Proposal for a Dagstuhl Seminar on
New Horizons in Parameterized Complexity

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Abstract

In 2019 the parameterized complexity community will celebrate two round dates: 30 years since the appearance of the paper of Abrahamson, Ellis, Fellows, and Mata in FOCS 1989, which can be considered as the starting point of PC, and 20 years since the appearance of the influential book of Downey and Fellows "Parameterized Complexity". In these three decades, there has been tremendous progress in developing the area. The central vision of Parameterized Complexity through all these years has been to provide the algorithmic and complexity-theoretic toolkit for studying multivariate algorithmics in different disciplines and subfields of Computer Science. To achieve this vision, several algorithmic and complexity theoretic tools such as *polynomial time preprocessing, aka, kernelization*, *color-coding*, *graph-decompositions*, *parameterized integer programming*, *iterative compression*, or *lower bounds methods based on assumptions stronger than* $\mathsf{P}\neq\mathsf{NP}$ have been developed. These tools are *universal* as they did not only help in the development of the core of Parameterized Complexity, but also led to its success in other subfields of Computer Science such as Approximation Algorithms, Computational Social Choice, Computational Geometry, problems solvable in P (polynomial time) to name a few. All cross-discipline developments result in flows of ideas and methods in both directions. In the last few years, we have witnessed several exciting developments of new parameterized techniques and tools in the following subfields of Computer Science and Optimization: Mathematical Programming, Computational Linear Algebra, Computational Counting, Derandomization, and Approximation Algorithms. A natural question is whether these domain-centric methods and tools are *universal*. That is, can they permeate boundaries of subfields and be employed wherever Parameterized Complexity approach can be used? *The main objective of the seminar is to initiate the discussion on which of the recent domain-specific algorithms and complexity advances can become useful in other domains.*

1 Seminar title: *New Horizons in Parameterized Complexity*

This seminar is meant to be the ninth in the series of the Dagstuhl "Parameterized Complexity" seminars held since 2001.

2 Organizers

- **Prof. Fedor V. Fomin,** University of Bergen, Norway
- **Prof. Dániel Marx**, Hungarian Academy of Sciences (MTA SZTAKI), Hungary
- **Prof. Saket Saurabh**, Institute of Mathematical Sciences, India
- **Dr. Meirav Zehavi**, Ben-Gurion University, Israel

Full addresses, phones and email contacts of the organisers are provided in the included curricula vitae.

3 Type of event, duration and size

- Dagstuhl seminar, 5 days, 45 participants

4 Topics

- Data structures, Algorithms and Complexity
- Parameterized Complexity
- Discrete Optimization
- Approximation

5 Keywords

Parameterized Complexity, fixed-parameter tractability, intractability

5.1 Proposed Seminar Dates

- Block-out Dates:
  - January 6–11, 2019
  - January 13–18, 2019
- Preferred Dates:
  - January 20–25, 2019
  - May 19–24, 2019

5.2 Description of the Seminar: Topics and goals

In 1989, Abrahamson, Ellis, Fellows, and Mata in the paper titled *On the Complexity of Fixed Parameter Problems (FOCS 1989)*, laid the foundation of the field of Parameterized Complexity, an alternative approach of handling computational intractability. The main idea of the approach taken by the Parameterized Complexity is to analyze the complexity in finer detail by considering additional problem parameters beyond the input size and expresses the efficiency of the algorithms in terms of these parameters. In this framework, many NP-hard problems have been shown to be (fixed-parameter) tractable (FPT) when certain structural parameters of the inputs are bounded.

