," only begins to hint at the multitude of variables to be taken into account when describing ecosystems as rich as that of the North Sea. Enormous data sets list quantities as diverse as haddock harvests (fisheries databases), fish stomach contents (there is a regular Europe-wide survey called Year of the Stomach), and detritus (such as discarded or dead fish) that sink to the seabed and provide nutrients to tiny bacteria (which then become food for fish). Plus there are non-catch species, birds, many types of plankton and a host of abiotic factors including temperature, salinity and currents.

Mike Langston (The University of Tennessee and Oak Ridge National Laboratory) and colleagues across the EU are using the Crown Rule and other FPT techniques, along with high performance computing technologies, to elucidate complex relationships within North Sea historical data. Due to extreme quantities of noise inherent in such data (such as drag nets on ferries and seamen with notebooks), paraclique and other methods are used to view high-dimensional correlation structures at interpretable levels of granularity, and to formulate models of putative relationships embedded in such complex multivariate data. Coastal sources of pollution are of great concern, as are long-term fisheries policy decisions. This work is supported by the International Council for the Exploration of the Sea.

E. J. Chesler and M. A. Langston. Combinatorial Genetic Regulatory Network Analysis Tools for High Throughput Transcriptomic Data. In *Proc. RECOMB Satellite Workshop on Systems Biology and Regulatory Genomics*, San Diego, California, December (2005).

M. A. Langston, D. J. Beare, R. W. Gauldie, A. J. Kenny, P. J. Kershaw, A. D. Perkins, J. Reid and K. Winpenny. Combinatorial Algorithms and High Performance Implementations for Elucidating Complex Ecosystem Relationships from North Sea Historical Data. In *Proc. International Council for the Exploration of the Sea Annual Science Conference*, Maastricht, The Netherlands, September (2006).

## Near-Perfect Phylogenetic Trees

Reconstructing a phylogenetic tree is perhaps the oldest NP-hard computational biology problem. Despite decades of progress, only recently have researchers succeeded in solving many real-world problem instances to optiomality. The most influential factor in this advancement has been the identification of the correct parameter, now popularly referred to as the *imperfectness* of a phylogeny, which characterizes the number of *recurrent* mutations on the DNA under study. Phylogenetic trees that mutate each character exactly once are called *perfect phylogenies* and their size is bounded by the number of characters. A *near-perfect* phylogeny (referred to as Binary Near-Perfect Phylogeny Reconstruction (BNPP)) relaxes the perfect phylogeny assumption by allowing at most $q$ additional mutations.

Formally, the input to the phylogeny reconstruction problem consists of $n$ species, each represented by a binary string (called *haplotype*) of length $m$. The problem is to determine the smallest Steiner (phylogenetic) tree that connects all the $n$ strings under Hamming distances. The problem is equivalent to finding a Steiner minimum tree given $n$ terminal vertices over an $m$-cube. The research team at CMU has shown that BNPP is $FPT$, and they have significantly improved the previous asymptotic bounds. They use a depth $q$ search tree that reduces the dimensionality of the problem at each step. All the leaves (kernel) contain Steiner tree problem instances with both dimensions and number of terminal points bounded by $O(q)$. Their algorithm computes the Steiner minimum tree in time $O(72^q + 8^q nm^2)$, under the assumption that the length of the minimum Steiner tree is at most $m + q$. The algorithm is intuitive and simple and one of the few theoretically sound phylogenetic tree reconstructin algorithms that is also expected to be practical.

They also consider a related problem where each of the $n$ input species are represented by $\{0, 1, 2\}$ strings (called *genotypes*). Each input string can be viewed as a combination of two binary strings (as in BNPP). Under the same assumptions, the optimum phylogeny for such a problem can be reconstructed in polynomial time for any constant $q$. This was previously only known for the special cases when $q = 0$ or 1. Proving $FPT$ or hardness for this problem is open.

G. E. Blelloch, K. Dhamdhere, E. Halperin, R. Ravi, R. Schwartz and S. Sridhar. Fixed Parameter Tractability of Binary Near-Perfect Phylogenetic Tree Reconstruction (BNPP). In *Proc. International Colloquium on Automata, Languages and Programming (ICALP)* (2006).

S. Sridhar, G. E. Blelloch, R. Ravi and R. Schwartz. Optimal Imperfect Phylogeny Reconstruction and Haplotyping. In *Proc. Computational Systems Bioinformatics (CSB)* (2006).

## Vertex-colored graphs

Danny Hermelin, doctoral student at Haifa University has contributed the following article. Recently, there have been quite a few biological applications involving vertex-colored graphs, most of which translate to $NP$-hard computational problems. Below we briefly survey three examples of such problems which have caught the attention of the $FPT$ community.

