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**Dana Fisman
Grigore Rosu (Eds.)**

Tools and Algorithms for the Construction and Analysis of Systems

**28th International Conference, TACAS 2022
Held as Part of the European Joint Conferences
on Theory and Practice of Software, ETAPS 2022
Munich, Germany, April 2–7, 2022
Proceedings, Part I**

Part I



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ETAPS Foreword

Welcome to the 25th ETAPS! ETAPS 2022 took place in Munich, the beautiful capital of Bavaria, in Germany.

ETAPS 2022 is the 25th instance of the European Joint Conferences on Theory and Practice of Software. ETAPS is an annual federated conference established in 1998, and consists of four conferences: ESOP, FASE, FoSSaCS, and TACAS. Each conference has its own Program Committee (PC) and its own Steering Committee (SC). The conferences cover various aspects of software systems, ranging from theoretical computer science to foundations of programming languages, analysis tools, and formal approaches to software engineering. Organizing these conferences in a coherent, highly synchronized conference program enables researchers to participate in an exciting event, having the possibility to meet many colleagues working in different directions in the field, and to easily attend talks of different conferences. On the weekend before the main conference, numerous satellite workshops took place that attract many researchers from all over the globe.

ETAPS 2022 received 362 submissions in total, 111 of which were accepted, yielding an overall acceptance rate of 30.7%. I thank all the authors for their interest in ETAPS, all the reviewers for their reviewing efforts, the PC members for their contributions, and in particular the PC (co-)chairs for their hard work in running this entire intensive process. Last but not least, my congratulations to all authors of the accepted papers!

ETAPS 2022 featured the unifying invited speakers Alexandra Silva (University College London, UK, and Cornell University, USA) and Tomáš Vojnar (Brno University of Technology, Czech Republic) and the conference-specific invited speakers Nathalie Bertrand (Inria Rennes, France) for FoSSaCS and Lenore Zuck (University of Illinois at Chicago, USA) for TACAS. Invited tutorials were provided by Stacey Jeffery (CWI and QuSoft, The Netherlands) on quantum computing and Nicholas Lane (University of Cambridge and Samsung AI Lab, UK) on federated learning.

As this event was the 25th edition of ETAPS, part of the program was a special celebration where we looked back on the achievements of ETAPS and its constituting conferences in the past, but we also looked into the future, and discussed the challenges ahead for research in software science. This edition also reinstated the ETAPS mentoring workshop for PhD students.

ETAPS 2022 took place in Munich, Germany, and was organized jointly by the Technical University of Munich (TUM) and the LMU Munich. The former was founded in 1868, and the latter in 1472 as the 6th oldest German university still running today. Together, they have 100,000 enrolled students, regularly rank among the top 100 universities worldwide (with TUM's computer-science department ranked #1 in the European Union), and their researchers and alumni include 60 Nobel laureates.

The local organization team consisted of Jan Křetínský (general chair), Dirk Beyer (general, financial, and workshop chair), Julia Eisentraut (organization chair), and Alexandros Evangelidis (local proceedings chair).

ETAPS 2022 was further supported by the following associations and societies: ETAPS e.V., EATCS (European Association for Theoretical Computer Science), EAPLS (European Association for Programming Languages and Systems), and EASST (European Association of Software Science and Technology).

The ETAPS Steering Committee consists of an Executive Board, and representatives of the individual ETAPS conferences, as well as representatives of EATCS, EAPLS, and EASST. The Executive Board consists of Holger Hermanns (Saarbrücken), Marieke Huisman (Twente, chair), Jan Kofroň (Prague), Barbara König (Duisburg), Thomas Noll (Aachen), Caterina Urban (Paris), Tarmo Uustalu (Reykjavik and Tallinn), and Lenore Zuck (Chicago).

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I'd like to take this opportunity to thank all authors, attendees, organizers of the satellite workshops, and Springer-Verlag GmbH for their support. I hope you all enjoyed ETAPS 2022.

