

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.¹

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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¹The 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

Shasha Hu



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