In these three decades, there has been tremendous progress in understanding which problems are fixed-parameter tractable and which problems are not (under standard complexity assumptions). For all these years the central vision of the Parameterized Complexity has been to provide the algorithmic and complexity-theoretic toolkit for studying multivariate algorithmics in different disciplines and subfields of Computer Science. To achieve this vision several algorithmic and complexity theoretic tools such as *polynomial time preprocessing, aka, kernelization*, *color-coding*, *graph-decompositions*, *parameterized integer programming*, *iterative compression*, or *lower bounds methods based on assumptions stronger than* $\mathsf{P}\neq\mathsf{NP}$ have been developed. These tools are *universal* as they not only helped in the development of the core of Parameterized Complexity but also led to its success in other subfields of Computer Science such as Approximation Algorithms, Computational Social Choice, Computational Geometry, problems solvable in P (polynomial time) to name a few. All cross-discipline developments result in flow of ideas and methods in both directions. In the last few years we have witnessed several exciting developments of new techniques and tools in different subfields of Computer Science, where Parameterized Complexity has been employed successfully. A natural question is whether these domain-centric methods and tools are *universal*. That is, if they can permeate boundaries of subfields and be employed wherever Parameterized Complexity can be. Thus,

> *the main objective of the seminar is to initiate the discussion on the following topic: which of the recent domain-specific algorithms and complexity advances can become useful in other domains.*

In order to achieve this goal we want to have a meeting which allows a fruitful dialogue between researchers working in the core of Parameterized Complexity and researchers from Mathematical Programming, Computational Linear Algebra, Counting and Computational Complexity responsible for the recent advances of parameterized algorithms and complexity in these areas. The proposed Dagstuhl seminar will help to explore possibilities of developing new tools and techniques due to this association.

Next we give a few concrete examples of new tools and techniques that have been developed recently in different domains for Parameterized Complexity which will be the topics for the discussion at the proposed seminar.

- ***Mathematical Programming.*** One of the classical results in Computer Science is the celebrated algorithm of Lenstra from 1985, which shows that INTEGER LINEAR PROGRAMMING FEASIBILITY is FPT parameterized by the number of variables. This paper received Fulkerson Prize in 1985 for an outstanding contribution in the area of discrete mathematics. This algorithm is in the universal toolbox of Parameterized Complexity and is used as a subroutine in many FPT algorithms. Recently, Onn developed an alternate FPT algorithm for this problem (in fact, a serious generalization of Lenstra) by developing the method of *Graver basis*. Onn has written a book on this: Nonlinear Discrete Optimization, published by European Mathematical Society. It is very plausible to assume that Graver basis is a universal tool which can be used for solving many problems. As an indication, very recently, Chen and Marx (Covering a tree with rooted subtrees – parameterized and approximation algorithms, SODA 2018) and Knop, Koutecký (Scheduling meets n-fold Integer Programming, Arxiv 2016) used this method successfully for solving problems in scheduling

  Another recent development related to the study of integer programming problems is due to Eisenbrand and Weismantel (Proximity results and faster algorithms for Integer Programming using the Steinitz Lemma, SODA 2018). This work of Eisenbrand and Weismantel brings the tools which allow to improve upon the longstanding best bound of Papadimitriou from 1981. Interestingly, this result was strongly motivated by developing lower bounds for integer programming based on Exponential Time Hypothesis obtained in the work of Fomin, Panolan, Ramanujan, Saurabh: Fine-grained complexity of integer programming: The case of bounded branch-width and rank (Arxiv 2016). The Steinitz lemma, the main tool of Eisenbrand and Weismantel, seems to be useful beyond this application and this has to be explored.
- ***Tools from Computational Linear Algebra.*** Sketching and sampling are the most widely used tools in designing algorithms for problems arising in Computational Linear Algebra—a common tool to deal with problems in Machine Learning. Recently,

Razenshteyn, Song and Woodruff ("Weighted Low Rank Approximations with Provable Guarantees, STOC 2016") developed a new technqie which they call "guess the sketch" to design parameterized algorithms for WEIGHTED LOW RANK APPROXIMATIONS. They also used this method to give solutions to several other fundamental problems like ADVERSARIAL MATRIX COMPLETION, WEIGHTED NON-NEGATIVE MATRIX FACTORIZATION and TENSOR COMPLETION. How these powerful tools are applicable for parameterized algorithms beyond Linear Algebra? What are the relations of sketching and lossy kernelization? Which of the complexity tools can be applied in Computational Algebra? All these questions are extremely interesting and important.

