Parameterized Complexity News

Newsletter of the Parameterized Complexity Community

November 2013 Vol.9, no. 3

www.fpt.wikidot.com ISSN 2203-109X

Welcome

Frances Rosamond, Editor, Charles Darwin University
Congratulations to award winners, graduates and new job holders. IPEC, ALGO and GROW had excellent parameterized talks and tutorials. We feature *Combinatorial Slice Theory* by IPEC Excellent Student Paper Awardee Mateus de Oliveira Oliveira, and new results by Stefan Kratsch, Geevarghese Philip, and Saurabh Ray on *Point Line Cover*, also reported at SODA, a favourite open problem of Daniel Lokshtanov and Mike Fellows. Neeldhara Misra writes on how to contribute to the FPT BLOG. Bart Jansen keeps up-to-date publications on the wiki (`www.fpt.wikidot.com`).

The new strange logo in the header of this newsletter attempts to emphasize the multivariate nature of PC. The upper corner has volcanos, lightning, and other explosive elements along with letters *k, m, t*. Wavy lines mean to indicate calmness in n^c now that the parameters have been isolated away. Surely, you don't want the field to be represented by this strange logo! Please submit logo designs and suggestions to Frances.Rosamond@cdu.edu.au.

Gregory Gutin–Royal Society Wolfson Research Merit Award

Congratulations to **Gregory Gutin**, Royal Holloway, London. Gregory has been awarded the Royal Society Wolfson Research Merit Award for *Parameterised Combinatorial Optimisation Problems.* The award provides a salary supplement for 5 years.

Stefan Szeider–Austrian Science Fund

Congratulations to **Stefan Szeider**, Vienna U. of Technology. Stefan has been awarded a 3-year Austrian Science Fund Award for Eur 340k on the topic of *Parameterized Compilation.* Stefan and his team will investigate connections between PC and Knowledge Compilation.

Tobias Freidrich, Frank Neumann–Australian Research Council (ARC)

Congratulations to **Frank Neumann**, Univ Adelaide and **Tobias Freidrich**, Friedrich Schiller Univ–Jena for a 300k ARC Award for *Parameterised Analysis of Bio-inspired Computing*, 2014–2016.

Figure 1: Top row: Stefan Szeider, Gregory Gutin, Tobias Freidrich, Frank Neumann. Bottom row: IPEC Award Winners M. de Oliveira Oliveira, B.M.P. Jansen, L. Mach (T. Toufar not pictured)

Contents of this issue:

IPEC Excellent Student Paper Awards

The 2013 IPEC Program Committee, with Co-Chairs Gregory Gutin (Royal Holloway, U. London) and Stefan Szeider (Vienna U. of Technology), has chosen the following for the 2013 IPEC Excellent Student Paper Awards. Awardees are

- *Subgraphs Satisfying MSO Properties on z-Topologically Orderable Digraphs* by Mateus de Oliveira Oliveira (KTH, Stockholm)
- *Amalgam Width of Matroids* by Lukas Mach (DIMAP, U. Warwick) and Tomas Toufar (Charles U., Prague)
- *On Sparsification for Computing Treewidth* by Bart M.P. Jansen (U. Bergen)

Nerode Award–Nominate now!

Nominations for the 2014 IPEC-EATCS Nerode Award should be sent by 1 January to the selection committee:

- Georg Gottlob, georg.gottlob@cs.ox.ac.uk
- Jan Arne Telle, telle@ii.uib.no
- Peter Widmayer, widmayer@inf.ethz.ch

Send a brief summary of the technical content of each nominated paper and a brief explanation of its significance. The year of publication should be at least two years and at most ten years before the year of the award nomination.

In 2013, the prize was awarded for the first time. Winners were Chris Calabro, Russell Impagliazzo, Valentine Kabanets, Ramamohan Paturi, Francis Zane. The award ceremony took place at IPEC'13 in Sophia-Antipolis. R. Paturi gave a keynote lecture. See `http://fpt.wikidot.com/eatcs-ipec-nerode-prize`.

