KERI

Key Event Receipt Infrastructure

A Secure Identifier Overlay for the Internet

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version 2.45

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Resources

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https://arxiv.org/abs/1907.02143
https://github.com/SmithSamuelM/Papers/blob/master/whitepapers/KERI_WP_2.x.web.pdf
https://github.com/SmithSamuelM/Papers/blob/master/presentations/KERI2_Overview.web.pdf
https://github.com/SmithSamuelM/Papers/blob/master/presentations/DuplicityGame_IIW_2020_A.pdf
https://github.com/SmithSamuelM/keri
https://github.com/SmithSamuelM/keripy

DIF
Identity and Discovery WG
https://github.com/decentralized-identity/keri
https://github.com/decentralized-identity/keripy

SSI Meetup
https://ssimeetup.org/key-event-receipt-infrastructure-keri-secure-identifier-overlay-internet-sam-smith-webinar-58/

Background References

Self-Certifying Identifiers:

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Certificate Transparency:

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Google, "Certificate Transparency,"
http://www.certificate-transparency.org/home

Laurie, B. and Kasper, E., "Revocation Transparency,"
https://www.links.org/files/RevocationTransparency.pdf

Human *Basis-of-Trust*

“in person”

I can know you – therefore I can trust you

“on the internet”

I can’t really know you – therefore I can’t really trust you

Replace human *basis-of-trust* with cryptographic *root-of-trust.*

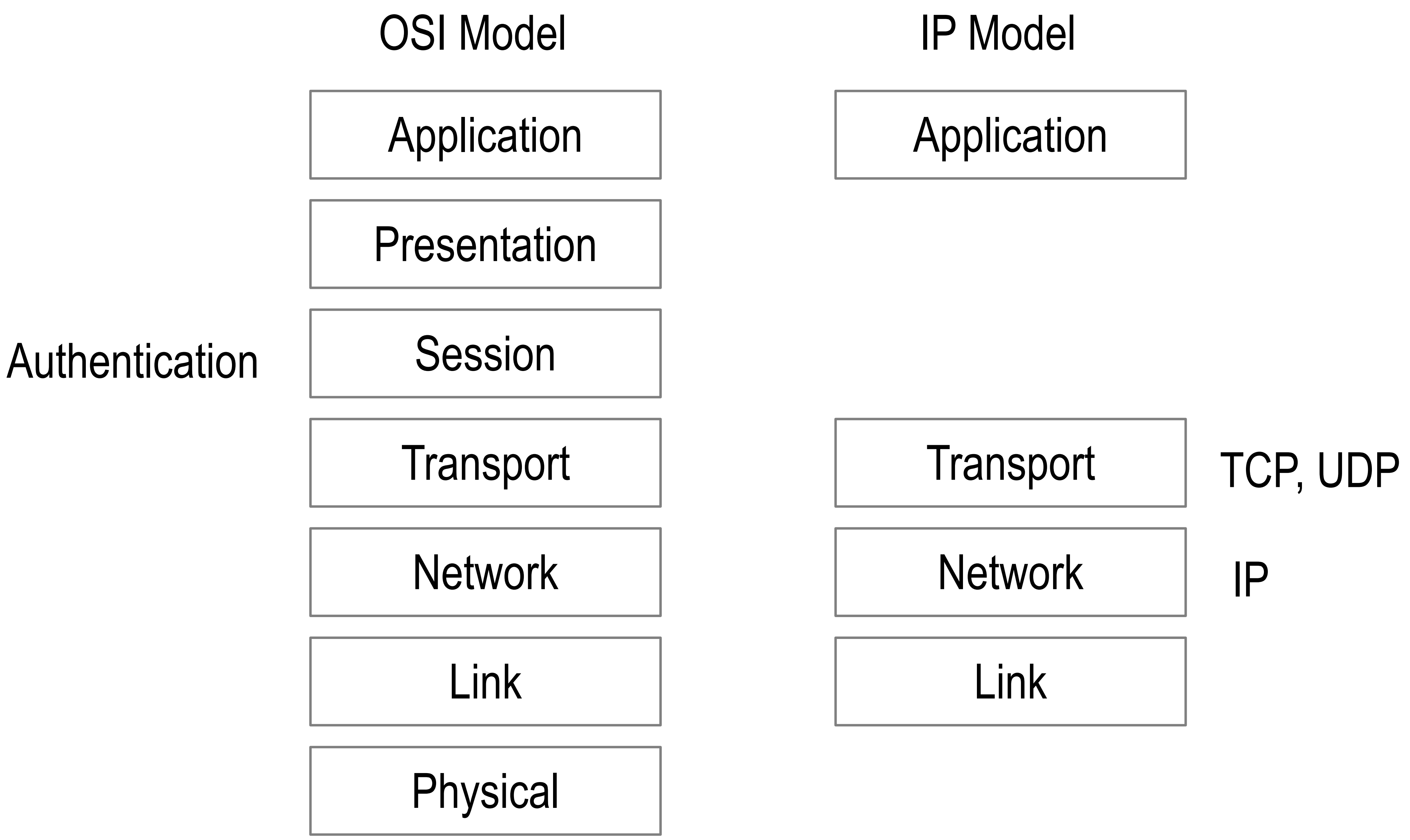
With verifiable digital signatures from asymmetric key crypto –
we may not trust in *"what"* was said, but we may trust in *"who"* said it.

We may *verify* that the *controller* of a private key, (*the who*), made a statement
but not the validity of the statement itself.

The *root-of-trust* is *consistent attribution* via verifiable integral non-repudiable statements

We may build trust over time in *what* was said via histories
of verifiably attributable (to *whom*) consistent statements i.e. *reputation*.

The Internet Protocol (IP) is *bro-ken* because it has no *security* layer.

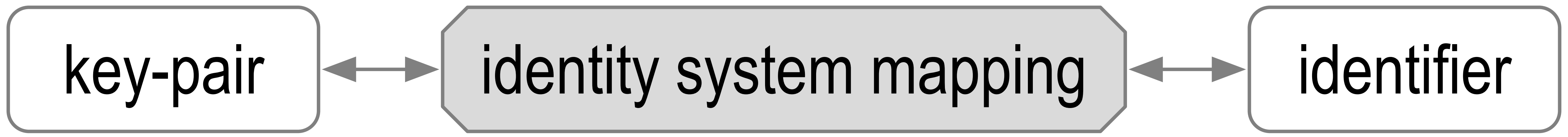


Instead …

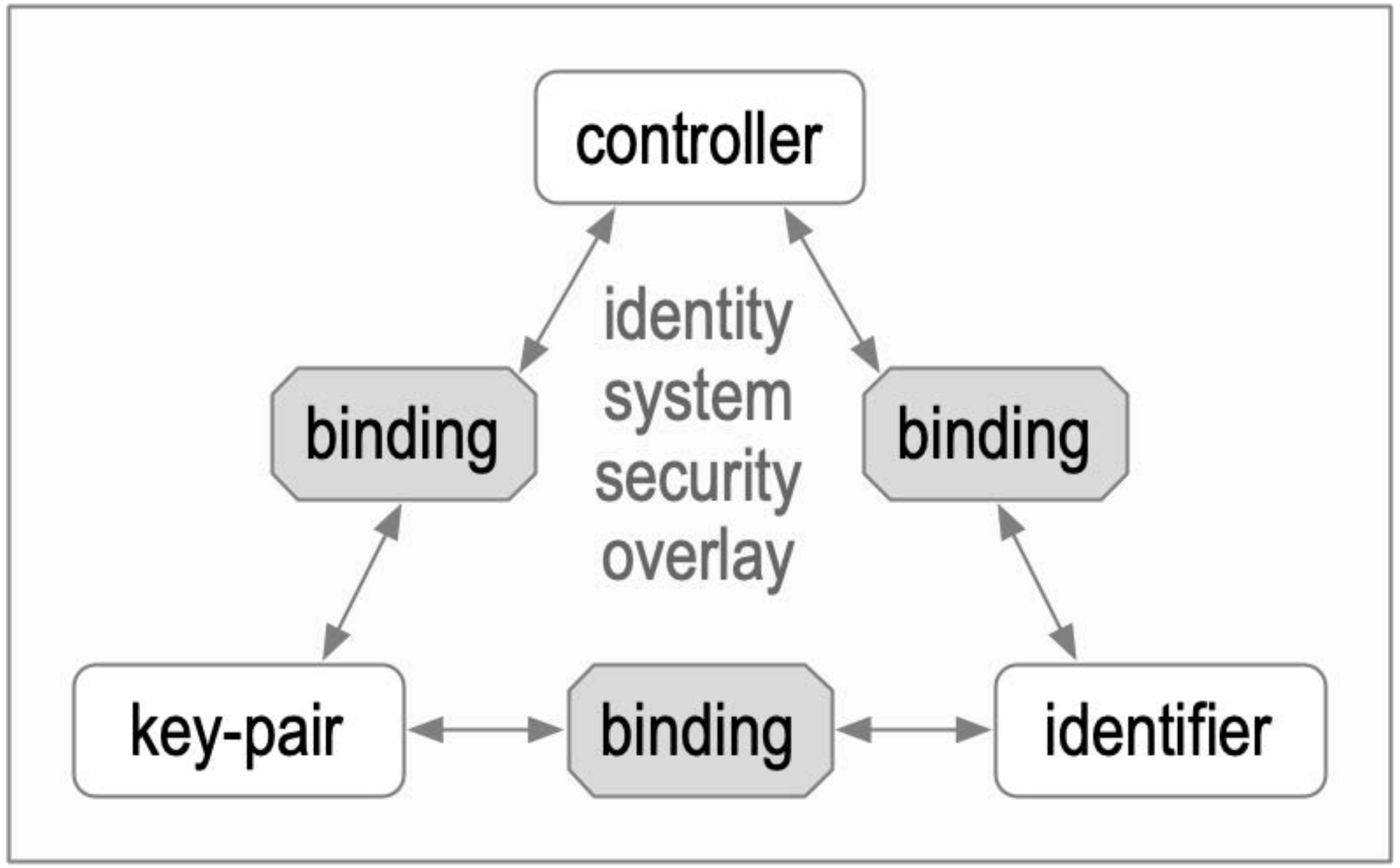
We use *bolt-on* identity system security overlays.
(DNS-CA …)

Identity System Security Overlay

Establish authenticity of IP packet's message payload.

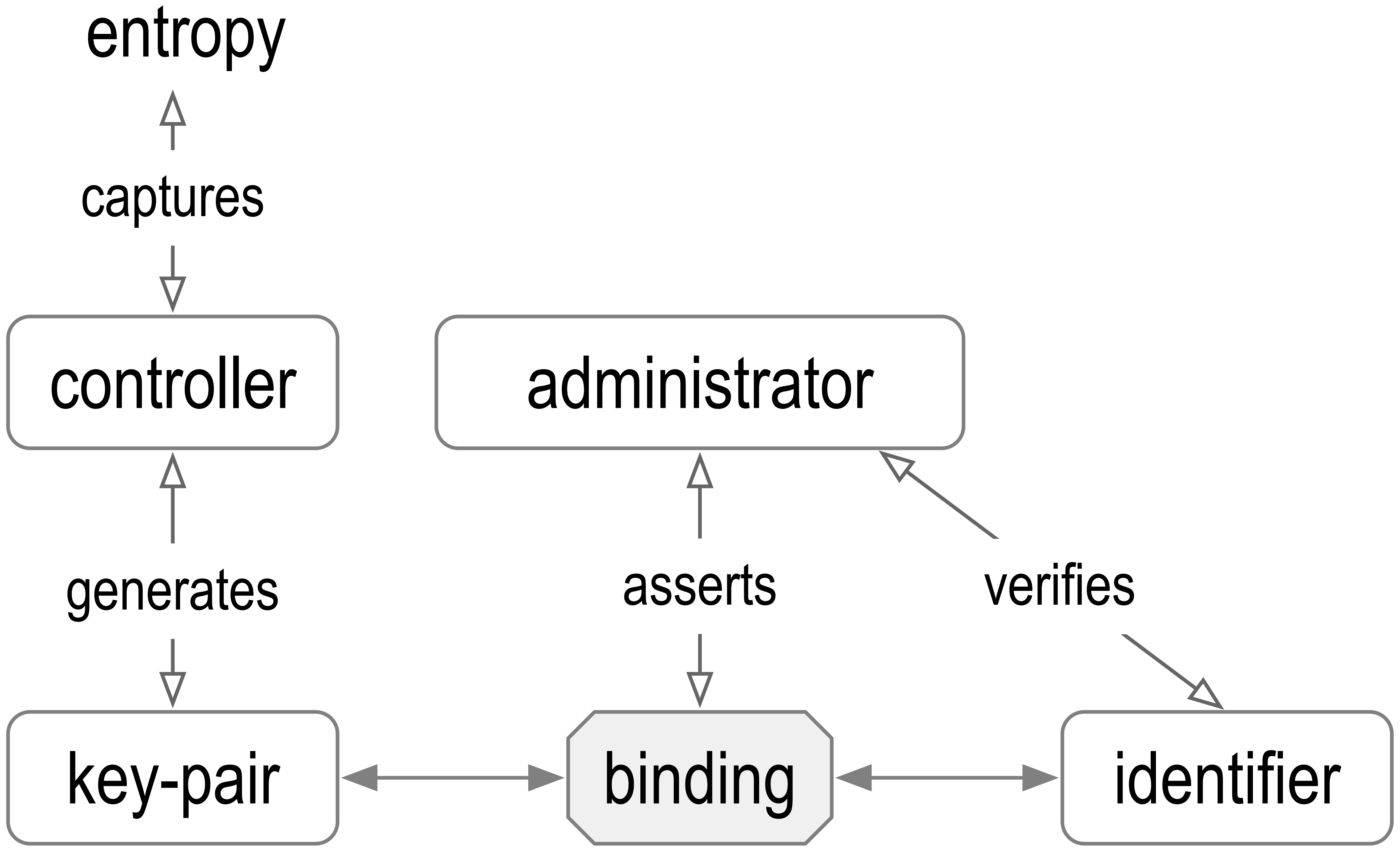


The overlay's security is contingent on the mapping's security.

