# 41st IARCS Annual Conference on Foundations of Software Technology and Theoretical Computer Science

**FSTTCS 2021, December 15–17, 2021, Virtual Conference**

Edited by

Mikołaj Bojańczyk

Chandra Chekuri

LIPICS

LIPIcs – Vol. 213 – FSTTCS 2021 www.dagstuhl.de/lipics

*Editors*

**Mikołaj Bojańczyk**
University of Warsaw, Poland
bojan@mimuw.edu.pl

**Chandra Chekuri**
University of Illinois, Urbana-Champaign, IL, US
chekuri@illinois.edu

*ACM Classification 2012*
Theory of computation; Computing methodologies; Software and its engineering

**ISBN 978-3-95977-215-0**

*Published online and open access by*
Schloss Dagstuhl – Leibniz-Zentrum für Informatik GmbH, Dagstuhl Publishing, Saarbrücken/Wadern, Germany. Online available at https://www.dagstuhl.de/dagpub/978-3-95977-215-0.

*Publication date*
December, 2021

*Bibliographic information published by the Deutsche Nationalbibliothek*
The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available in the Internet at https://portal.dnb.de.

*License*
This work is licensed under a Creative Commons Attribution 4.0 International license (CC-BY 4.0): https://creativecommons.org/licenses/by/4.0/legalcode.
In brief, this license authorizes each and everybody to share (to copy, distribute and transmit) the work under the following conditions, without impairing or restricting the authors' moral rights:
- Attribution: The work must be attributed to its authors.

The copyright is retained by the corresponding authors.

Digital Object Identifier: 10.4230/LIPIcs.FSTTCS.2021.0

## LIPIcs – Leibniz International Proceedings in Informatics

LIPIcs is a series of high-quality conference proceedings across all fields in informatics. LIPIcs volumes are published according to the principle of Open Access, i.e., they are available online and free of charge.

*Editorial Board*

- Luca Aceto (*Chair*, Reykjavik University, IS and Gran Sasso Science Institute, IT)
- Christel Baier (TU Dresden, DE)
- Mikolaj Bojanczyk (University of Warsaw, PL)
- Roberto Di Cosmo (Inria and Université de Paris, FR)
- Faith Ellen (University of Toronto, CA)
- Javier Esparza (TU München, DE)
- Daniel Král' (Masaryk University - Brno, CZ)
- Meena Mahajan (Institute of Mathematical Sciences, Chennai, IN)
- Anca Muscholl (University of Bordeaux, FR)
- Chih-Hao Luke Ong (University of Oxford, GB)
- Phillip Rogaway (University of California, Davis, US)
- Eva Rotenberg (Technical University of Denmark, Lyngby, DK)
- Raimund Seidel (Universität des Saarlandes, Saarbrücken, DE and Schloss Dagstuhl – Leibniz-Zentrum für Informatik, Wadern, DE)

**ISSN 1868-8969**

**https://www.dagstuhl.de/lipics**

# Contents

Preface
*Mikołaj Bojańczyk and Chandra Chekuri* ..... 0:ix

Program Committee
..... 0:xi

List of External Reviewers: Track A
..... 0:xiii

List of External Reviewers: Track B
..... 0:xv

## Invited Talks

BQP After 28 Years
*Scott Aaronson* ..... 1:1–1:1

State Complexity of Population Protocols
*Javier Esparza* ..... 2:1–2:1

Approximately Counting Graph Homomorphisms and Retractions
*Leslie Ann Goldberg* ..... 3:1–3:1

Indistinguishability Obfuscation from Well-Founded Assumptions
*Huijia (Rachel) Lin* ..... 4:1–4:1

The Complexity of Gradient Descent
*Rahul Savani* ..... 5:1–5:2

## Regular Papers

Scheduling in the Secretary Model
*Susanne Albers and Maximilian Janke* ..... 6:1–6:22

One-Way Functions and a Conditional Variant of MKTP
*Eric Allender, Mahdi Cheraghchi, Dimitrios Myrisiotis, Harsha Tirumala, and Ilya Volkovich* ..... 7:1–7:19

Generalizations of Length Limited Huffman Coding for Hierarchical Memory Settings
*Shashwat Banchhor, Rishikesh Gajjala, Yogish Sabharwal, and Sandeep Sen* ..... 8:1–8:23