Figure 2: Ramamohan Paturi receiving Nerode Award from Hans Bodlaender, Gregory Gutin and Stefan Szeider

Report on IPEC 2013

The IPEC-2013 Report by Stefan Szeider (`http://fpt.wdfiles.com/local--files/welcome/stats.pdf`) shows a record breaking 29 papers accepted out of 58 submissions. Many thanks to the IPEC Committee, Co-Chairs, authors, PC members, all reviewers, and ALGO organizers.

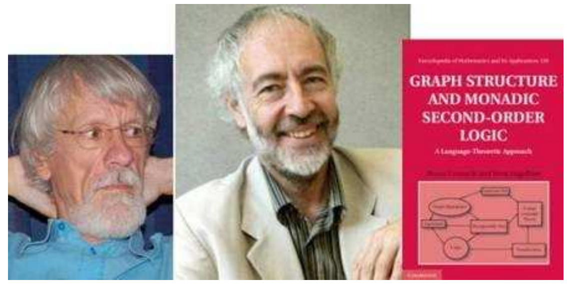

Figure 3: Joost Engelfriet and Bruno Courcelle. Congratulations.

Bruno Courcelle and Joost Engelfriet, New Book

Congratulations to **Bruno Courcelle**, Univ. Bordeaux and **Joost Engelfriet**, Univ. Leiden on their book, *Graph Structure and Monadic Second-Order Logic: A Language-Theoretic Approach. Part of Encyclopedia of Mathematics and its Applications*, vol. 138, Cambridge University Press, June 2012 (728 pages) (Preface by Maurice Nivat).

Chapter 1.5 reviews FPT, and gives algorithmic consequences of the (weak) Recognizability Theorem. "This theorem has actually two versions, relative to the two graph algebras defined in Section 1.4, and yields two Fixed-Parameter Tractability Theorems."

FPT BLOG

by Neeldhara Misra, IIS, Bangalore, BLOG Editor

Sign up for the FPT blog at `http://www.fptnews.org/contribute`. The blog is for sharing open problems, announcements, expositions, reports of events, anecdotes, pictures, and experiences from events of relevance (for example, ADFOCS, IPEC, GROW, etc.)and so forth. A report from WORKER 2013 (thanks to Bart Jansen!) is on the blog. General updates and announcements would also be welcome in making the FPTNEWS blog an active and up-to-date resource.

FLoC 2014

The Sixth Federated Logic Conference (FLoC 2014) will be part of the Vienna Summer of Logic, the *largest logic event in history*, with over 2000 expected participants. FLoC 2014 will host eight conferences (CAV, CSF, ICLP, IJCAR, ITP, CSL-LICS, RTA-TLCA, SAT) and many workshops. Stefan Szeider, FLoC workshop chair.

Mike Fellows, Serge Gaspers, and **Toby Walsh** will offer *Parameterized Complexity of Computational Reasoning*, a 2–day–workshop 17–18 July at FLoC.

FUN with Algorithms

Submissions by January 15. Conference July 1–3, 2014, Lipari Island, Sicily, Italy. Conference Chairs: Alfredo Ferro and Fabrizio Luccio; PC Chair: Peter Widmayer. See the cool logo by E. Demaine `www.di.unipi.it/fun14`.

Combinatorial Slice Theory and Parameterized Complexity

by Mateus de Oliveira Oliveira, KTH Royal Institute of Technology

In a recent work (1) we introduced the notion of z-topological order for digraphs and used it to obtain an algorithmic metatheorem connecting the monadic second order logic of graphs with several digraph width measures. In this short note we will give a brief description of our meta-theorem from the perspective of combinatorial slice theory. We believe that the techniques we described here can be applied in other contexts within parameterized complexity theory.

