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Formal Methods – The Next 30 Years

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Preface

This volume contains the papers presented at the 23rd Symposium on Formal Methods (FM 2019), held in Porto, Portugal, in the form of the Third World Congress on Formal Methods, during October 7–11, 2019. These proceedings also contain five papers selected by the Program Committee (PC) of the Industry Day (I-Day).

FM 2019 was organized under the auspices of Formal Methods Europe (FME), an independent association whose aim is to stimulate the use of, and research on, formal methods for software development. It has been more than 30 years since the first VDM symposium in 1987 brought together researchers with the common goal of creating methods to produce high-quality software based on rigor and reason. Since then the diversity and complexity of computer technology has changed enormously and the formal methods community has stepped up to the challenges those changes brought by adapting, generalizing, and improving the models and analysis techniques that were the focus of that first symposium. The theme for FM 2019, "The Next 30 Years," was a reflection on how far the community has come and the lessons we can learn for understanding and developing the best software for future technologies.

To reflect the fact that it has been 20 years since FM 1999 in Toulouse and 10 years since FM 2009 in Eindhoven, FM 2019 was organized as a World Congress, and we composed a PC of renowned scientists from 42 different countries spread across all continents except for Antarctica. We originally received a stunning total of 185 abstract submissions, which unfortunately resulted in 'only' 129 paper submissions from 36 different countries. Each submission went through a rigorous review process in which 95% of the papers were reviewed by four PC members. Following an in-depth discussion phase lasting two weeks, we selected 37 full papers and 2 short tool papers, an acceptance rate of 30%, for presentation during the symposium and inclusion in these proceedings. The symposium featured keynotes by Shriram Krishnamurthi (Brown University, USA), Erik Poll (Radboud University, The Netherlands), and June Andronick (CSIRO-Data61 and UNSW, Australia). We hereby thank these invited speakers for having accepted our invitation. The program also featured a Lucas Award and FME Fellowship Award Ceremony.

We are grateful to all involved in FM 2019. In particular the PC members and subreviewers for their accurate and timely reviewing, all authors for their submissions, and all attendees of the symposium for their participation. We also thank all the other committees (I-Day, Doctoral Symposium, Journal First Track, Workshops, and Tutorials), itemized on the following pages, and particularly the excellent local organization and publicity teams. In addition to FM 2019 they also managed the FM week consisting of another 8 conferences, 17 workshops, and 7 tutorials, as well as 'X', the secret project of a colloquium in honor of Stefania Gnesi based on a Festschrift to celebrate her 65th birthday.

We are very grateful to our platinum sponsors: Amazon Web Services (AWS), Google, and Sony; our gold sponsors: Springer, Semmle, ASML, and PT-FLAD Chair in Smart Cities & Smart Governance; our silver sponsors: Oracle Labs, Runtime Verification Inc., Standard Chartered, GMV, United Technologies Research Center (UTRC), and Efacec; our bronze sponsors i2S, Foundations of Perspicuous Software Systems Collaborative Research Center, and the Mathematical research center of the University of Porto (CMUP); and our basic sponsors: Natixis and Neadvance.

Finally, we thank Springer for publishing these proceedings in their FM subline and we acknowledge the support from EasyChair in assisting us in managing the complete process from submissions to these proceedings to the program.

August 2019

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Formal Methods for Security Functionality and for Secure Functionality (Invited Presentation)

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With cyber security becoming a growing concern, it has naturally attracted the attention of researchers in formal methods. One recent success story here is TLS: the development of the new TLS 1.3 specification has gone hand-in-hand with efforts to verify security properties of formal models [5] and the development of a fully verified implementation [3]. Earlier well-known success stories in using formal methods for security are the verifications of operating system kernels or hypervisors, namely seL4 [7] and Microsoft's Hyper-V [10].

These examples – security protocols and OS kernels – are applications whose primary purpose is to provide security. It is natural to apply formal methods to such systems: they are by their very nature security-critical and they provide some security functionality that we can try to specify and verify.

However, we want *all* our systems to be secure, not just these security systems. There is an important difference between *secure* functionality and *security* functionality, or – given that most functionality and most security problems are down to software – between *software security* and *security software* [11]. Many, if not most, security problems arise in systems that have no specific security objective, say PDF viewers or video players, but which can still be hacked to provide attackers with unwanted functionality they can abuse.

Using formal methods to prove security is probably not on the cards of something as complex as a PDF viewer or video player. Just defining what it would mean for such a system to be secure is probably already infeasible. Still, formal methods can be useful, to prove the absence of certain types of security flaws or simply find security flaws. Successes here have been in the use of static analysis in source code analysers, e.g. tools like Fortify SCA that look for flaws in web applications and tools like Coverity that look for memory vulnerabilities in C(++) code. Another successful application of formal methods is the use of symbolic (or concolic) execution to generate test cases for security testing, as in SAGE [6] or, going one step further, not just automatically finding flaws but also automatically generating exploits, as in angr [16].

Downside of these approaches is that they are post-hoc and can only look for flaws in existing code. The *LangSec* paradigm [4, 9], on the other hand, provides ideas on how to prevent many security problems *by construction*. Key insights are that most security flaws occur in input handling and that there are several root causes in play here. Firstly, the input languages involved (e.g. file formats and network protocols) are complex, very expressive, and poorly, informally, specified. Secondly, there are *many* of these input languages, sometimes nested or stacked. Finally, parsers for these languages are typically hand-written, with parsing code scattered throughout the application code in so-called shotgun parsers [12]. With clearer, formal specifications of input languages and generated parser code much security misery could be avoided. (Recent initiatives in tools for parser generation here include Hammer [1] and Nail [2].) Given that formal languages and parser generation are some of the most basic and established formal methods around, it is a bit of an embarrassment to us as formal methods community that sloppy language specifications and hand-coded parsers should cause so many security problems.

Some security flaws in input handling are not so much caused by *buggy* parsing of inputs, but rather by the *unexpected* parsing of input [13]. Classic examples of this are command injection, SQL injection, and Cross-Site Scripting (XSS). Tell-tale sign that unwanted parsing of input may be happening in unexpected places is the heavy use of strings as data types [14].

Information or data flow analysis can be used to detect such flaws; indeed, this is a standard technique used in the source code analysis tools mentioned above. These flaws can also be prevented by construction, namely by using type systems. A recent example of this is the ‘Trusted Types’ browser API [8] by Google, where different types are used to track different kinds of data and different trust level of data to prevent XSS vulnerabilities, esp. the DOM-based XSS vulnerabilities that have proved so difficult to root out.

To conclude, formal methods cannot only be used to *prove* security of security-critical applications and components – i.e. the security software –, but they can be much more widely used to *improve* security by ruling out of the root causes behind security flaws in input handling, and do so by construction, and hence improve software security in general. Moreover, some very basic and lightweight formal methods can be used for this: methods that we teach – or should be teaching – our students in the first years of their Bachelor degree, such as regular expressions, finite state machines, grammars, and types. Indeed, in my own research I have been surprised to see how useful the simple notion of finite state machine for describing input sequences is to discover security flaws [15].

That we have not been able to get these basic techniques into common use does not say much for our success in transferring formal methods to software engineering practice. Still, looking at the bright side, it does suggest opportunities for improvement.

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