The Convex Recoloring of Trees problem is defined as follows: Given a vertex-colored tree $T$, and a positive integer $k$, can at most $k$ vertices of $T$ be recolored so that any color class of vertices induces a connected component in $T$. Such a coloring is referred to as a convex coloring or a connected coloring. This problem arises in the context of maximum parsimony approaches to phylogenetics. The problem was proved to be $NP$-hard (even for the restricted case of paths) by Moran and Snir, who also gave a bounded search tree algorithm running in $O(k(k/lgk)^k n^4)$ time. This has recently been substantially improved to a Poly($k$) kernel based algorithm (with the kernel size bounded to $O(k^2)$) by Bodlaender, Fellows, Langston, Ragan, Rosamond and Weyer. Closely related to the problem above is the Connected Coloring Completion (CCC) problem, which has recently been studied by Chor, Fellows, Ragan, Razgon, Rosamond, Snir. In this problem, we are given a general vertex-colored graph $G$ (i.e. not necessarily a tree) which has uncolored vertices. The goal is to color the uncolored vertices so that the resulting coloring is connected. Chor et al. show that the problem is $NP$-hard, but fixed parameter tractable when parameterized by the number $k$ of uncolored vertices, solvable in time $O^*(8^k)$. Parameterized by (only) the treewidth (that is, the number of uncolored vertices is not fixed), then the problem is $FPT$. Generalizing slightly to the $r - CCC$ problem, where instead of each color class inducing a single connected component, $r$ components are allowed, they show that, parameterizing by treewidth, the $2 - CCC$ problem is hard for $W[1]$, and that for all $r$, the $r - CCC$ problem is in $XP$.

The Graph Motif problem is another example of a vertex-colored graph application in computational molecular biology. In this problem, we are given a vertex-colored graph $G$ and a multi-set of colors $M$, and the goal is to determine whether there is a connected subset of vertices in $G$ which is colored by all (but no more than) the colors in $M$. The problem was introduces by Lacroix, Ferenandes and Sagot in the context of metabolic network analysis. They showed that the problem is $NP$-hard for trees, but fixed-parameter tractable for parameter $k = |M|$ in this case. This result has been recently been extended by Fellows, Fertin, Hermelin and Vialette who proved that the problem is in $FPT$ for any general graph, but $W[1]$-hard even for trees, when parameterized by the number of different colors in $M$ rather than its cardinality.

We believe that the above three examples are only the tip of the iceberg in terms of vertex-colored graph problems that might be interesting to investigate in the context of fixed-parameter tractability. Also, there are some open issues concerning these three examples. For instance, can the kernelization technique of Bodlaender, Fellows, Langston, Ragan, Rosamond and Weyer for Convex Recoloring of Trees be improved to a linear size kernel? How about efficient kernelizations for Coloring Completion and Graph Motif? There is also room for introducing new parameters and considering interesting special subcases.

H. L. Bodlaender, M. R. Fellows, M. A. Langston, M. A. Ragan, F. A. Rosamond and M. Weyer. Kernelization for Convex Recoloring. In *Proc. Algorithms and Complexity in Durham* (2006).

## Established FPT Races

The results for some problems 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 | Sources |
|---|---|---|---|
| Vertex Cover | $1.2738^k$ | $2k$ | 1 |
| FVS | $10.567^k$ | $k^3$ | 2 |
| Planar DS | $2^{15.13\sqrt{k}}$ | $67k$ | 3 |
| 1-Sided Crossing Min | $1.4656^k$ | | 4 |
| Max Leaf | $9.4815^k$ | $4k$ | 5 |
| Set Splitting | $2.6494^k$ | $2k$ | 6 |
| Nonblocker | $2.5154^k$ | $5k/3$ | 7 |
| 3-D Matching | $2.77^{3k}$ | | 8 |
| Edge Dominating Set | $2.62^k$ | $8k^2$ | 9 |
| $k-$Path | $4^k$ | | 10 |
| Convex Recolouring | $2^{O(k)}$ | $O(k^2)$ | 11 |
| VC-max degree 3 | $1.1899^k$ | | 12 |
| Clique Cover | $2.27^k$ | $k^2$ | 13 |

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2) K. Burrage, V. Estivill-Castro, M. Fellows, M. Langston, S. Mac and F. Rosamond. The Undirected Feedback Vertex Set Problem Has a Poly(k) Kernel. H. L. Bodlaender. A Cubic Kernel for Feedback Vertex Set. Technical Report UU-CS-2006-042. Utrecht University. *IPEC 2006*.
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## Research Ideas

### Parameterized Complexity and Stability of Approximation: A Tale of Two Programs

**Mike Fellows**

**24 October 2006**

**1. Introduction.**

Clearly, the potential interaction between parameterized complexity and approximation is huge, and the area is poorly mapped and barely explored at this point. At IWPEC 2006 there were three papers introducing closely related notions of parameterized approximation [CH06, CGG06, DFMcC06]. A survey of most of the ideas and results to date in this area, and an attempt to systematize the discussion, can be found in the recent survey paper of Daniel Marx [Ma06a].

