

# Coprime-Factor Security Architecture

Technical Report v3.0

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## Abstract

Coprime-Factor Security is a quantitative defense-in-depth framework that engineers independence across security layers to minimize correlated failures. Rather than assuming isolation between cryptography, trust anchors, control planes, runtime, and supply chain, it **enforces demonstrable separation** using measurable independence criteria and architectural patterns.

We define two primary metrics:

- **Independence Score (IS)** — weighted pairwise disjointness across seven dimensions
- **Common-Mode Risk Index (CMRI)** — worst-case shared-dependency exposure

We introduce operational patterns — dual-primitive encryption, dual policy consensus, split-vendor key ceremony, divergent transport, and twin attestation — and provide a scoring method, drift detection loop, and fail-safe execution rules.

Coprime-Factor Security generalizes principles used in **ASIL-M multi-root attestation** to full security stacks, providing a repeatable architecture for reducing correlated compromise risk in high-assurance systems.

**Keywords:** correlated failure, independence metrics, defense-in-depth, cryptographic diversity, supply-chain trust, attestation diversity, AxoDen

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## 1 Context & Relationship to ASIL-M

ASIL-M demonstrates multi-root trust for AI inference.

Coprime Security is the **general parent architecture**:

Domain	ASIL-M	Coprime-Factor Security
Scope	AI inference trust	Full security stack
Guarantee	$\pi \rightarrow 0$ enforced at attestation layer	Independence engineered across entire stack
Thresholds	$IS \geq 0.85$ + semantic guard	$IS \geq 0.85$ / $CMRI \leq 0.10$
Artifacts	Canonical Attestation Record	Org-wide independence and failure audit trail

Table 1: Comparison of ASIL-M and Coprime-Factor Security

**Takeaway:** Coprime Security = ASIL-M principle applied system-wide.

## 2 Related Work

Prior research domains address independence partially:

Area	Relevance
Saltzer & Schroeder	Classical security design principles
NIST SP 800-160	System security engineering
Common Criteria / ISO 15408	Assurance & independence levels
IEC 61508 / DO-178C	Safety separation & independence requirements
Threshold cryptography / BFT	Formal independence assumptions in distributed protocols
SLSA / in-toto	Supply-chain provenance & build independence
Zero-trust runtime	Environment trust, not cross-stack independence

Table 2: Related work domains

**Novel contribution:** A unified model + metrics + implementation patterns for engineered **cross-domain independence**, not assumed independence.

**Note:** “Coprime” is used as a **design metaphor** for engineered pairwise independence, not a literal number-theoretic mapping.

## 3 Executive Summary

- **Goal:** Minimize correlated failure across layers.
- **Method:** Structure each security layer so exploiting one does not help exploit another.
- **Outcome:** Independently-verifiable, metric-driven defense-in-depth.

## 4 Principles & Independence Criteria

For layers  $L_i, L_j$ , ensure disjointness across:

- Crypto families & RNGs
- Trust roots (CA/KMS/HSM vendors, firmware lines)
- Codebase & build pipeline

- Runtime / kernel / hypervisor
- Ops credentials & reviewer paths
- Supply-chain & CI/CD provenance
- Control-plane policy engines

If a single catastrophic dependency overlaps, that pair = **not independent** (score 0).

## 5 Formal Model

### 5.1 Independence Score (IS)

Dimensions: {crypto, trust, code, runtime, ops, supply, control}

Let  $s_d^{(i,j)} \in [0, 1]$  be independence per dimension.

Let weights  $w_d \geq 0$  with  $\sum w_d = 1$ .

$$\text{IS} = \frac{1}{\binom{k}{2}} \times \sum_{i < j} \sum_d w_d \cdot s_d^{(i,j)} \quad (1)$$

**Hard-fail rule:** If any mandatory dimension is not independent  $\rightarrow$  score = 0.

### 5.2 Common-Mode Risk Index (CMRI)

Binary overlap indicator  $O_d^{(i,j)} \in \{0, 1\}$ .

