Community reference material for zero-knowledge proofs

(A brief update and a call for participation)

Daniel Benarroch (QEDIT) and Luís Brandão (NIST)

Presented at the ZKProof Community Event
October 29, 2019 @ Amsterdam, Netherlands
Outline

1. Introduction

2. A few aspects revised for the Ref. 0.2

3. Recommendations

4. Conclude
Outline

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Goals of the presentation
- Inform about the ZKProof Community Reference
- Motivate collaboration
Outline 1

1. Introduction

2. A few aspects revised for the Ref. 0.2

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1. Introduction

The ZKProof Community Reference

Helps onboard newcomers

Informs practitioners

Promote best practices

D2. Purpose. For example: The purpose of developing the ZKProof reference document is to provide, within the principles laid out by the ZKProof charter, a reference for the development of zero-knowledge-proof technology that is secure, practical and interoperable.

D3. Aim. For example: The aim of the document is to consolidate the reference material developed in collaborative processes during the ZKProof workshops. The document intends to be accessible to a large audience, which includes the general public, the media, the industry, developers and cryptographers.

D4. Scope. For example: The document intends to cover material relevant for the development of secure, practical and interoperable technology, as identified in the purpose. The document will also elaborate on introductory concepts or works, as a way to enable an easier understanding of more advanced techniques. When a focus is chosen from several alternative options, the document should try to include a rationale describing, if possible, comparative advantages, disadvantages and applicability. However, the document does not intend to be a thorough survey about ZKPs, and does not need to cover every conceivable scenario.

Excerpt from the “NIST comments on the initial ZKProof documentation” (April 06, 2019)
Documentation from the get-go

- First workshop fully dedicated to compile knowledge into 3 documents
- Had several chairs, and many contributors
- First steps towards a reference - building infrastructure
Introduction

What is a zero-knowledge proof?

A zero-knowledge proof makes it possible to prove a statement is true while preserving confidentiality of secret information. There are numerous uses of zero-knowledge proofs, the table below gives a few examples where proving claims about confidential data can be useful.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Legal age for purchase</th>
<th>Hedge fund secrecy</th>
<th>Asset transfer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Confidential info</td>
<td>Exact age and personal data</td>
<td>Composition of portfolio</td>
<td>Past transactions</td>
</tr>
<tr>
<td>I am an adult</td>
<td>We are not bankrupt</td>
<td>I own this asset</td>
<td></td>
</tr>
</tbody>
</table>

Scenario

- Zero-knowledge proofs definitions (and variants)
- Security assumptions (and their validity)
- Syntax and frameworks for building ZKPs (GKR, MPC-in-the-head, Bulletproofs, pairing-based, IOPs)
- Nuances for understanding ZKPs
Implementation Track

- Abstracted model - front-ends / back-ends
- Interoperability types (proof, systems, frameworks, etc…)
- Benchmarking of schemes
- SRS generation (secure MPC)
- DSLs, APIs, Formats
- Secure implementations, trust and correctness
1. Introduction

In this track we aim to overview existing techniques for building ZKP based systems, including designing the protocols to meet the best-practice security requirements. One can distinguish between high-level and low-level applications, where the former are the protocols designed for specific use-cases and the latter are the underlying operations needed to define a ZK predicate. We call gadgets the sub-circuits used to build the actual constraint system needed for a use-case. In some cases, a gadget can be interpreted as a security requirement (e.g.: using the commitment verification gadget is equivalent to ensuring the privacy of underlying data).

As we will see, the protocols can be abstracted and generalized to admit several use-cases; similarly, there exist compilers that will generate the necessary gadgets from commonly used programming languages. Creating the constraint systems is a fundamental part of the applications of ZKP, which is the reason why there is a large variety of front-ends available.

Gadget libraries (commitments, signatures, encryption, etc...)

Use-cases exploration

- Identity
- Asset Transfers
- Regulation compliance

“baby” protocols for use-cases

Best practices for building proof statements (predicates)
Current state

- LaTeX transport by NIST ← Community Reference document (0.1)

- 2nd Workshop with many sessions focused on adding content

- Editorial process defined (contributions, comments, etc...)

- Total of about 15 contributions for first round
Screenshots of the GitHub repository

https://github.com/zkpstandard/zkreference

LaTeX source

Currently 26 issues
Outline 2

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A few revised aspects in the Ref. 0.2

Now: version 0.1.x (integrating contributions)

Soon: draft 0.2, expected 2nd half Nov.

Public feedback: editors@zkproof.org
A few revised aspects in the Ref. 0.2

Examples in next slides:

1. High-level ZKP examples
2. Transferability/deniability
3. Types of proof: knowledge vs. membership

Goal: convey some conceptual nuances

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High-level examples of ZKP

The challenge of explaining ZKPs to people outside of the area.

At what level do we explain ZKPs, when we explain ZKPs at a high level?

(redundancy intended)
High-level examples of ZKP

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At what level do we explain ZKPs, when we explain ZKPs at a high level?