The purpose of these notes is to report on a perspective that emerges from considering another ambitious recent research program that largely seems to have been overlooked so far by the parameterized complexity research community, the program of *stability of approxima-*

*tion* first articulated by Juraj Hromkovic in the seminal "manifesto" paper [Hr99].

**2. Motivations.**

Both *parameterized complexity* and *stability of approximation* are fundamentally concerned with the basic mathematical object of a *parameterized problem.* Both programs see a fundamental predicament of theoretical computer science emerging from the fact that most natural problems turn out to be hard in a variety of ways. One might say that a typical problem $\Pi$ is hard to solve exactly in the worst case, and is also hard to approximate. Both programs propose a "slicewise" attack on the situation, by parameterizing the fundamental object of study.

The difference is that:

• In the parameterized complexity program, the parameter is mathematically mobilized to attack time complexity, under the motto

*Tractability by the slice!*

• In the stability of approximation program, the parameter is mathematically mobilized to attack inapproximability, under the motto

*Approximability by the slice!*

It makes perfectly good sense to combine and synergize these approaches in studying problem complexity. We assume that we have a parameterized problem $\Pi$. ("How to parameterize" is, of course, an interesting issue that both programs face.)

Given that we have the $n$ and the $k$ to work with, we can set a pair of objectives by choosing:

(1) A time complexity regime, and

(2) An approximation regime.

The following table organizes some of the pairs of choices that seem interesting, and gives us a kind of a map of this intellectual terrain:

| | P-TIME | FPT | XP |
|---|---|---|---|
| 1 | parameterized | complexity | theory |
| $(1+1/k)$ | FPTAS | EPTAS<br>FPT-AS, c, d, e | PTAS |
| *const* | APX | a, b, 5, 13, 14 | 11 |
| *lin*$(k)$ | f, 10 | g, 7 | 8 |
| *poly*$(k)$ | 3, 6 | 12 | 9 |
| $g(k)$ | 1 | h, 2 | 4 |

Table 1: Some Possible Choices of Time Complexity and Approximation Regimes for Parameterized Problems.

In the table, the letters correspond to some concrete examples of results taken from the survey of Daniel Marx, and the numbers correspond to some concrete questions described below. In the first row, the chosen approximation regime is "1", i.e., no error, and so this row is about standard parameterized complexity theory. In the second row, we can recognize a few well-explored possibilities, the subject of *fully polynomial time approximation schemes* (FPTAS), and the box where the massive PTAS industry goes, and also the very natural and much less explored place where one finds *efficient PTAS* (EPTAS) — in all of these cases the parameter $k$ is employed to specify the goodness of approximation. Daniel Marx defined the notion of an *FPT approximation scheme* (FPT-AS), and this shares the same general location as EPTAS, and is a particularly nice example of combining the practical objectives of the two programs (the notion is defined for an aggregate parameterization, where part of the parameter describes the goodness of approximation).

The table is not too precise about what exactly the parameter is — the intention is only suggestive of interesting directions to explore.

**3. Some Examples.**

(a) Graph Coloring has an FPT 2-approximation parameterized by graph genus [DHK05].

(b) Metric TSP With Deadlines, parameterized by the number of deadlines, can be 2.5 approximated in FPT time [BHKK06].

(c) Min $k$-Median in $d$ Dimensions parameterized by $(k, d, \epsilon)$ can be approximated to within a factor of $(1 + \epsilon)$ of optimal in FPT time [HM04], an example of an FPT-AS.

(d) Partial Vertex Cover, parameterized by $(k, \epsilon)$, has an FPT approximation scheme. That is, it can be approximated to within a factor of $(1 + \epsilon)$ of optimal in FPT time [Ma06a]. The problem asks for $k$ vertices that cover a maximum number of edges of a graph.

(e) Minimum Sum Edge Coloring has an FPT-AS, aggregately parameterized by $\epsilon$ and graph treewidth [Ma04]. This problem is APX-hard and therefore there is no possibility of a PTAS without parameterization (by treewidth or something else).

(f) Directed Feedback Vertex Set parameterized by the size of an optimal solution, can be approximated by a factor of $\log k \log\log k$ in polynomial time [CGG06].

(g) Topological Bandwidth parameterized by the cost $k$ of an optimal solution, can be approximated to within a factor of $k$ in FPT time [BF95].