- ***Tools from the world of Computational Counting.*** Parameterized Complexity of counting problems has seen a recent surge in its developments. In particular, Curticapean and Marx adapted the classic methods in this area like Holant methods to use for parameterized settings (Tight conditional lower bounds for counting perfect matchings on graphs of bounded treewidth, cliquewidth, and genus, SODA 2016). Representation-theoretic tools in rank based methods were recently developed in (Curticapean, Lindzey, Nederlof, A Tight Lower Bound for Counting Hamiltonian Cycles via Matrix Rank, SODA 2018).
- ***Tools from Derandomization.*** Recently, in a major breakthrough Fenner, Gurjar, and Thierauf gave a deterministic parallel algorithm for BIPARTITE PERFECT MATCHING (Bipartite Perfect Matching is in quasi-NC, STOC 2016) running in quasi-polynomial time. They obtain this result by almost complete derandomization of the famous Isolation Lemma when applied to yield an efficient randomized parallel algorithm for the BIPARTITE PERFECT MATCHING problem. After this several new results in this directions have been obtained. Recently, Lokshtanov, Misra, Panolan, Saurabh and Zehavi (Quasipolynomial Representation of Transversal Matroids with Applications in Parameterized Complexity, ITCS 2018) used this tool in designing parameterized algorithms. It seems that the tools used here could be useful in derandomization of parameterized algorithms based on isolation lemma and polynomial identity testing.
- ***Tools from Computational Complexity and Approximation Algorithms.*** Several recent exciting connections between parameterized and approximation algorithms, parameterized complexity and non-approximability were established, again due to developing of new tools. Using a new complexity-theoretical assumption, *Gap Exponential Time Hypothesis* (Gap-ETH), which states that no $2^{o(n)}$-time algorithm can distinguish between a satisfiable 3-SAT formula and one which is not even $(1-\varepsilon)$-satisfiable for some constant $\varepsilon > 0$, Chalermsook, Cygan, Kortsarz, Laekhanukit, Manurangsi, Nanongkai, and Trevisan addressed several basic questions on FPT-approximation (From Gap-ETH to FPT-Inapproximability: Clique, Dominating Set, and More, FOCS 2017). Apart from using this new hypothesis successfully, authors also use methods and tools used in the theory of development of PCP (Probabilistically Checkable Proofs). On the other hand, Chen and Lin gave constant factor FPT-inapproximability for SET COVER and DOMINATING SET under $\mathsf{FPT} \neq \mathsf{W}[1]$ assumption without using PCP (The Constant Inapproximability of the Parameterized Dominating Set Problem, FOCS 2016). Lokshtanov, Panolan, Ramanujan, and Saurabh introduced the notion of lossy kernelization (Lossy Kernelization, STOC 2017). This framework builds on the notion of kernelization from parameterized complexity. However, as opposed to the original notion of kernelization, this definitions combine well with approximation algorithms and heuristics. The

kernels built in this framework combine tools from combinatorics, combinatorial optimization and techniques used in the design of approximation algorithms (or hardness of approximation).

We believe this is the opportune moment to bring together researchers from the fields of Parameterized Algorithms/Complexity, Approximation Algorithms, Mathematical Programming, Computational Complexity, Computational Linear Algebra and Computational Counting to discuss the new tools and techniques and to encourage further developments. Thus, the purpose of this workshop is to bring together experts from these fields, consolidate the results achieved in the recent years, discuss future research directions, and explore further the applications potential of the methods and techniques discussed above.

Impact on the research community. We believe that the tools developed in Mathematical Programming, Computational Linear Algebra, Computational Counting, Derandomization, and Approximation Algorithms will start to play very important role in different branches of Parameterized Complexity and will become part of its universal toolbox. The proposed seminar has a potential to pave the road for further developments of the area for the the next 5-10 years. The seminar will help to improve known and to develop new tools for FPT algorithms by importing into the area tools from the above mentioned fields.