(compare the following: With a ZKP, can I prove?:

- I am an adult
- My car license-plate starts with an ‘A’
- My favorite color is in \{blue, red, green\}
- I know a Chess solution to the “8 queens puzzle”

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Compare the following: With a ZKP, can I prove?:

▶ I am an adult [I surely have a birthdate, but how to confirm it is correct?]
▶ My car license-plate starts with an ‘A’ [Do you even know if I have a car?]
▶ My favorite color is in \{ blue, red, green \} [Can lie about it]
▶ I know a Chess solution to the “8 queens puzzle” [Well defined]
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The *statement* (and the implicit simplified *witness*) may be insufficient ...

to allow an actively interested listener to build more intuition.
Example scenarios for zero-knowledge proofs:

**Version high-high level:**
- Prove adulthood, without revealing the birth date;
- Prove solvency (not bankrupt), without showing portfolio composition;
- Prove a chessboard config is valid, without revealing sequence of moves;
Example scenarios for zero-knowledge proofs:

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**Version high level:**

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<th>Statement being proven</th>
<th>Witness treated as confidential</th>
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A ZKP proves that a *statement* is truthful and reveals nothing else (?)
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What kind of statement is proven? (About a public instance $x$.)

- Statement of membership: $x \in L$
- Statement of knowledge: I known witness $w$ such that $(x, w) \in R$

Sometimes interchangeable, but not always!

Examples ...
- Prove:
  - knowledge of discrete log $w$: $x = g^w$
  - that the graphs in the pair $x = (G_1, G_2)$ are non-isomorphic, i.e., $x \in \text{GNI}$
  - knowledge of a hash pre-image $w$: $x = H(w)$
  - that a value $x$ has a hash pre-image, i.e., $x \in \{ y' = H(w) : w \in \ast \}$

Why is this important?
The security properties are different: soundness (ZKP of membership) vs. extractability (ZKP of knowledge).
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Each of them can be considered a feature ... or a bug!? 

Traditional ZKPs are deniable (i.e., non-transferable) 

Certain applications benefit from transferable proofs / publicly verifiable

Non-interactive setting: can you do a deniable ZKPoK of witness \( w \)?

Yes, e.g., prove knowledge of \( w \) OR of the verifier's private key (within a PKI).

Interactive setting: can it be transferable? Yes, e.g., Fiat-Shamir based.

A funny case: give a non-transferable proof that you possess a transferable proof.

Example: an auditor obtains a transferable ZKP transcript; later it responds deniably to a query from an ongoing investigation.

A composability case: Assume a deniable proof ... what if the underlying communication protocol authenticated all the messages?
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Later: 3rd ZKProof Workshop (April 2020) — organize more contributions.
Intellectual Property (expectations)

ZKProof is an open initiative that seeks to promote the secure and interoperable use of zero-knowledge proofs. To foster open development and wide adoption, it is valuable to promote technologies with open-source implementations, unencumbered by royalty-bearing patents. However, some useful technologies may fall within the scope of patent claims. Since ZKProof seeks to represent the technology, research and community in an inclusive manner, it is valuable to set expectations about the disclosure of intellectual property and the handling of patent claims.

The members of the ZKProof community are hereby strongly encouraged to provide information on known patent claims potentially applicable to the guidance, requirements, recommendations, proposals and examples provided in ZKProof documentation, including by disclosing known pending patent applications or any relevant unexpired patent. Particularly, such disclosure is promptly required from the patent holders, or those acting on their behalf, as a condition for providing content contributions to the “Community Reference” and to “Proposals” submitted to ZKProof for consideration by the community. Furthermore, any technology that is promoted in said ZKProof documentation and that falls within patent claims should be made available under licensing terms that are reasonable, and demonstrably free of unfair discrimination, preferably allowing free open-source implementations.

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Recommendations

The reference document will improve if complemented with recommendations and examples of interoperable components.

Next slides:

- Security levels
- Metrics
- Intellectual property
- NIST-PEC proposal of a use-case suite
3. Recommendations

Security level parameters

In terms of computational security in benchmarks:

- The reference requires $\kappa \geq 128$; suggests one more $\kappa \in \{192, 256\}$
- Soundness despite long pre- or online computation
- Zero-knowledge despite long pre-, online, or post-computation
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**Statistical security** (in interactive case):

- The reference **requires** $\sigma \geq 64$; **suggests** one more $\sigma \in \{40, 80, 128\}$
- One-shot online security for statistical soundness
- Fiat-Shamir may require $\sigma \approx \kappa$ (statistical $\rightarrow$ computational)
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Exceptions for lower security levels (to be careful):

- if needing short term comp. security, e.g., for temporary binding or hiding;
- if predicate being proven is protected by less security strength.
Benchmarking suggestions

The Reference gives a few generic suggestions.

Measure and compare several metrics:
- Communication and computational complexity
- Per phase (prove vs. verify), per implementation platform
- Many nuances: Parallelizability, Batching, memory, disk, cpu, tradeoffs
BENCHMARKING SUGGESTIONS

THE REFERENCE GIVES A FEW GENERIC SUGGESTIONS.  