Finally, a big thanks to Jan, Julia, Dirk, and their local organization team for all their enormous efforts to make ETAPS a fantastic event.

February 2022

Marieke Huisman
ETAPS SC Chair
ETAPS e.V. President

Preface

TACAS 2022 was the 28th edition of the International Conference on Tools and Algorithms for the Construction and Analysis of Systems. TACAS 2022 was part of the 25th European Joint Conferences on Theory and Practice of Software (ETAPS 2022), which was held from April 2 to April 7 in Munich, Germany, as well as online due to the COVID-19 pandemic. TACAS is a forum for researchers, developers, and users interested in rigorous tools and algorithms for the construction and analysis of systems. The conference aims to bridge the gaps between different communities with this common interest and to support them in their quest to improve the utility, reliability, flexibility, and efficiency of tools and algorithms for building computer-controlled systems.

There were four submission categories for TACAS 2022:

1. Research papers advancing the theoretical foundations for the construction and analysis of systems.
2. Case study papers with an emphasis on a real-world setting.
3. Regular tool papers presenting a new tool, a new tool component, or novel extensions to an existing tool.
4. Tool demonstration papers focusing on the usage aspects of tools.

Papers of categories 1–3 were restricted to 16 pages, and papers of category 4 to six pages.

This year 159 papers were submitted to TACAS, consisting of 112 research papers, five case study papers, 33 regular tool papers, and nine tool demo papers. Authors were allowed to submit up to four papers. Each paper was reviewed by three Program Committee (PC) members, who made use of subreviewers. Similarly to previous years, it was possible to submit an artifact alongside a paper, which was mandatory for regular tool and tool demo papers.

An artifact might consist of a tool, models, proofs, or other data required for validation of the results of the paper. The Artifact Evaluation Committee (AEC) was tasked with reviewing the artifacts based on their documentation, ease of use, and, most importantly, whether the results presented in the corresponding paper could be accurately reproduced. Most of the evaluation was carried out using a standardized virtual machine to ensure consistency of the results, except for those artifacts that had special hardware or software requirements. The evaluation consisted of two rounds. The first round was carried out in parallel with the work of the PC. The judgment of the AEC was communicated to the PC and weighed in their discussion. The second round took place after paper acceptance notifications were sent out; authors of accepted research papers who did not submit an artifact in the first round could submit their artifact at this time. In total, 86 artifacts were submitted (79 in the first round and seven in the second) and evaluated by the AEC regarding their availability, functionality, and/or reusability. Papers with an artifact that was successfully evaluated include one or more badges on the first page, certifying the respective properties.

Selected authors were requested to provide a rebuttal for both papers and artifacts in case a review gave rise to questions. Using the review reports and rebuttals, the Program and the Artifact Evaluation Committees extensively discussed the papers and artifacts and ultimately decided to accept 33 research papers, one case study, 12 tool papers, and four tool demos.

This corresponds to an acceptance rate of 29.46% for research papers and an overall acceptance rate of 31.44%.

Besides the regular conference papers, this two-volume proceedings also contains 16 short papers that describe the participating verification systems and a competition report presenting the results of the 11th SV-COMP, the competition on automatic software verifiers for C and Java programs. These papers were reviewed by a separate Program Committee (PC); each of the papers was assessed by at least three reviewers. A total of 47 verification systems with developers from 11 countries entered the systematic comparative evaluation, including four submissions from industry. Two sessions in the TACAS program were reserved for the presentation of the results: (1) a summary by the competition chair and of the participating tools by the developer teams in the first session, and (2) an open community meeting in the second session.

We would like to thank all the people who helped to make TACAS 2022 successful. First, we would like to thank the authors for submitting their papers to TACAS 2022. The PC members and additional reviewers did a great job in reviewing papers: they contributed informed and detailed reports and engaged in the PC discussions. We also thank the steering committee, and especially its chair, Joost-Pieter Katoen, for his valuable advice. Lastly, we would like to thank the overall organization team of ETAPS 2022.

April 2022

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