A slice $\mathbf{S}$ is a digraph whose vertices are partitioned into a center and two in- and out-frontiers which are are used to perform composition. Slices may be regarded as the building blocks of digraphs, in the same way that letters are the building blocks of words. The *width* of a slice is the size of its largest frontier. Let $\mathbf{\Sigma}(c,q)$ be a finite set consisting of all slices of width at most c, with at most one center vertex, and whose frontier vertices are labeled with numbers from $\{1,...,q\}$ in such a way that the labeling is injective on each frontier. A slice language $\mathcal{L}$ over $\mathbf{\Sigma}(c,q)$ is a possibly infinite subset of the free monoid $\mathbf{\Sigma}(c,q)^*$ such that whenever a string $\mathbf{U} = \mathbf{S}_1\mathbf{S}_2...\mathbf{S}_n$ belongs to $\mathcal{L}$, $\mathbf{S}_1$ has empty in-frontier, $\mathbf{S}_n$ has empty out-frontier and the composition $\mathbf{S}_i \circ \mathbf{S}_{i+1}$ is well defined for $i \in \{1,...,n-1\}$. In this case, composing all slices in $\mathbf{U}$ yields a digraph $\mathring{\mathbf{U}} = \mathbf{S}_1 \circ \mathbf{S}_2 \circ ... \circ \mathbf{S}_n$. Thus we may consider that each slice language $\mathcal{L}$ represents a possibly infinite set of digraphs $\mathcal{L}_{\mathcal{G}} = \{\mathring{\mathbf{U}} \mid \mathbf{U} \in \mathcal{L}\}$ obtained by composing all slices in each string $\mathbf{U} \in \mathcal{L}$. A slice language is regular if it can be represented via a finite automaton over an alphabet of slices.

Let $G = (V,E)$ be a directed graph. For subsets of vertices $V_1, V_2 \subseteq V$ we let $E(V_1,V_2)$ denote the set of edges with one endpoint in V_1 and another endpoint in V_2. We say that a linear ordering $\omega = (v_1, v_2, ..., v_n)$ of the vertices of V is a z-topological ordering of G if for every *directed* simple path $p = (V_p, E_p)$ in G and every i with $1 \leq i \leq n$, we have that $|E_p \cap E(\{v_1...,v_i\},\{v_{i+1},...,v_n\})| \leq z$. In other words, ω is a z-topological ordering if every *directed* simple path of G bounces back and forth at most z times along ω. We say that a unit decomposition $\mathbf{U} = \mathbf{S}_1\mathbf{S}_2...\mathbf{S}_m$ with $m \geq n$ is compatible with $\omega = (v_1,...,v_n)$ if there exist $j_1, j_2, ..., j_n$ with $j_k > j_{k-1}$ such that v_i is the center vertex of $\mathbf{S}_{j_i}$. Observe that we need to use double sub-indexes j_k because since m may be greater than n, $\mathbf{U}$ may have some slices with no vertex in the center. A slice language $\mathcal{L}$ is z-*saturated* if for each digraph $H \in \mathcal{L}$ and each z-topological ordering ω of H, all unit decompositions of H compatible with ω are in $\mathcal{L}$. Finally, a digraph H is the union of k paths if $H = \bigcup_{i=1}^{k} p_i$ for paths $p_1, ..., p_k$ in H. Our first lemma establishes a connection between z-topological orders, regular slice languages and the monadic second order logic of graphs.

Lemma 1 *For any $k, z \in \mathbf{N}$, any $q \geq k \cdot z$ and any MSO_2 formula φ, there is a regular slice language $\mathcal{L}(\varphi,z,k,q)$ over $\mathbf{\Sigma}(z\cdot k, q)$ such that $\mathbf{U} \in \mathcal{L}$ if and only if $\mathring{\mathbf{U}} \models \varphi$ and $\mathring{\mathbf{U}}$ is the union of k paths.*

Next we will show how to use Lemma 1 to obtain algorithmic results. If $\mathbf{S}$ is a slice then a sub-slice of $\mathbf{S}$ is a slice $\mathbf{S}'$ that is a subgraph of $\mathbf{S}$. If $\mathbf{U} = \mathbf{S}_1\mathbf{S}_2...\mathbf{S}_n$ is a unit decomposition of a digraph G, then a sub-unit decomposition of $\mathbf{U}$ is a unit decomposition $\mathbf{U}' = \mathbf{S}'_1\mathbf{S}'_2...\mathbf{S}'_n$ such that $\mathbf{S}'_i$ is a sub-slice of $\mathbf{S}_i$.