Weights  $\alpha_d \geq 0$ ,  $\sum \alpha_d = 1$ .

$$C(i, j) = \sum_d \alpha_d \cdot O_d^{(i,j)} \quad (2)$$

$$\text{CMRI} = \max_{i < j} C(i, j) \quad (3)$$

### 5.3 Engineering Bound

If each layer has compromise probability  $\pi$  and  $\text{IS} \geq \tau$ , then worst-case correlated breach bound:

$$P(\text{breach}) \leq k\pi + \binom{k}{2} \cdot (1 - \tau) \cdot \pi \quad (4)$$

**Interpretation:** Increasing IS directly shrinks correlated compromise term.

**Targets:**

- Launch:  $\text{IS} \geq 0.85$ ,  $\text{CMRI} \leq 0.10$
- Tier-1 critical:  $\text{IS} \geq 0.90$ ,  $\text{CMRI} \leq 0.05$

## 6 Reference Architecture

Planes:

User  $\rightarrow$  Edge  $\rightarrow$  App  $\rightarrow$  Data  $\rightarrow$  Control  $\rightarrow$  Audit

The architecture implements independence across six key layers (see Figure 1 for complete diagram):

- **AuthN:** FIDO2/HSM-A AND TOTP/HSM-B
- **Transport:** TLS vs WireGuard dual overlay
- **Policy:** OPA AND Cedar
- **Storage:** AES/KMS-A + ChaCha/KMS-B
- **Build trust:** Sigstore + independent internal CA
- **Runtime:** microVM vs container kernel separation
- **Audit:** Merkle internal + external anchor

## 7 Patterns

ID	Pattern	Purpose
P1	Dual-Primitive Encryption	Crypto & key independence
P2	Dual Policy Consensus	Control-plane independence
P3	Split-Vendor Key Ceremony	Hardware RNG/vendor separation
P4	Divergent Transport	Separate channels & cipher families
P5	Twin Attestation	Multi-root trust enforcement

Table 3: Operational patterns for independence

## 8 Example Config

Listing 1: Example configuration demonstrating independence patterns

```

1  authn:
2    require: AND
3    factors:
4      - type: fido2
5        hsm: vendorA
6      - type: totp
7        hsm: vendorB
8
9  transport:
10   tls:
11     lib: rustls
12   admin_overlay:
13     type: wireguard
14
15  policy:
16   engines:
17     - opa
18     - cedar
19   decision: AND
20
21  data:
22   layer1:
23     aead: aes-gcm
24     kms: KMS-A
25   layer2:
26     aead: chacha20
27     kms: KMS-B

```

```

28
29 attestation:
30     require:
31         - sigstore-fulcio
32         - org-ca

```

## 9 Threat Model & Controls

### 9.1 Threats

- Software monoculture exploits
- Supply-chain compromises
- Insider abuse of control-plane paths
- Cryptographic break/downgrade
- Hypervisor / cloud control-plane breach

### 9.2 Kill Switches

- Hard fail → deny privileged ops
- AND→OR override only via board-supervised M-of-N ceremony

## 10 Verification & Testing

### 10.1 Drills

- Disable 1 HSM → expect degraded mode only
- Inject signed but invalid binary → attestation fail
- Force TLS lib CVE scenario → overlay must sustain protection

### 10.2 Mini-Case (data breach drill)

- Compromise KMS-A keys
- Verify ChaCha/KMS-B layer protects data
- Score recomputed; audit logs reflect degraded independence

## 11 Metrics & SLOs

Metric	Target
IS	$\geq 0.85$ ( $\geq 0.90$ Tier-1)
CMRI	$\leq 0.10$ ( $\leq 0.05$ Tier-1)
Dual coverage	$\geq 99\%$ privileged ops dual-gated
APR	$\geq 70\%$ reduction in single-path exploitability

Table 4: Metrics and Service Level Objectives

## 12 Rollout Plan

- 0: Model dependencies, baseline IS/CMRI
- 1: Deploy P1-P3 on critical service
- 2: Add P4-P5, automate scoring
- 3: Extend to Tier-1 systems; enforce IS gates

## 13 Governance & Audit

- Quarterly independence review
- Dual third-party supply-chain proofs
- External timestamp anchoring (e.g., RFC-3161)
- Exemption process w/ compensating controls

## 14 Limitations & Tradeoffs

- Cost & operational complexity
- Harder for single-cloud tenants to reach runtime independence
- Cultural shift: security monoculture → **security dual-culture**

## A Coprime Analogy

Coprime = metaphor: pairwise-engineered independence.

Goal: compromise **must** require independent attack paths.

