

# Abstraction and refinement in probabilistic systems

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## Abstract

We summarise a verification method for probabilistic systems that is based on abstraction and refinement, and extends traditional assertional styles of verification.

The approach makes extensive use of the expectation transformers of *pGCL* [17, 16, 13], a compact probabilistic programming language with an associated logic of real-valued functions. Analysis of large systems is made tractable by abstraction which, together with algebraic and logical reasoning, results in strong and general guarantees about probabilistic-system properties.

Although our examples are specific (to *pGCL*), our overall goal in this note is to advocate the hierarchical development of probabilistic programs via levels of abstraction, connected by refinement, and to illustrate the proof obligations incurred by such an approach.

## 1 Introduction

The verification of large hybrid systems presents a challenge for formal methods, a challenge which is especially acute when those systems operate within a context of uncertainty and randomisation. In such contexts randomisation must be incorporated in the analysis — in particular, system properties are no longer satisfied absolutely, but can only be guaranteed up to some probability that, in turn, impacts on performance and reliability. In addition the analysis is complicated by the interaction of probability with other system features, substantially increasing the verification’s overhead.

Standard logics and methods do not accommodate probability; yet decades of experience there has shown that rigorous techniques for controlling system complexity rely on abstraction and refinement. Simple properties are extracted directly from the details of the system and are then themselves used to prove “second-order properties”, such as “with probability 1/3 eventually the system will terminate”.

The crucial point is that the main business of verification can take place without reference to the real system (and

all its intricacies) provided a body of simple properties has been extracted beforehand; program refinement provides the formal “glue” linking the derived properties to the original system. Indeed these two features together provide what we call the “intellectual advantage” of logical approaches generally.<sup>1</sup>

A wide variety of logics have been developed as possible bases for verifying randomised systems [5, 3]; the expectation transformer approach [9, 17, 13] in particular integrates traditional assertional-styles of program verification with probability. It is based on a logic of real-valued functions (called “expectations”), where the real values give access to the explicit probabilities defined in the system. The semantics is designed to work even at the level of program code, and has an in-built notion of program refinement which encourages a prover to move between various levels of abstraction. Moreover the refinement’s compositionality (see below), by which we mean that the refinement relation is preserved even by contexts, allows the activity of proof to be distributed amongst smaller, more manageable parts of the system, without disturbing the validity of the overall verification. As in any proof-based method, the results provide very strong guarantees of correctness independently of system-specific characteristics such as size; and any assumptions about operating conditions, for example, are naturally documented throughout the proofs.

Typical of refinement based methods — and what distinguishes them from algorithmic methods such as model checking — is the extensive use of program logics and algebras. Rather than building an explicit model of a particular system and analysing it directly with specialised algorithms, the programs that make up the system are considered to have a common mathematical structure in their own right. These can be described precisely by logical axioms which can be cited at any stage to justify a proof step. The expectation transformers’ logic of probabilistic programs combines a weakened form of “expectation logics” found in standard probability theory [18], together with the logic based on Dijkstra’s predicate transformers from standard programming theory [2].

Taking expectations as the basis for the logic, rather than a possibly simpler “logic of probabilities” turns out

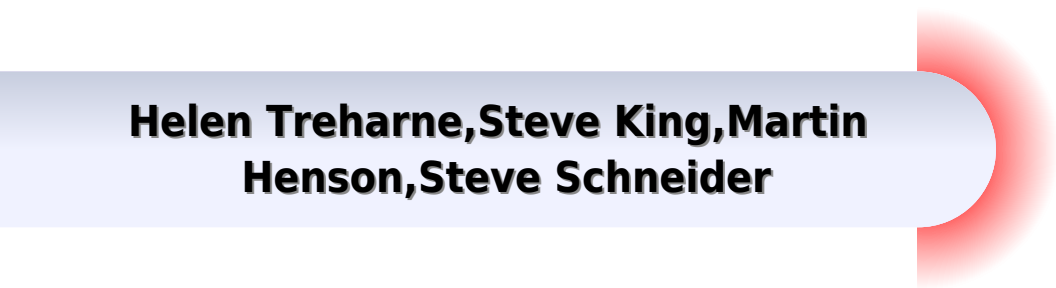
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<sup>1</sup>The intended analogy is with the “mechanical advantage” of physical systems in which simple well-chosen tools amplify an applied force.

