Proposal for a Dagstuhl Seminar on
Randomization in Parameterized Complexity

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Abstract

The application proposes a seminar bringing together researchers from the fields of parameterized algorithms/complexity and randomization. While the usage of randomization, except very few classical examples such as Color Coding, has largely been neglected in the traditional parameterized complexity the situation begin to change rapidly in the last 4-7 years. There is no doubt that randomized algorithms will be one of the mainstreams in parameterized complexity in the next 5-10 years.

The goal of the proposed seminar is to bring together people from the parameterized complexity community and specialists from the randomized world. We intend to

- review the current state of the art of randomized techniques in parameterized algorithms,
- discuss new problem domains where these techniques can be applied, and
- search for new randomized techniques targeted for specific parameterized problems.

1 Seminar title: *Randomization in Parameterized Complexity*

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

2 Organizers

- **Dr. Marek Cygan,** University of Warsaw, Poland
- **Prof. Fedor V. Fomin,** University of Bergen, Norway
- **Dr. Danny Hermelin**, Ben Gurion University, Israel
- **Dr. Magnus Wahlström**, Royal Holloway, University of London, United Kingdom

Full address, phones, emails 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, complexity
- Randomness
- Artificial Intelligence
- Data bases

5 Keywords

Parameterized complexity, fixed-parameter tractability, randomness, intractability

5.1 Proposed Seminar Dates

- Block-out Dates:
  - August 21st–August 27th, 2016
  - January 1st–January 7th, 2017
  - January 8th–January 14th, 2017
- Preferred Dates:
  - January 15th–January 21st, 2017
  - January 22nd–January 28th, 2017

5.2 Description of the Seminar: Topics and goals

Parameterized complexity is an 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 when certain structural parameters of the inputs are bounded. In the past two decades, there has been tremendous progress in understanding which problems are fixed-parameter tractable and which problems are not (under standard complexity assumptions).

5.3 Topics of the seminar

The main focus of the proposed Dagstuhl seminar on parameterized complexity is *randomness* in parameterized algorithms and complexity. We believe that this is the right moment to organize this seminar for the following reasons. For a long time in parameterized algorithms and complexity, randomized techniques, except for a very few notable examples such as color coding, were mostly neglected. However, within the last 5–7 years the situation has changed drastically. Here are just a few of the recent examples of how randomized techniques were used to advance in different areas of parameterized algorithms and complexity.

- Randomized reductions from multiple to a unique solution like Isolation lemma of Mulmuley, Vazirani & Vazirani, were used by Cygan et al. (FOCS 2011) to develop Count& Count technique for single-exponential treewidth-based algorithms for connectivity problems. This in turn implied the fastest known algorithm for Feedback Vertex Set parameterized by the solution size.

- Randomized algebraic techniques like Schwartz-Zippel Lemma for fast testing (in various algebras) of polynomials for identity with zero or linear monomials, were used to obtain several breakthroughs in parameterized algorithms including algorithms for k-Path of Koutis and Williams (ICALP 2008, 2009), and the impressive advance of Björklund on the Hamiltonian path problem (FOCS 2010) which provided the first improvement on this classical problem after fifty years of stagnation. Randomized algebraic techniques were also used for polynomial compression by Wahlström (STACS 2013) and by Cygan, Kratsch & Nederlof (STOC 2013) in the rank-based approach for counting Hamiltonian cycles modulo two.

- Randomized methods for limited independent sample spaces were used by Alon, Yuster and Zwick in their classical Color-coding paper (J. ACM 1995). The extensions of this approach like divide and color (Chen et al. SODA 2007 and Kneis et al. WG 2006) and chromatic coding of Alon, Lokshtanov & Saurabh (ICALP 2009) were used to obtain faster parameterized algorithms, including the first parameterized subexponential algorithm for Feedback Arc Set in Tournaments. Other domain- and problem-specific sampling techniques include the shadow removal technique of Marx and Razgon (STOC 2011) and the randomized contractions used by Chitnis et al. (FOCS 2012), both of which have been used heavily in subsequent work.

- Probabilistic method and moment inequalities were used to obtain a sequence of advances for different "above guarantee parameterization" problems like MAX-r-SAT by Alon et al. (SODA 2010).