MEASURE AND COMPARE SEVERAL METRICS:  
- Communication and computational complexity  
- Per phase (prove vs. verify), per implementation platform  
- Many nuances: Parallelizability, Batching, memory, disk, cpu, tradeoffs  

SEVERAL FUNCTIONS IN ZKP (KNOWLEDGE OF PRE-IMAGE OR OF COMMITTED INPUT/OUTPUT): SHA-256, AES-128, matrix-multiplication, Scrypt, number theoretical transforms (small and big fields), ...
Beyond benchmarking

How about when efficiency is not an issue at all?
Byeond benchmarking

How about when efficiency is not an issue at all?

Proposal: a use-case suite could be good to facilitate experimentation by new implementors.

- Collect fully functional open-source implementations of very concrete use-cases, e.g., proving adulthood based on a digital certificate.
- NIST-PEC wants to propose such a suite (≈6 months) including use-cases on ZKP, SMPC, ...
A use-case: public auditability from public randomness

<table>
<thead>
<tr>
<th>Public</th>
<th>Inherently private</th>
<th>Derived private</th>
</tr>
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<tbody>
<tr>
<td># (i)</td>
<td>Rand id</td>
<td>Name (N)</td>
</tr>
<tr>
<td>1</td>
<td>371</td>
<td>Cai</td>
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<td>Ann</td>
</tr>
<tr>
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<td>Dan</td>
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Publicize a table with all attributes committed... then prove in ZK:
1. \( a_i \in \mathbb{A} \) (e.g., salary level);
2. \( b_i \in \mathbb{B} \) (e.g., years at work);
3. \( w_i = f(a_i, b_i) \) (correct weight calculation);
4. \( \sum_i w_i = 1 \) (correct sum of probabilities);
5. \( \{N_i\} = \text{NAMES} \) (no repeated names from an appropriate set);

Derive \( R : 0 < R \leq 1 \) (random) from Beacon and get \( #_j : W_{\text{max}}(1, j - 1) < R \leq W_j \)

▶ Prove in ZK that \( j \) is consistent with \( R \) and the table of commitments.
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4. \( W_i = w_i + W_{i-1} \) (correct probability accumulation);
5. \( \{N_i\} = \text{NAMES} \) (no repeated names from an appropriate set); ...
A use-case: public auditability from public randomness

<table>
<thead>
<tr>
<th># (i)</th>
<th>Rand id</th>
<th>Public</th>
<th>Inherently private</th>
<th>Derived private</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Rand id</td>
<td>Name (N)</td>
<td>a₁</td>
</tr>
<tr>
<td>1</td>
<td>371</td>
<td>Cai</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>942</td>
<td>Eve</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>3</td>
<td>107</td>
<td>Bob</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>527</td>
<td>Ann</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>5</td>
<td>123</td>
<td>Dan</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>

Publicize a table with all attributes **committed** ... then **prove in ZK**:

1. \( a_i \in A \) (e.g., salary level); \( b_i \in B \) (e.g., years at work);
2. \( w_i = f(a_i, b_i) \) (correct weight calculation);
3. \( \sum_i w_i = 1 \) (correct sum of probabilities);
4. \( W_i = w_i + W_{i-1} \) (correct probability accumulation);
5. \{Nᵢ\} = NAMES (no repeated names from an appropriate set); ...

Derive \( R : 0 < R \leq 1 \) (random) from Beacon and get \( \# \ j : W_{\text{max}(1,j-1)} < R \leq W_j \)

- **Prove in ZK** that \( j \) is consistent with \( R \) and the table of commitments
3. Recommendations

Intellectual Property (expectations)

ZKProof is an open initiative that seeks to promote the secure and interoperable use of zero-knowledge proofs. To foster open development and wide adoption, it is valuable to promote technologies with open-source implementations, unencumbered by royalty-bearing patents. However, some useful technologies may fall within the scope of patent claims. Since ZKProof seeks to represent the technology, research and community in an inclusive manner, it is valuable to set expectations about the disclosure of intellectual property and the handling of patent claims.

The members of the ZKProof community are hereby strongly encouraged to provide information on known patent claims potentially applicable to the guidance, requirements, recommendations, proposals and examples provided in ZKProof documentation, including by disclosing known pending patent applications or any relevant unexpired patent. Particularly, such disclosure is promptly required from the patent holders, or those acting on their behalf, as a condition for providing content contributions to the “Community Reference” and to “Proposals” submitted to ZKProof for consideration by the community. Furthermore, any technology that is promoted in said ZKProof documentation and that falls within patent claims should be made available under licensing terms that are reasonable, and demonstrably free of unfair discrimination, preferably allowing free open-source implementations.

The ZKProof documentation will be updated based on received disclosures about pertinent patent claims. Please email information to editors@zkproof.org.
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Outline 4

1. Introduction

2. A few aspects revised for the Ref. 0.2

3. Recommendations

4. Conclude
Discussion

Suggested questions for brainstorming:

► What is best way to contribute and to attract community?

► What is the applicability of the Z.C.Reference to your setting!?

► Use-cases of interest for the suite?

What else would you like to see in the Z.C.Reference?
Discussion part 2

What about more concretely?

- A library of secure gadgets for usage
- A proper review of elliptic curve parameters for different usages

What else do we need to standardize to build the ZK infrastructure for adoption?