Formal Methods in Systems Engineering

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Springer-Verlag
London Berlin Heidelberg New York
Paris Tokyo Hong Kong
Barcelona Budapest

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ISBN-13:978-3-540-19751-5 e-ISBN-13:978-1-4471-1975-3
DOI: 10.1007/978-1-4471-1975-3

Library of Congress Cataloging-in-Publication Data applied for

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Typesetting: Camera ready by editors

34/3830-543210 Printed on acid-free paper

Preface

Digital systems are becoming ever more pervasive in our modern, technological society. More and more aspects of our lives rely increasingly heavily on such systems. Many of these applications are of great complexity and criticality. This criticality may be of a safety nature such as “fly-by-wire” avionics and nuclear power station control systems, or of a security nature such as financial transaction systems and databases of sensitive information. In any case it is of great importance that these systems perform correctly and reliably.

Set against this is the fact that digital systems engineering has not come of age. It is in some ways better thought of as being still in an “arts and crafts” stage rather than as a true engineering or scientific discipline. Nevertheless, systems engineering is rising to meet the challenge of mastering the complexity and providing suitably high levels of assurance of correct and reliable behaviour for such critical applications.

Over the last few decades significant strides have been made in the theoretical foundations of the subject but there are still many open questions. Methods and tools such as structured methods and compilers have also developed. These improve the situation but do not solve the underlying problem.

A comparatively new line of attack comes under the name of “formal methods”. In some ways this is perhaps a slightly unfortunate and misleading title but is probably here to stay. It is unfortunate in that it suggests the essence of the approach is formality, that is, comprising elaborate, abstruse symbol manipulations. Certainly such symbol-pushing exercises can play a role but they are by no means the totality of the approach, as the ensuing pages will demonstrate.

Formal methods can be roughly defined as the application of mathematical techniques to the specification and development of digital systems. Such techniques include the use of a mathematical notation to increase the precision of specifications, the use of abstraction and modularity to reduce a problem to “mind-sized” chunks, and the use of analytic techniques to establish that a design or specification has certain properties. More precise definitions can be found in the text, notably in Joseph Goguen’s Introduction.

The underlining thesis of this book is the belief that formal methods can make an impact on these problems. They should also help to produce better quality products in more reliable timescales and budgets. By using the more advanced proof and refinement techniques, they can be used to produce systems with high assurance of “correct” behaviour (although this will tend to have a trade-off in terms of production timescales and cost). It must however be acknowledged that on the whole formal methods have yet to make a significant impact on “real”,

industrial-scale systems engineering. It is an important question, with both technical and social ramifications, as to why this is the case.

In the light of this a workshop (FM'89) was organised and held in July 1989 in Halifax, Nova Scotia to try to assess the state of the art in formal methods and make recommendations for future research and development in the field. The workshop was sponsored by the governments of Canada, the UK and the US and drew together some 50 experts in the field from academia, industry and government in the 3 countries.

One of the key conclusions to emerge from this workshop was that in order to facilitate the transfer of the technology and make formal methods effective in industrial applications it would be necessary to understand how to integrate them with existing software engineering practice, such as quality assurance, structured design, testing and so on. There is a common perception of formal methods as all-or-nothing approaches which exclude other techniques. In fact they can and should co-exist in a fruitful symbiosis with existing practice, and are best viewed as another weapon in the engineer's armoury to achieve quality, dependable systems.

This was chosen as the theme of a follow-on workshop held in September 1991 in Drymen, Scotland with a similar, and partly overlapping, group of participants. This book documents the outcome of the workshop and is intended to give a perspective on the state of the art with regard to the practical use of formal methods in industry. Much of the material was presented as invited talks at the workshop and developed subsequently. Also included are reports from three parallel working groups held during the workshop. These present, as far as can be attained, the consensus of the practitioners on the use of formal methods under the headings:

- Modelling
- Quality assurance
- Design methods

The first of these was aimed at understanding the role of mathematical modelling techniques in specification and design. The second was to study how formal methods could interact with and complement existing quality assurance techniques. The last was similarly intended to investigate the integration of formal methods into existing design methods.

To complete the appreciation of the state of the art, a survey of formal methods tools and applications was conducted throughout 1992 and the results of this are given in the appendix.

After the Introduction by Joseph Goguen chapters 2 and 3 deal with some social aspects of formal methods. Margaret Tierney examines the role of formal methods and the way they are commonly perceived. In particular she discusses the way they

have tended to be associated with the high-criticality, defence-type applications. In the third chapter, Donald MacKenzie examines the idea of “proof”, in particular formal proof, and shows that it is far from being as cut-and-dried as is commonly thought.

Three further chapters address approaches to the problem of developing large systems. The first of these is by Jean-Raymond Abrial. He is the driving force behind the development of the B-technologies. This is a unified and elegant approach, comprising a notation, method and supporting tools. In this chapter he outlines the ideas behind this approach and some of the lessons learnt. The next chapter is by Pamela Zave. This describes research done with Michael Jackson on techniques for the composition of specifications. By using such techniques, a problem may be broken down into manageable pieces which can then be combined in a controlled fashion. The third is by John Wordsworth, and addresses the often rather neglected issue of ways in which formal methods can be used to improve documentation throughout the development life cycle.

The remaining chapters document various experiences gained in the course of the application of certain formal methods to “real” applications. Anthony Hall draws on his experience in the design and development of an air traffic control system for the CAA. In particular he addresses the issue of what constitutes a “good” specification. Finally Victor Basili examines the nature of “quality”, emphasising that QA should be process-oriented rather than product-oriented.

The FM workshops were unusual in the way that they deliberately drew together key players from industry, government and academia. In this way the providers, funders and consumers of the technology all had an opportunity to meet and discuss their hopes and concerns. We hope that this book will make a contribution to the awareness of the potential (and limitations) of an important new technology.

February 1993

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Acknowledgements

We should like to thank the CSE in Canada, CESC in the UK and NSA in the States for sponsoring the workshop on which this material is based.

Thanks to Stephanie Smit of Elsevier for permission to reproduce the contribution from Jean-Raymond Abrial.

Thanks to Mark Hewitt, Colin O’Halloran and Paul Rathbone for help with the L^AT_EX typesetting.

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