- Randomized techniques for constructing and working with linear representations of matroids are central to the polynomial kernel for Odd Cycle Transversal by Kratsch and Wahlström (SODA 2012), and when combined with the representative sets lemma led to further advances in kernelization (Kratsch and Wahlström, FOCS 2012) and parameterized algorithms (Fomin, Lokshtanov & Saurabh, SODA 2014).

- Additionally, studies in the derandomization of the above techniques have brought several important results, including the construction of representative sets for set families of Fomin, Lokshtanov & Saurabh (SODA 2014) and the rank-based approach to dynamic programming on tree decompositions (Bodlaender et al., ICALP 2013).

We believe that with this growing use of random methods in the field, this is the right time for a seminar to discuss the role of randomness in parameterized complexity and to encourage further developments.

5.4 Seminar goals

In more mature subfields of theoretical computer science randomization plays two roles in problem solving. For many problems, even though we do know deterministic algorithms,

randomization allows for simpler, faster or more appealing solutions. For other problems, however, randomization is the only way we know how to cope with a problem, as in the case of polynomial identity testing, or deciding whether there exists a perfect matching with exactly b red edges in an edge-colored bipartite graph. For decades the only known polynomial time solutions for those problems are randomized. The first goal to be achieved with the proposed seminar is to

- *establish domains for simpler and/or more efficient FPT algorithms via randomization.*

We believe that at this point parameterized complexity is mature enough to identify in which cases randomization plays which of the two mentioned roles. For example currently the only known polynomial time compression for the K-Set-Cycle problem is randomized (Wahlström, STACS 2013). Randomized Cut&Count based algorithms for connectivity problems parameterized by treewidth have matching lower bounds based on the Strong Exponential Time Hypothesis, is it possible to get same running times deterministically? Currently answers to such questions are unknown and for this reason we think that bringing researchers involved in studying randomization from different than FPT perspective will bring value to the community, as it may help to

- *identify problems which intrinsically need randomization,*

which is the second goal of the seminar.

In many cases, it is worthwhile studying problems whose inputs are generated by some underlying distribution. For instance, the study of algorithms on random graphs began already in the late 70s, and is by now a well developed field. The idea behind studying such problems is that they facilitate average-case analysis which is considered more practically relevant when compared to worst-case analysis. However, the study of such problems has so far been almost completely neglected by the parameterized complexity community. Thus, in the seminar we will

- *study parameterized problems whose instances are generated by some underlying distribution.*

More broadly speaking, in computer science as a whole randomness also plays several other roles, beyond the construction of algorithms with good (expected) worst-case properties. For example, there is rich research into the properties of random objects, including the study of various random graph models; the threshold properties of random k-SAT formulas, and associated algorithms (e.g., the celebrated constructive version of the Lovász Local Lemma by Moser and Tardos); and various assumptions of selectively randomized input, such as smoothed analysis, or random permutation assumptions in the study of online algorithms. Another goal of the seminar is thus to

- *stimulate the development of a similarly broadened role of randomness within parameterized complexity.*

To achieve this goal we invite several leading researchers in random methods which are outside of the area of parameterized complexity.

Impact on the research community Randomization start to play very important role in different branches of parameterized complexity. 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 more randomized and algebraic techniques into the area.

6 Related Seminars

The proposed seminar would continue the seminar series on parameterized algorithms and complexity. The previous seminars in this series are 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:

- The Constraint Satisfaction Problem: Complexity and Approximability (seminar 15301)
- Bidimensional Structures: Algorithms, Combinatorics and Logic (seminar 13121)
- Exponential Algorithms: Algorithms and Complexity Beyond Polynomial Time (seminar 13331)
- Algorithms for Optimization Problems in Planar Graphs (seminar 13421)
- Graph Modification Problems (seminar 14071)

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 of randomized techniques in parameterized algorithms and complexity. As for seminar 13331 (and the previous seminars in that series, 10441 and 08431), the focus there is more on fast exponential-time algorithms in terms of the input size, whereas the proposed seminar focuses on how parameters capture the hardness of the considered problem instances, which is the core concept of parameterized complexity.

