

# RFC-014: Coq Extraction for TCB

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## Abstract

This RFC specifies the use of Coq proof assistant for verified implementation of the Trusted Computing Base, with extraction to OCaml for production use. Prove once, trust forever.

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## Motivation

The Prime Directive (RFC-002):

*If it's in the TCB, it's in OCaml. Otherwise it's in Chicken Scheme.*

But even OCaml can have bugs. The TCB handles: – Ed25519 signatures – SHA-512 hashing – Signature chain verification

A single bug breaks everything.

Coq provides:

1. **Machine-checked proofs:** Theorems verified by computer
2. **Extraction:** Generate OCaml from proofs
3. **Correctness by construction:** Implementation matches specification
4. **Eternal validity:** Proofs don't expire

From the Coq motto:

*The proof is in the code.*

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## Specification

### Trusted Computing Base

CYBERSPACE TCB

Ed25519	SHA-512	Verify
Proven	Proven	Proven

Coq Extraction

OCaml  
~1000 LOC

Proven in Coq. Extracted to OCaml. Called from Scheme.

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## Coq Specifications

### Types

```
(* Byte arrays *)
Definition bytes := list byte.

(* Keys *)
Record ed25519_public_key := {
  pk_bytes : bytes;
  pk_length : length pk_bytes = 32
}.

Record ed25519_private_key := {
  sk_bytes : bytes;
  sk_length : length sk_bytes = 64
}.

(* Signatures *)
Record ed25519_signature := {
  sig_bytes : bytes;
  sig_length : length sig_bytes = 64
}.

(* Hashes *)
Record sha512_hash := {
  hash_bytes : bytes;
```

```

    hash_length : length hash_bytes = 64
  }.

```

## Signature Specification

```

(* Abstract signature scheme *)
Module Type ED25519_SPEC.
  Parameter sign : ed25519_private_key -> bytes -> ed25519_signature.
  Parameter verify : ed25519_public_key -> bytes -> ed25519_signature -> bool.

  (* Correctness: valid signatures verify *)
  Axiom sign_verify_correct :
    forall sk pk msg,
      pk = derive_public sk ->
        verify pk msg (sign sk msg) = true.

  (* Security: cannot forge without private key *)
  Axiom unforgeability :
    forall pk msg sig,
      verify pk msg sig = true ->
        exists sk, pk = derive_public sk /\ sig = sign sk msg.
End ED25519_SPEC.

```

## Hash Specification

```

Module Type SHA512_SPEC.
  Parameter hash : bytes -> sha512_hash.

  (* Determinism *)
  Axiom hash_deterministic :
    forall x, hash x = hash x.

  (* Collision resistance (assumed) *)
  Axiom collision_resistant :
    forall x y, hash x = hash y -> x = y. (* Idealized *)
End SHA512_SPEC.

```

## Chain Verification

```

(* Certificate chain verification *)
Fixpoint verify_chain
  (root : ed25519_public_key)
  (certs : list signed_cert)
  (target_tag : tag) : bool :=
  match certs with

```

```

| nil => false
| cert :: rest =>
    let issuer_key := cert_issuer cert in
    let subject_key := cert_subject cert in
    let cert_tag := cert_tag cert in
    (* Check issuer matches current key *)
    andb (key_eq root issuer_key)
    (* Check signature valid *)
    (andb (verify issuer_key (cert_content cert) (cert_signature cert))
    (* Check tag grants permission *)
    (andb (tag_implies cert_tag target_tag)
    (* Continue chain *)
    (match rest with
    | nil => true
    | _ => verify_chain subject_key rest target_tag
    end)))
end.

(* Theorem: Valid chain implies authorization *)
Theorem chain_authorization :
  forall root certs tag,
    verify_chain root certs tag = true ->
    authorized root tag.
Proof.
  (* Proof by induction on chain length *)
  ...
Qed.

```

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## Extraction to OCaml

### Extraction Directives

```

Require Import ExtrOcamlBasic.
Require Import ExtrOcamlString.

(* Extract to OCaml types *)
Extract Inductive bool => "bool" ["true" "false"].
Extract Inductive list => "list" ["[]" "(::)"].

(* Link to libsodium *)
Extract Constant ed25519_sign => "Sodium.Ed25519.sign".
Extract Constant ed25519_verify => "Sodium.Ed25519.verify".
Extract Constant sha512_hash => "Sodium.SHA512.hash".