Approximation Algorithms for Flexible Graph Connectivity
*Sylvia Boyd, Joseph Cheriyan, Arash Haddadan, and Sharat Ibrahimpur* ..... 9:1–9:14

Tight Chang's-Lemma-Type Bounds for Boolean Functions
*Sourav Chakraborty, Nikhil S. Mande , Rajat Mittal, Tulasimohan Molli, Manaswi Paraashar, and Swagato Sanyal* ..... 10:1–10:22

Approximate Trace Reconstruction via Median String (In Average-Case)
*Diptarka Chakraborty, Debarati Das, and Robert Krauthgamer* ..... 11:1–11:23

41st IARCS Annual Conference on Foundations of Software Technology and Theoretical Computer Science (FSTTCS 2021).
Editors: Mikołaj Bojańczyk and Chandra Chekuri
Leibniz International Proceedings in Informatics
LIPICS Schloss Dagstuhl – Leibniz-Zentrum für Informatik, Dagstuhl Publishing, Germany

Approximating the Center Ranking Under Ulam
*Diptarka Chakraborty, Kshitij Gajjar, and Agastya Vibhuti Jha* ..... 12:1–12:21

Towards Stronger Counterexamples to the Log-Approximate-Rank Conjecture
*Arkadev Chattopadhyay, Ankit Garg, and Suhail Sherif* ..... 13:1–13:16

Functional Lower Bounds for Restricted Arithmetic Circuits of Depth Four
*Suryajith Chillara* ..... 14:1–14:15

On (Simple) Decision Tree Rank
*Yogesh Dahiya and Meena Mahajan* ..... 15:1–15:16

Reachability and Matching in Single Crossing Minor Free Graphs
*Samir Datta, Chetan Gupta, Rahul Jain, Anish Mukherjee, Vimal Raj Sharma, and Raghunath Tewari* ..... 16:1–16:16

Approximating the Number of Prime Factors Given an Oracle to Euler's Totient Function
*Yang Du and Ilya Volkovich* ..... 17:1–17:10

Fully Dynamic Algorithms for Knapsack Problems with Polylogarithmic Update Time
*Franziska Eberle, Nicole Megow, Lukas Nölke, Bertrand Simon, and Andreas Wiese* 18:1–18:17

Largest Similar Copies of Convex Polygons in Polygonal Domains
*Taekang Eom, Seungjun Lee, and Hee-Kap Ahn* ..... 19:1–19:13

A Faster Algorithm for Finding Closest Pairs in Hamming Metric
*Andre Esser, Robert Kübler, and Floyd Zweydinger* ..... 20:1–20:21

ETH Tight Algorithms for Geometric Intersection Graphs: Now in Polynomial Space
*Fedor V. Fomin, Petr A. Golovach, Tanmay Inamdar, and Saket Saurabh* ..... 21:1–21:16

On Fair and Efficient Allocations of Indivisible Public Goods
*Jugal Garg, Pooja Kulkarni, and Aniket Murhekar* ..... 22:1–22:19

Time Space Optimal Algorithm for Computing Separators in Bounded Genus Graphs
*Chetan Gupta, Rahul Jain, and Raghunath Tewari* ..... 23:1–23:15

Near-Optimal Cayley Expanders for Abelian Groups
*Akhil Jalan and Dana Moshkovitz* ..... 24:1–24:23

Matchings, Critical Nodes, and Popular Solutions
*Telikepalli Kavitha* ..... 25:1–25:19

Fast and Exact Convex Hull Simplification
*Georgiy Klimenko and Benjamin Raichel* ..... 26:1–26:17

Lower Bounds and Improved Algorithms for Asymmetric Streaming Edit Distance and Longest Common Subsequence
*Xin Li and Yu Zheng* ..... 27:1–27:23

An ETH-Tight Algorithm for Multi-Team Formation
*Daniel Lokshtanov, Saket Saurabh, Subhash Suri, and Jie Xue* ..... 28:1–28:9

Dominating Set in Weakly Closed Graphs is Fixed Parameter Tractable
*Daniel Lokshtanov and Vaishali Surianarayanan* ..... 29:1–29:17

Popular Matchings in the Hospital-Residents Problem with Two-Sided Lower Quotas
*Meghana Nasre, Prajakta Nimbhorkar, Keshav Ranjan, and Ankita Sarkar* ..... 30:1–30:21