Lemma 2 *Let $\mathbf{U}$ be a unit decomposition in $\mathbf{\Sigma}(q,q)^*$. Then the set $\mathcal{L}(\mathbf{U},c,q)$ of all sub-unit decompositions of $\mathbf{U}$ of width at most c is a finite regular slice language over $\mathbf{\Sigma}(c,q)$.*

Let $\mathbf{U} = \mathbf{S}_1\mathbf{S}_2...\mathbf{S}_n$ be a unit decomposition in $\mathbf{\Sigma}(q,q)^*$ where $\mathbf{S}_i$ has frontiers (I_i, O_i). Then we say that $\mathbf{U}$ is normalized if for each $\mathbf{S}_i$ the numbers assigned to its in-frontier vertices lie in $\{1,...,|I_i|\}$ and the numbers assigned to its out-frontier vertices lie in $\{1,...,|O_i|\}$. Now we are in a position to state our main technical theorem.

Theorem 1 *Let G be a digraph, $\omega = (v_1, v_2, ..., v_n)$ be a z-topological ordering of G and $\mathbf{U} \in \mathbf{\Sigma}(q,q)^*$ be a normalized unit decomposition of G. Then the set of all subgraphs of G that satisfy φ and that are the union of k paths is represented by the regular slice language $\mathcal{L}(U,\varphi,z,k,q) = \mathcal{L}(\mathbf{U}, z\cdot k, q) \cap \mathcal{L}(\varphi,z,k,q)$.*

The algorithmic relevance of Theorem 1 stems from the fact that the slice language $\mathcal{L}(\mathbf{U},\varphi,z,k,q)$ can be represented by a deterministic finite automaton $\mathcal{A}(\mathbf{U},\varphi,z,k,q)$ on $f(\varphi,z,k)\cdot q^{O(k\cdot z)}$ states for some computable function $f(\varphi,z,k)$. Notice that if $G = (V,E)$ then q can be at most $|E|$. Additionally, since $\mathcal{L}(\mathbf{U},\varphi,z,k,q)$ is finite, $\mathcal{A}(\mathbf{U},\varphi,z,k,q)$ is acyclic. We should also notice that each such subgraph of G corresponds to a unique sub-unit-decomposition in $\mathcal{L}(\mathbf{U},\varphi,z,k,q)$, and thus to a unique accepting path in $\mathcal{A}(\mathbf{U},\varphi,z,k,q)$. Therefore counting the number of subgraphs of G that at the same time satisfy φ and are the union of k-paths, reduces to counting the number of accepting paths in $\mathcal{A}(\mathbf{U},\varphi,z,k,q)$. Since

$\mathcal{A}(\mathbf{U}, \varphi, z, k, q)$ is acyclic, counting the number of accepting paths in it can be done in polynomial time via standard dynamic programming techniques.

We end this short note with an example of how this approach can be used to solve interesting combinatorial problems on z-topologically orderable digraphs. Suppose we want to count the number of Hamiltonian cycles on a z-topologically orderable digraph $G = (V, E)$ with n vertices. Given a z-topological ordering $\omega = (v_1, v_2, ..., v_n)$ of G, it is trivial to compute a normalized unit decomposition $\mathbf{U}$ of G belonging to $\mathbf{\Sigma}(|E|, |E|)^*$. Our formula φ will express that the graphs we are aiming to count are cycles, namely, connected graphs in which each vertex has degree precisely two. Such a formula can be easily specified in MSO_2 . Since any cycle is the union of two directed paths, we have $k = 2$. Thus one can count the number of Hamiltonian cycles in G in time $|E|^{O(2z)}$. We observe that Hamiltonicity can be solved within the same time bounds for other directed width measures, such as directed tree-width (2). However our approach can be applied to an infinite number of other problems, namely, one problem for each MSO_2 formula. We refer to (1) for many other examples of natural problems that can be solved using our approach.

[1] M. de Oliveira Oliveira: Subgraphs satisfying MSO properties on z-topologically orderable digraphs. 8th International Symposium on Parameterized and Exact Computation (2013). To appear.