(h) CLIQUEWIDTH has a factor of $2^{O(k)}$ FPT approximation algorithm [Oum05].

**4. Some Concrete Open Problems.**

(1) Can DOMINATING SET (parameterized by the size of a solution) be $g(k)$ approximated in polynomial time? The question of whether it can be so approximated in FPT time has been a matter of repeated discussion in the parameterized complexity community (starting with [DF99] and the like), but in fact, we do not seem to know the answer to this perhaps even simpler question highlighted by the table, when we consider the various possible "combined" outcomes for this fundamental problem.

(2) Can DOMINATING SET (same parameterization) be $g(k)$ approximated in FPT time?

(3) Can MINIMUM DOMINATING SET, parameterized by treewidth, be $poly(k)$ approximated in polynomial time? (The input is not given with a tree decomposition.) One could ask an analogous question for the MAXIMUM INDEPENDENT SET problem, but for this we have an answer: Daniel Marx has described such an algorithm [Ma06b].

(4) Can GRAPH $k$-COLORING be $g(k)$ approximated in XP time?

(5) Can GRAPH BANDWIDTH, parameterized by the minimum domination number, be approximated to a constant factor in FPT time?

(6) Can CLIQUE COVER, parameterized by treewidth, be $poly(k)$ approximated in polynomial time?

(7) Can MINIMUM DOMINATING SET for $t$-interval graphs, parameterized by $t$, be $lin(k)$ approximated in FPT time? The problem can be approximated to within a factor of $O(t^2)$ in polynomial time [BHLR06]. A $t$-interval graph is representable as the intersection graph of families of $t$ intervals. The DOMINATING SET problem, parameterized by the solution size, is $W[1]$-hard for any fixed $t \geq 4$.

(8) Can GRAPH BANDWIDTH, parameterized by graph genus, be $lin(k)$ approximated in XP time?

(9) Can MINIMUM DOMINATING SET, parameterized by genus, be $poly(k)$ approximated in XP-time?

(10) Can MINIMUM DOMINATING SET for $t$-interval grpahs, parameterized by $t$, be $lin(k)$ approximated in polynomial time?

(11) Can GRAPH $k$-COLORING be constant factor approximated in XP time?

(12) Can BANDWIDTH, parameterized by genus, be $poly(k)$ approximated in FPT time?

(13) Can CLIQUE, parameterized by the size of a maximum clique, be 2-approximated in FPT time?

(14) Can TOURNAMENT DOMINATING SET, parameterized by the solution size, be constant factor approximated in FPT time?

**5. Discussion.**

As noted by Daniel Marx in his survey [Ma06a], one cannot plausibly claim that error guarantees of 10,000% have any direct practical value. The PTAS industry has arguably done serious damage to theoretical computer science as a reputable enterprise, what with algorithms running in time $O(n^{15,000,000})$ for 20% error coupled with a loose rhetoric of algorithmic breakthroughs for hard practical problems.

A more reasonable perspective is that understanding the tradeoffs between theoretical worst-case running time and approximation performance, and the structural and algorithmic insights that lead to "best possible" qualitative theoretical results, may prove useful in a general way in designing algorithms for hard problems (including "smarter" heuristics). This food-chain is reasonably well-articulated in parameterized complexity and fixed-parameter algorithmics, the *leitmotif* of which is to pay better attention to: (1) limited input distributions, (2) limited computational objectives, (3) numbers in appropriate ranges of magnitudes (e.g., the distinction between 100 in the exponent and 100 in the big O), and (4) systematic and general parametric structure theories (e.g., treewidth and graph minors).

There are interesting applications of *all* of the locations in the matrix. For example, $g(k)$ approximation in FPT time obviates the need for iterative compression to run all the way up to $n$ (one can start with an approximate solution). For another application, approximation in polynomial time can be key to efficient kernelization / data-reduction algorithms.

The table above, as a way of organizing some perspective on how the two core programs can interact around the common interest in taking a slicewise approach to the difficulties of computation, seems notable for the ease with which it suggests a host of very natural concrete open problems, and even almost entire kinds of outcomes that should be quite general (eventually represented by hundreds of examples) but that are still unpopulated.

In studying the tradeoffs for a particular parameterized problem $\Pi$, movement upwards in the table is good, as is movement to the left. Theoretical machinery for detecting plausible barriers to such movements in qualitative classification would be interesting to develop. Parameterized complexity ($W[1]$-hardness and the like) should be useful to detecting barriers to migration from column 3 to column 2. Barriers to vertical migration might possibly be related to issues arising in the study of lower bounds to kernelization (at least in column 2).

The matrix suggests a host of interesting natural directions that deserve investigation in the cartesian product of the two programs.