Property B: Two-Coloring Non-Uniform Hypergraphs
*Jaikumar Radhakrishnan and Aravind Srinivasan* ..... 31:1–31:8

Harmonic Algorithms for Packing $d$-Dimensional Cuboids into Bins
*Eklavya Sharma* ..... 32:1–32:22

Resilience of Timed Systems
*S. Akshay, Blaise Genest, Loïc Hélouët, S. Krishna, and Sparsa Roychowdhury* .. 33:1–33:22

On the Complexity of Intersection Non-emptiness for Star-Free Language Classes
*Emmanuel Arrighi, Henning Fernau, Stefan Hoffmann, Markus Holzer, Ismaël Jecker, Mateus de Oliveira Oliveira, and Petra Wolf* ..... 34:1–34:15

Complexity of Coverability in Bounded Path Broadcast Networks
*A. R. Balasubramanian* ..... 35:1–35:16

On Classical Decidable Logics Extended with Percentage Quantifiers and Arithmetics
*Bartosz Bednarczyk, Maja Orłowska, Anna Pacanowska, and Tony Tan* ..... 36:1–36:15

Branching Automata and Pomset Automata
*Nicolas Bedon* ..... 37:1–37:13

History Determinism vs. Good for Gameness in Quantitative Automata
*Udi Boker and Karoliina Lehtinen* ..... 38:1–38:20

Local First-Order Logic with Two Data Values
*Benedikt Bollig, Arnaud Sangnier, and Olivier Stietel* ..... 39:1–39:15

Diagrammatic Polyhedral Algebra
*Filippo Bonchi, Alessandro Di Giorgio, and Paweł Sobociński* ..... 40:1–40:18

From Local to Global Determinacy in Concurrent Graph Games
*Benjamin Bordais, Patricia Bouyer, and Stéphane Le Roux* ..... 41:1–41:14

Quantitative Verification on Product Graphs of Small Treewidth
*Krishnendu Chatterjee, Rasmus Ibsen-Jensen, and Andreas Pavlogiannis* ..... 42:1–42:23

Synthesizing Computable Functions from Rational Specifications over Infinite Words
*Emmanuel Filiot and Sarah Winter* ..... 43:1–43:16

Confluence of Conditional Rewriting in Logic Form
*Raúl Gutiérrez, Salvador Lucas, and Miguel Vítores* ..... 44:1–44:18

On the Expressive Equivalence of TPTL in the Pointwise and Continuous Semantics
*Raveendra Holla, Nabarun Deka, and Deepak D'Souza* ..... 45:1–45:21

Separating Regular Languages over Infinite Words with Respect to the Wagner

Hierarchy
*Christopher Hugenroth* ..... 46:1–46:13

Normal Sequences with Non-Maximal Automatic Complexity
*Liam Jordon and Philippe Moser* ..... 47:1–47:16

Approximate Bisimulation Minimisation
*Stefan Kiefer and Qiyi Tang* ..... 48:1–48:16

Simple Derivation Systems for Proving Sufficient Completeness of Non-Terminating Term Rewriting Systems
*Kentaro Kikuchi and Takahito Aoto* ..... 49:1–49:15

Parikh Images of Register Automata
*Sławomir Lasota and Mohnish Pattathurajan* ..... 50:1–50:14

Concrete Categorical Model of a Quantum Circuit Description Language with Measurement
*Dongho Lee, Valentin Perrelle, Benoît Valiron, and Zhaowei Xu* ..... 51:1–51:20

Linear-Time Temporal Logic with Team Semantics: Expressivity and Complexity
*Jonni Virtema, Jana Hofmann, Bernd Finkbeiner, Juha Kontinen, and Fan Yang* 52:1–52:17

# Preface

This volume contains the proceedings of the 41st IARCS Annual Conference on Foundations of Software Technology and Theoretical Computer Science (FSTTCS 2021). The conference was originally planned to be held on December 15–17, 2021 in BITS Pilani, K K Birla Goa Campus, Goa, India. Due to the COVID-19 pandemic, the conference was moved to a virtual format, with the same dates.

The conference has two tracks. Track A focusing on algorithms, complexity and related issues, and Track B focusing on logic, automata and other formal method aspects of computer science. Each track had its own Program Committee (PC) and chair (Chandra Chekuri for Track A and Mikołaj Bojańczyk for Track B). This volume constitutes the joint proceedings of the two tracks, published in the LIPIcs series under a Creative Common license, with free online access to all.