6 Related Seminars

The proposed seminar would continue the seminar series on parameterized algorithms and complexity. The previous seminars in this series are Randomization in Parameterized Complexity (seminar 17041), Optimality and Tight Results in Parameterized Complexity (seminar 14451), Data Reduction and Problem Kernels (seminar 12241), Parameterized complexity and approximation algorithms (seminar 09511), Structure Theory and FPT Algorithmics for Graphs, Digraphs and Hypergraphs (seminar 07281), Exact Algorithms and Fixed-Parameter Tractability (seminar 05301), Fixed Parameter Algorithms (seminar 03311), and Parameterized Complexity (seminar 01311). The proposed seminar has some thematic overlap with the following recent and upcoming seminars:

- Algorithms for Optimization Problems in Planar Graphs (seminar 16221)
- Structure and Hardness in P (seminar 16451)
- The Constraint Satisfaction Problem: Complexity and Approximability (seminar 18231)
- Synergies between Adaptive Analysis of Algorithms, Parameterized Complexity, Compressed Data Structures and Compressed Indices (seminar 18281)
- Algorithmic Enumeration: Output-sensitive, Input-Sensitive, Parameterized, Approximative (seminar 18421)

The field of Parameterized Complexity has matured to a point where it is natural to see several seminars on specialized topics that also include Parameterized Algorithms to some extent. While the other seminars focus on applying Parameterized Algorithms to their respective problem domains, the proposed seminar aims to advance the field by studying the recent advances in Parameterized Algorithms and Complexity.

7 List of potential participants

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   Approximation, Optimization

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   Logic, Parameterized Complexity

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   Optimization, FPT

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Parameterized Complexity and Algorithms

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Discrete Optimization

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Parameterized Complexity

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Parameterized Complexity

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Parameterized Complexity and Algortihms

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Parameterized Complexity and Algorithms

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Logic, Algorithms, Discrete Mathematics

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Parameterized Complexity, Optimization, randomization

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Parameterized Complexity

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Parameterized Complexity, Kernelization, Graph Theory

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Counting

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Parameterized Complexity, Combinatorial Optimization

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Parameterized Complexity, Constraint Satisfaction Problems, Graph Theory

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Parameterized Complexity, Succinct Data Structures

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Approximation, Derandomization

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Logic, Parameterized Complexity

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Complexity, Approximation

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Parameterized Complexity, Kernelization

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Algorithms, Complexity

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   Apprximation, Fine Grained

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   Logic, Graph Theory

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   Randomization, Approximation

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   Parameterized Complexity, Social Choice

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Algorithms, Bayesian Networks

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Fedor Fomin received his PhD in 1997 from the Faculty of Mathematics and Mechanics, St. Petersburg State University. Since 2002, he is a professor in Algorithms, at the Department of Informatics, University of Bergen.

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Selected Publications

1. M. Cygan, F. V. Fomin, A. Golovnev, A. Kulikov, I. Mihajlin, J. Pachocki, and A. Socała, *Tight bounds for graph homomorphism and subgraph isomorphism*, Journal of the ACM 64 (3), article No. 18, (2017).

2. H. Bodlaender, F. V. Fomin, D. Lokshtanov, E. Penninkx, S. Saurabh, and D. M. Thilikos, *(Meta) Kernelization*, Journal of the ACM 63 (5), article No. 44, (2016).

3. F. V. Fomin, D. Lokshtanov, F. Panolan, and S. Saurabh, *Efficient computation of representative families with applications in parameterized and exact algorithms*, Journal of the ACM 63 (4), article No. 29, (2016).

4. H. L. Bodlaender, P. G. Drange, M. S. Dregi, F. V. Fomin, D. Lokshtanov, and M. Pilipczuk, *A $c^k n$ 5-approximation algorithm for treewidth*, SIAM Journal on Computing 45(2) (2016), pp. 317–378.

5. F. V. Fomin and Y. Villanger, *Subexponential parameterized algorithm for minimum fill-in*, SIAM Journal on Computing, 42(6) (2013), pp. 2197-2216.

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1. Tractable hypergraph properties for constraint satisfaction and conjunctive queries. Journal of the ACM, 60(6):42, 2013. (Preliminary version in STOC 2010.)

2. Homomorphisms Are a Good Basis for Counting Small Subgraphs 49th Annual ACM Symposium on the Theory of Computing (STOC 2017), 210-223, 2017. (with: Radu Curticapean amd Holger Dell)

3. Closest substring problems with small distances. SIAM Journal on Computing, 38(4):1382-1410, 2008. (Preliminary version in FOCS 2005.)