[2] T. Johnson, N. Robertson, P. D. Seymour, and R. Thomas: Directed tree-width. J. Comb. Theory, Ser. B, 82(1):138–154 (2001).

Point Line Cover

by Geevarghese Philip, MPI-Saarbrücken, on work with Stefan Kratsch, TU-Berlin, and Saurabh Ray, MPI-Saarbrücken

Point Line Cover (PLC) has been posed quite a few times in open problem sessions of meetings of the PC community. The input to this problem is a set $\mathcal{P}$ of n points in the plane and a positive integer k; the parameter is k. The question is whether there is a set of at most k lines in the plane such that every point in $\mathcal{P}$ lies on one of these lines. It is an easy exercise to show that this problem has a kernel with at most k^2 points. The open problem, posed by Daniel Lokshtanov (4) in his PhD Thesis—and also at many of those problem sessions—is to find a smaller kernel, or to show that none exists. We show (3) that this problem cannot have a kernel on $k^{2-\varepsilon}$ points for any $\varepsilon > 0$, unless $\mathsf{coNP} \subseteq \mathsf{NP/poly}$ and the Polynomial Hierarchy collapses to the third level.

As might be expected, we make use of Dell and van Melkebeek's kernel size lower bound machinery (1). We first devise a polynomial-time reduction from Vertex Cover to Point Line Cover in which the parameter scales by a constant factor. Recall that per Dell and van Melkebeek, Vertex Cover has no kernel—in fact, no polynomial-time computable encoding (*compression*) of *any* sort—of size $\mathcal{O}(k^{2-\varepsilon})$ for any $\varepsilon > 0$, unless $\mathsf{coNP} \subseteq \mathsf{NP/poly}$. Our reduction implies that PLC has no compression of size $\mathcal{O}(k^{2-\varepsilon})$ either, under the same assumptions. Sadly, this does not directly yield the desired lower bound on the number of *points* in a kernel for PLC. This is because the best known polynomial-time encoding of an instance of PLC on n points takes up $\Theta(n^2 \log n) = \omega(n^2)$ bits (2). So we cannot rule out the possibility that every compressed instance of PLC of size $\mathcal{O}(k^2)$ contains only $\mathcal{O}(k)$ *points*. Perhaps an example will make this clearer: an algorithm which yields kernels of PLC with $k^{\frac{3}{2}}$ *points* can happily exist in spite of our reduction. This is possible because the best way we know how to represent a PLC instance with $k^{\frac{3}{2}}$ points takes up $\Omega(k^3 \log k)$ bits, well above the lower bound of $\omega(k^{2-\varepsilon})$ implied by our reduction. We would be well-served by a polynomial-time encoding of PLC instances on n points to $\mathcal{O}(n\, polylog(n))$ bits, but finding such an encoding is an old open problem in Computational Geometry (2).

So we need another way around the encoding problem, and we turn to *order types* and the Oracle Communication Protocol of Dell and van Melkebeek. The first player in this two-player protocol—Alice—holds the input x and is polynomially bounded; the second player Bob is computationally unbounded. The goal is to decide whether x is a **yes** instance of a language L, and the cost of this protocol is the number of bits sent *from* Alice *to* Bob. Dell and van Melkebeek show, *inter alia*, that Vertex Cover has no such protocol of cost $\mathcal{O}(k^{2-\varepsilon})$ unless $\mathsf{coNP} \subseteq \mathsf{NP/poly}$. In turn, our reduction from Vertex Cover to Point Line Cover shows that if PLC has such a protocol of cost $\mathcal{O}(k^{2-\varepsilon})$, then $\mathsf{coNP} \subseteq \mathsf{NP/poly}$.