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## Exercise Corner

**Exercise Corner: Maximum Satisfied Formulas.** This exercise was motivated by some investigations of some parameterized problems that involve counting.

*Exercise:* Show that the following problem is in $W[1]$.

MAXIMUM SATISFIED FORMULAS

*Input:* A collection $\mathcal{C}$ of monotone DNF formulas over a set of variables $V$, where each formula is an $r$-disjunction of $s$-conjuncts, and positive integers $k$ and $t$.

*Parameter:* $(r, s, k)$

*Question:* Is there a weight $k$ truth assignment to $V$ that satisfies at least $t$ of the expressions in $\mathcal{C}$?

*Hint:* Use the Turing approach.

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## Conferences

Please note that the IWPEC website is being hosted by Carleton University at `www.scs.carleton.ca/~dehne/iwpec`.

### Dagstuhl Seminar 07281

*Structure Theory and FPT Algorithmics for Graphs, Digraphs and Hypergraphs*, 08.07.07 - 13.07.07. Organized by Erik Demaine (MIT - Cambridge, USA) Gregory Gutin (RHUL - London, GB) Daniel Marx (HU Berlin, D) Ulrike Stege (University of Victoria, CDN)

### WG 2007, 33rd International Workshop on Graph-Theoretic Concepts in Computer Science

Dornburg near Jena, Germany. Paper submission deadline: 2 March 2007. Conference: 21 - 23 June 2007. Organizing Committee: H. Muller, R. Niedermeier, F. Huffner. (See `http://wwwteo.informatik.uni-rostock.de/wg2007/`).

## IWPEC 2006

The proceedings are published as Springer LNCS 4169. Parameterized Complexity is well represented at conferences including the 2006 IWPEC which was held at ETH, Zurich in conjunction with ESA/WABI and brilliantly organized by Hans Bodlaender and Mike Langston. Appreciation goes to them and to the Program Committee and referees. The papers presented revealed several emerging and exciting new themes including *parameterized approximation* (and randomized $FPT$ approximation), *parameterized enumeration*, new investigations into *upper and lower bounds*, and new investigations into the search for systematic methods of finding reduction rules, with the goal of *linear or polynomial size problem kernels*.

Reports were given on the parameterized complexity of maximality and minimality problems, on the independence and domination of geometric graphs, on minimum profile problems, on data structures for Boolean functions, and others. There were brilliant papers on specific problems showing new gadgets and a spectrum of increasingly sophisticated techniques including modular decomposition and tree decomposition, greedy localization and color coding, branch and reduce, enumeration, and random separation. Practical implementations and experiments using parameterized algorithms on protein domain sequence data were described for the problem CLUSTER EDITING.

## WABI 2006

The proceedings are published as Springer LNBI 4175. Practical implementations of parameterized algorithms were also described in the co-located **WABI (Workshop on Algorithms in Bioinformatics)**. For example, one WABI paper presented a parameterized algorithm that solves the GENOTYPE PHASING problem and, at the same time, computes the corresponding phylogenetic network with the minimum number of single crossover recombinations. (The goal of the genotype phasing problem is to determine haplotypes from their corresponding genotype data.) Experiments on biological data sets reported increased accuracy and efficiency of the FPT method over some other methods. Another WABI paper described an efficient parameterized algorithm based on the parameter treewidth for RNA folding including pseudoknots. Three sets of RNA sequences were used to compare the performance of the $FPT$ algorithm with algorithms PKNOTS and HotKnots.

## ACiD 2006

The excellent **Second Algorithms and Complexity in Durham Conference (ACiD) (2006)** was organized by Hajo Broersma, Stefan Dantchev, Matthew Johnson and Stefan Szeider. As at the first workshop in 2005, there were many papers about parameterized complexity, including a parameterized view on matroid optimization problems, kernelization for convex recoloring, parameterized enumerability for the database theorist (including WEIGHTED HITTING SET is $FPE$), vertex and edge covers with clustering properties, finding regular induced subgraphs, fast solving of maximum independent set problem for graphs with maximal degree three, finding paths between colourings, and parameterized complexity of the pursuit-evasion problem (which asks if a robber can elude capture by $c$ cops for $t$ turns, starting from some initial position in a given graph $G$).

The complexity of MATRIX ROBUSTNESS (checking whether deleting any k rows from a full-rank matrix changes the matrix rank) was discussed with an application to power system observability. The algorithm was implemented on real and synthetic instances and favorably compared to pseudorank and linear programming heuristics. A highlight of the workshop was the plenary by Detlef Seese who gave a high-level overview of the affect of restricted structure (such as bounded bandwidth, treewidth, branchwidth,...) on complexity and hailed the field of Parameterized Complexity as a "breakthrough" for dealing with hard problems.