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   Combinatorics, Probabilistic Methods

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Randomization

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Parameterized Complexity

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Parameterized Complexity, Probability, Logic

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Parameterized Complexity

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Parameterized Complexity, Social Choice

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Parameterized Complexity and Algorithms

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   Logic

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Logic

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Constraint Satisfaction Problems, Parameterized Algorithms

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Selected Publications

1. M. Cygan, D. Lokshtanov, M. Pilipczuk, M. Pilipczuk, and S. Saurabh, *Minimum bisection is fixed parameter tractable*, Proceedings of 46th Annual Symposium on the Theory of Computing (STOC 2014), 2014, pp. 323–332.

2. M. Cygan, J. Nederlof, and S. Kratsch, *Fast hamiltonicity checking via bases of perfect matchings*, Proceedings of 45th Annual Symposium on the Theory of Computing (STOC 2013), 2013, pp. 301–310.

3. R. Chitnis, M. Cygan, M. Hajiaghayi, M. Pilipczuk, M. Pilipczuk, *Designing FPT Algorithms for Cut Problems Using Randomized Contractions.*, Proceedings of the 53th Annual Symposium on Foundations of Computer Science (FOCS 2012), IEEE, 2011, pp. 460–469.

4. M. Cygan, J. Nederlof, M. Pilipczuk, M. Pilipczuk, J. M. M. van Rooij, and J. O. Wojtaszczyk, *Solving Connectivity Problems Parameterized by Treewidth in Single Exponential Time*, Proceedings of the 52th Annual Symposium on Foundations of Computer Science (FOCS 2011), IEEE, 2011, pp. 150 – 159.

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Selected Publications

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

2. F. V. Fomin, D. Lokshtanov, N. Misra, and S. Saurabh, *Planar F-Deletion: Approximation, kernelization and optimal FPT algorithms*, Proceedings of the 53rd Annual Symposium on Foundations of Computer Science (FOCS 2012), IEEE, 2012, pp. 470–479.

3. F. V. Fomin, D. Lokshtanov, and S. Saurabh, *Efficient computation of representative sets with applications in parameterized and exact algorithms*, Proceedings of the 25th ACM-SIAM Symposium on Discrete Algorithms (SODA 2014), ACM and SIAM, 2014, pp. 142–151.

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*, Proceedings of the 54th Annual Symposium on Foundations of Computer Science (FOCS 2013), IEEE, 2013, pp. 499– 508.

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Selected Publications

1. M. Cygan, F. Grandoni, and D. Hermelin, *Tight Kernel Bounds for Problems on Graphs with Small Degeneracy - (Extended Abstract)*, Proceedings of the 20th annual European Symposium on Algorithms (ESA 2013), 2013, pp. 361-372.

2. D. Hermelin and X. Wu, *Weak compositions and their applications to polynomial lower bounds for kernelization*, Proceedings of the 23th ACM-SIAM Symposium on Discrete Algorithms (SODA 2012), ACM and SIAM, 2012, pp. 104–113.

3. D. Hermelin, M. Mnich, E.J. van Leeuwen, and G.J. Woeginger, *Domination When the Stars Are Out*, Proceedings of the 38th International Colloquium on Automata, Languages and Programming (ICALP 2011), 2011, pp. 462-473.

4. H. L. Bodlaender, R. G. Downey, M. R. Fellows, and D. Hermelin, *On problems without polynomial kernels*, Journal of Computer and System Sciences, 75(8) (2009), pp. 423-434.

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Selected Publications

1. S. Kratsch and M. Wahlström, *Compression via Matroids: A Randomized Polynomial Kernel for Odd Cycle Transversal*, ACM Transactions on Algorithms (TALG), 10(4):20, 2014.

2. S. Kratsch and M. Wahlström, *Representative Sets and Irrelevant Vertices: New Tools for Kernelization*, Proceedings of the 53rd Annual Symposium on Foundations of Computer Science (FOCS 2012), IEEE, 2012, pp. 450–459.

3. M. Wahlström, *Half-integrality, LP-branching and FPT Algorithms*, Proceedings of the 25th Annual ACM-SIAM Symposium on Discrete Algorithms (SODA 2014), ACM and SIAM, 2014, pp. 1762–1781.

4. M. Wahlström, *Abusing the Tutte Matrix: An Algebraic Instance Compression for the K-set-cycle Problem*, Proceedings of the 30th International Symposium on Theoretical Aspects of Computer Science (STACS 2013), LIPIcs, 2013, pp. 341–352.