The conference comprises of 5 invited talks, 27 contributed talks in Track A, and 20 in Track B. This volume contains all the contributed papers from the two tracks, and the abstracts of all the invited talks. The conference received a total of 122 submissions with 73 in Track A and 49 in Track B. This edition of FSTTCS implemented, for the first time, an author rebuttal phase during the paper review and selection process. We thank all the authors who submitted their papers to FSTTCS 2021. We are especially grateful to the PC members for their tireless work, and all the external reviewers for their expert opinion in the form of timely reviews.

We thank all the invited speakers for accepting our invitation: Scott Aaronson (University of Texas at Austin), Javier Esparza (Technische Universität München), Leslie Ann Goldberg (University of Oxford), Huijia (Rachel) Lin (University of Washington), and Rahul Savani (University of Liverpool).

The main conference is to be accompanied by four workshops: *iVerif: Artificial Intelligence and Verification* (organized by Shibashis Guha and Guillermo A. Perez), *QISE: Quantum Information Science and Engineering* (organized by Jaikumar Radhakrishnan and Manoj Nambiar), *Trends in Transformations* (organized by Emmanuel Filiot and S. Krishna), and *VeriCrypt* (organized by Karthikeyan Bhargavan and Aseem Rastogi).

We are indebted to the organising committee members: A. Baskar (BITS Pilani), Pritam Bhattacharya (BITS Pilani), Amaldev Manuel (IIT Goa), and A.V. Sreejith (IIT Goa) for managing the logistics of the conference and affiliated workshops. They made all the necessary arrangements for the virtual conference, and they are doing this for a second year in row due to the Covid pandemic. We thank S.P. Suresh (CMI, Chennai) for maintaining the conference web page and promptly addressing our update requests. We thank the friendly staff at Dagstuhl LIPIcs, Michael Didas and Michael Wagner, for helping us put together the proceedings. Finally, we thank the members of the Steering Committee, especially Jaikumar Radhakrishnan, and the PC Chairs from FSTTCS 2020 (Nitin Saxena and Sunil Simon), for providing pertinent information and advice about various aspects of the conference.

Mikołaj Bojańczyk and Chandra Chekuri
November 2021

41st IARCS Annual Conference on Foundations of Software Technology and Theoretical Computer Science (FSTTCS 2021).
Editors: Mikołaj Bojańczyk and Chandra Chekuri
Leibniz International Proceedings in Informatics
LIPICS Schloss Dagstuhl – Leibniz-Zentrum für Informatik, Dagstuhl Publishing, Germany

# Program Committee

## Track A

- Amey Bhangale (University of California, Riverside)
- Chandra Chekuri (University of Illinois, Urbana-Champaign) — co-chair
- Ashish Chiplunkar (Indian Institute of Technology, Delhi)
- Keerti Choudhary (Indian Institute of Technology, Delhi)
- Omar Fawzi (INRIA, Lyon)
- Uriel Feige (Weizmann Institute of Science)
- Anna Gál (University of Texas, Austin)
- Sushmita Gupta (Institute of Mathematical Sciences, Chennai)
- Valentine Kabanets (Simon Fraser University)
- Sanjeev Khanna (University of Pennsylvania)
- Sudeshna Kolay (Indian Institute of Technology, Kharagpur)
- Ravishankar Krishnaswamy (Microsoft Research India)
- Kamesh Munagala (Duke University)
- Sriram Pemmaraju (University of Iowa)
- Rahul Saladi (Indian Institute of Science, Bengaluru)
- Swagato Sanyal (Indian Institute of Technology, Kharagpur)

## Track B

- S Akshay (IIT Bombay)
- Mikołaj Bojańczyk (University of Warsaw) — co-chair
- Dmitry Chistikov (University of Warwick)
- Thomas Colcombet (IRIF, Paris)
- Anuj Dawar (University of Cambridge)
- Manfred Droste (University of Leipzig)
- Barbara König (University of Duisburg-Essen)
- Rupak Majumdar (MPI-SWS)
- Filip Mazowiecki (MPI-SWS)
- Andrzej Murawski (University of Oxford)
- Joanna Ochremiak (CNRS, Bordeaux)
- M Praveen (Chennai Mathematical Institute)
- Karin Quaas (University of Leipzig)
- Ocan Sankur (IRISA, Rennes)
- Helmut Seidl (Technical University Munich)
- Georg Zetzsche (MPI-SWS)