Informally, two ordered sets of n points each are said to have the same *order type* if for any three indices $i, j, k \in [n]$, the location—left, on, or right—of point j with respect to the line from point i to point k is the same for both point sets. Two point sets are said to have the same order type if some pair of orderings of the two sets have the same order type. If two point sets $\mathcal{P}, \mathcal{Q}$ have the same order type, then for any $k \in \mathbb{N}$ it holds that $(\mathcal{P}, k)$ and $(\mathcal{Q}, k)$ are equivalent instances of PLC. Goodman and Pollack (2) proved that the number of order types defined by point sets where no three points lie on a line is $n^{\mathcal{O}(n)}$. We extend this result to order types of arbitrary n-point sets, and devise an algorithm to enumerate all such order types. This gives us an oracle communication protocol of cost $\mathcal{O}(n \log n)$ for deciding instances of PLC with n points, as follows. Recall that in the protocol Alice starts off holding the input.

1. Alice computes the order type X of the n-point set which she holds. She sends the value n to Bob. Bob computes a sorted list of all order types of n-point sets.

2. Alice and Bob now engage in a conversation designed for Bob to locate, by binary search in his

list, the order type X. Bob finds the median order type M in his list and sends it to Alice. Alice replies with a bit which tells whether X is after M in sorted order or not. Bob prunes his list accordingly and repeats the process till he is left with a single order type.

3. Bob now knows the order type X. He computes the size OPT of a smallest point-line cover for X, and sends OPT to Alice. Alice compares OPT with the number k in her input to find the answer.

Since Bob's sorted list has $n^{\mathcal{O}(n)}$ elements to start with, the cost of this protocol—the number of bits sent from Alice to Bob—is bounded by $\mathcal{O}(n \log n)$. Suppose PLC had a kernel with $\mathcal{O}(k^{2-\varepsilon})$ points. Given an instance of PLC, Alice could first find this kernel, and then apply the above protocol to solve the problem. The cost of this protocol would be $\mathcal{O}(k^{2-\varepsilon} \log(k^{2-\varepsilon})) = \mathcal{O}(k^{2-\varepsilon} \log k) = \mathcal{O}(k^{2-\varepsilon'})$ for some $0 < \varepsilon' < \varepsilon$ which, as we saw above, implies $\mathsf{coNP} \subseteq \mathsf{NP/poly}$.

[1] Holger Dell and Dieter van Melkebeek. Satisfiability Allows No Nontrivial Sparsification Unless The Polynomial-Time Hierarchy Collapses. In *Proceedings of the 42nd ACM Symposium on Theory of Computing, STOC 2010, Cambridge, Massachusetts, USA, 5-8 June 2010*, pages 251–260. ACM, 2010.

[2] Jacob E. Goodman and Richard Pollack. The complexity of point configurations. *Discrete Applied Mathematics*, 31: 167–180, 1991.

[3] Stefan Kratsch, Geevarghese Philip, and Saurabh Ray. Point Line Cover: The Easy Kernel is Essentially Tight. *ArXiv e-prints 1307.2521*, July 2013. `http://arxiv.org/abs/1307.2521/`. Accepted at SODA 2014.

[4] Daniel Lokshtanov. *New Methods in Parameterized Algorithms and Complexity.* PhD thesis, University of Bergen, Norway, 2009.

CONGRATULATIONS New PhDs

Lars Prädel, *Approximation Algorithms for Geometric Packing Problems*, Univ. Kiel, Supervisor: Klaus Jansen. Congratulations, Dr. Prädel.

Christina Robenek (Otte), *Approximation Algorithms for 2-Dimensional Packing and Related Scheduling Problems*, Univ. Kiel, Supervisor: Klaus Jansen. Congratulations, Dr. Robenek.

Stefan Rümmele, *The Parameterized Complexity of Nonmonotonic Reasoning*, TU Wien, Supervisor: Prof. Reinhard Pichler. Congratulations, Dr. Rümmele.

Narges Simjour, *Parameterized Enumeration of Neighbour Strings and Kemeny Aggregations*, Univ Waterloo, Supervisor: Prof. Naomi Nishimura. Narges has accepted a position at Google in Waterloo. Congratulations, Dr. Simjour.

Wedding Bells

Congratulations to these gorgeous newly weds. All best wishes!! Congratulations and best wishes to Christina Tusche and Stefan Kratsch.

Figure 4: Mansoureh NR and Siamak Tazari, Judy Goldsmith and Andrew Klapper tied the knot after dating for 24 years, Alena and Ondre.