

Implementations of Benaloh Encryption Scheme in Cryptol and C++

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Abstract. We present a verification framework that utilizes Z3, an SMT Solver, with Cryptol as a front-end, domain specific language. An implementation is also provided in C++. The advantage of this approach is that it allows us to establish trust in our implementation. This is enabled by existing tools that can compare two programs and determine if they satisfy the same specification - a critical step in the journey to build verifiable elections.

Keywords: verifiable elections, cryptol · formal verification

1 Benaloh Encryption

The Benaloh Voting Scheme [1] employs the similarly named homomorphic encryption scheme to bring about the dawn of trusted elections. This has some significant implications for democratic structures ranging from boards to nation states. Therefore, the correct implementation of this voting scheme (amongst many other mathematically verified cryptographic schemes) becomes crucial for their widespread adoption.

2 Cryptol

Cryptol [2] is a domain-specific language primarily used for creating and verifying cryptographic algorithms. It offers a unique blend of features tailored for the efficient specification, implementation, and verification of cryptographic systems. This comes in the form of random and exhausting testing as well as formal verification that is built into the language. Tools support for generating executable code makes Cryptol a strong candidate for document reference implementations and prototypes.

To take advantage of the verification features, a developer specifies what properties need to be preserved in the program. Once this is done, one can use the `:check` command to automatically generate random test cases. If a more exhaustive testing approach is required, the `:exhaust` command offers the best guarantee within some bounded domain. A formal verification approach, providing

mathematical certainty, can be achieved using the `:prove` command. For example, if you have a property like `property addCommutative x y = x + y == y + x`, you can verify this using `:prove addCommutative`, which checks whether addition is commutative over the specified data types. Cryptol’s integration of these testing and verification methodologies that are tailored for cryptographic application provides a solid framework for our verification needs.

3 Implementation

The code we contributed has a reference implementation of the Benaloh Cryptographic Scheme [3] in both Cryptol and C++. This approach is valuable since it allows us to establish a source-of-truth, a reference implementation that is proven correct in Cryptol, and compare its behaviour to an optimized implementation that is written in C++. Using this development framework provides a stronger guarantee of correctness for critical cryptographic implementations.

Cryptol The goal of this implementation was to verify that the encryption and decryption scheme works as we would expect. Properties such as `property encryptDecryptIdentity y = decrypt (encrypt y)` are checked using random testing, exhaustive testing and proven to hold given sample prime numbers. Given time constraints, it is challenging to do this verification quickly without access to stronger machines and faster algorithms for primality testing. Furthermore, since the underlying tools are designed for undecidable fragments of First Order Logic, we do not have the ability to direct which engines are used by Cryptol.

C++ Using the standard cryptographic libraries and compilers, we get an executable binary that provides a concrete implementation of the functions we proved correct using Cryptol. The biggest challenge were ensuring proper memory management, modular operations and data encapsulation. Making use of early breaks and common programming paradigms was helpful in getting faster termination compared to the Cryptol implementation. Another challenge was with using existing automatic verification tools¹ with external libraries. Even though these tools are able to model functions as logical statements, the numerical properties that we need to verify were hard to scale for arbitrary primes.

4 Conclusion

Developing provably correct cryptographic schemes is critical to the safety of our lives in the modern world. Ensuring that the systems we use correctly implement the proven schemes is even more important. Developing and verifying the Benaloh Encryption Scheme within the proposed framework allows for an end-to-end pipeline that preserves the integrity of the final implementation. Even

¹ <https://github.com/jetafese/seahorn>

though this approach does not hinder against all types of attacks, it bridges the gap between a mathematically proven cryptographic scheme and its implementation.

References

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