Appreciation goes to the **2004 IWPEC** presenters and Organizing Committee (R. Downey, M. Fellows, and F. Dehne). The 2004 proceedings are published as Springer LNCS 3162.

Appreciation also goes to the **2005 ACiD** workshop (H. Broersma, M. Johnson, and S. Szeider), as well as to the organizers of the **2004 Dagstuhl**. Proceedings from these workshops reveal steady progress in conquering the unknown.

Parameterized Complexity is found in other conferences, of course. Rod Downey is on the Program Committee for the 22nd IEEE Computational Complexity Conference(CCC) that will be held in San Diego 13-16 June, 2007. Martin Grohe is on STOC 2007 Program Committee. Fedor Fomin is on the Program Committee for SODA 2007.

### IWPEC 2008

Thinking ahead, IWPEC 2008 is scheduled to be in Victoria, B.C., Canada on May 14, 15, 16, to preceed STOC which will follow on May 18, 19, 20. Ulrike Stege is the local host.

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## Grant Successes

Congratulations to Catherine McCartin who has been awarded the 2006 Hatherton Award for best paper by a New Zealand PhD, within two years of graduating. The award was in recognition of the paper, "Parameterized Counting Problems" in *Annals of Pure and Applied Logic*, 138, pp 147-182, 2006.

Congratulations to Faisal N. Abu-Khzam, now at the Lebanese American University in Beirut who has received an $80K grant from the Oak Ridge National Lab (USA). The project is entitled: *Modeling Cellular Mechanisms for Efficient Bioethanol Production through Petascale Comparative Analysis of Biological Networks.* Faisal says, "The project includes high performance graph algorithms and development of FPT methods for many hard problems that have applications in molecular biology. In particular, we will be looking for better algorithms for HITTING SET and and MAXIMUM COMMON SUBGRAPH."

Pablo Moscato, R. J. Scott and M. A. Langston have received an Australian Research Council grant award for *Application of novel exact combinatorial optimization techniques and metaheuristic methods for problems in cancer research*.

Congratulations to Rolf Niedermeier for an ITKO Project Grant *Iterative Compression for Solving Hard Network Problems*.

Mike Fellows, Vladimir Estivill-Castro and Michael Langston have been awarded a four-year Australian Research Council grant for *Efficient Pre-Processing of Hard Problems: New Approaches, Basic Theory and Applications*.

Liming Cai has recently been awarded a large NIH research grant on his computational biology project *Searching Genomes for Non-Coding RNAs by Their Structure* (co-PIs: Russell Malmberg of Plant Biology and Michael McEachern of Genetics at UGA).

A joint proposal by R. Niedermeier's group and V. Raman's group has been approved by the Department of Science and Technology, India (DST-DAAD) and DAAD-Germany). Somnath Sikdar, student of Venkatesh, has visited Rolf's group already on this project for some months.

## Humboldt Research Award

We are pleased to announce that Mike Fellows will receive the Humboldt Research Award of the German Alexander von Humboldt Foundation. We appreciate R. Niedermeier and D. Seese for their sponsorship, and we look forward to collaborations in Germany.

Mike has also been awarded an Institute for Advanced Study Distinguished Fellowship at Durham University, UK as part of the Durham University Legacy of Charles Darwin year.

Mike and Fran will also visit Bergen for three months, April-June 2007, and head to Jena to begin the Humboldt visit in July.

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## Resources

Textbooks that include discussion of Parameterized Complexity include:
(1) Richard Johnsonbaugh and Marcus Schaefer, *Algorithms*, Prentice-Hall, 2004, and
(2) J. Kleinberg and E. Tardos, *Algorithm Design*, Addison-Wesley, 2005.
Does anyone know of other textbook that do?

Marco Cesati's excellent compendium is `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.

Rolf Neidermeier's group puts their publications and many other helpful items on their excellent web page `http://www.minet.uni-jena.de/www/fakultaet/theinf1/publications`.

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# New Results and Publications

## Open Problems from IWPEC 2006

The Open Problem Session from IWPEC has been written up by H. Bodlaender. The document can be obtained by request from `fptnews@yahoo.com`.

## Implementations

Frank Dehne reports that his Ph.D. student, Xuemei Luo, has been adapting their cluster edit implementation to help Biochemists in Ottawa find new clusters in the yeast protein interaction graph.

## Publications and Manuscripts

Faisal N. Abu-Khzam had many trials attempting to reach Zurich for IWPEC. After obtaining a travel grant, finding someone to handle his summer class, and securing a visa, he then couldn't get a flight! "It was right after the war, and many airlines were still not serving our airport." However, Faisal's paper about pseudo-kernelization has been accepted for publication in the TOCS journal, and he has found a quadratic kernel for 3-Hitting Set. The kernelization algorithm is based on an extension of crown reduction to hypergraphs. Faisal has several other interesting projects that will be reported on in the next newsletter.