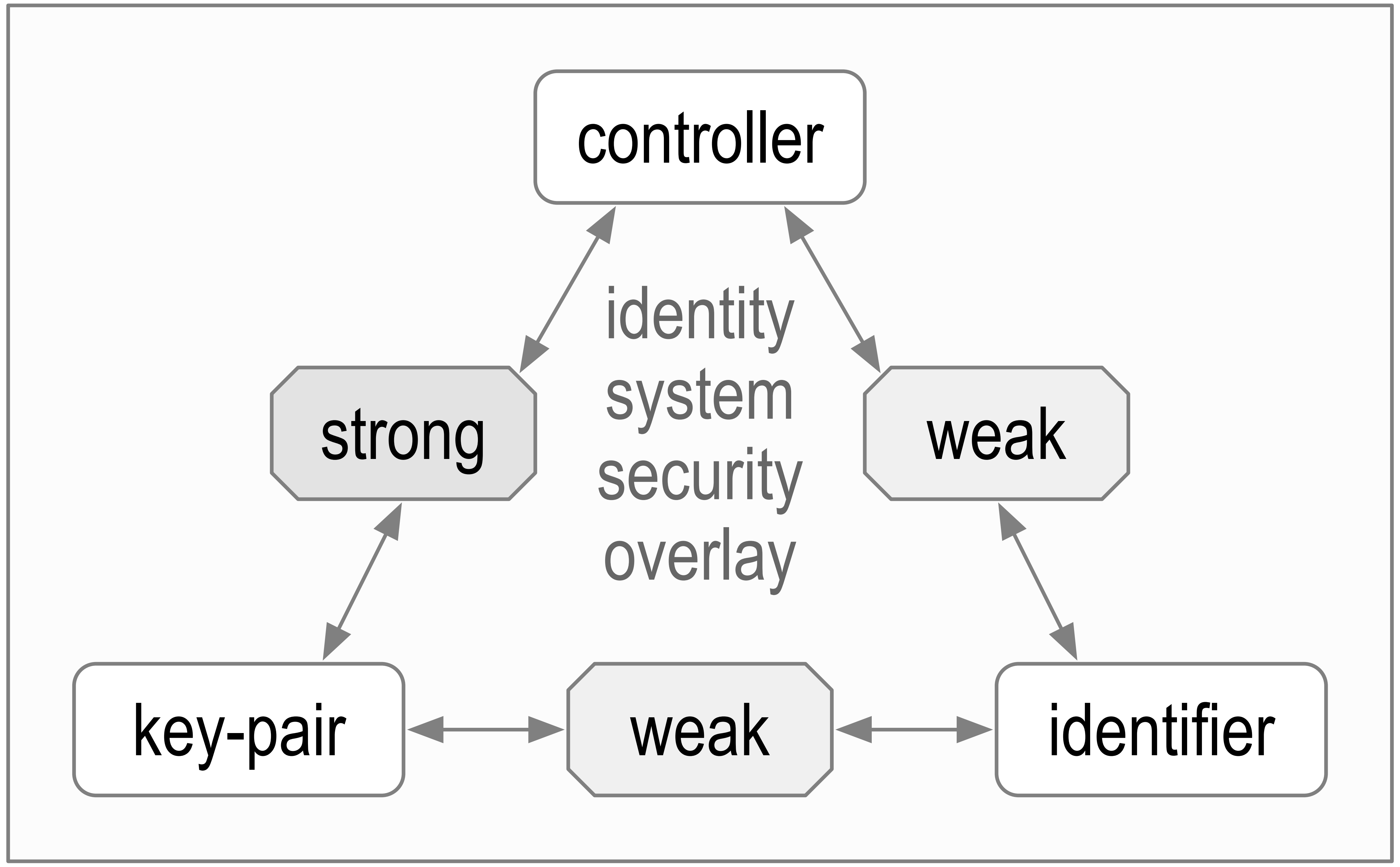


Identifier Issuance

Administrative Identifier Issuance and Binding



admin-certifying

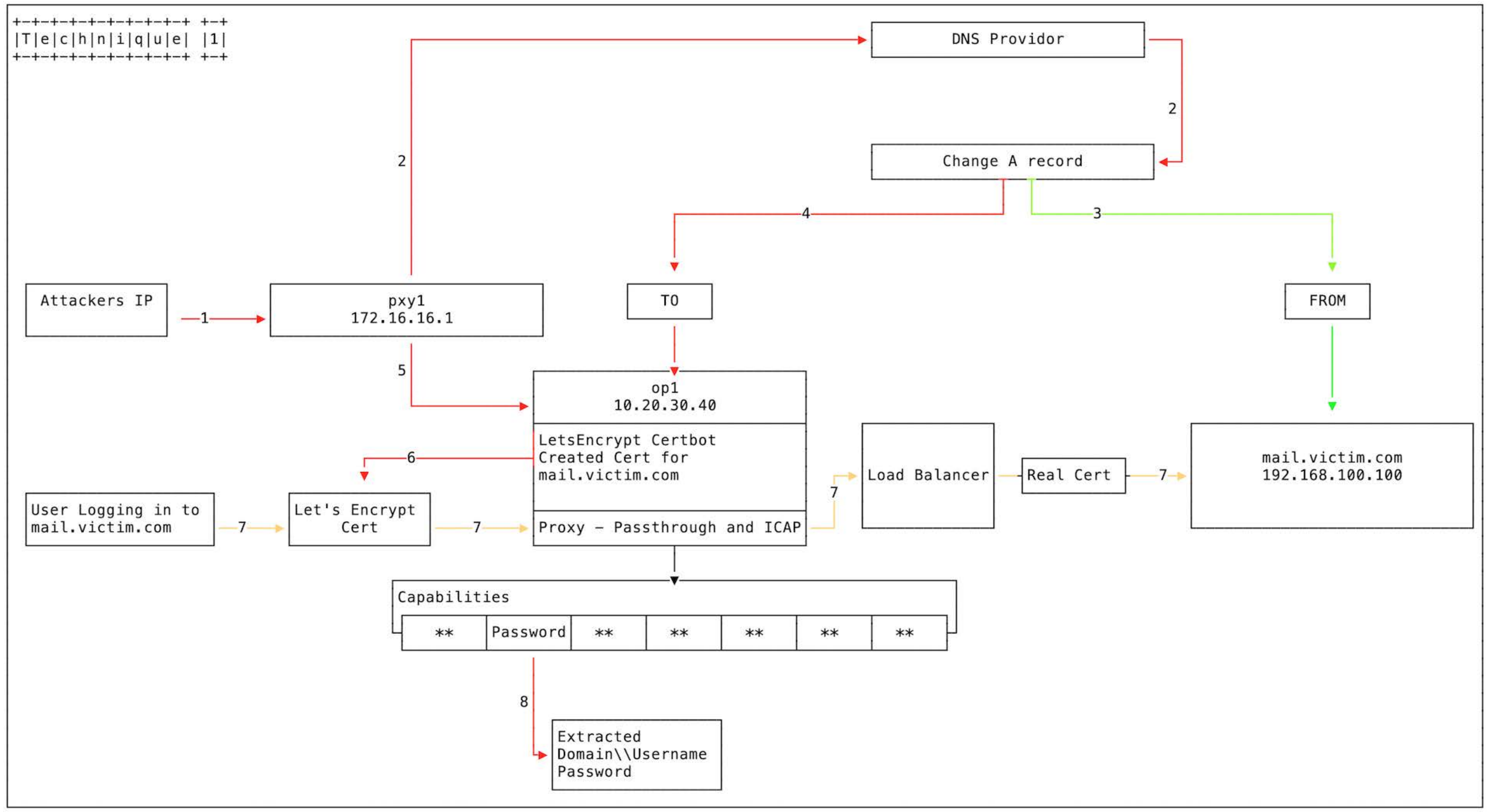


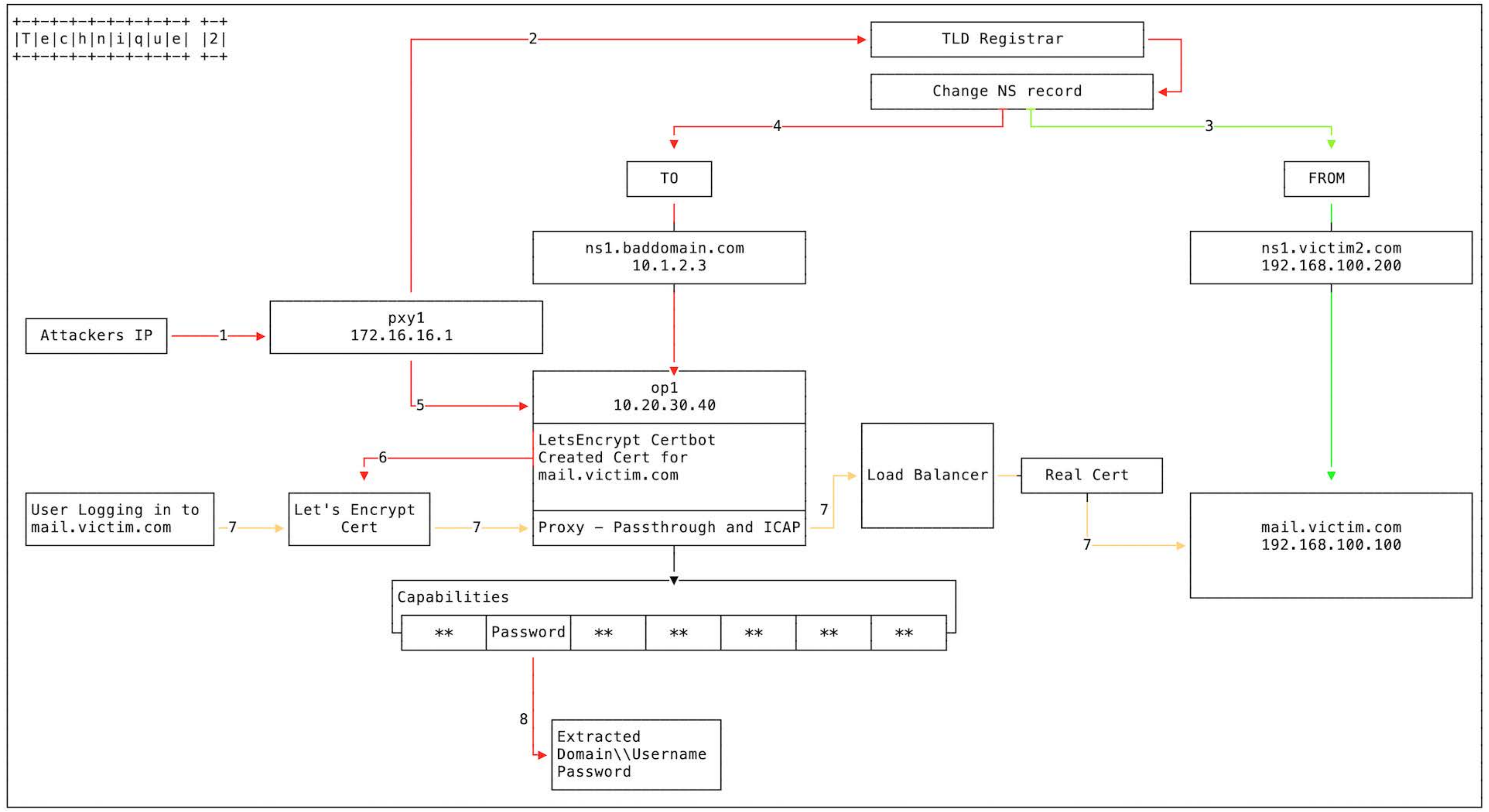
Admin-Certifying Identifier Issuance

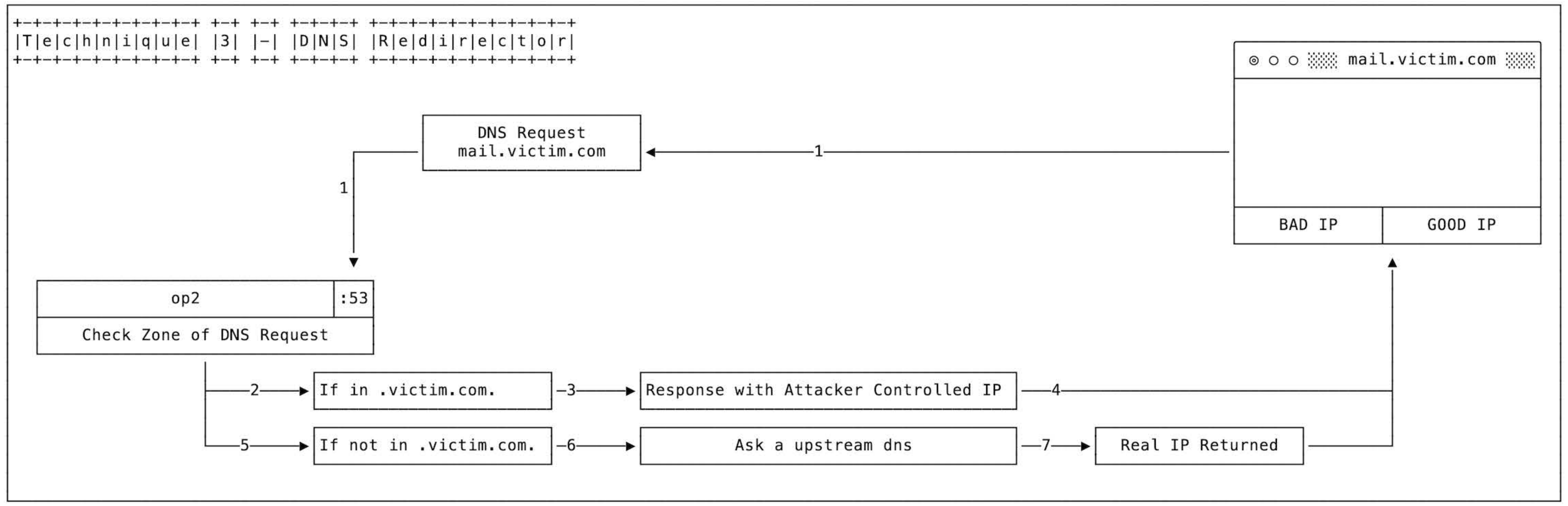
DNS Hijacking

A DNS hijacking wave is targeting companies at an almost unprecedented scale. Clever trick allows attackers to obtain valid TLS certificate for hijacked domains.

https://arstechnica.com/information-technology/2019/01/a-dns-hijacking-wave-is-targeting-companies-at-an-almost-unprecedented-scale/







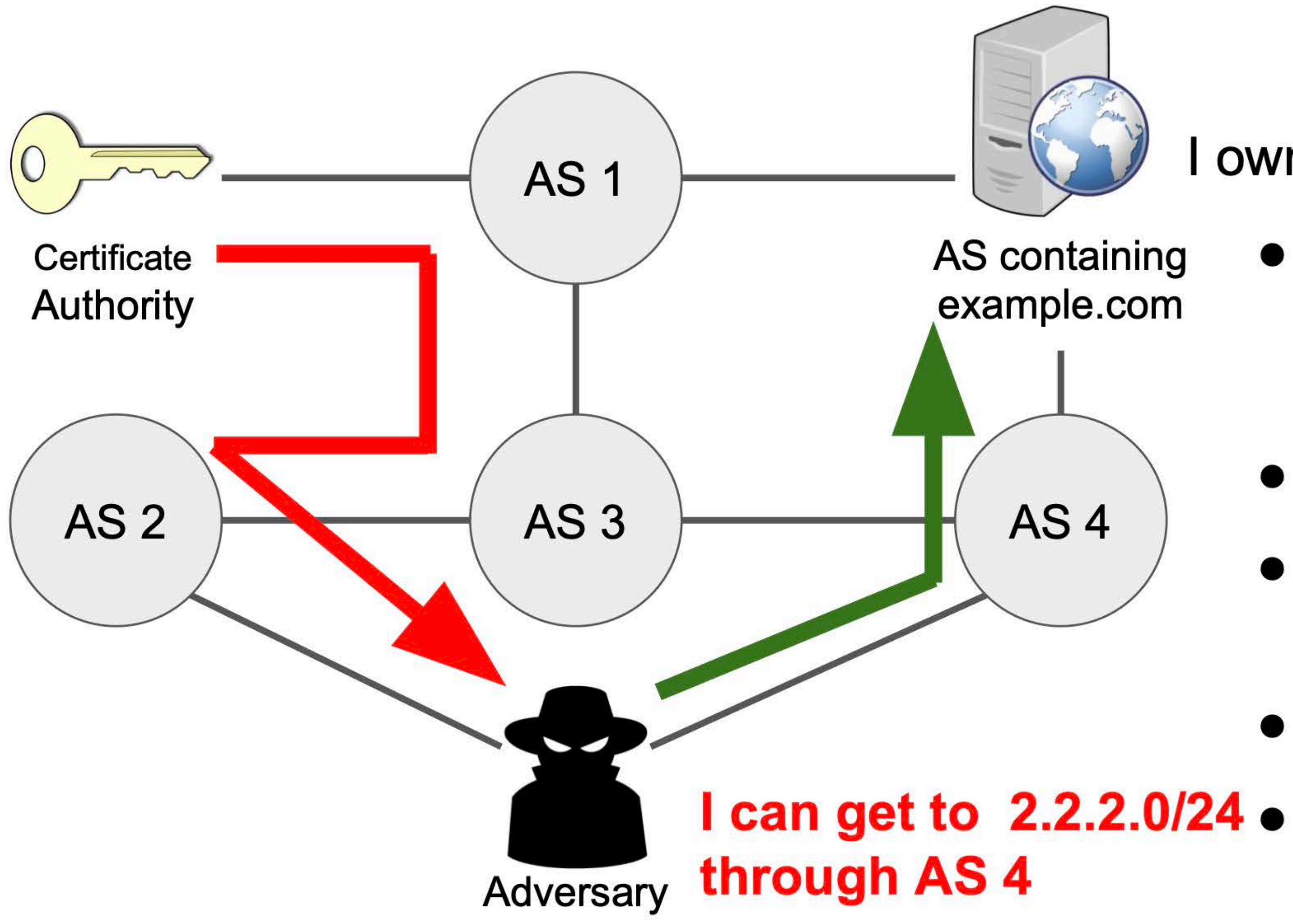
BGP Hijacking: AS Path Poisoning

Spoof domain verification process from CA. Allows attackers to obtain valid TLS certificate for hijacked domains.

Birge-Lee, H., Sun, Y., Edmundson, A., Rexford, J. and Mittal, P., “Bamboozling certificate authorities with {BGP},” vol. 27th {USENIX} Security Symposium, no. {USENIX} Security 18, pp. 833-849, 2018 https://www.usenix.org/conference/usenixsecurity18/presentation/birge-lee

Gavrichenkov, A., “Breaking HTTPS with BGP Hijacking,” BlackHat, 2015 https://www.blackhat.com/docs/us-15/materials/us-15-Gavrichenkov-Breaking-HTTPS-With-BGP-Hijacking-wp.pdf

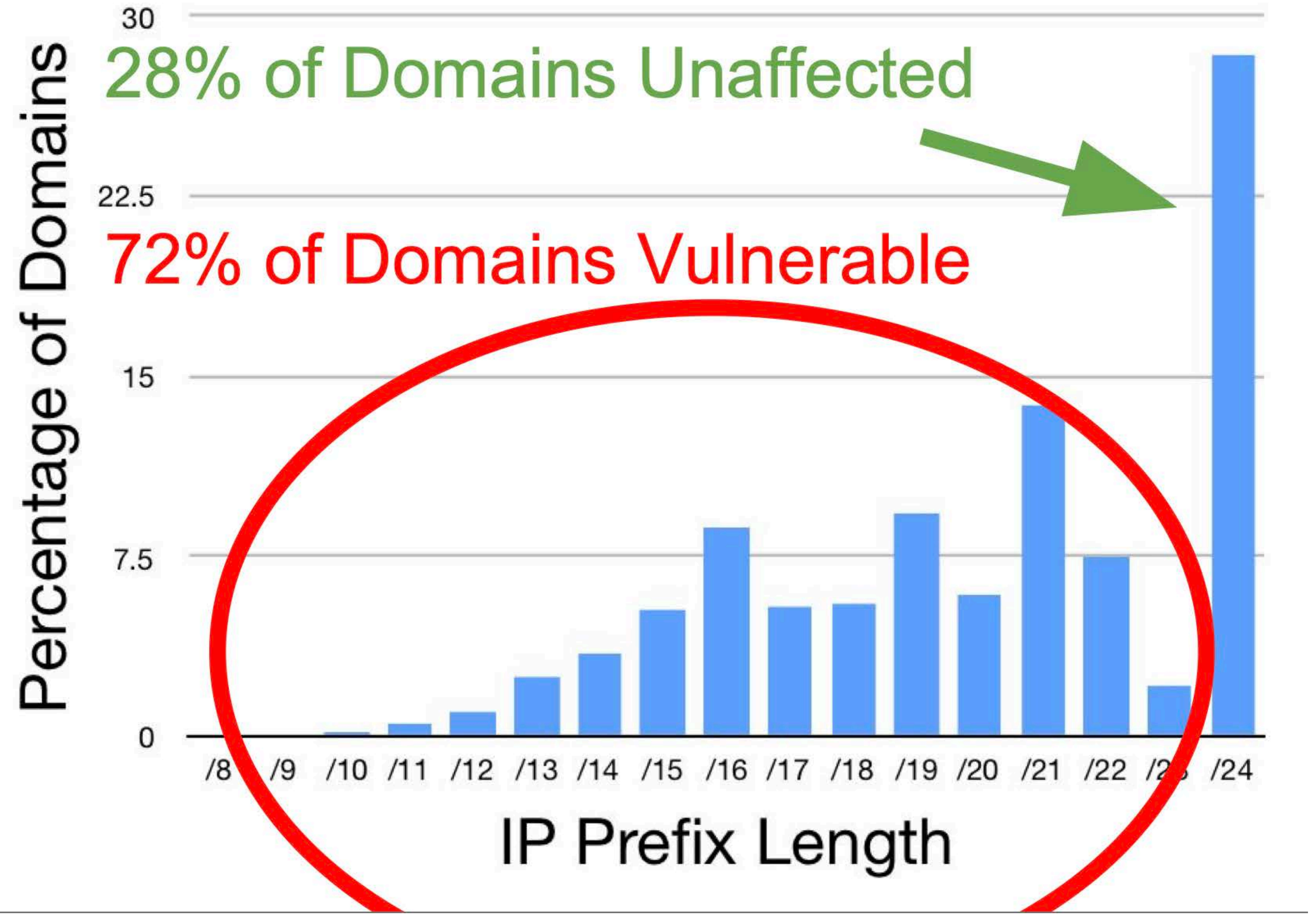
AS path poisoning



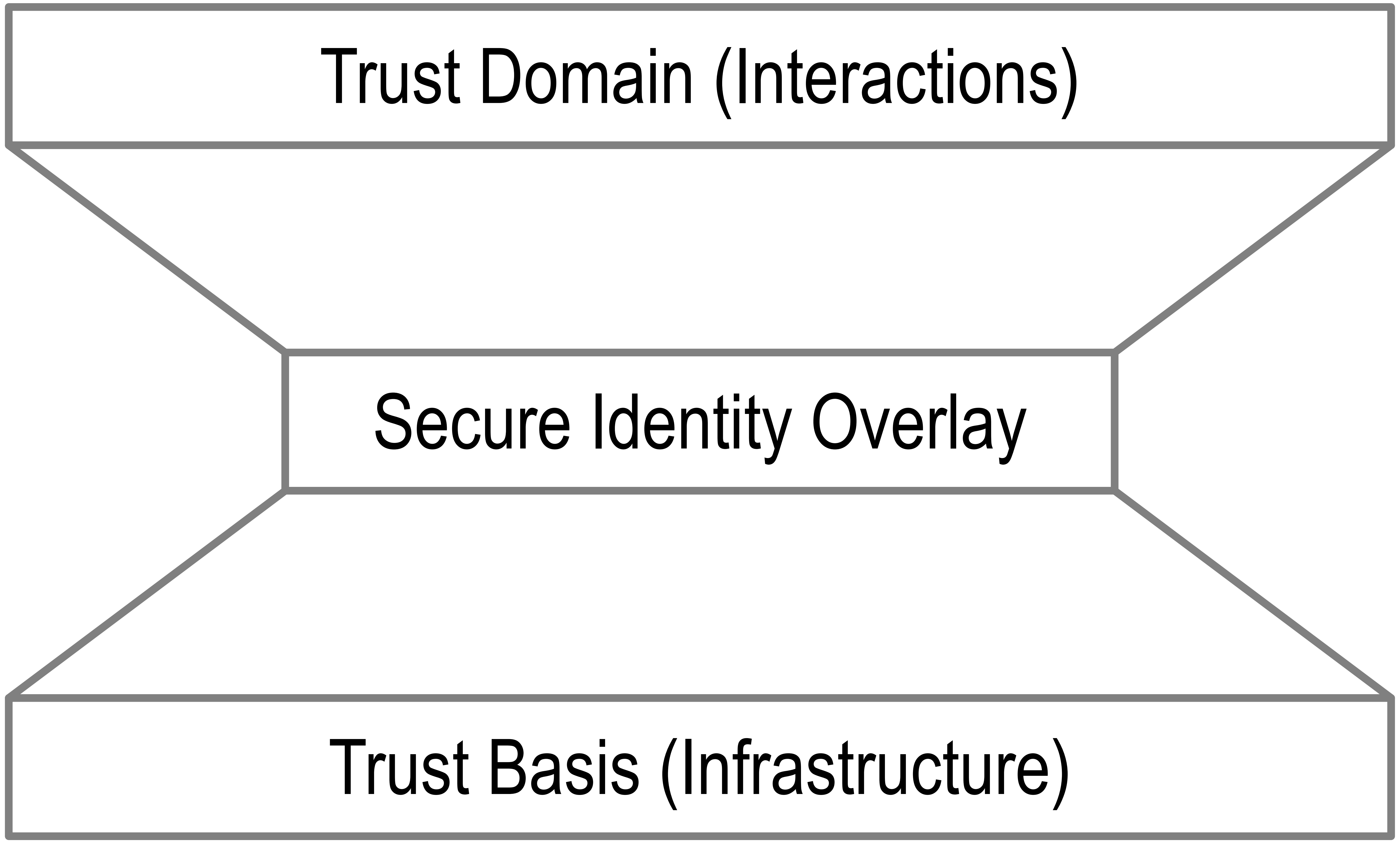
- Everyone sees announcement but looks less suspicious
- Connectivity preserved
- Almost any AS can perform
- Very stealthy
- Perfect setup to intercept traffic with certificate