```

```
(* Generate OCaml *)
Extraction "tcb.ml" verify_chain sign verify hash.
```

## Generated OCaml

```
(* tcb.ml - Extracted from Coq *)

let rec verify_chain root certs target_tag =
  match certs with
  | [] -> false
  | cert :: rest ->
    let issuer_key = cert_issuer cert in
    let subject_key = cert_subject cert in
    key_eq root issuer_key &&
    Sodium.Ed25519.verify issuer_key (cert_content cert) (cert_signature cert) &&
    tag_implies (cert_tag cert) target_tag &&
    (match rest with
     | [] -> true
     | _ -> verify_chain subject_key rest target_tag)
```

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## Integration with Scheme

### FFI Layer

```
(* tcb_ffi.ml - FFI bindings for Chicken Scheme *)

let () = Callback.register "tcb_verify_chain" verify_chain
let () = Callback.register "tcb_sign" sign
let () = Callback.register "tcb_verify" verify
let () = Callback.register "tcb_hash" hash
```

### Scheme Bindings

```
;; crypto-ffi.scm
(module crypto-ffi
  (ed25519-sign ed25519-verify sha512-hash verify-chain)

  (import (chicken foreign))

  ;; Call into verified OCaml
  (define ed25519-sign
    (foreign-lambda* blob ((blob key) (blob msg))
      "return tcb_sign(key, msg);"))
```

```

(define verify-chain
  (foreign-lambda* bool ((blob root) (pointer certs) (pointer tag))
    "return tcb_verify_chain(root, certs, tag);"))

...)
```

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## Proof Obligations

### What We Prove

1. **Signature correctness:** Valid signatures verify
2. **Chain soundness:** Valid chain implies authorization
3. **Hash properties:** Determinism, length preservation
4. **Type safety:** No buffer overflows, no null pointers

### What We Assume

1. **Cryptographic hardness:** Ed25519 unforgeability
2. **libsodium correctness:** Implementation matches spec
3. **OCaml runtime:** Extraction target is correct
4. **Hardware:** CPU executes instructions correctly

### Trust Chain

```

Mathematical proof (Coq)
  ↓
Extraction (verified by Coq)
  ↓
OCaml code (typed, memory-safe)
  ↓
libsodium (audited, widely deployed)
  ↓
CPU instructions (trust hardware)
```

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## Development Workflow

### 1. Specify in Coq

```

(* Define types and operations *)
(* State properties and theorems *)
```

## 2. Prove Correctness

```
(* Prove theorems *)  
(* Coq checks proofs mechanically *)
```

## 3. Extract to OCaml

```
$ coqc -R . Cyberspace tcb.v  
$ coqc -R . Cyberspace extract.v  
$ ls *.ml  
tcb.ml tcb_types.ml
```

## 4. Compile and Link

```
$ ocamlfind ocamlopt -package sodium -linkpkg \  
tcb.ml tcb_ffi.ml -o tcb.cmxa
```

## 5. Call from Scheme

```
(import crypto-ffi)  
(ed25519-sign key message) ; Calls verified code
```

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## Existing Verified Libraries

### Fiat-Crypto

- Verified elliptic curve implementations
- Used by BoringSSL, Chrome
- Extraction to C, Java, Go

### HACL\*

- Verified cryptographic library
- Written in F\* (similar to Coq)
- Used by Firefox, Wireguard

### Potential Use

```
Require Import Fiat.Crypto.Ed25519.  
(* Use pre-verified Ed25519 implementation *)
```

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## Security Considerations

### Verified Components

- Signature operations
- Hash operations
- Chain verification logic

### Unverified (Trusted)

- FFI layer (small, auditable)
- libsodium bindings
- Scheme runtime

### Audit Surface

Total TCB: ~1000 lines OCaml  
Verified: ~800 lines (extracted from ~2000 lines Coq)  
Trusted: ~200 lines (FFI, bindings)

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## References

1. Coq Development Team. The Coq Proof Assistant Reference Manual.
  2. Erbsen, A., et al. (2019). Simple High-Level Code for Cryptographic Arithmetic.
  3. Protzenko, J., et al. (2017). Verified Low-Level Programming Embedded in F\*.
  4. Chlipala, A. (2013). Certified Programming with Dependent Types.
  5. RFC-002: Cyberspace Architecture
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## Changelog

- **2026-01-06** – Initial specification
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**Implementation Status:** Proposed **Proof Assistant:** Coq **Extraction Target:** OCaml **TCB Size:** ~1000 lines