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Jan Friso Groote · Kim Guldstrand Larsen (Eds.)

# Tools and Algorithms for the Construction and Analysis of Systems

27th International Conference, TACAS 2021  
Held as Part of the European Joint Conferences  
on Theory and Practice of Software, ETAPS 2021  
Luxembourg City, Luxembourg, March 27 – April 1, 2021  
Proceedings, Part I

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# ETAPS Foreword

Welcome to the 24th ETAPS! ETAPS 2021 was originally planned to take place in Luxembourg in its beautiful capital Luxembourg City. Because of the Covid-19 pandemic, this was changed to an online event.

ETAPS 2021 was the 24th 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. Organising these conferences in a coherent, highly synchronised conference programme 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 take place that attract many researchers from all over the globe.

ETAPS 2021 received 260 submissions in total, 115 of which were accepted, yielding an overall acceptance rate of 44.2%. 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 2021 featured the unifying invited speakers Scott Smolka (Stony Brook University) and Jane Hillston (University of Edinburgh) and the conference-specific invited speakers İşil Dillig (University of Texas at Austin) for ESOP and Willem Visser (Stellenbosch University) for FASE. Invited tutorials were provided by Erika Ábrahám (RWTH Aachen University) on analysis of hybrid systems and Madhusudan Parthasarathy (University of Illinois at Urbana-Champaign) on combining machine learning and formal methods.

ETAPS 2021 was originally supposed to take place in Luxembourg City, Luxembourg organized by the SnT - Interdisciplinary Centre for Security, Reliability and Trust, University of Luxembourg. University of Luxembourg was founded in 2003. The university is one of the best and most international young universities with 6,700 students from 129 countries and 1,331 academics from all over the globe. The local organisation team consisted of Peter Y.A. Ryan (general chair), Peter B. Roenne (organisation chair), Joaquin Garcia-Alfaro (workshop chair), Magali Martin (event manager), David Mestel (publicity chair), and Alfredo Rial (local proceedings chair).

ETAPS 2021 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 Kofron (Prague), Barbara König (Duisburg), Gerald Lüttgen (Bamberg), Caterina Urban (INRIA), Tarmo Uustalu (Reykjavik and Tallinn), and Lenore Zuck (Chicago).

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I'd like to take this opportunity to thank all the authors, attendees, organizers of the satellite workshops, and Springer-Verlag GmbH for their support. I hope you all enjoyed ETAPS 2021.

Finally, a big thanks to Peter, Peter, Magali and their local organisation team for all their enormous efforts to make ETAPS a fantastic online event. I hope there will be a next opportunity to host ETAPS in Luxembourg.

February 2021

Marieke Huisman  
ETAPS SC Chair  
ETAPS e.V. President

# Preface

TACAS 2021 was the 27th edition of the International Conference on Tools and Algorithms for the Construction and Analysis of Systems conference series. TACAS 2021 was part of the 24th European Joint Conferences on Theory and Practice of Software (ETAPS 2021), which although originally planned to take place in Luxembourg City, was held as an online event on March 27 to April 1 due to the COVID-19 pandemic.

TACAS is a forum for researchers, developers, and users interested in rigorously based 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 types of submissions for TACAS:

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

This year 141 papers were submitted to TACAS, consisting of 90 research papers, 29 regular tool papers, 16 tool demo papers, and 6 case study papers. Authors were allowed to submit up to four papers. Each paper was reviewed by three Program Committee (PC) members, who made extensive 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 standardised virtual machine to ensure consistency of the results, except for those artifacts that had special hardware 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 here. In total, 72 artifacts were submitted (63 in the first round and 9 in the second), of which 57 were accepted and 15 rejected. This corresponds to an acceptance rate of 79 percent. Papers with an accepted artifact include a badge on the first page.

Selected authors were requested to provide a rebuttal for both papers and artifacts in case a review gave rise to questions. In total 166 rebuttals were provided. Using the review reports and rebuttals the Programme and the Artifact Evaluation Committees extensively discussed the papers and artifacts and ultimately decided to accept 32 research papers, 7 tool papers, 6 tool demos, and 2 case studies.

Besides the regular conference papers, this two-volume proceedings also contains 8 short papers that describe the participating verification systems and a competition report presenting the results of the 10th 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 30 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.

March/April 2021

Jan Friso Groote  
Kim Guldstrand Larsen  
Frédéric Lang  
Thierry Lecomte  
Thomas Neele  
Peter Gjøøl Jensen  
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