Vulnerability of domains: sub-prefix attacks

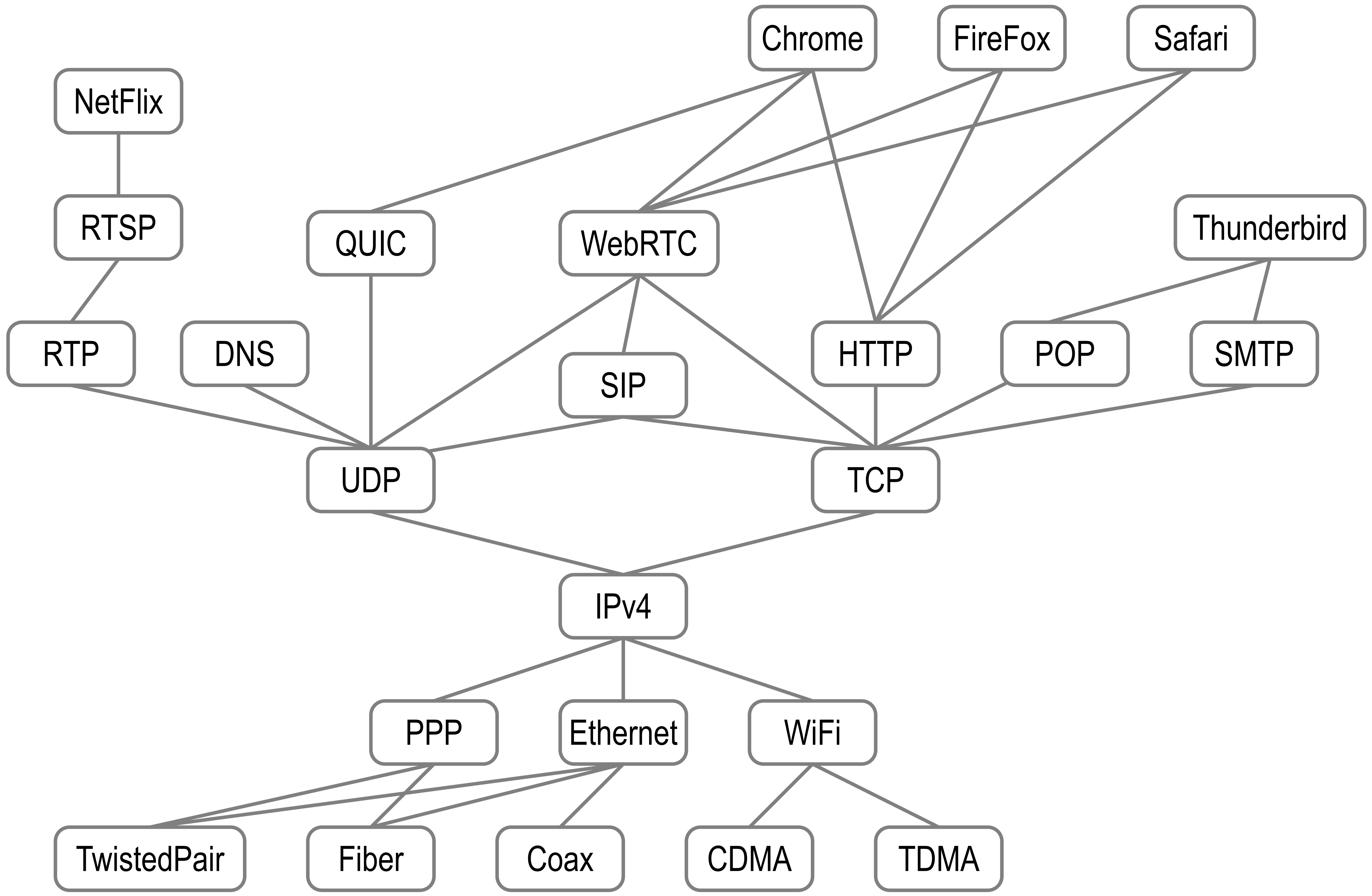
- Any AS can launch
- Only prefix lengths less than /24 vulnerable (filtering)

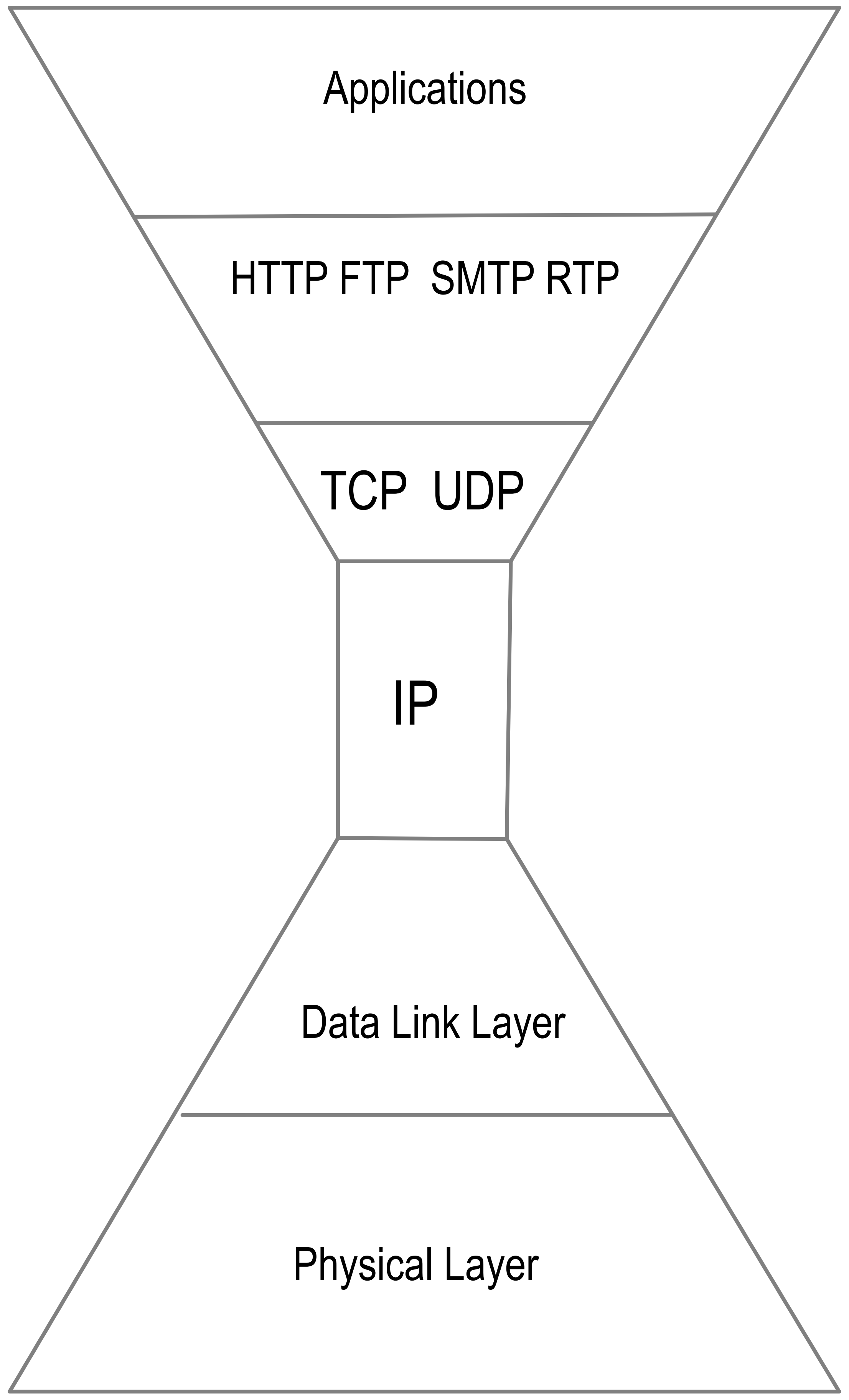


Identity System Security Overlay

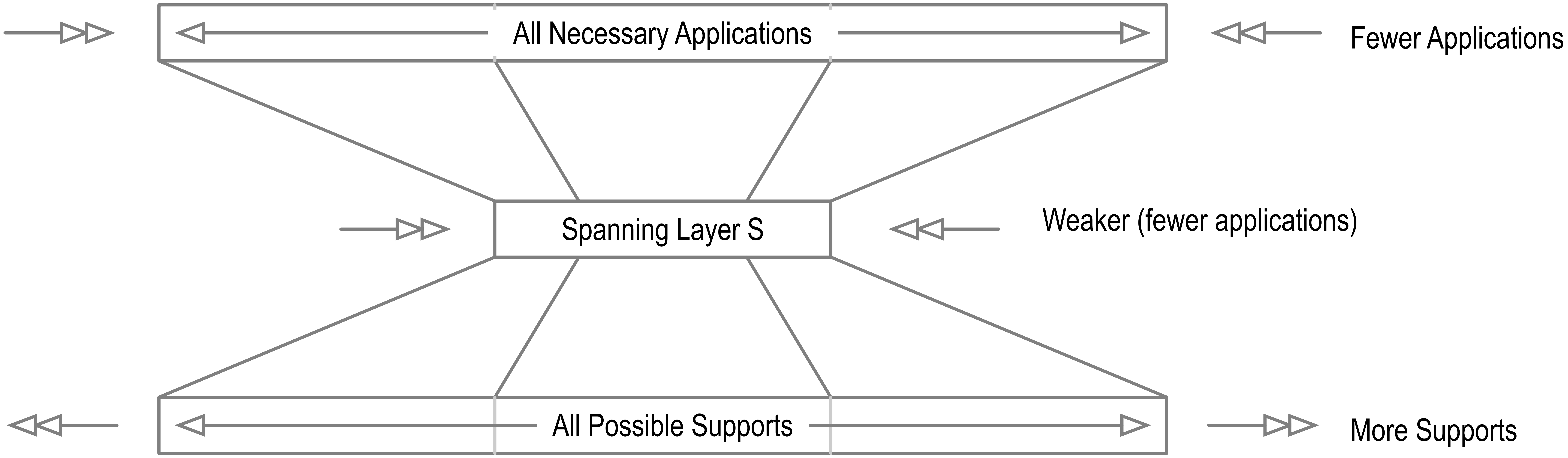


Spanning Layer



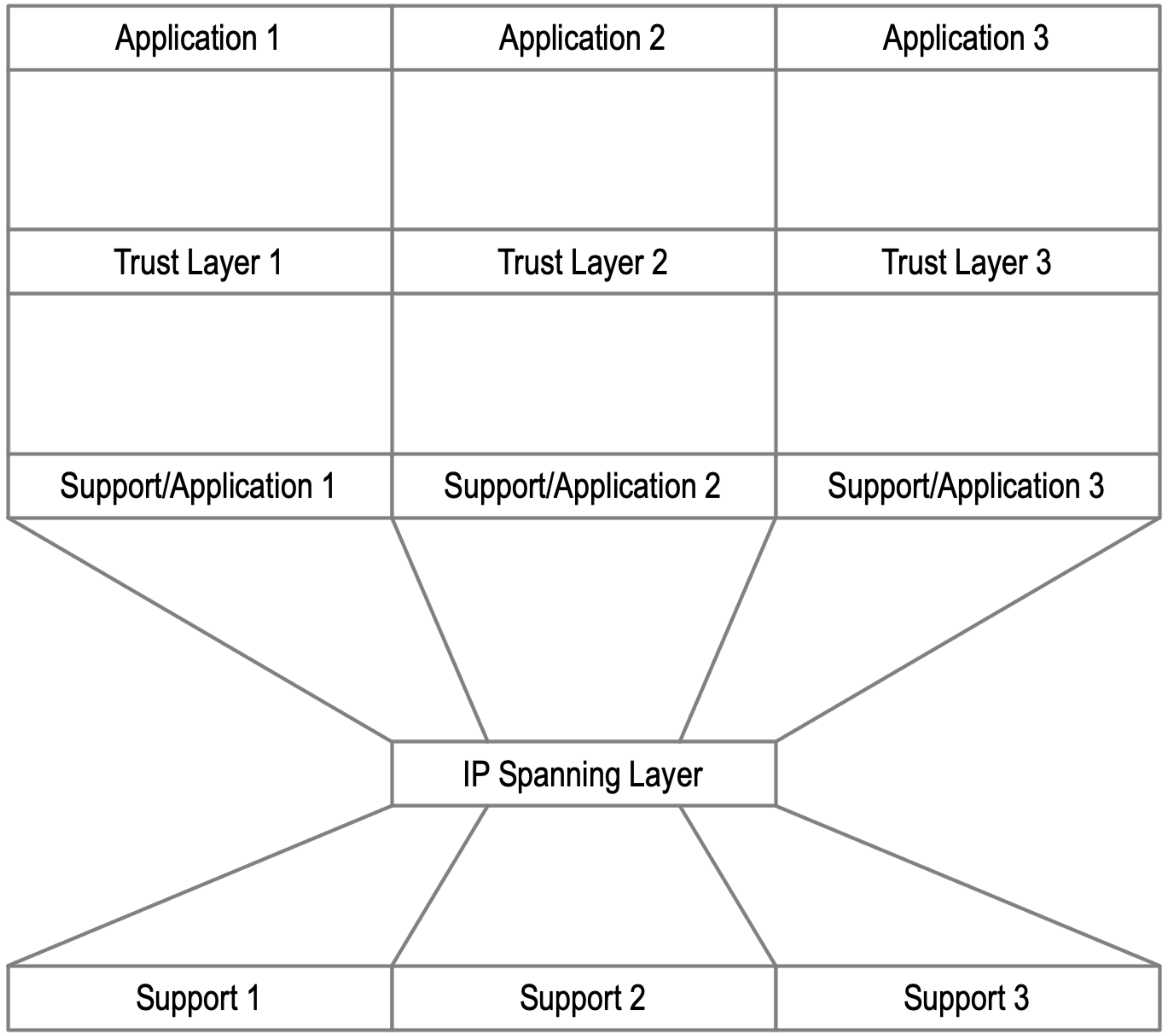


Hourglass

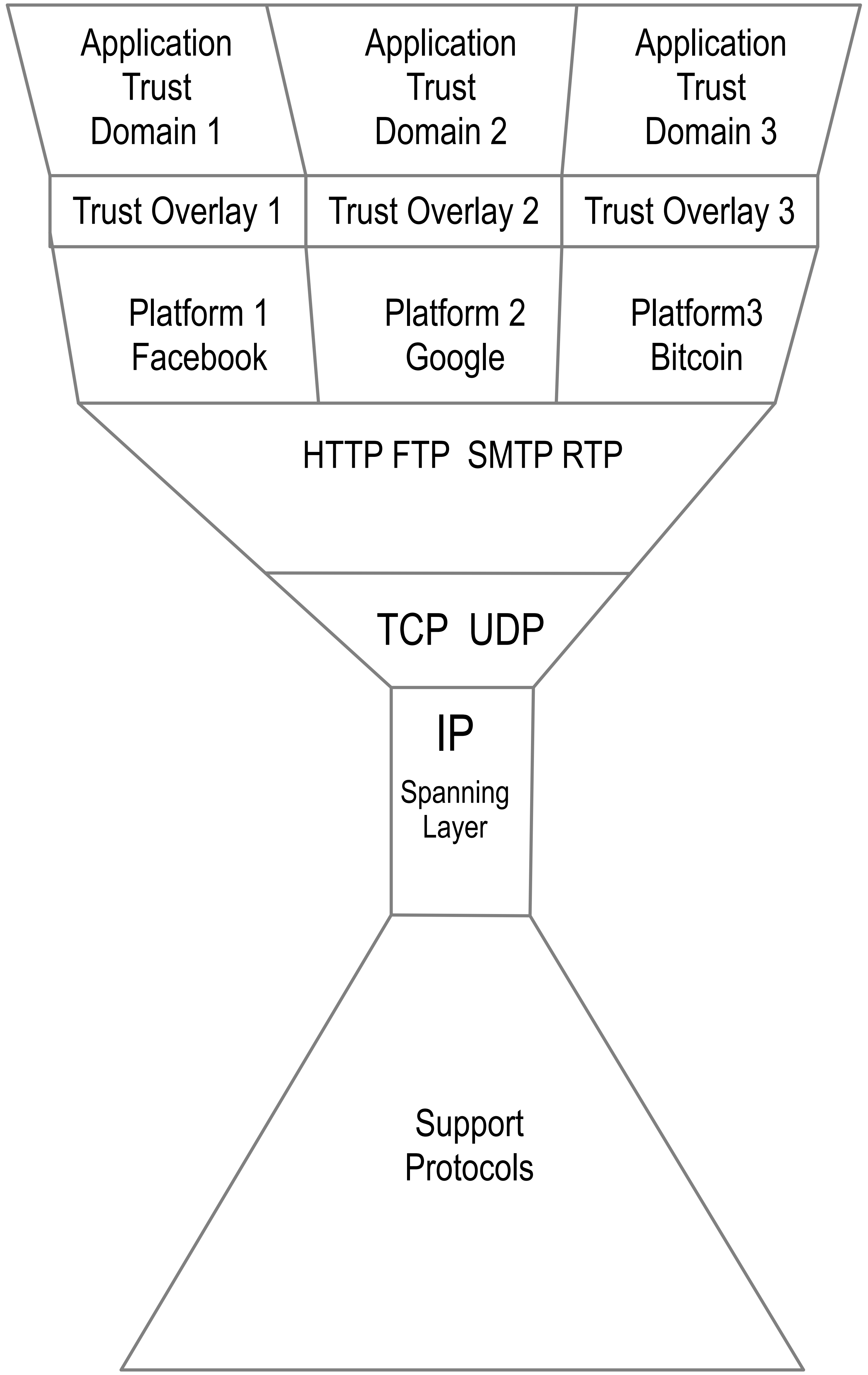


All Necessary Applications
Fewer Applications
Spanning Layer S
Weaker (fewer applications)
All Possible Supports
More Supports