## The Computer Journal

Coming soon is a Special Issue of *The Computer Journal* on Parameterized Complexity. The Chief Editor is Fionn Murtagh and Guest Editors are R. Downey, M. Fellows and M. Langston. A total of 15 surveys are expected as well as an Introduction and Overview of Parameterized Complexity by Mike Fellows and Rod Downey.

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. *Width Parameters Beyond Treewidth and Their Applications* by Georg Gottlob, Petr Hlineny, Sang-il Oum and Detlef Seese.

7. *Fixed-Parameter Algorithms for Artificial Intelligence, Constraint Satisfaction and Database Problems* by Georg Gottlob and Stefan Szeider.

8. *Fixed-Parameter Algorithms in Phylogenetics* by Jens Gramm, Arfst Nickelsen and Till Tantau.

9. *Some Parameterized Problems on Digraphs* by Gregory Gutin and Anders Yeo.

10. *Techniques for Practical Fixed-Parameter Algorithms* by Falk Huffner, Rolf Niedermeier and Sabastian Wernicke.

11. *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.

12. *Parameterized Complexity and Approximation Algorithms* by Daniel Marx.

13. *An Overview of Techniques for Designing Parameterized Algorithms* by Christian Sloper and Jan Arne Telle.

14. *Parameterized Complexity in Cognitive Modeling: Foundations, Applications and Opportunities* by Iris van Rooij and Todd Wareham.

15. *Parameterized Complexity of Geometric Problems in Graph Drawings and Computational Geometry* by Sue Whitesides.

## Bidimensionality

We "sample" one of the surveys above by this brief report on *Bidimensionality.*

Mohammad Taghi Hajiaghayi (see `http://www.mit.edu/~hajiagha`) and Eric Demaine have introduced the newly developing theory of bidimensional graph problems in a series of 16 papers published e.g. in several journals and conferences (including SODA, FOCS, STOC, JACM, SICOMP, SIDMA, TALG, and Algorithmica). The theory provides general techniques for designing efficient $FPT$ algorithms and approximation algorithms for $NP$-hard graph problems in broad classes of graphs. The theory applies to graph problems that are *bidimensional* in the sense that (1) the solution value for the $k \times k$ grid graph (and similar graphs) grows with $k$, typically as $\Omega(k^2)$, and (2) the solution value goes down when contracting edges and optionally when deleting edges. Examples of such problems include feedback vertex set, vertex cover, minimum maximal matching, face cover and many more.

Bidimensional problems have many structural properties; for example, any graph in an appropriate minor-closed class has treewidth bounded above in terms of the problem's solution value, typically by the square root of that value. These properties lead to efficient–often subexponential–fixed-parameter algorithms, as well as polynomial-time approximation schemes, for many minor-closed graph classes. One type of minor-closed graph class of particular relevance has *bounded local treewidth*, in the sense that the treewidth of a graph is bounded above in terms of the diameter. As a major result, Hajiaghayi and Demaine show that such a bound is always at most linear (the previous bound was doubly exponential).

Bidimensionality theory unifies and improves several previous results. The theory is based on algorithmic and combinatorial extensions to parts of the Robertson-Seymour Graph Minor Theory, in particular initiating a parallel theory of graph contractions. The foundation of this work is the topological theory of drawings of graphs on surfaces and a major result of Hajiaghayi and Demaine says any graph excluding a fixed graph $H$ as a minor, of treewidth $w$ has an $\Omega(w)X\Omega(w)$ grid graph as a minor. This improves and generalizes several important results of others. For more, see the upcoming survey in *The Computer Journal*.

# Out and About

## Position Changes

Henning Fernau is now Professor of Computer Science at the University of Trier, Germany.

Dimitrios M. Thilikos is now Assistant Professor at the Section of Mathematical Analysis in the Mathematics Department at the National and Capodistrian University of Athens, Athens, Greece.

Congratulations to Marcus Schaeffer who has been promoted to Associate Professor at DePaul University in Chicago.

Congratulations to Liming Cai on his new little daughter Lillian, now nine-months old.

Danny Hermelin (doctoral student, Haifa University) and Moritz Muller (doctoral student, University of Freiburg) are visiting Mike Fellows and Fran Rosamond at the Parameterized Complexity Mobile Research Laboratory (PCMRL), currently stationed on the Gold Coast, Australia. "It is a remarkable coincidence that the PCMRL is located at one of the world's premier surfing beaches," commented M. Langston.

Arkadii Slinko is on sabbatical in Canada, currently in Montreal.