41st IARCS Annual Conference on Foundations of Software Technology and Theoretical Computer Science (FSTTCS 2021).
Editors: Mikołaj Bojańczyk and Chandra Chekuri
Leibniz International Proceedings in Informatics
LIPICS Schloss Dagstuhl – Leibniz-Zentrum für Informatik, Dagstuhl Publishing, Germany

# List of External Reviewers: Track A

Akanksha Agrawal
Anastasios Sidiropoulos
Aritra Banik
Bhaswar Bhattacharya
Daniel Lokshtanov
Denis Pankratov
Diptarka Chakraborty
Edin Husic
Fahad Panolan
Gopinath Mishra
Huan Li
Jannik Peters
Jie Xue
Josh Alman
Katarina Cechlarova
Lenwood Heath
Michael Lampis
Mrinal Kumar
Nikhil Mande
Oliver Kullmann
Pallavi Jain
Pingan Cheng
Pradeesha Ashok
Pranabendu Misra
Ramprasad Saptharishi
Rohit Vaish
Sagar Kale
Sai Sandeep
Sanjukta Roy
Satyadev Nandakumar
Sayantan Chakraborty
Shahbaz Khan
Shreyas Pai
Sourya Roy
Sundar Vishwanathan
Tanmay Inamdar
Tom van der Zanden
Vibha Sahlot
Waldo Gálvez
Yanyi Liu
Amer Mouawad
Arijit Ghosh
Ashutosh Gupta
Chaitanya Swamy
Daniel Stefankovic
Devvrit K
Dishant Goyal
Eduard Eiben
Gil Cohen
Gramoz Goranci
Janani Sundaresan
Jayadev Acharya
Joeseph Mitchell
Kasturi Varadarajan
Lawqueen Kanesh
Meirav Zehavi
Michal Wlodarczyk
Nikhil Balaji
Nithin Varma
Palash Dey
Pankaj Agarwal
Pooja Kulkarni
Prajakta Nimbhorkar
Pratibha Choudhary
Rohit Gurjar
Roohani Sharma
Sahil Singla
Sándor Kisfaludi-Bak
Sathish Govindarajan
Sayan Bandyapadhyay
Sepehr Assadi
Shahin Kamali
Soumen Maity
Sujata Ghosh
Syamantak Das
Tatiana Starikovskaya
Varun Gupta
Vijaykrishna Gurunathan
Xinhang Lu
Yassine Hamoudi

41st IARCS Annual Conference on Foundations of Software Technology and Theoretical Computer Science (FSTTCS 2021).
Editors: Mikołaj Bojańczyk and Chandra Chekuri
Leibniz International Proceedings in Informatics
LIPICS Schloss Dagstuhl – Leibniz-Zentrum für Informatik, Dagstuhl Publishing, Germany

# List of External Reviewers: Track B

Mohamed Faouzi Atig
Pascal Baumann
Damien Busatto-Gaston
Olivier Carton
Antonio Casares
Frank Drewes
Petter Ericson
Nathanaël Fijalkow
Marie Fortin
Giovanna Guaiana
Shibashis Guha
Christoph Haase
Willem Heijltjes
Loic Helouet
Naohiko Hoshino
Rasmus Ibsen-Jensen
Petr Jancar
Arthur Jaquard
Kohei Kishida
Dietrich Kuske
Florin Manea
Tomas Masopust
Karla Messing
Richard Mörbitz
Torsten Mütze
Masaki Nakamura
Naoki Nishida
Vincent Penelle
Guillermo Perez
Gabriele Puppis
Ritam Raha
R. Ramanujam
Alexander Rubtsov
Arnaud Sangnier
Markus L. Schmid
Lia Schütze
Anastasia Sofronova
S P Suresh
Lidia Tendera
K. S. Thejaswini
Ramanathan Thinniyam Srinivasan
Marie Van Den Bogaard
Gerco van Heerdt
Dominic Verdon
Fabio Zanasi
Damien Zufferey

41st IARCS Annual Conference on Foundations of Software Technology and Theoretical Computer Science (FSTTCS 2021).
Editors: Mikołaj Bojańczyk and Chandra Chekuri
Leibniz International Proceedings in Informatics
LIPICS Schloss Dagstuhl – Leibniz-Zentrum für Informatik, Dagstuhl Publishing, Germany