Platform Locked Trust

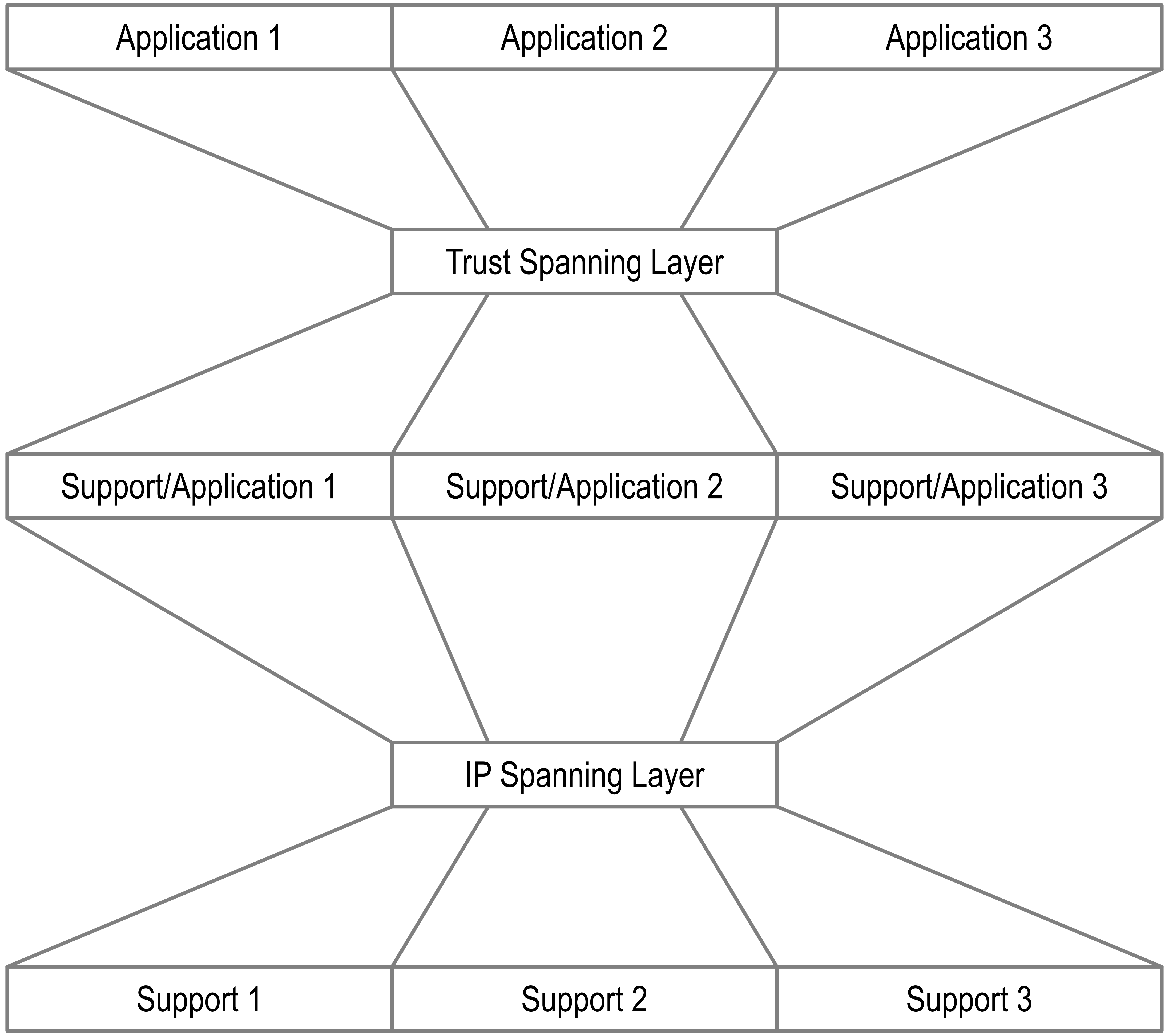


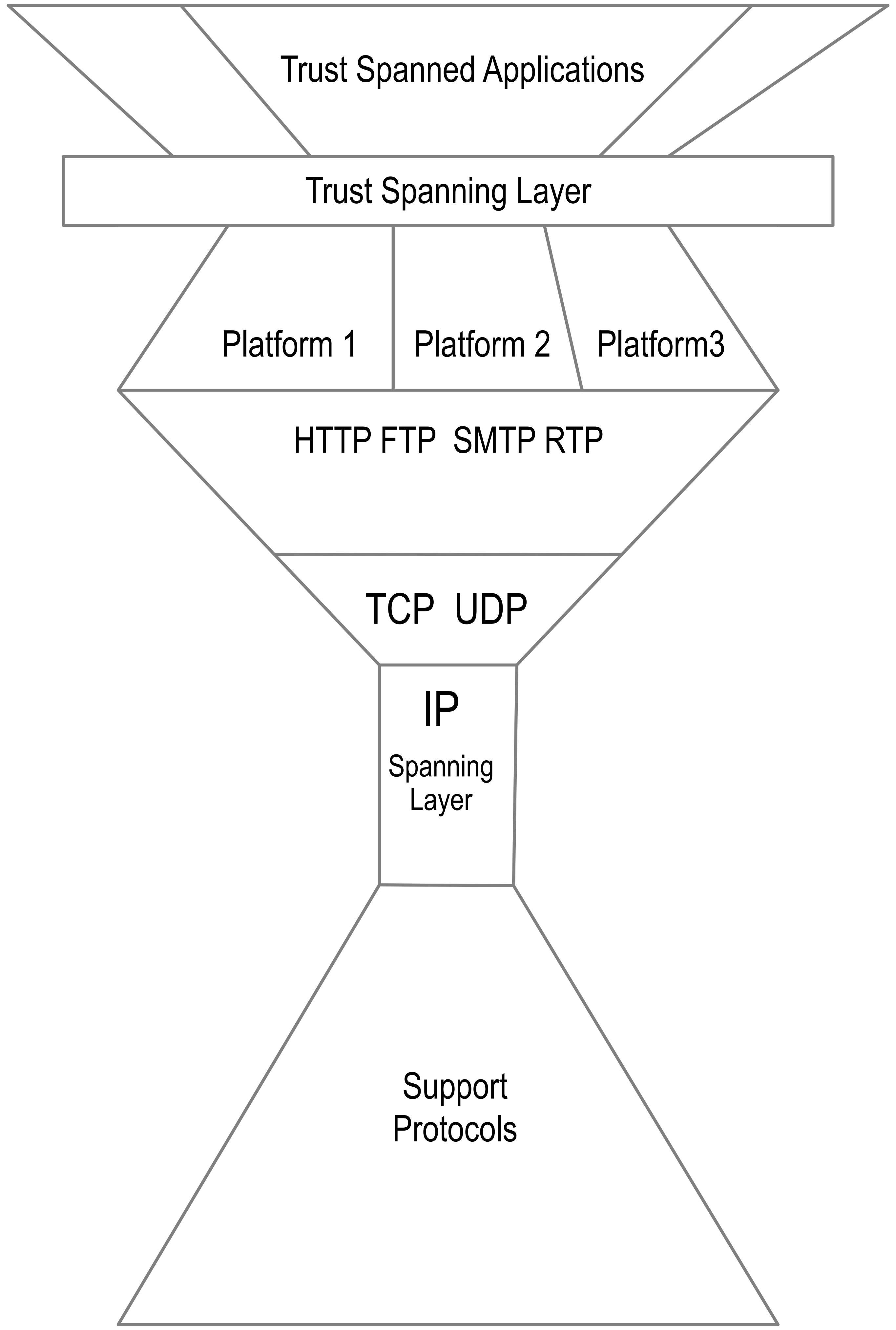
Trust Domain Based Segmentation



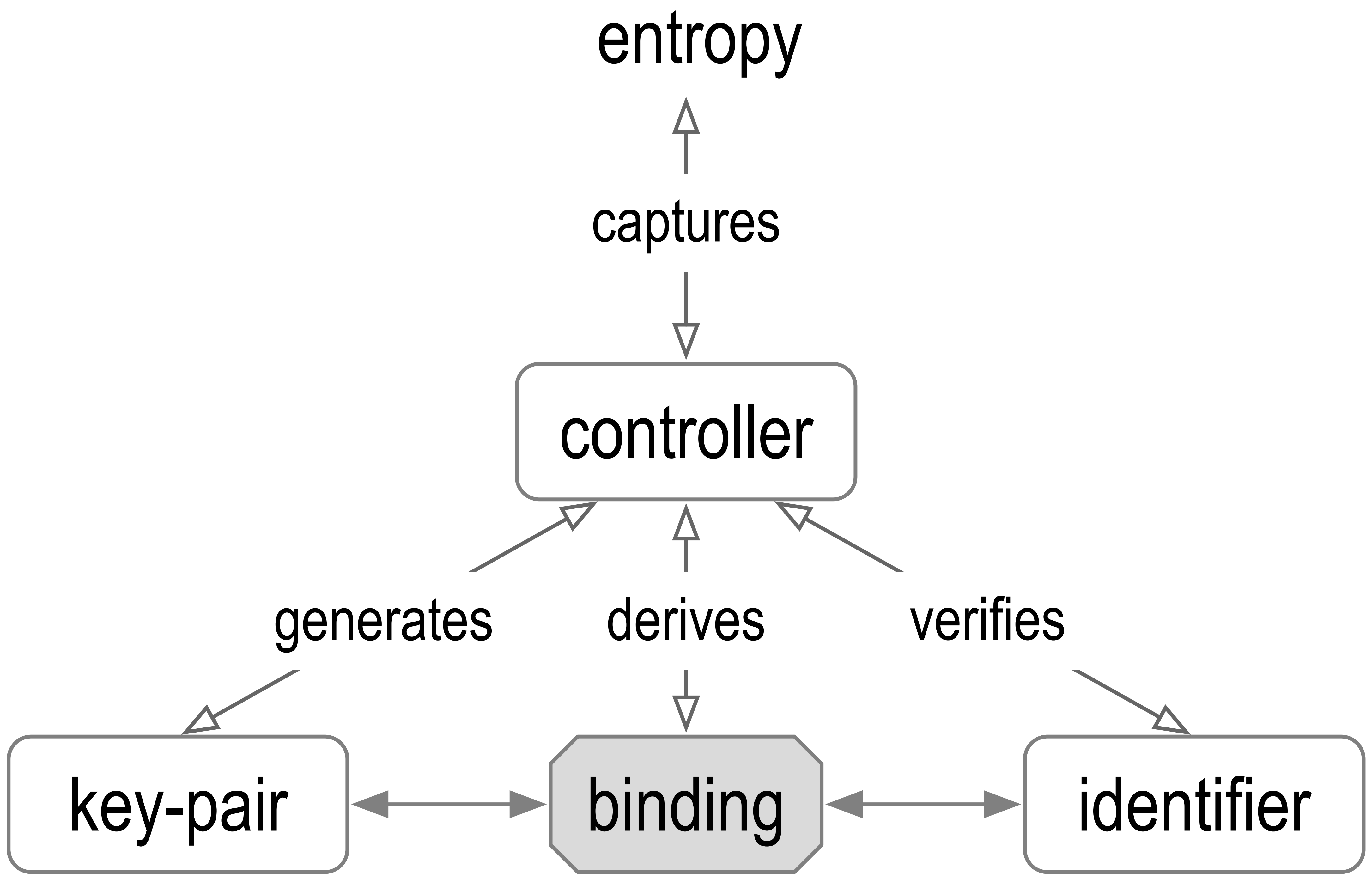
Each trust layer only spans platform specific applications
Bifurcates the internet trust map
No spanning trust layer

Waist and Neck

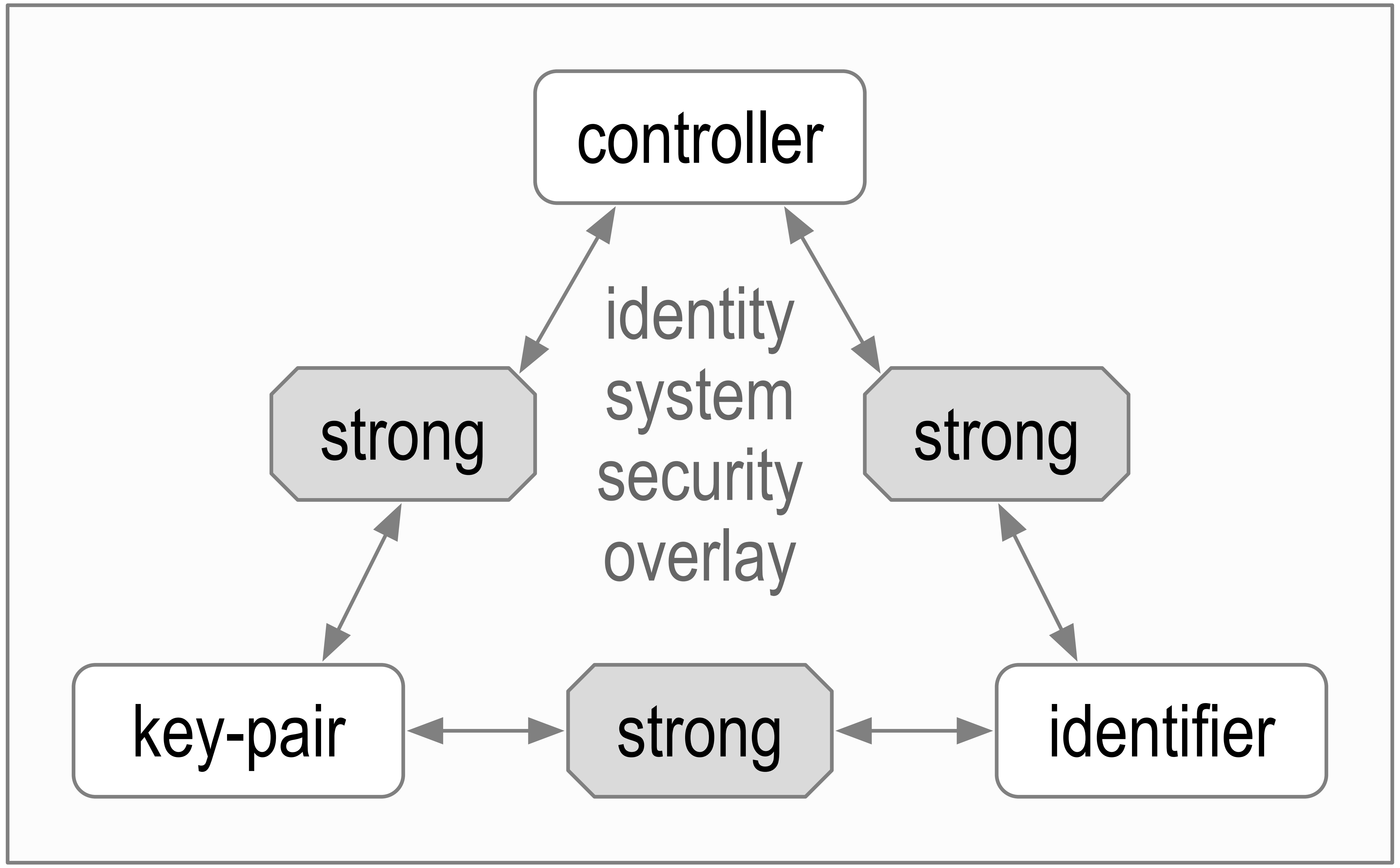




Self-Certifying Identifier Issuance and Binding

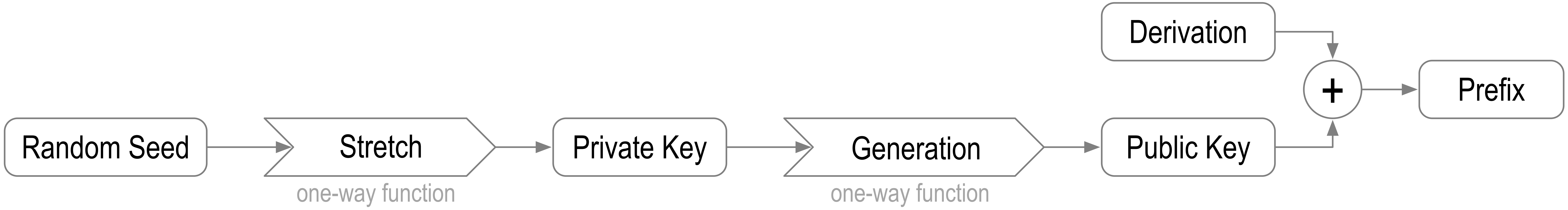


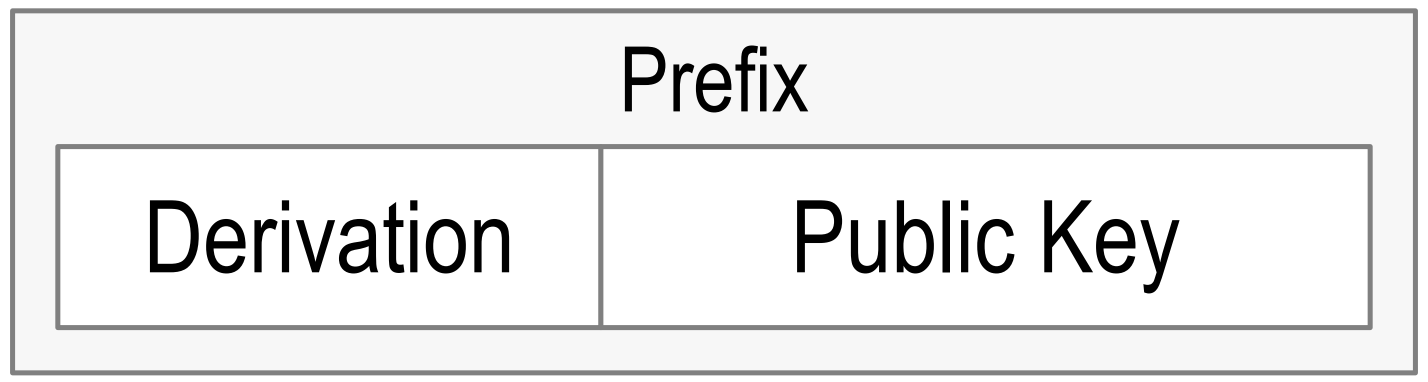
self-certifying

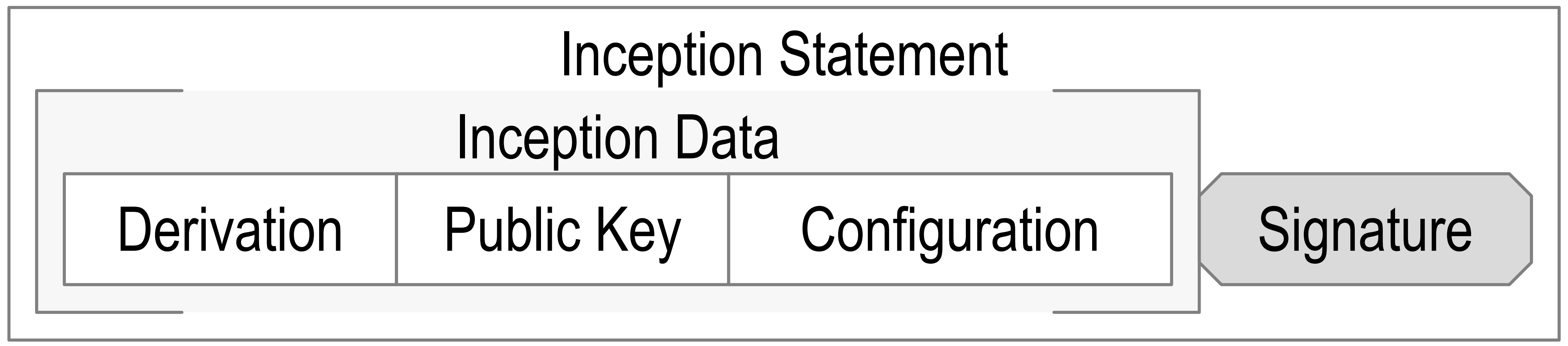


Self-Certifying Identifier Issuance

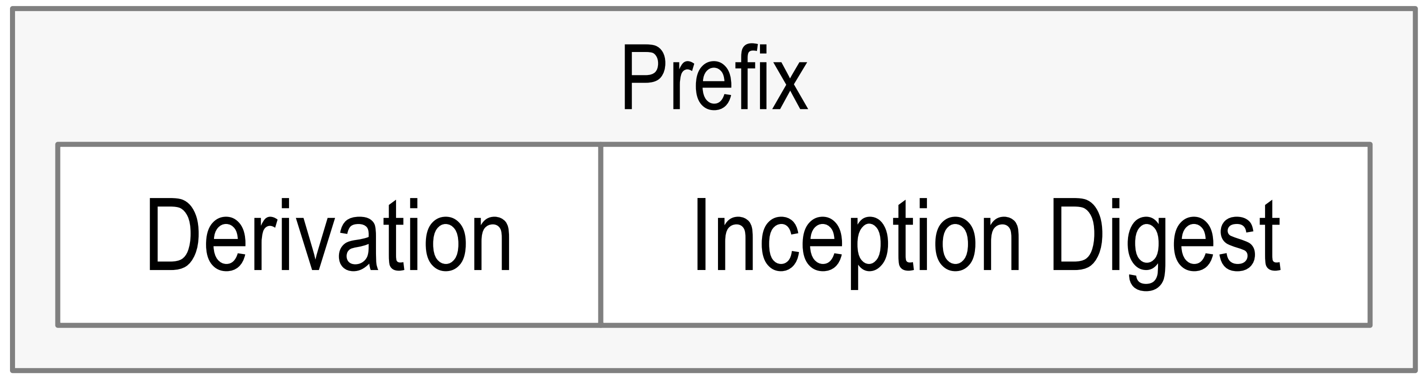
Basic

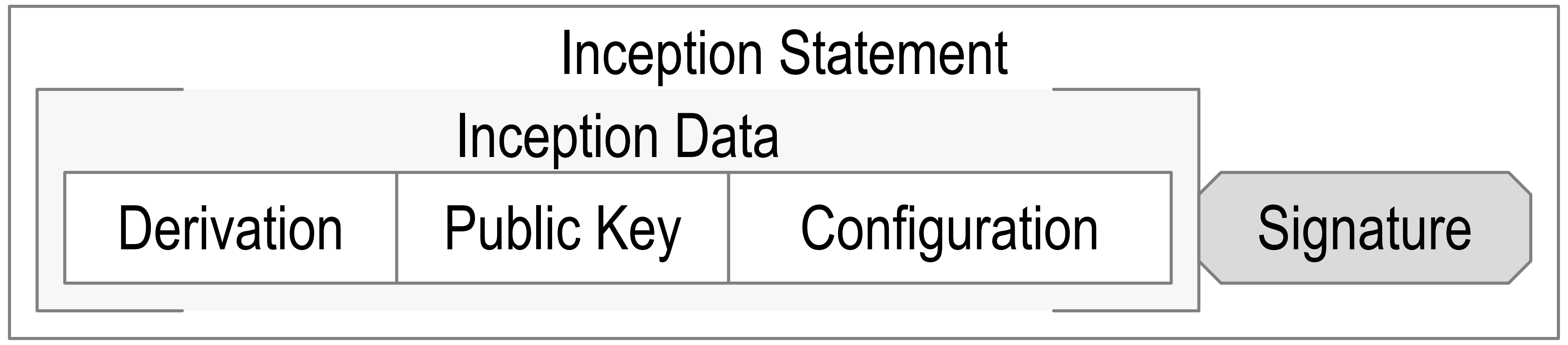

Derivation
+
Prefix
Random Seed
Stretch
one-way function
Private Key
Generation
one-way function
Public Key


