Proofs, Provers, Processes at Scale

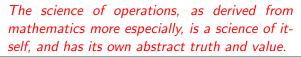
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Ada Lovelace and Turing







It is of course important that some efforts be made to verify the correctness of assertions that are made about a routine. There are essentially two types of method available, the theoretical and the experimental. In the extreme form of the theoretical method a watertight mathematical proof is provided for the assertion. In the extreme form of the experimental method, the routine is tried out on the machine with a variety of initial conditions and is pronounced fit if the assertions hold in each case.

Alan Turing (quoted by D. MacKenzie in *Risk and Reason*)



Scale in Perspective

- Formal methods span a spectrum of problems and solutions.
- Scale can involve
 - Problem size
 - Ost
 - Ø Performance
 - Productivity
 - Usability
 - Maintainability
 - Ø Degree of automation
 - Observe of specialization
 - O Expressiveness
 - 4 Abstraction level
 - Background libraries



- Methods like static and dynamic program analysis validate/falsify small properties of big systems through aggressive over/under-approximation.
- Model checking algorithmically verifies/falsifies limited properties of models of systems and is quite effective for bug-finding.
- Automated synthesis techniques can target small programs or small pieces of larger programs.
- Program derivation can handle larger programs but requires manual guidance (which is not a bad thing).
- Program verification can require a significant annotation and proof overhead.



What is Achievable Now?

- The seL4 project estimates that it takes about 3 to 4 weeks per 1000 lines of proof.¹
- The project produced 10KLOC with about 200KLOP (kilo-lines of proof) at 18 person-years.
- Even though lines of proof is not a meaningful metric, this seems like a good ROM estimate.
- In terms of (equivalent) lines of C code, if one roughly estimates that each line of code requires an average (with a substantial variance) of 10 lines of proof (seL4 was 20), verified code productivity can be around 7 KLOC/year.
- For critical system code, productivity levels are around 4 to 7KLOC.
- However, proof maintenance can be considerably harder than code maintenance.

¹Productivity for Proof Engineering Mark Staples, Ross Jeffery, June Andronick, Toby Murray, Gerwin Klein, Rafal Kolanski, ESEM'14



Abstraction scales

- Engineers are used to working with abstractions in the form of models.
- Formal reasoning must also move up the value chain to capture models.
- These models can be easily supported by code generation to multiple languages and platforms.
- Proofs and counterexamples are easier to construct and maintain since abstract models support proof patterns and effective automation through decision procedures and model checking.
- MATLAB Simulink/Stateflow is an example of the success of model-based software engineering.



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Looking Ahead

- For a more scalable success story for model-based approaches, we need systematic ways of mapping highly reusable mathematical models to executable code/hardware in domains such as
 - Grammars and parsers
 - Compilers
 - Cryptography
 - Cyber-physical systems
 - Signal processing
 - Machine learning
 - File systems, and
 - Cryptographic/Distributed protocols.
- Within a decade, domain experts can be expected to create tens of thousands of (equivalent) lines of code a year.
- The bigger challenge is ridding computing of its *original sins* so that formal claims can be supported with *efficient arguments* whose cost can be amortized through reuse.

