RFC-007: Threshold Signature Governance

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Implementation: script.scm, cyberspace.scm

Abstract

This RFC specifies the threshold signature system for Cyberspace governance, enabling K-of-N multi-party authorization for critical operations. Democracy in code: no single point of failure, no rogue administrator.

Motivation

Critical operations require collective authorization:

- **Release signing:** Multiple maintainers must approve
- **Deployment:** Operations team quorum required
- **Key ceremonies:** Distributed trust for root keys
- **Emergency response:** Prevent unilateral action

Traditional approaches fail: - **Shared passwords:** Who has it? Who used it? - **Sudo access:** Root is root - **Approval workflows:** Soft controls, bypassable

Threshold signatures provide cryptographic enforcement:

> **K valid signatures required. Not K-1. Not bypass. Mathematics.**

Specification

Tiered Signing Model

SIGNING TIERS		
Development	1-of-1	Single developer can iterate
Staging	2-of-2	Peer review required
Production	3-of-5	Governance council quorum
Emergency	5-of-7	Full council for critical ops

Script Signature Record

```
(define-record-type <script-signature>
  (make-script-signature signer signature timestamp)
  script-signature?
  (signer signature-signer)        ; Ed25519 public key (32 bytes)
  (signature signature-value)      ; Ed25519 signature (64 bytes)
  (timestamp signature-timestamp)) ; Unix epoch seconds
```

Signing a Script

```
(define (sign-script script-content private-key #!optional public-key)
  "Sign script content with a private key"
  ...)
```

Process: 1. Convert content to blob if string 2. Derive public key from private (if not provided) 3. Sign content with Ed25519 4. Record timestamp 5. Return script-signature record

Verifying Single Signature

```
(define (verify-script script-content signature-record)
  "Verify a script signature"
  (ed25519-verify (signature-signer signature-record)
                  content-blob
                  (signature-value signature-record)))
```

Threshold Verification

```
(define (verify-threshold-script script-content signature-records threshold)
  "Verify threshold signatures on a script
   Returns: #t if at least K signatures are valid"
  (let* ((valid-sigs (filter (lambda (sig)
                               (verify-script script-content sig))
                             signature-records))
         (valid-count (length valid-sigs)))
    (>= valid-count threshold)))
```

Signature File Format

```
;; deploy.sig
((signature "hex-signature" "hex-pubkey" 1767685100)
 (signature "hex-signature" "hex-pubkey" 1767685200)
 (signature "hex-signature" "hex-pubkey" 1767685300))
```

Each entry contains: - Signature bytes (hex-encoded) - Signer public key (hex-encoded) - Timestamp (Unix epoch)

CLI Interface

cyberspace verify

```
$ cyberspace verify deploy.scm deploy.sig \
    --threshold 3 \
    --keys alice.pub bob.pub carol.pub dave.pub eve.pub

=== Cyberspace Script Verification ===

Script:     deploy.scm
Signatures: deploy.sig
Threshold:  3
```

```
Keys:       5 provided

Found 3 signature(s) in file
  Signature 1: ✓ VALID (signer: cbc9b260da65f6a7...)
  Signature 2: ✓ VALID (signer: a5f8c9e3d2b1f0e4...)
  Signature 3: ✓ VALID (signer: 7d3e8b2c1a0f5e4d...)

✓ SUCCESS: Script verified with 3-of-3 threshold
```

cyberspace run

```
$ cyberspace run deploy.scm deploy.sig \
    --threshold 3 \
    --keys alice.pub bob.pub carol.pub dave.pub eve.pub

=== Cyberspace Script Verification ===
...
✓ SUCCESS: Script verified with 3-of-5 threshold

=== Executing Script ===
(seal-release "2.0.0"
  message: "Major release with new governance model"
  preserve: #t)
```

Governance Scenarios

Production Deployment (3-of-5)

```
;; Governance Council: Alice, Bob, Carol, Dave, Eve
;; Threshold: 3 signatures required

(define deployment-script
  "(seal-release \"2.0.0\"
    message: \"Major release\"
    preserve: #t)")

;; Alice signs
(define sig-alice
  (sign-script deployment-script alice-private alice-public))

;; Carol signs
(define sig-carol
  (sign-script deployment-script carol-private carol-public))

;; Dave signs
(define sig-dave
  (sign-script deployment-script dave-private dave-public))

;; Verify threshold
(verify-threshold-script deployment-script
                         (list sig-alice sig-carol sig-dave)
                         3)
```

```
;; => #t
```

Insufficient Signatures

```
;; Only 2 signatures
(define insufficient-sigs
  (list sig-alice sig-carol))

(verify-threshold-script deployment-script insufficient-sigs 3)
;; => #f (rejected: need 3, got 2)
```

Tampered Script Detection

```
;; Attacker modifies script
(define tampered-script
  "(seal-release \"2.0.0\"
    message: \"HACKED - deploying malware\"
    preserve: #t)")

(verify-threshold-script tampered-script sufficient-sigs 3)
;; => #f (signatures don't match modified content)
```

Multi-Signature vs Shamir

Two threshold approaches exist:

Multi-Signature (This RFC)

```
Each party: own keypair
Signing:    each signs independently
Verify:     count valid signatures ≥ K
Use case:   governance, approvals
```

Advantages: - Each party maintains own key - Clear audit trail (who signed) - Simple revocation (by key) - No key reconstruction

Shamir Splitting (RFC-008)

```
Single key: split into N shares
Signing:    K parties reconstruct, sign once
Verify:     single signature
Use case:   key backup, recovery
```

Advantages: - Single signature output - Key never fully assembled (in advanced schemes) - Smaller signature files

For governance, multi-signature is preferred: - Accountability (which individuals approved) - No reconstruction ceremony - Works asynchronously

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Security Considerations

Threat Model

Protected against: - Single compromised key (need K) - Rogue administrator (need quorum) - Script tampering (signatures fail) - Replay of old scripts (timestamps, context)

Not protected against: - K compromised keys - All parties colluding - Side-channel on signing devices

Key Management

1. **Generation:** Secure random via libsodium
2. **Storage:** Hardware tokens preferred, encrypted files acceptable
3. **Distribution:** Out-of-band verification of public keys
4. **Rotation:** New ceremony, revoke old keys

Threshold Selection

Scenario	Threshold	Rationale
Development	1-of-1	Fast iteration
Staging	2-of-2	Peer review
Production	3-of-5	Majority quorum
Root key	5-of-7	Supermajority
Emergency	N-of-N	Full consensus

Audit Integration

Every verified execution records:

```
(audit-append
  actor: (threshold-verifier-list)
  action: (list 'script-execute script-hash)
  motivation: "Production deployment authorized"
  context: (list 'threshold 3 'signatures 3))
```

Audit trail shows: - Which signers authorized - What script was executed - When authorization occurred - Threshold requirements met

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Implementation Notes

Dependencies

- crypto-ffi - Ed25519 operations
- cert - SPKI integration
- audit - Trail recording

Performance

- Signature verification: ~10µs per Ed25519 verify
- Threshold check: O(N) where N = signature count
- No network round-trips (offline verification)

References

1. Boneh, D., et al. (2001). Short Signatures from the Weil Pairing.
2. Gennaro, R., et al. (2016). Threshold-optimal DSA/ECDSA signatures.
3. NIST SP 800-57. Recommendation for Key Management.
4. RFC-004: SPKI Authorization Integration

Changelog

- **2026-01-06** - Initial specification

Implementation Status: Complete **Test Status:** Passing (test-threshold-sig.scm)
CLI Tool: cyberspace verify/run