Prefix
Derivation
Public Key


Inception Statement
Inception Data
Derivation
Public Key
Configuration
Signature

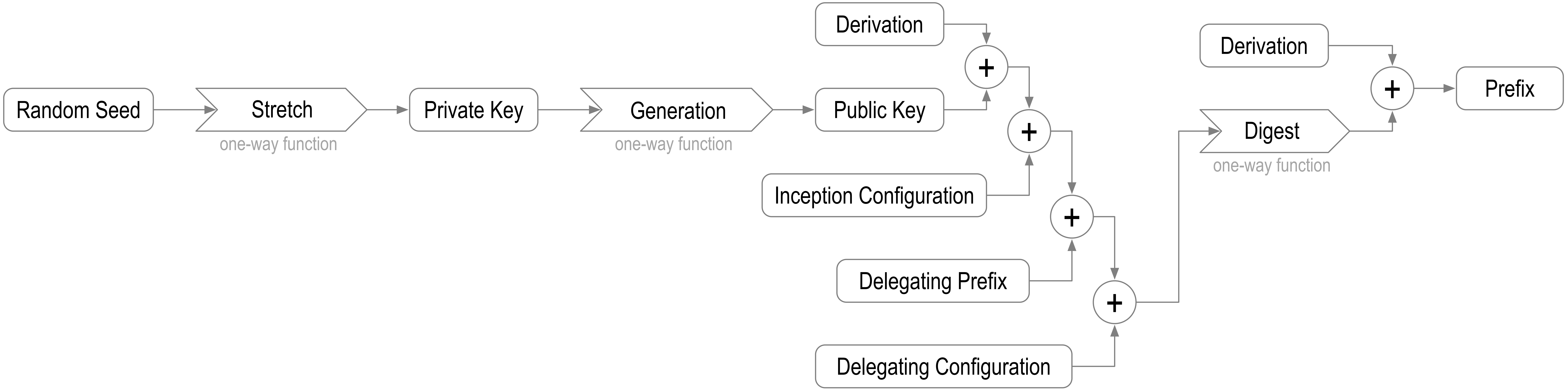
Self-Addressing

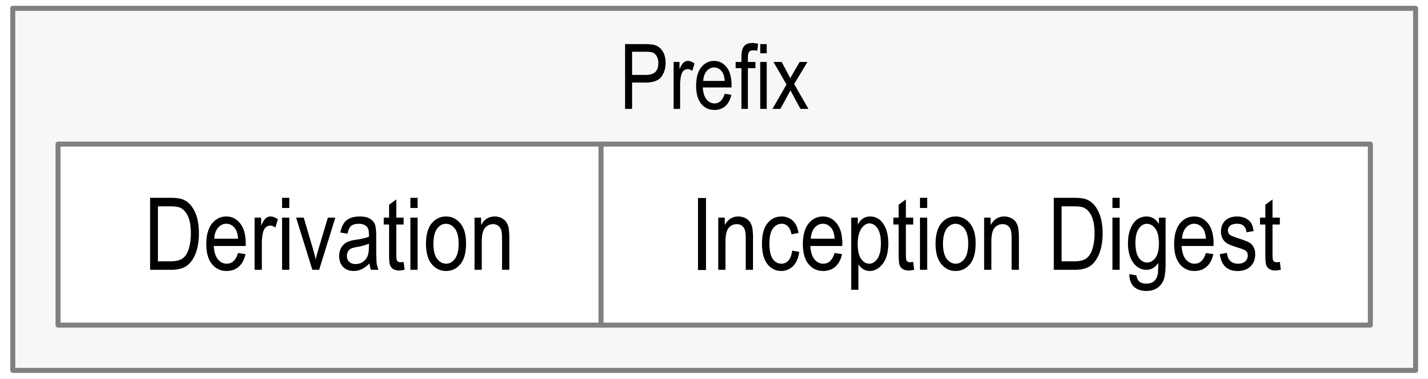


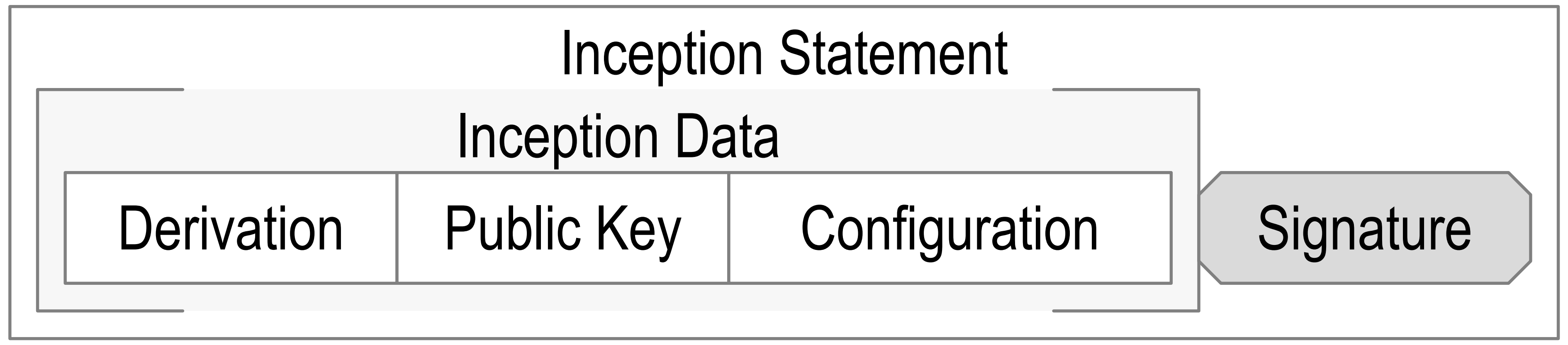


Multi-Sig Self-Addressing

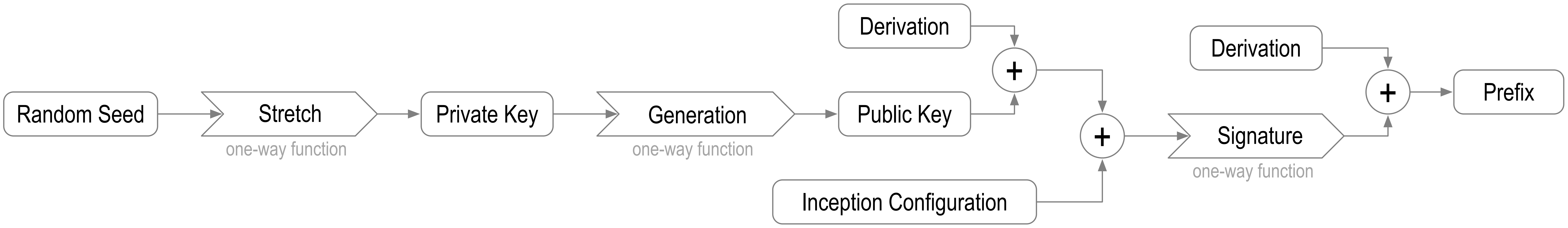
Delegated Self-Addressing

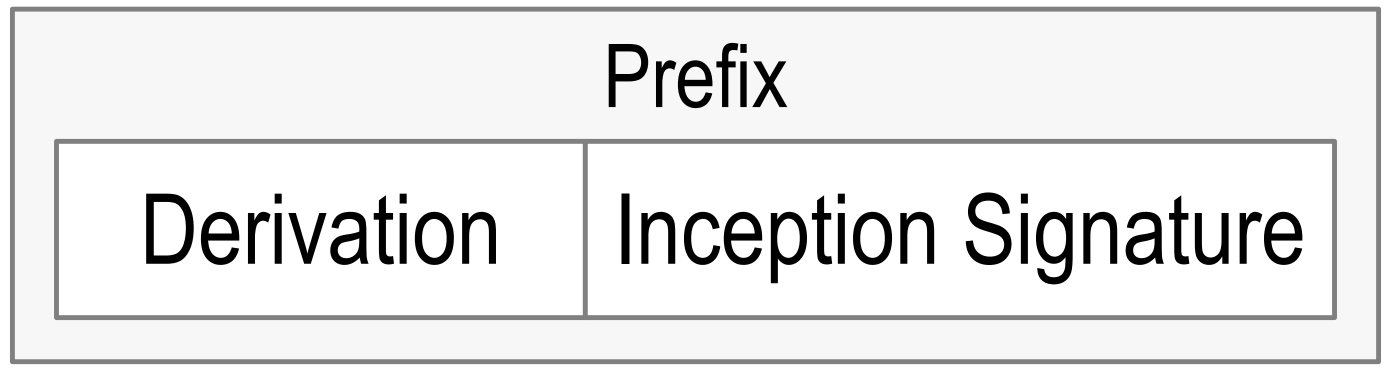


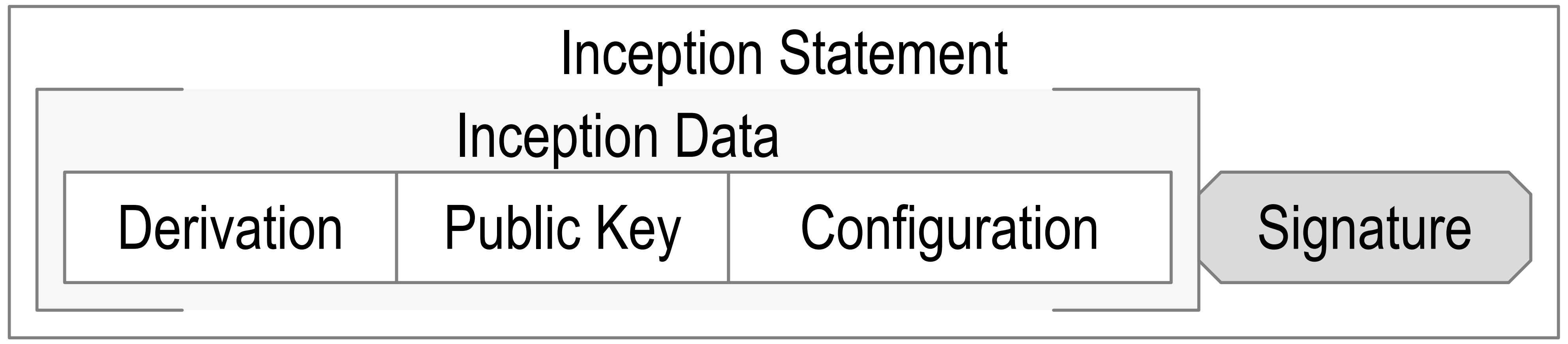




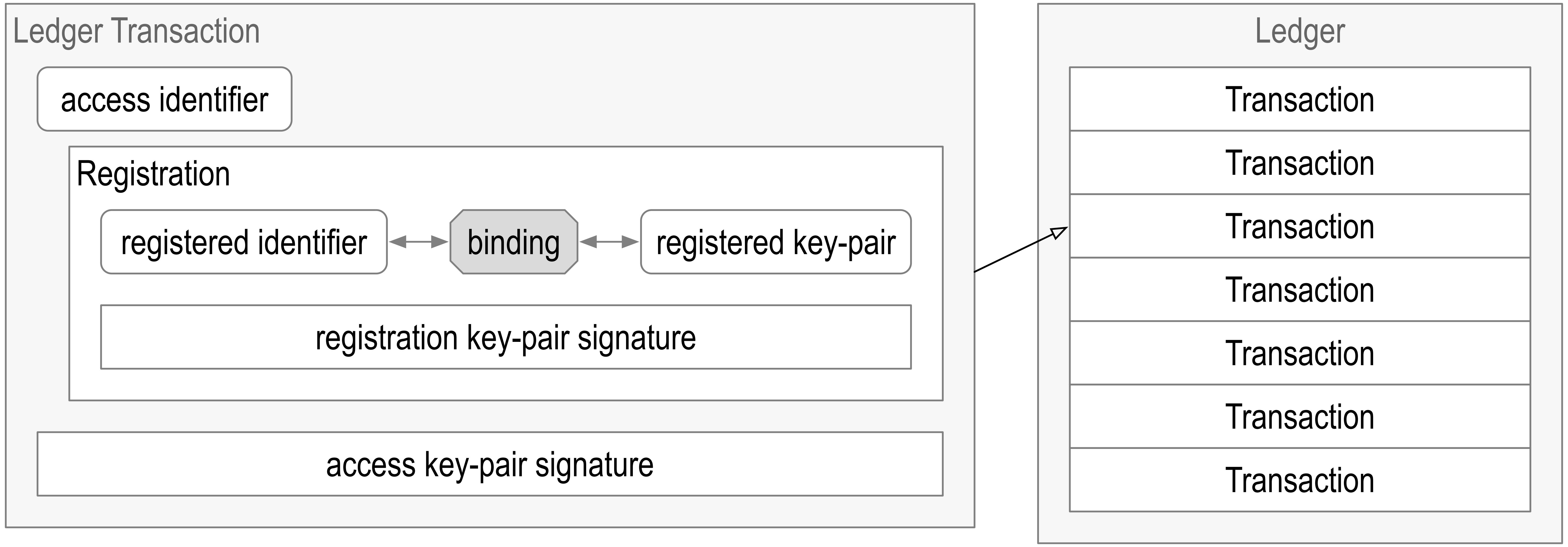
Self-Signing

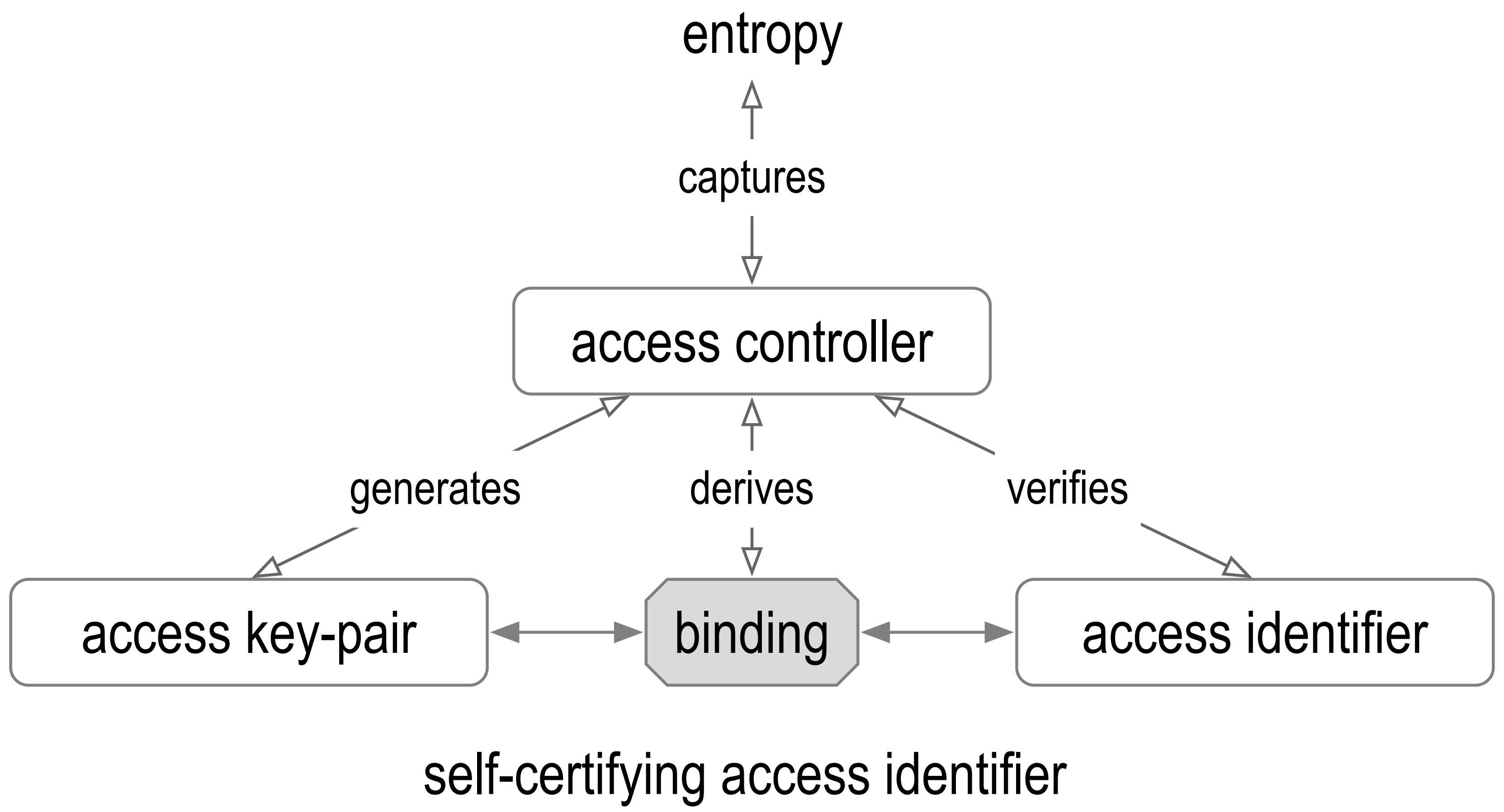






Ledger Registration





The access identifier may have a self-certifying primary root-of-trust, but the registered identifier does not, even if its format appears to be self-certifying.

Autonomic Identifier (AID) and Namespace (AN)

auto nomos = self rule

autonomic = self-governing, self-controlling, etc.

An *autonomic* namespace is

self-certifying and hence *self-administrating.*

ANs are *portable* = truly self-sovereign.

autonomic prefix = self-cert + UUID + URL = universal identifier

Autonomic Identity System

why, *how* – *who* controls *what*, *when*, and *how*?