4. Covering a tree with rooted subtrees–parameterized and approximation algorithms. In Proceedings of the 29th Annual ACM-SIAM Symposium on Discrete Algorithms (SODA 2018), accepted. (with: Lin Chen).

5. Approximation schemes for Steiner Forest on planar graphs and graphs of bounded treewidth. Journal of the ACM, 58(5):21, 2011. (with MohammadHossein Bateni and MohammadTaghi Hajiaghayi)

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His main research interest is Parameterized Complexity and its applications for graph algorithms and combinatorial optimization. His recent interest lies in developing lower and upper bounds on lossy kernels and problems on matroids. kernelization. He served on the program committee of several international conferences, including ICALP 2012, ICALP 2013, ESA 2015, ISAAC 2015, ISAAC 2016, and SODA 2016. He was the co-chair of the 5th International Symposium on Parameterized and Exact Computation (IPEC 2010) and 36th IARCS Annual Conference on Foundations of Software Technology and Theoretical Computer Science (FSTTCS 2016). He was a co-organizer of Dagstuhl Seminar 12241.

Recent Related Publications:

1. Fedor V. Fomin, Daniel Lokshtanov, Fahad Panolan, and Saket Saurabh: Efficient Computation of Representative Families with Applications in Parameterized and Exact Algorithms. J. ACM 63(4): 29:1-29:60 (2016)

2. Daniel Lokshtanov, Fahad Panolan, M. S. Ramanujan, and Saket Saurabh: Lossy kernelization. STOC 2017: 224-237

3. Fedor V. Fomin, Daniel Lokshtanov, Michal Pilipczuk, and Saket Saurabh, Marcin Wrochna: Fully polynomial-time parameterized computations for graphs and matrices of low treewidth. SODA 2017: 1419-1432

4. Daniel Lokshtanov, M. S. Ramanujan and Saket Saurabh: When Recursion is Better than Iteration: A Linear-Time Algorithm for Acyclicity with Few Error Vertices. Proceedings of the ACM-SIAM Symposium on Discrete Algorithms (SODA 2018)

5. Daniel Lokshtanov, Pranabendu Misra, Fahad Panolan, Saket Saurabh and Meirav Zehavi: Quasipolynomial Representation of Transversal Matroids with Applications in Parameterized Complexity. Proceedings of the Innovations in Theoretical Computer Science (ITCS 2018)

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Her main research interests lie in the fields of Parameterized Complexity and Kernelization, including applications to graph problems and geometric problems. She served/will serve on the program committee of IPEC 2016, CSR 2018 and IPEC 2018. She organized the 1st Workshop on Rangoli of Algorithms (RoA 2016) in Chennai, India, and Recent Advances in Parameterized Complexity in Tel-Aviv, Israel.

Selected Publications

1. D. Lokshtanov, F. Panolan, S. Saurabh, R. Sharma and M. Zehavi, *Covering Small Independent Sets and Separators with Applications to Parameterized Algorithms*, Proceedings of the 29th Annual ACM-SIAM Symposium on Discrete Algorithms (SODA 2018).

2. T. Le, D. Lokshtanov, S. Saurabh, S. Thomasse and M. Zehavi, *Subquadratic Kernels for Implicit 3-Hitting Set and 3-Set Packing Problems*, Proceedings of the 29th Annual ACM-SIAM Symposium on Discrete Algorithms (SODA 2018).

3. P. Ashok, F. V. Fomin, S. Kolay, S. Saurabh and M. Zehavi, *Exact Algorithms for Terrain Guarding*, Proceedings of the 33rd Annual Symposium on Computational Geometry (SoCG 2017), pp. 11:1-11:15.

4. M. Zehavi, *Mixing Color-Coding Related Techniques*, Proceedings of the 23th annual European Symposium on Algorithms (ESA 2015), pp. 1037-1049.

5. A. Agrawal, D. Lokshtanov, P. Misra, S. Saurabh and M. Zehavi, *Feedback Vertex Set Inspired Kernel for Chordal Vertex Deletion*, Proceedings of the 28th Annual ACM-SIAM Symposium on Discrete Algorithms (SODA 2017), pp. 1383-1398.