# Abstraction Refinement And Proof For Probabilistic Systems

**Helen Treharne, Steve King, Martin  
Henson, Steve Schneider**



## **Abstraction Refinement And Proof For Probabilistic Systems:**

**Abstraction, Refinement and Proof for Probabilistic Systems** Annabelle McIver, Carroll Morgan, 2005 Illustrates by example the typical steps necessary in computer science to build a mathematical model of any programming paradigm Presents results of a large and integrated body of research in the area of quantitative program logics *Principles of Verification: Cycling the Probabilistic Landscape* Nils Jansen, Sebastian Junges, Benjamin Lucien Kaminski, Christoph Matheja, Thomas Noll, Tim Quatmann, Mariëlle Stoelinga, Matthias Volk, 2024-11-12 This Festschrift is dedicated to Joost Pieter Katoen in recognition of his outstanding research teaching and organizational successes Joost Pieter received his Master s and later his Ph D from the University of Twente and his Professional Doctorate in Engineering from Eindhoven University of Technology He had research positions at the University of Erlangen Nuremberg and Philips Research and visiting professorships in France Australia and the UK Since 2004 he has been a professor at RWTH Aachen University and is part time associated with the University of Twente Joost Pieter s main areas of research are formal methods computer aided verification concurrency theory probabilistic computation and semantics Among many recognitions for this work he is an ACM Fellow he was elected as a member of the Academia Europaea the Royal Holland Society of Science and Humanities the North Rhine Westphalian Academy of Science Humanities and the Arts and the Leopoldina the German National Academy of Sciences he received an honorary doctorate from Aalborg University He was awarded an ERC Advanced Grant he has won best paper distinguished paper or test of time awards at key conferences such as ETAPS IEEE SRDS POPL CONCUR and LOPSTR and he has given keynotes at dozens of major events He has chaired the Steering Committee of the European Joint Conferences on Theory and Practice of Software ETAPS and the TACAS conference he has been Program Chair General Chair or Program Committee member of hundreds of major conferences and workshops and a board member of key journals he has served on research boards such as the EPSRC doctoral committees school and university committees and IFIP working groups and he coauthored *Principles of Model Checking* a highly influential textbook Throughout his career Joost Pieter has been a remarkably successful teacher and mentor supervising students and hosting postdoctoral researchers many of whom have won awards for their research and advanced to senior positions and he has collaborated in research and publications with a wide range of scientists These successes are reflected in the papers contributed to this volume FM 2009: Formal Methods Ana Cavalcanti, Dennis Dams, 2009-10-26 th FM 2009 the 16 International Symposium on Formal Methods marked the 10th anniversary of the First World Congress on Formal Methods that was held in Toulouse France We wished to celebrate this by advertising and organizing FM 2009 as the Second World Congress in the FM series aiming to once again bring together the formal methods communities from all over the world The statistics displayed in the table on the next page include the number of countries represented by the Programme Committee members as well as of the authors of submitted and accepted papers Novel this year was a special track on tools and industrial applications Submissions

of papers on these topics were especially encouraged but not given any special treatment It was just as hard to get a special track paper accepted as any other paper What we did promote however was a discussion of how originality contri tion and soundness should be judged for these papers The following questions were used by our Programme Committee

**Foundations of Probabilistic Programming** Gilles Barthe,Joost-Pieter Katoen,Alexandra Silva,2020-12-03 What does a probabilistic program actually compute How can one formally reason about such probabilistic programs This valuable guide covers such elementary questions and more It provides a state of the art overview of the theoretical underpinnings of modern probabilistic programming and their applications in machine learning security and other domains at a level suitable for graduate students and non experts in the field In addition the book treats the connection between probabilistic programs and mathematical logic security what is the probability that software leaks confidential information and presents three programming languages for different applications Excel tables program testing and approximate computing This title is also available as Open Access on Cambridge Core [Software Engineering for Robotics](#) Ana Cavalcanti,Brijesh Dongol,Rob Hierons,Jon Timmis,Jim Woodcock,2021-07-05 The topics covered in this book range from modeling and programming languages and environments via approaches for design and verification to issues of ethics and regulation In terms of techniques there are results on model based engineering product lines mission specification component based development simulation testing and proof Applications range from manufacturing to service robots to autonomous vehicles and even robots than evolve in the real world A final chapter summarizes issues on ethics and regulation based on discussions from a panel of experts The origin of this book is a two day event entitled RoboSoft that took place in November 2019 in London Organized with the generous support of the Royal Academy of Engineering and the University of York UK RoboSoft brought together more than 100 scientists engineers and practitioners from all over the world representing 70 international institutions The intended readership includes researchers and practitioners with all levels of experience interested in working in the area of robotics and software engineering more generally The chapters are all self contained include explanations of the core concepts and finish with a discussion of directions for further work Chapters Towards Autonomous Robot Evolution Composition Separation of Roles and Model Driven Approaches as Enabler of a Robotics Software Ecosystem and Verifiable Autonomy and Responsible Robotics are available open access under a Creative Commons Attribution 4 0 International License via link [springer com](https://www.springer.com) **Parsing Techniques** Dick Grune,Ceriel J.H. Jacobs,2007-10-29 Parsing also referred to as syntax analysis has been and continues to be an essential part of computer science and linguistics Today parsing techniques are also implemented in a number of other disciplines including but not limited to document preparation and conversion typesetting chemical formulae and chromosome recognition This second edition presents new developments and discoveries that have been made in the field Parsing techniques have grown considerably in importance both in computational linguistics where such parsers are the only option and computer science where advanced compilers often use