Root-of-Trust

cryptographic autonomic identifier = *why*, *how*

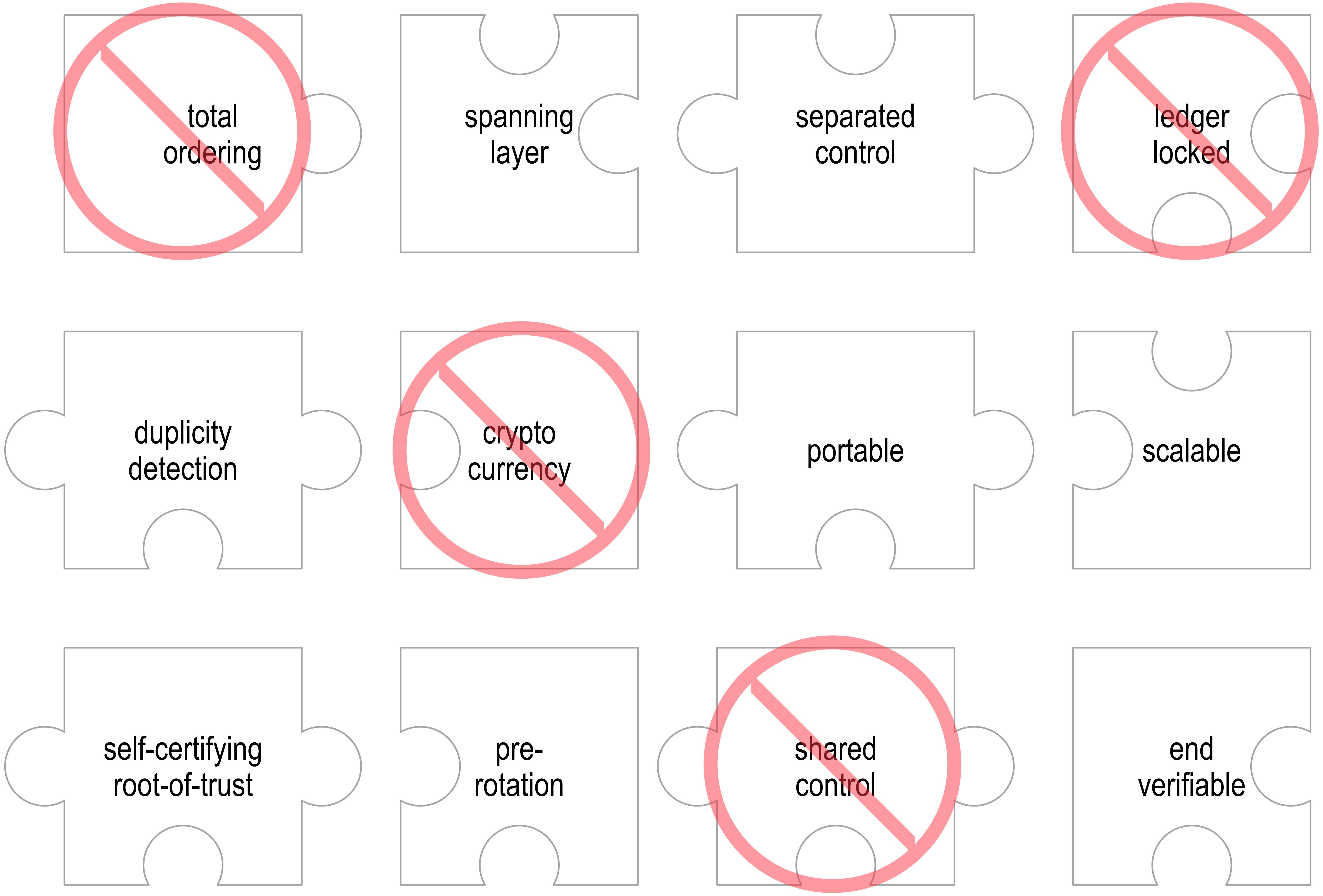
Source-of-Truth

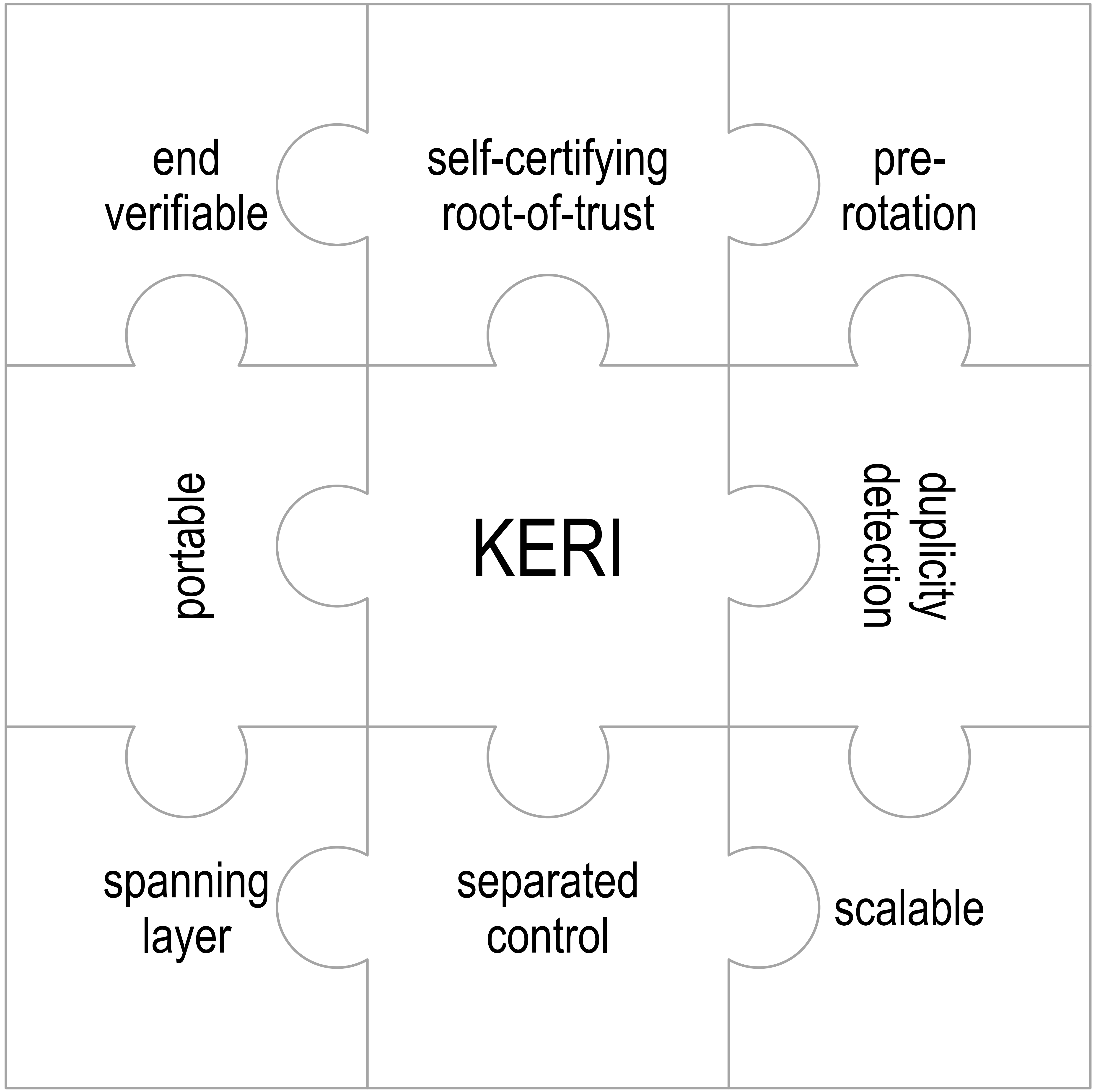
controller of the private key = *who*

Loci-of-Control

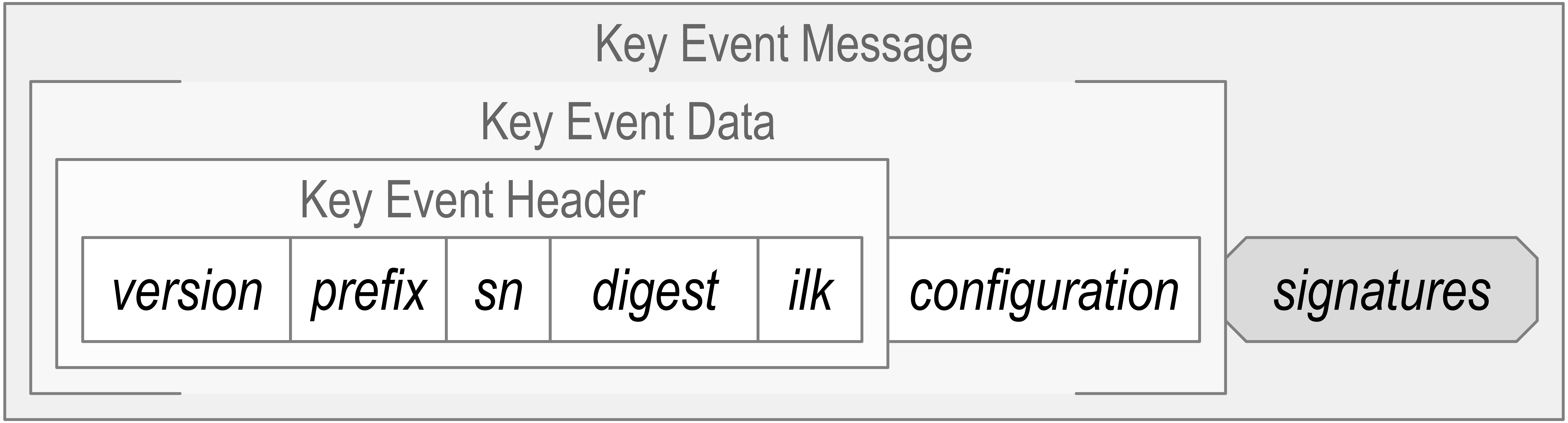
authoritative operation = *what*, *when*, *how*

System Design Trade Space

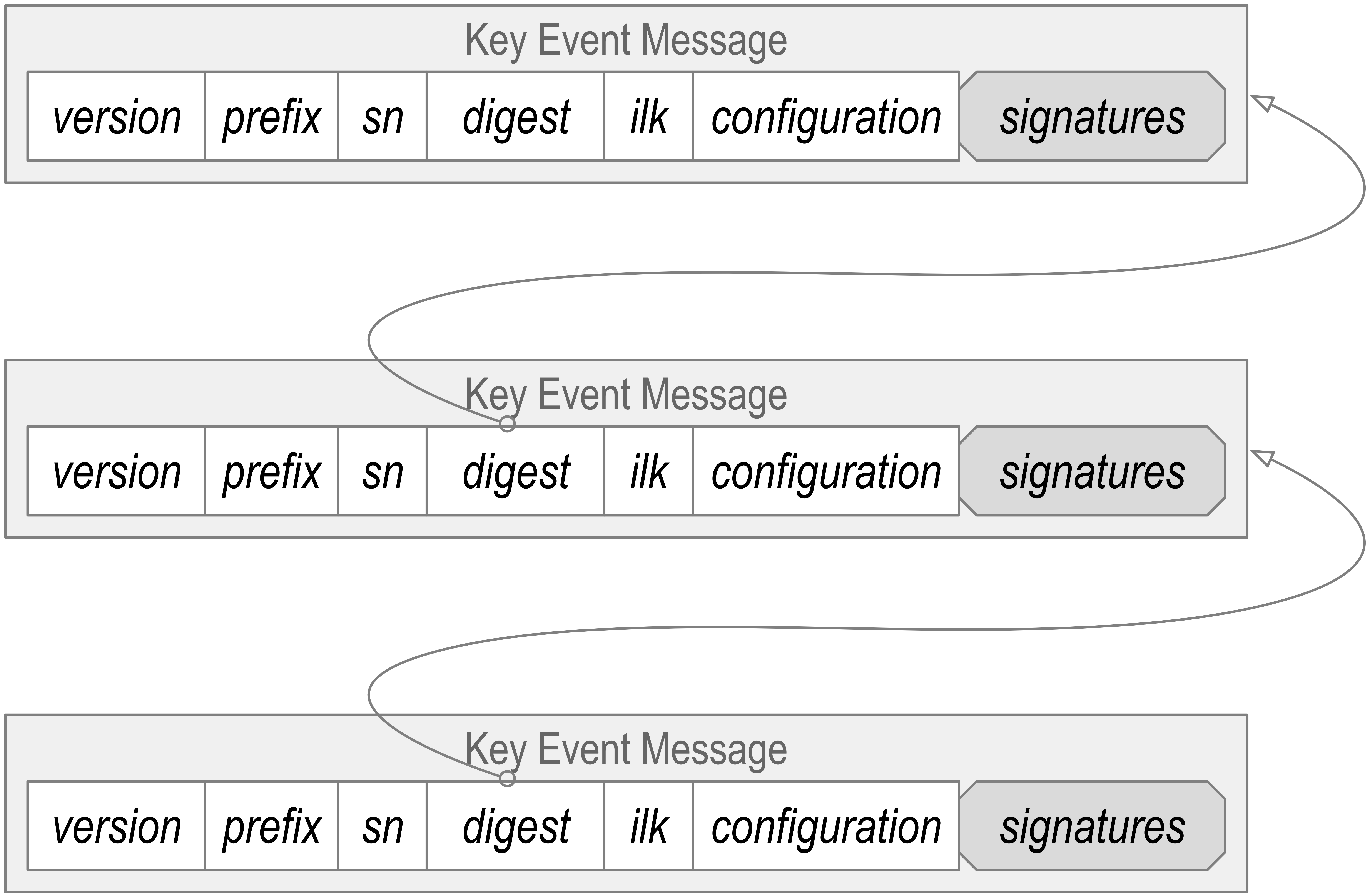



end
verifiable
self-certifying
root-of-trust
pre-
rotation
portable
KERI
duplicity
detection
spanning
layer
separated
control
scalable

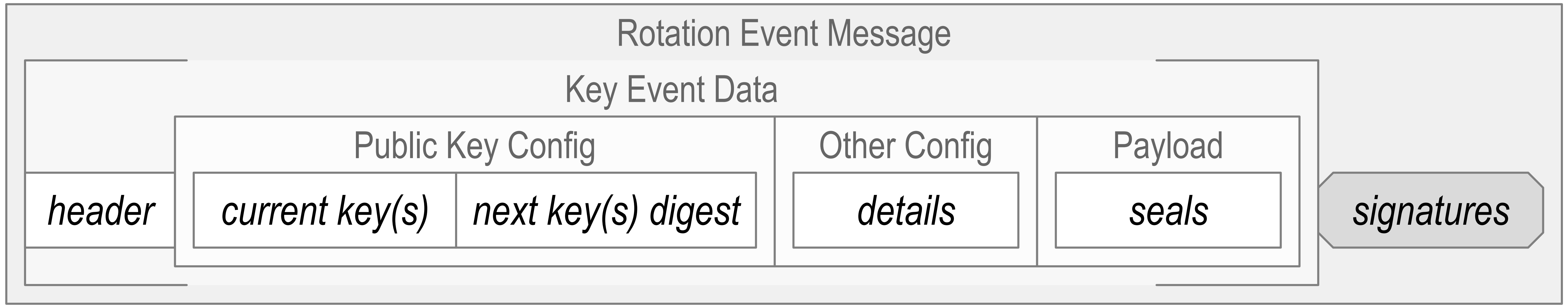
Key Event Message

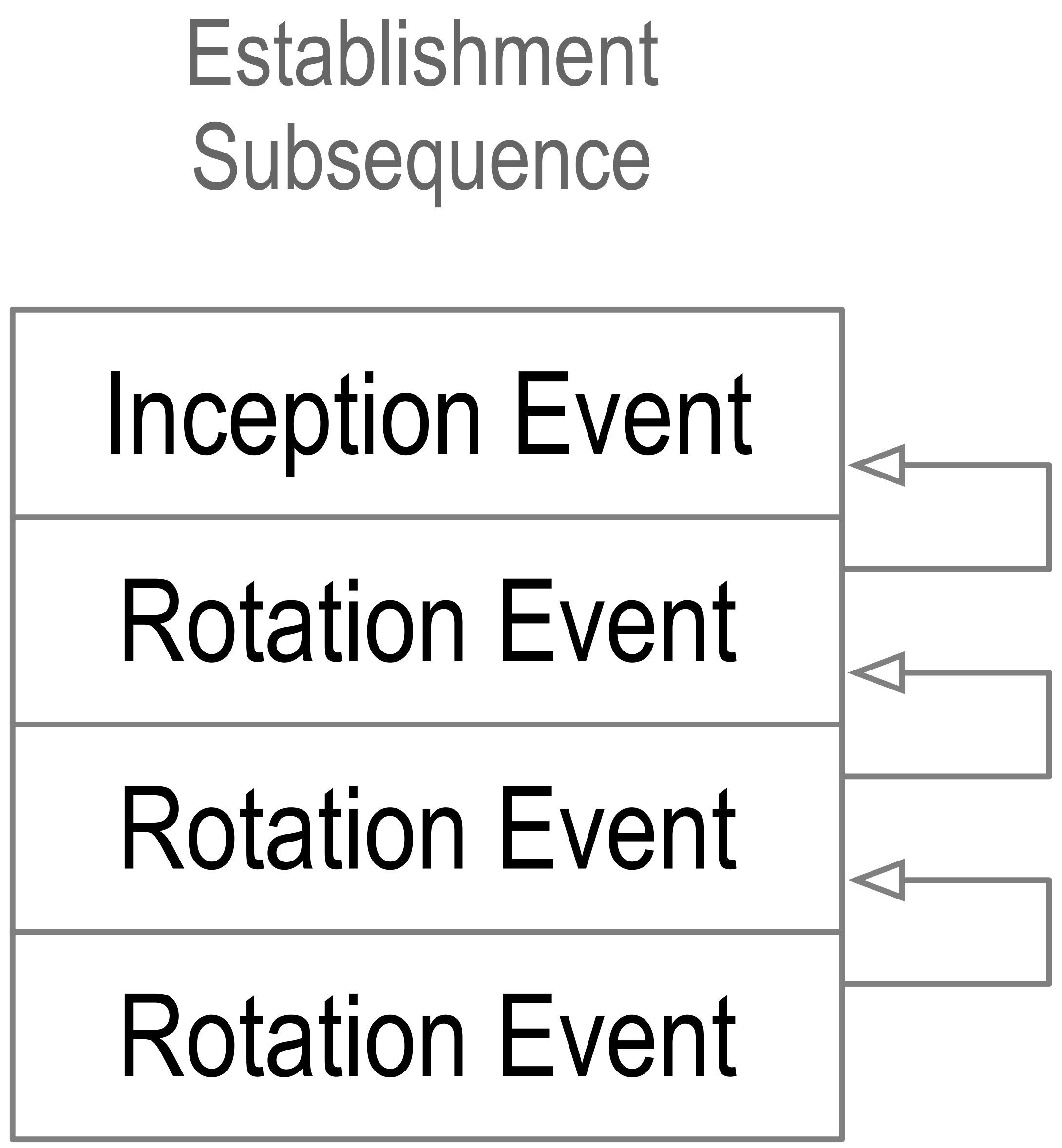


Event Chaining

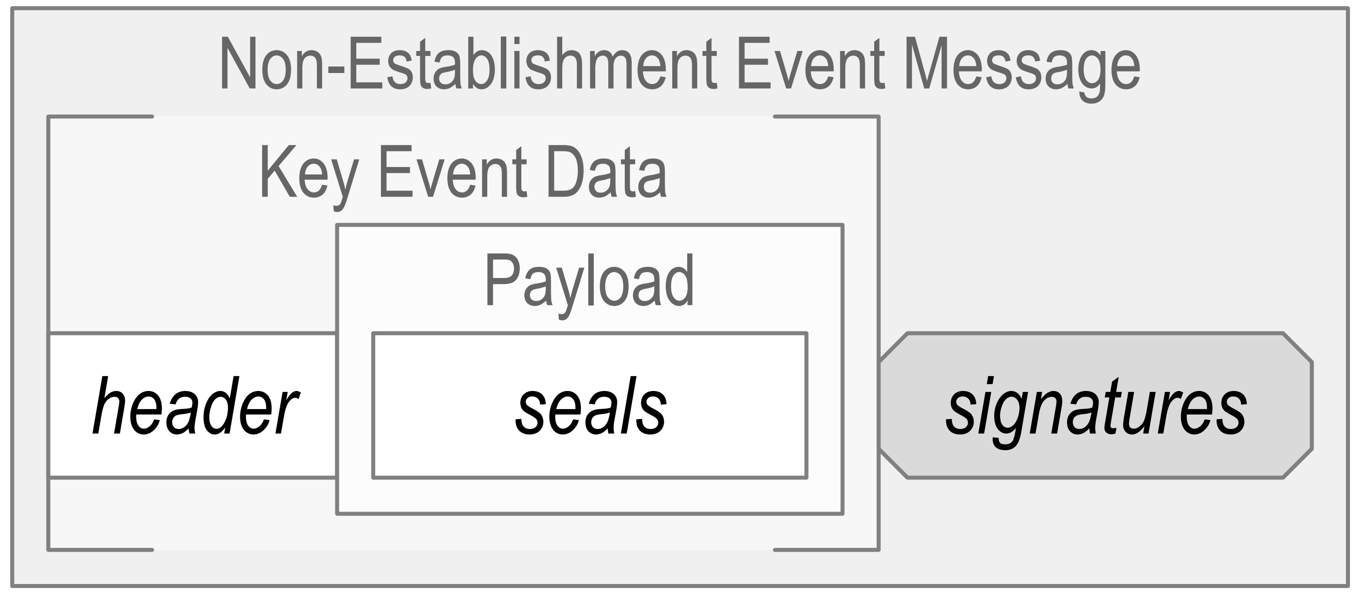


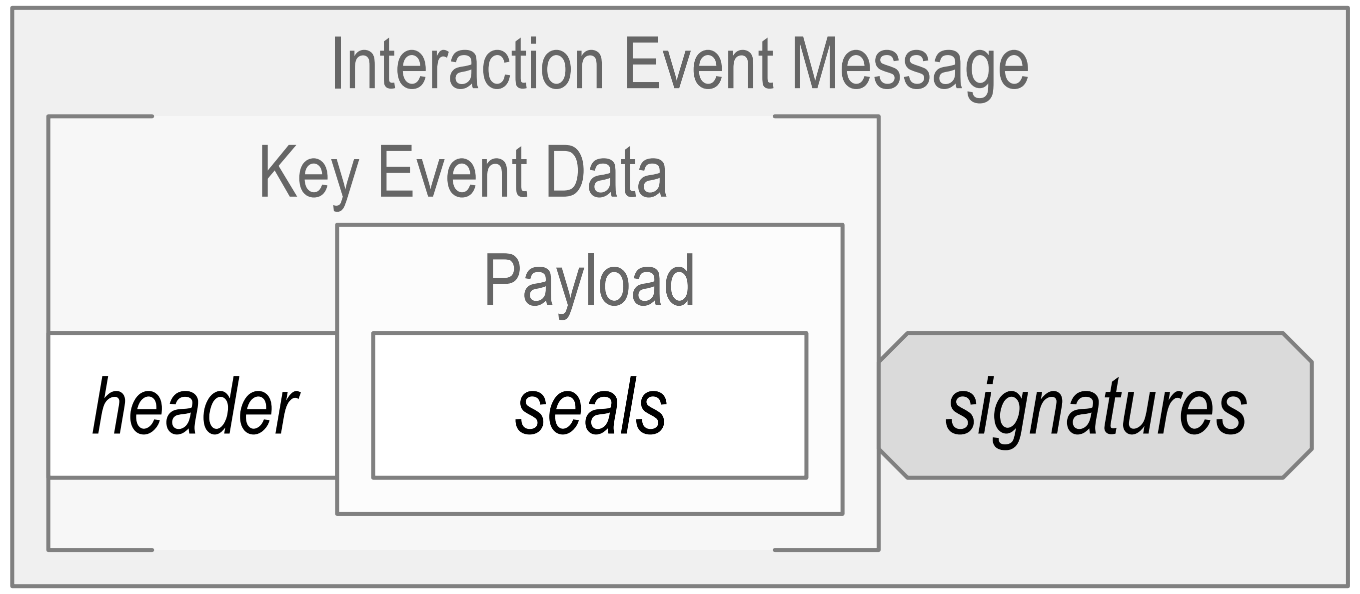
Establishment Events

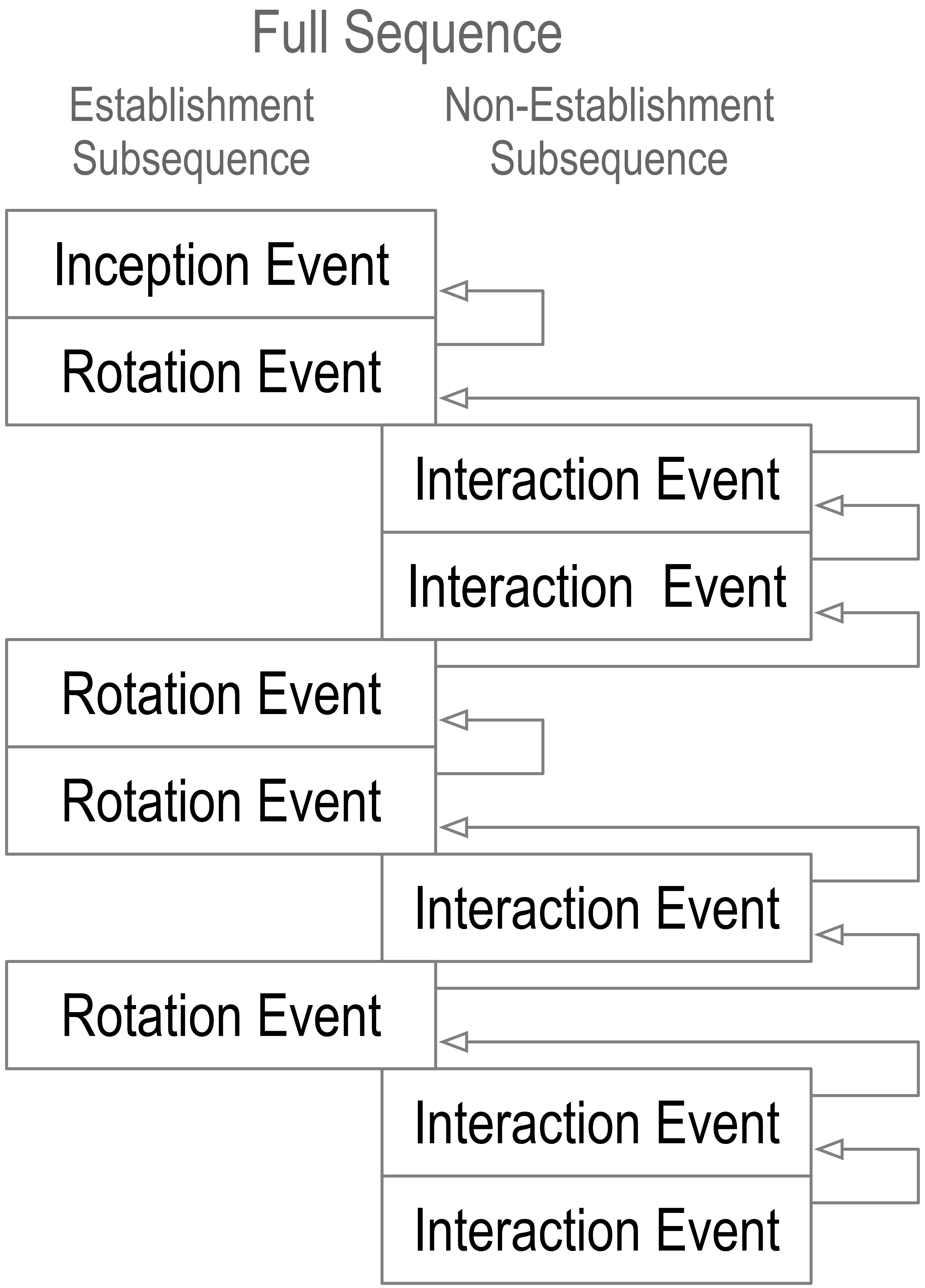




Non-Establishment Events







Seal (Anchor)

seal provides *evidence of authenticity*

A *seal* anchors arbitrary data to an event in the key event sequence thereby providing proof of control authority for that data at the location of the anchoring event.