## B Mini-Case Exercises

### B.1 Attestation loss on one root

- Expected: degrade, higher logging, no privileged paths

### B.2 TLS library CVE

- Secondary channel remains secure; CMRI re-evaluated

### B.3 Internal CA compromise

- Sigstore lane continues; alert + emergency ceremony

## C Summary Tables

### C.1 Independence Dimensions

Crypto | Trust Root | Code | Runtime | Ops | Supply | Control

### C.2 Patterns

DPE | DPC | SVK | DT | TA

### C.3 Thresholds

IS  $\geq 0.85$  / CMRI  $\leq 0.10$

Tier-1: IS  $\geq 0.90$  / CMRI  $\leq 0.05$

## D Architecture Sketch

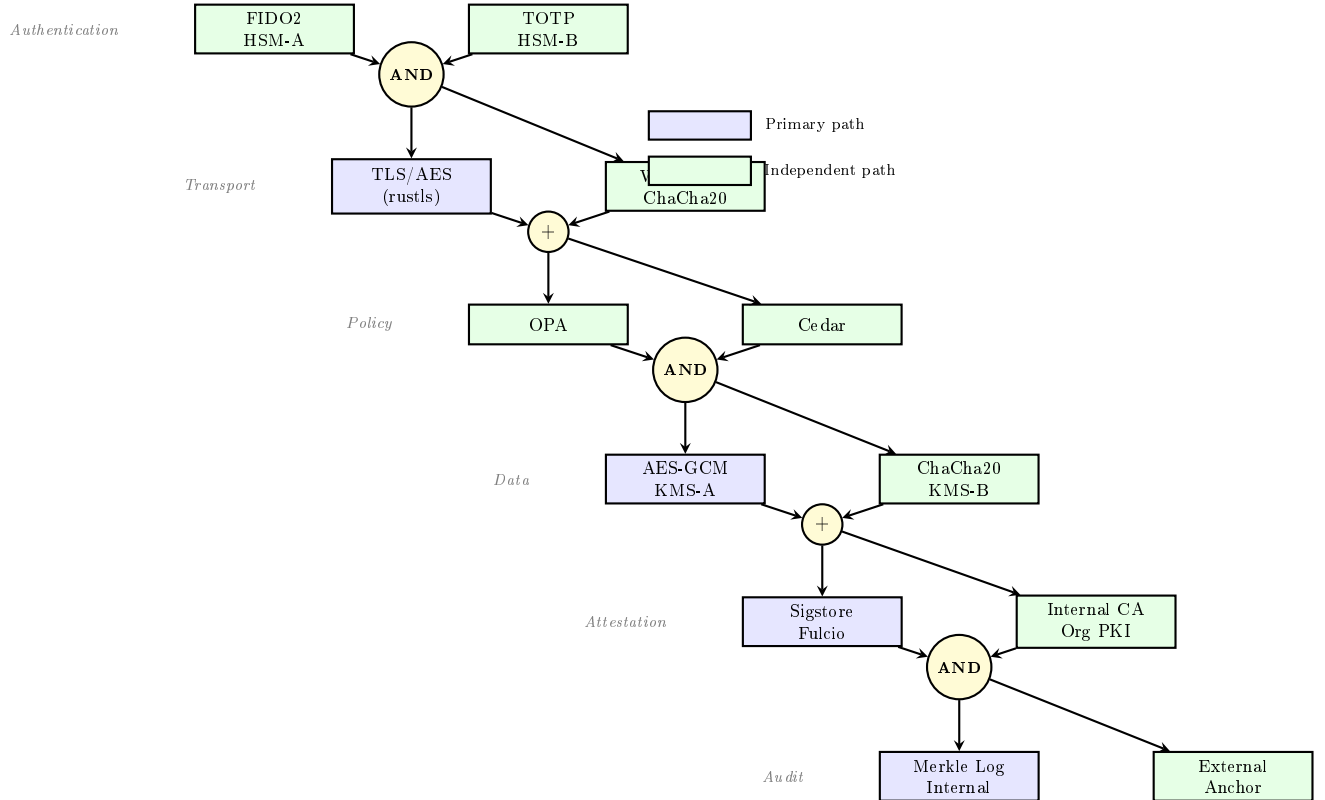


Figure 1: Coprime-Factor Security Architecture showing dual-path independence across layers. Each layer employs distinct cryptographic primitives, trust roots, and vendors to minimize correlated failure risk. **AND** operators enforce that both paths must succeed; **+** operators indicate additive protection.

**Outcome:** Correlated compromise becomes provably harder and auditable. Attackers must independently breach both paths at each layer to succeed.

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