Judy Goldsmith writes that she is managing a large research group (7 faculty, about 10 or 12 students) on an AI project. "We're trying to design decision-support software for social welfare ('welfare to work') programs. So we're looking at planning under uncertainty with constraints, preference elicitation and representation, automated model-building, and HCI for non-technical users."

# Announcements

David Manlove and Rob Irving from the Computing Science Department at the University of Glasgow have recently been awarded an EPSRC grant for a 3 year research project on matching algorithms. They are currently seeking to appoint a post-doc on this project. Please see `http://www.dcs.gla.ac.uk/~rwi/postdoc.htm`.

# Occasions

## Congratulations, Doctor!

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

**Hongbing Fan.** *A Combinatorial Switch Block Design Technique for Reconfigurable Interconnection Networks*, Department of Computer Science, University of Victoria, British Columbia, Canada. Advisor: John Ellis. Dr Fan is Assistant Professor in the Department of Physics and Computer Science at Wilfrid Laurier University is Waterloo, Ontario.

**Jiong Guo.** *Algorithm Design Techniques for Parameterized Graph Modification Problems*, Institut fur Informatik, Friedrich-Schiller-Universitat, Jena, Gemany. Advisor: Rolf Niedermeier. Dr. Guo has accepted a Postdoctoral position at the Theoretische Informatik I, Institute for Informatik, Friedrich-Schiller-University, Jena, Fed. Rep. Germany.

**MohammadTaghi Hajiaghayi**. *The Bidimensionality Theory and Its Algorithmic Applications*, Applied Mathematics and Computer Science, Massachusetts Institute of Technology. Advisors: Erik D. Demaine and Tom Leighton. Dr. Hajiaghayi received his Master of Mathematics from the University of Waterloo with advisor Naomi Nishimura. Following a position as Postdoctoral Associate in the Computer Science and Artificial Intelligence Laboratory at MIT, Dr. Hajiaghayi is now a Postdoctoral Fellow in the School of Computer Science at Carnegie Mellon University.

**Panos Giannopoulos.** *Geometric Matching of Weighted Point Sets.* Department of Computer Science, Utrecht University.

**Chunmei Liu.** Department of Computer Science, University of Georgia. Advisor: Liming Cai. Dr. Liu is Assistant Professor in the Department of Computer Science at Howard University. Liu and Song have a paper at ISAAC 2006 on *Exact algorithms for finding a minimum independent dominating set in a graph*, and they have just submitted a paper to RECOMB 2007, "which is mainly about solving the string barcoding problem using methods in parameterized computation".

**Francois Nicolas.** *Alignment, consensus sequence, similarity search: complexity and approximability.* Department of Computer Science, University of Montpellier, France. Advisor: Eric Rivals.

**Arash Rafiey.** *Extremal and Optimization Problems on Dense Directed and Edge-Colored Graphs.* Department of Computer Science, University of London. Advisor: Gregory Gutin. They have co-authored the recent paper *The Linear Arrangement Problem Parameterized Above Guaranteed Value.* Dr. Rafiey has joined the School of Computing, Simon Fraser University as a Postdoc, working with Professor Pavol Hell and Professor Arvind Gupta.

**Igor Razgon**. *Search Space Reduction for Constraint Satisfaction Problems.* Department of Computer Science, Ben-Gurion University, Israel. Advisor: Amnon Meisels. Dr. Razgon has a result submitted to Information Processing Letters that solves the Convex Recoloring problem in $2^{O(k)}$. Dr. Razgon has been offered a two-year postdoctoral position by Abdul Sattar at Griffith University, Brisbane, Australia.

**Yinglei Song.** *Effective models and efficient algorithms for structural bioinformatics.* Department of Computer Science, University of Georgia. Advisor: Liming Cai. Dr. Song is now Assistant Professor at Philander Smith College.

**Ge Xia**. *Parameterized algorithms and computational lower bounds: a structural approach* Department of Computer Science, Texas A&M University. Advisor: Jianer Chen. Dr. Xia is Assistant Professor in Computer Science at Lafayette College, Easton, Pennsylvania.

## Soon to become Doctors

**Mark Weyer** has almost completed his Ph.D. with Joerg Flum at the University of Freiburg. Mark is working with M. Grohe at the Humboldt-Universsitt zu Berlin.

**Saket Saurabh** has almost completed his Ph.D. with Venketesh Raman as advisor at the Institute for Mathematical Sciences, Chennai and is on a 'pre-doc' visit to Fedor Fomin's group in Bergen from September 2006 to May 2007.

**Jizhen Zhao.** has just defended his thesis under advisor Liming Cai from the Department of Computer Science at the University of Georgia at Atlanta.