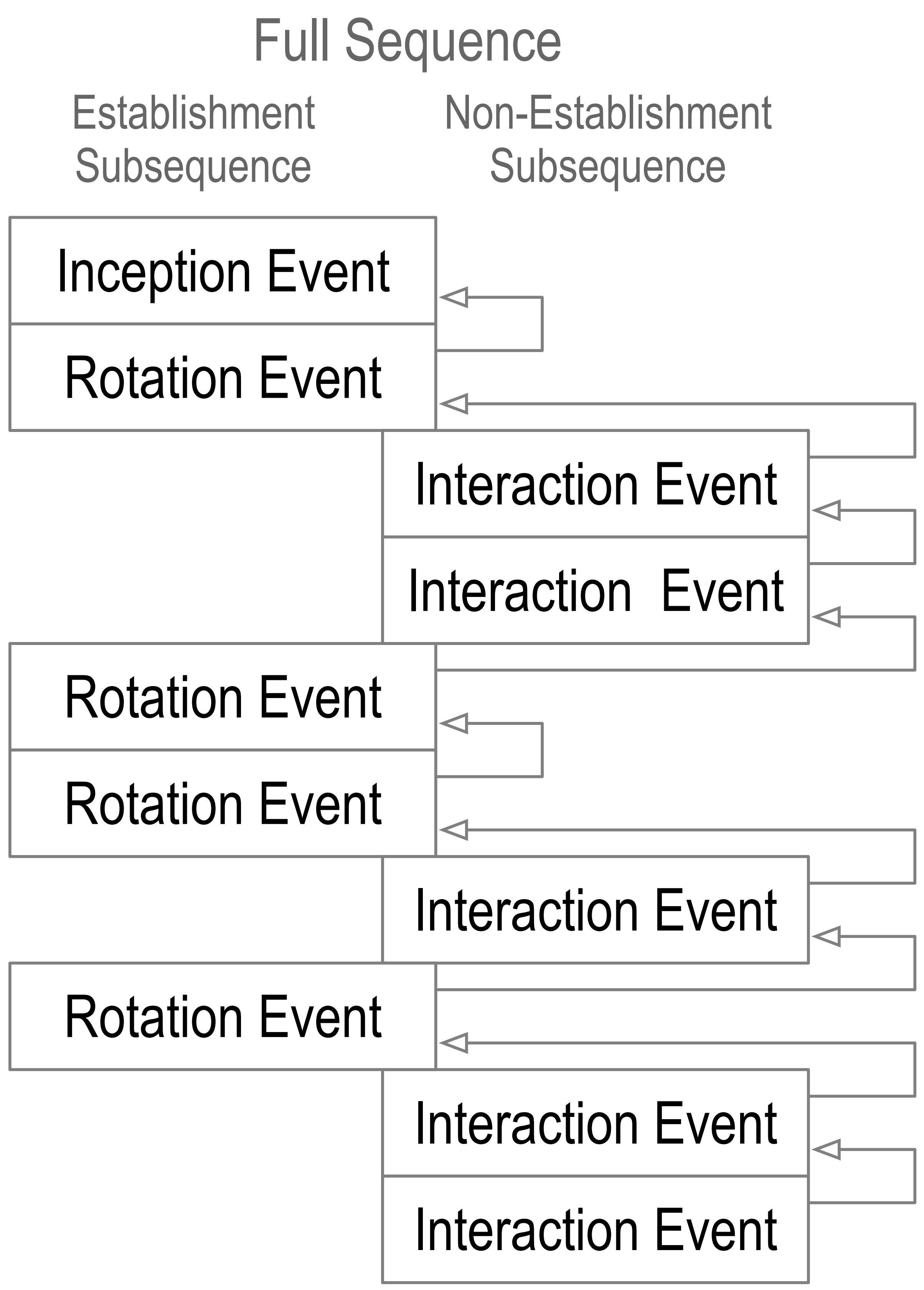
Seals make KERI both privacy preserving and *data semantic agnostic.*

Context independent extensibility via externally layered APIs for anchored data instead of context dependent extensibility via internal linked data or tag registries.

Interoperability is total w.r.t. establishment of control authority.

Minimally sufficient means.

Inconsistency and Duplicity



inconsistency: lacking agreement, as two or more things in relation to each other

duplicity: acting in two different ways to different people concerning the same matter

Internal vs. External Inconsistency

Internally inconsistent log = not verifiable.

Log verification from self-certifying root-of-trust protects against internal inconsistency.

Externally inconsistent log with a purported copy of log but both verifiable = duplicitous.

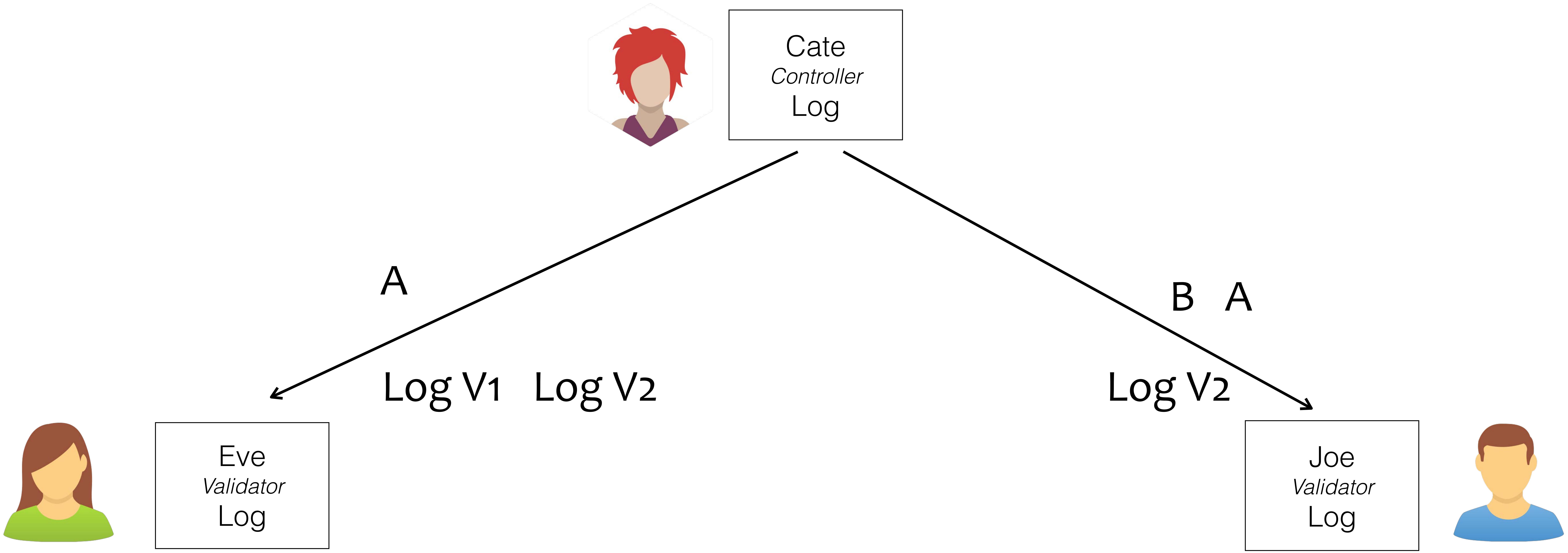
Duplicity detection protects against external inconsistency.

Duplicity Game

Cate promises to provide a consistent pair-wise log.

Local Consistency Guarantee

How may Cate be duplicitous and not get caught?



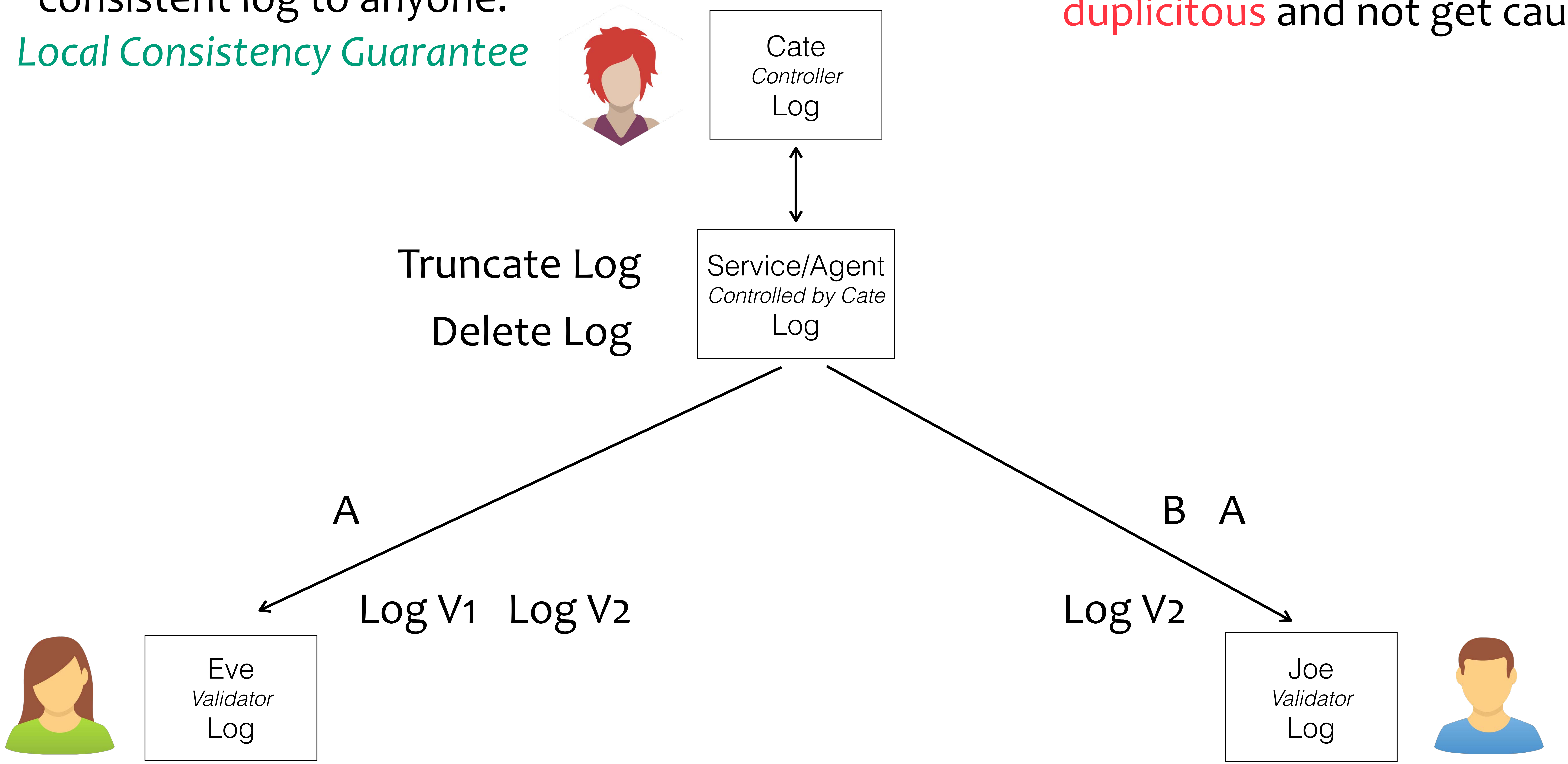
private (one-to-one) interactions

Duplicity Game

Service promises to provide a consistent log to anyone.

Local Consistency Guarantee

How may Cate/Service/Agent be duplicitous and not get caught?



highly available, private (one-to-one) interactions


Duplicity Game
Service promises to provide exact same log to everyone.
Global Consistency Guarantee
How may Cate and/or service be duplicitous and not get caught?
Cate
Controller
Log
Breaking the promise of global consistency is a provable liability.
Global consistency may only matter after A and B need to interact not before.
Service
Controlled by Cate
Log
isolate network
isolate network
?
A
log V1
A
Truncate Log
Delete Log
log V2
Doug
Global Duplicity
Log
Eve
Validator
Log
Ambient Duplicity Detection
Joe
Validator
Log
global consistent, highly available, and public (one-to-any) interactions

KEY Event Based Provenance of Identifiers

KERI enables cryptographic *proof-of-control-authority* (*provenance*) for each identifier.

A *proof* is in the form of an identifier's *key event receipt log* (KERL).

KERLs are *End Verifiable*:

End user alone may verify. Zero trust in intervening infrastructure.

KERLs may be *Ambient Verifiable*:

Anyone may verify *anylog*, *anywhere*, at *anytime*.

KERI = self-cert root-of-trust + certificate transparency + KA^{2}CE + recoverable + post-quantum.

KERI for the *DID*ified

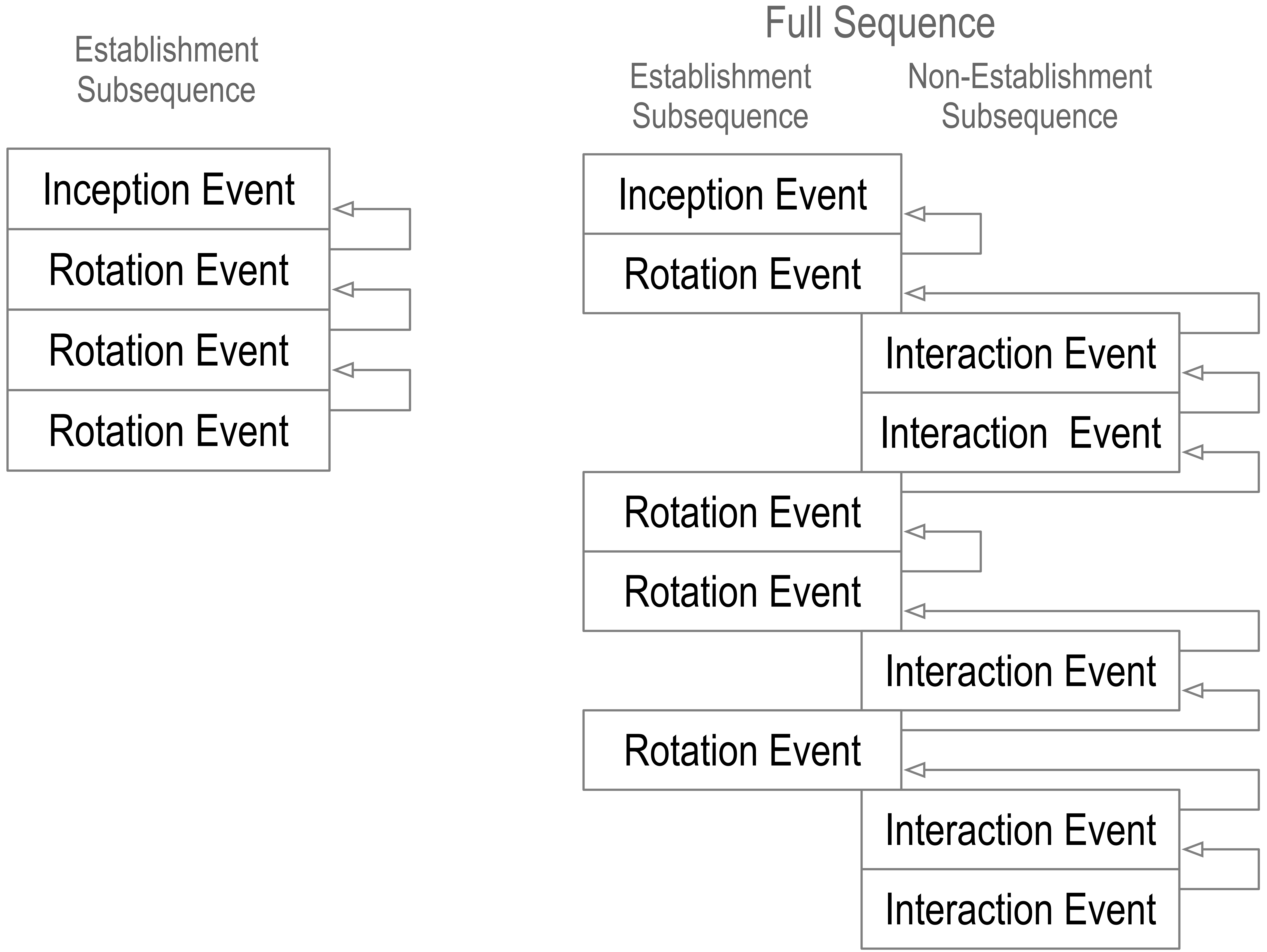
KERI non-transferable ephemeral with derivation prefix ~ did:key