general CF parsers Parsing techniques provide a solid basis for compiler construction and contribute to all existing software enabling Web browsers to analyze HTML pages and PostScript printers to analyze PostScript Some of the more advanced techniques are used in code generation in compilers and in data compression In linguistics the importance of formal grammars was recognized early on but only recently have the corresponding parsing techniques been applied Also their importance as general pattern recognizers is slowly being acknowledged This text Parsing Techniques explores new developments such as generalized deterministic parsing linear time substring parsing parallel parsing parsing as intersection non canonical methods and non Chomsky systems To provide readers with low threshold access to the full field of parsing techniques this new edition uses a two tiered structure The basic ideas behind the dozen or so existing parsing techniques are explained in an intuitive and narrative style and problems are presented at the conclusion of each chapter allowing the reader to step outside the bounds of the covered material and explore parsing techniques at various levels The reader is also provided with an extensive annotated bibliography as well as hints and partial solutions to a number of problems In the bibliography hundreds of realizations and improvements of parsing techniques are explained in a much terser yet still informal style improving its readability and usability The reader should have an understanding of algorithmic thinking especially recursion however knowledge of any particular programming language is not required

**Computer Aided Verification** Daniel Kroening, Corina S. Păsăreanu, 2015-07-15 The two volume set LNCS 9206 and LNCS 9207 constitutes the refereed proceedings of the 27th International Conference on Computer Aided Verification CAV 2015 held in San Francisco CA USA in July 2015 The total of 58 full and 11 short papers presented in the proceedings was carefully reviewed and selected from 252 submissions The papers were organized in topical sections named model checking and refinements quantitative reasoning software analysis lightning talks interpolation IC3 PDR and Invariants SMT techniques and applications HW verification synthesis termination and concurrency

**Integrated Formal Methods** John Derrick, Stefania Gnesi, Diego Latella, Helen Treharne, 2012-06-26 This book constitutes the refereed proceedings of the 9th International Conference on Integrated Formal Methods IFM 2012 held Pisa Italy in June 2012 The 20 revised full papers presented together with 2 invited papers were carefully reviewed and selected from 59 submissions The papers cover the spectrum of integrated formal methods ranging from formal and semiformal notations semantics proof frameworks refinement verification timed systems as well as tools and case studies

**Relational and Algebraic Methods in Computer Science** Peter Höfner, Peter Jipsen, Wolfram Kahl, Martin Eric Müller, 2014-04-08 This book constitutes the proceedings of the 14th International Conference on Relational and Algebraic Methods in Computer Science RAMiCS 2014 held in Marienstatt Germany in April May 2014 The 25 revised full papers presented were carefully selected from 37 submissions The papers are structured in specific fields on concurrent Kleene algebras and related formalisms reasoning about computations and programs heterogeneous and categorical approaches applications of relational and algebraic methods and developments

related to modal logics and lattices

**ZB 2005: Formal Specification and Development in Z and B** Helen

Treharne, Steve King, Martin Henson, Steve Schneider, 2005-04-25 This book constitutes the refereed proceedings of the 4th International Conference of Z and B users ZB 2005 held in Guildford UK in April 2005 The 25 revised full papers presented together with extended abstracts of 2 invited papers were carefully reviewed and selected for inclusion in the book The papers document the recent advances for the Z formal specification notation and for the B method ranging from foundational theoretical and methodological issues to advanced applications tools and case studies

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