KERI private direct mode (one-to-one) ~ did:peer

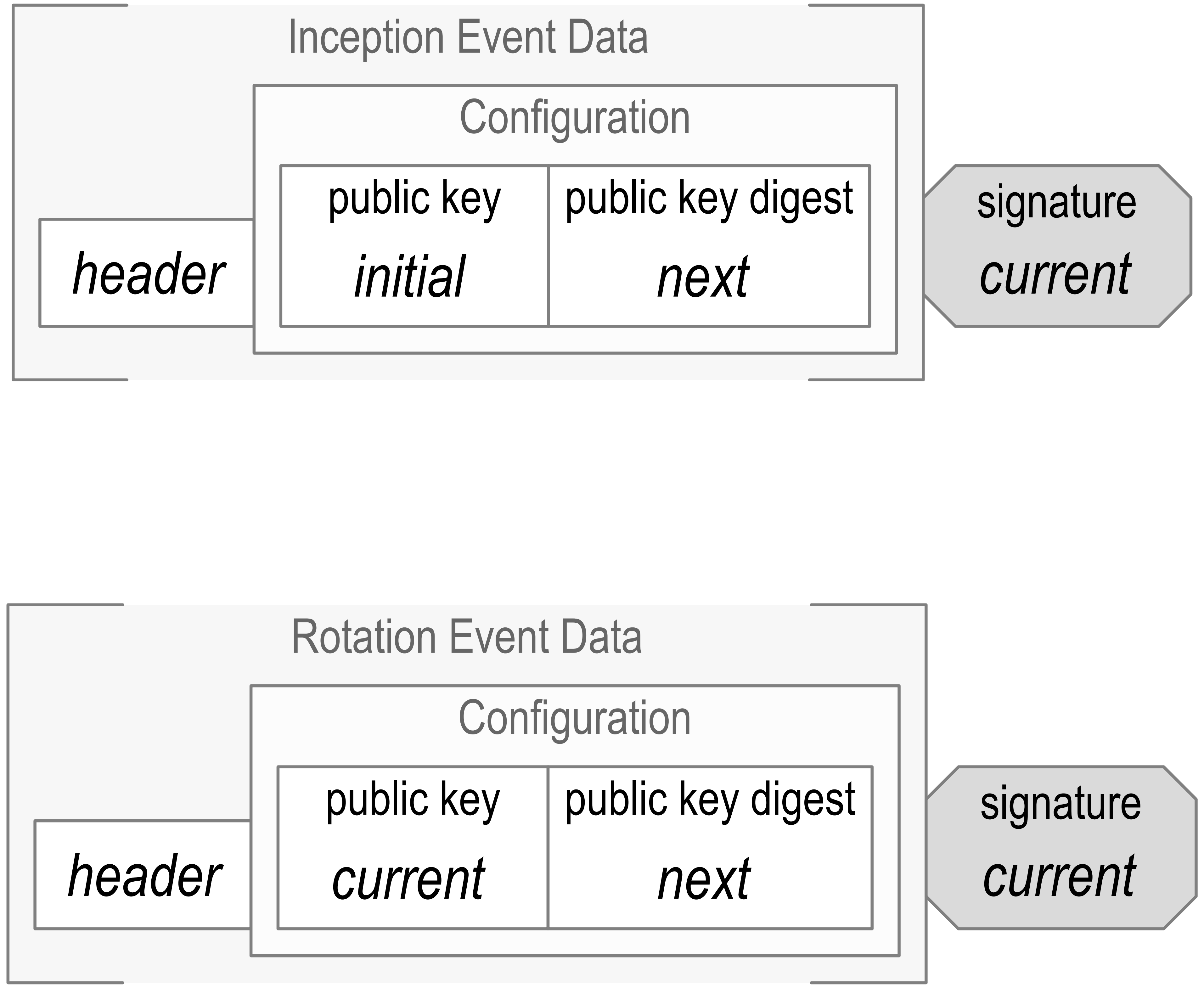
KERI public persistent indirect mode (one-to-any) ~ did:sov etc

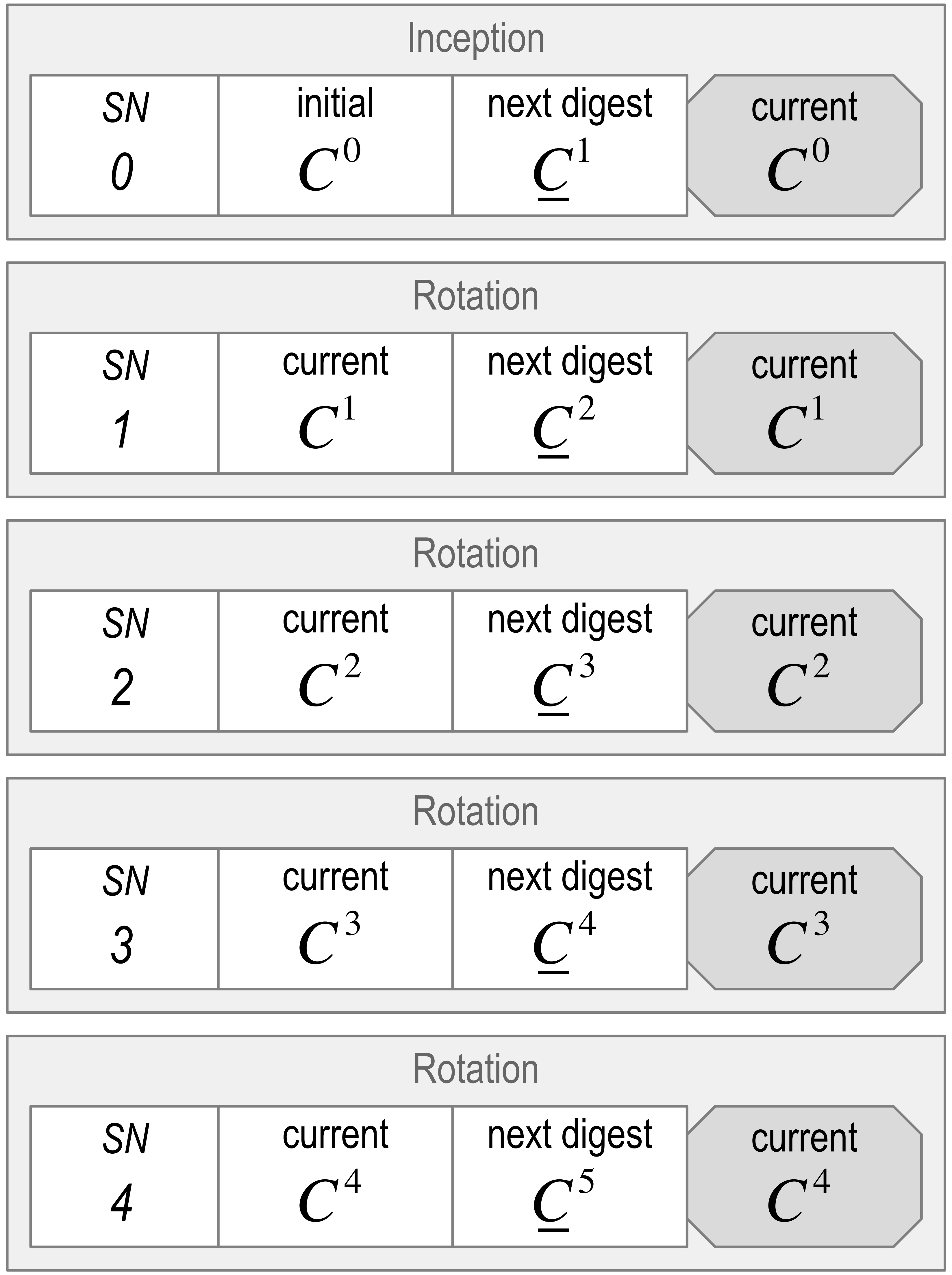
KERI = did:uni (did:un) (all of the above in one method)

Event Sequencing



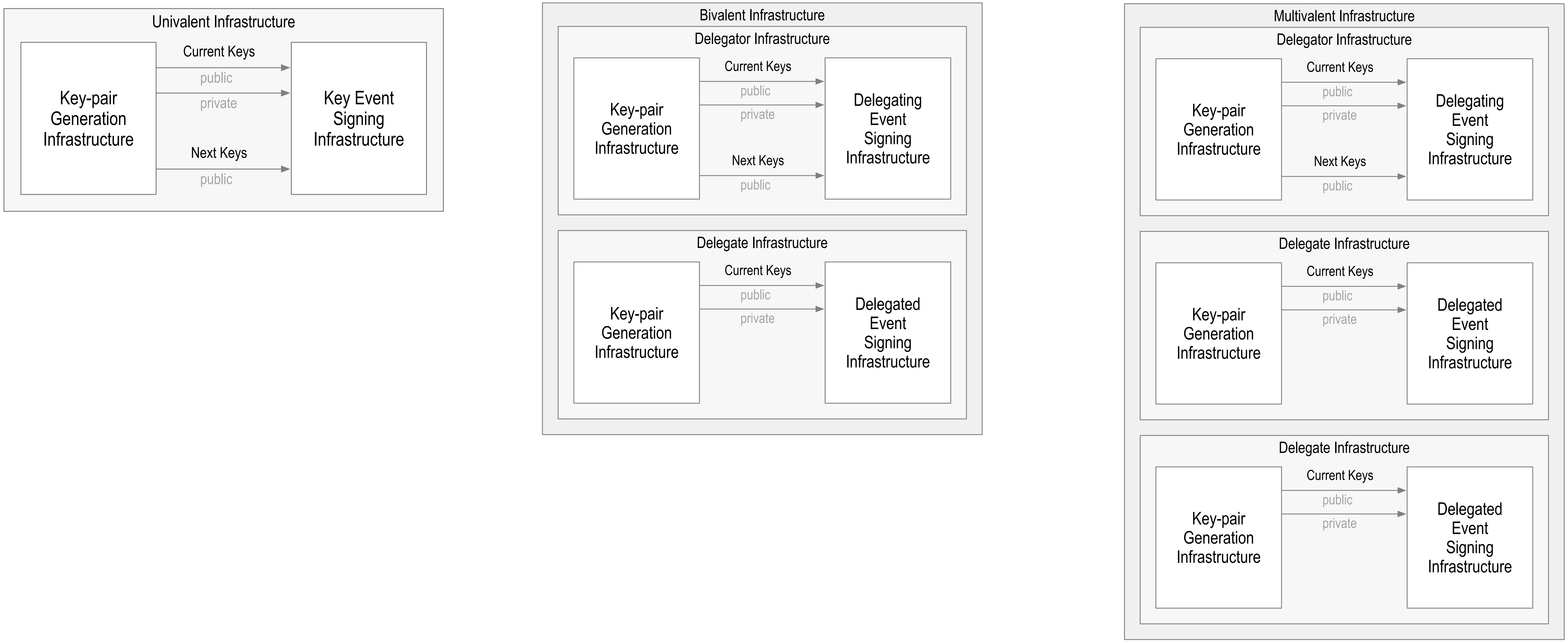
Pre-Rotation



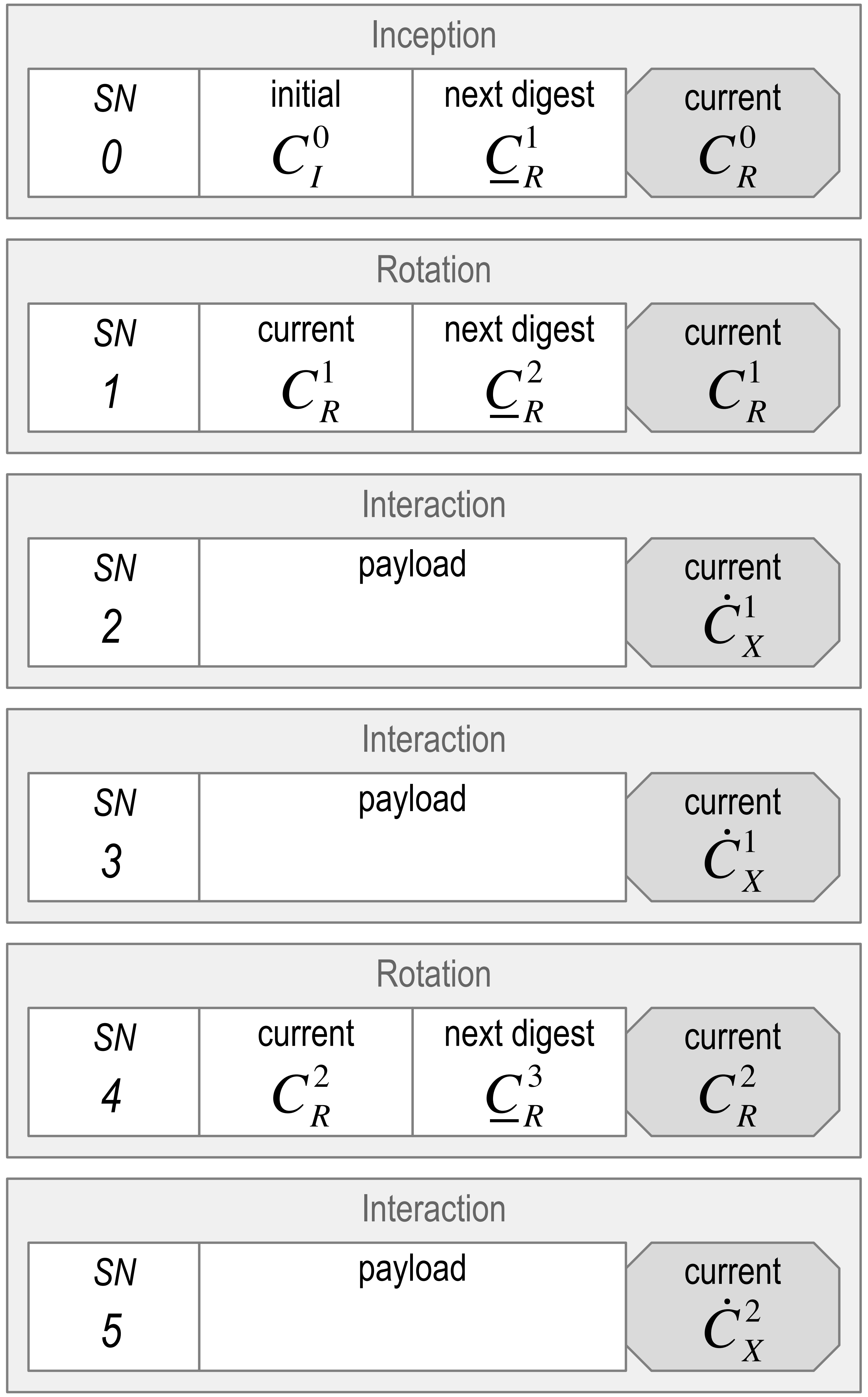


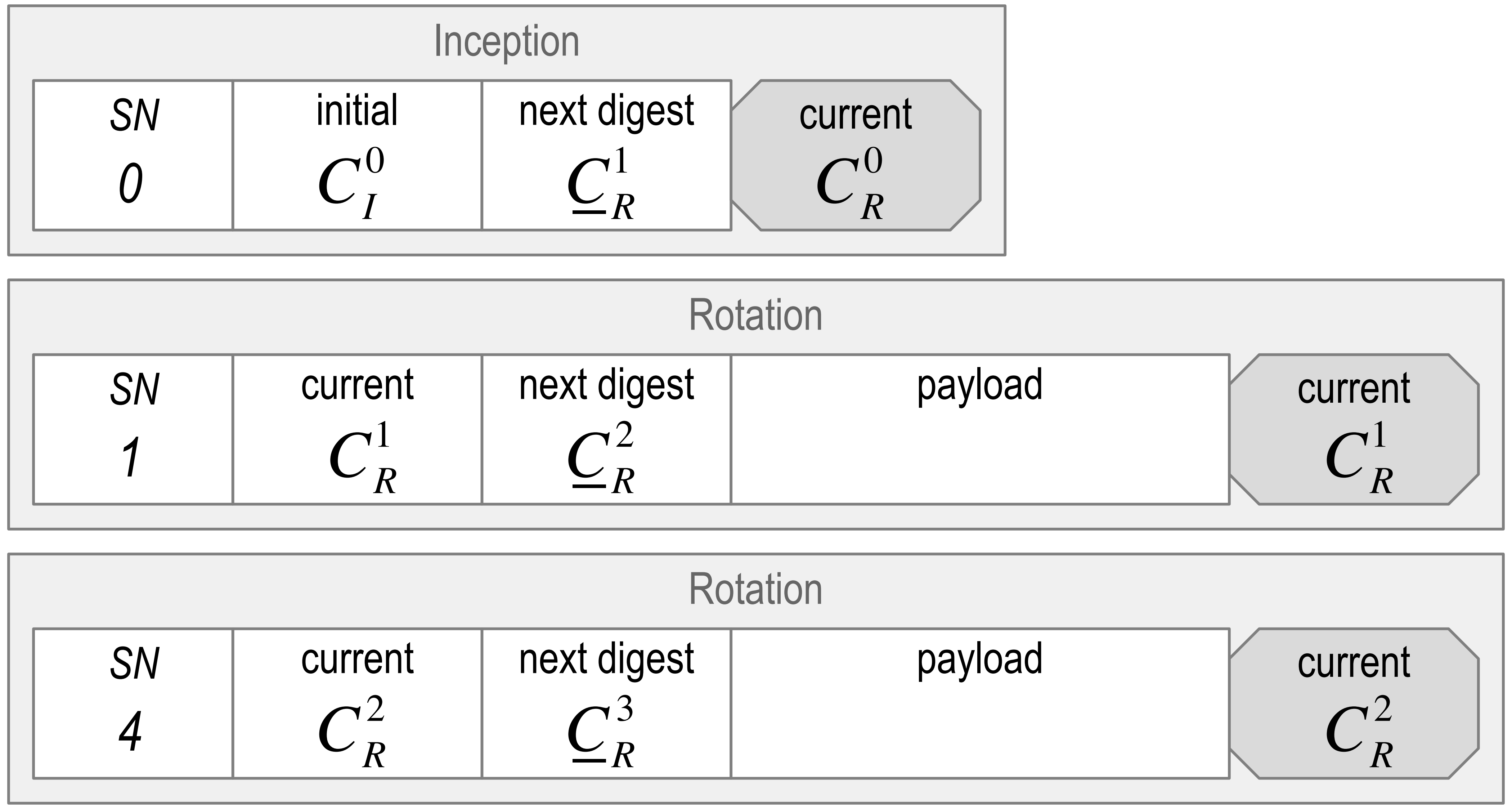
Digest of *next* key(s) makes pre-rotation post-quantum secure

Key Infrastructure Valence



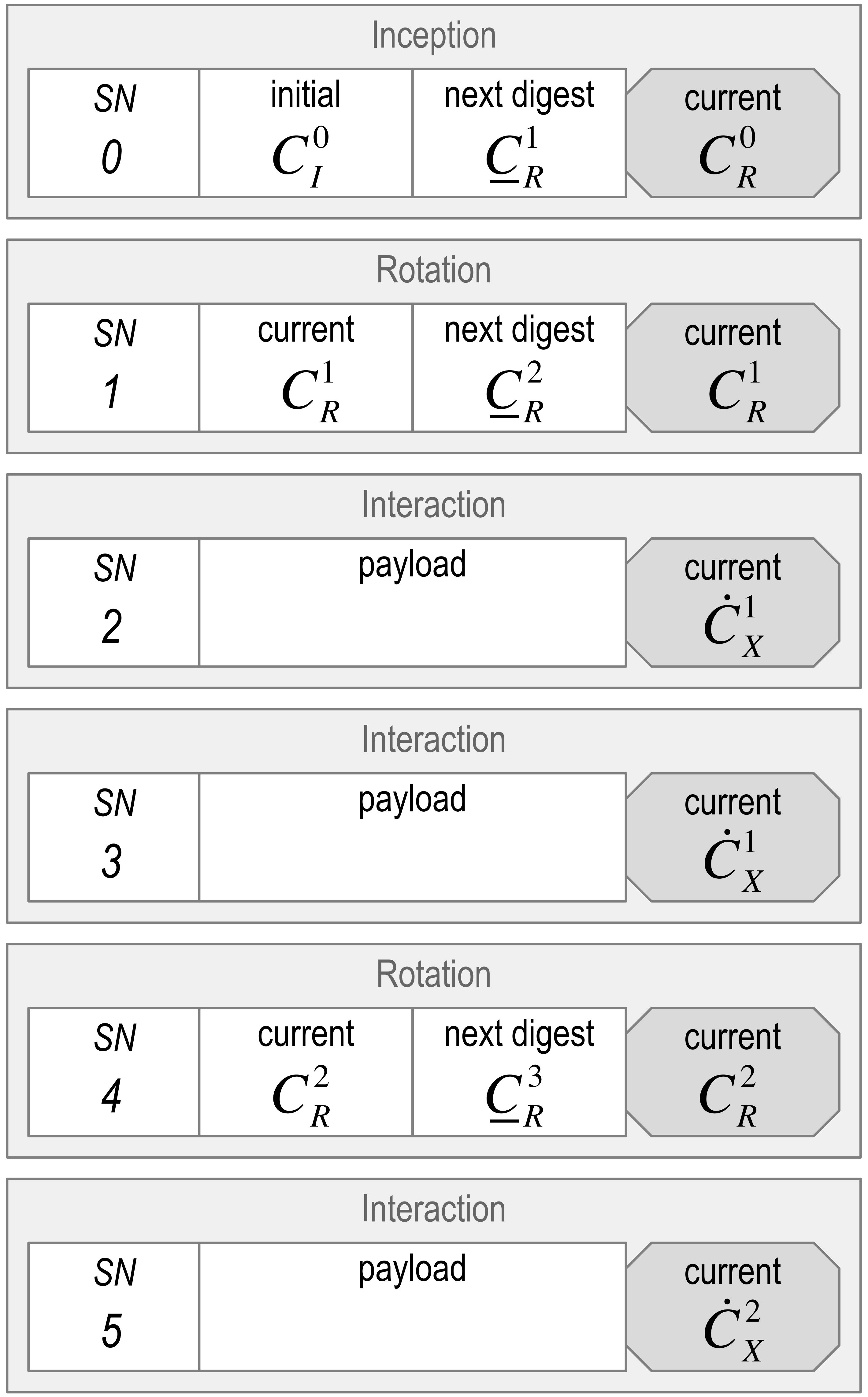
Repurposed Keys



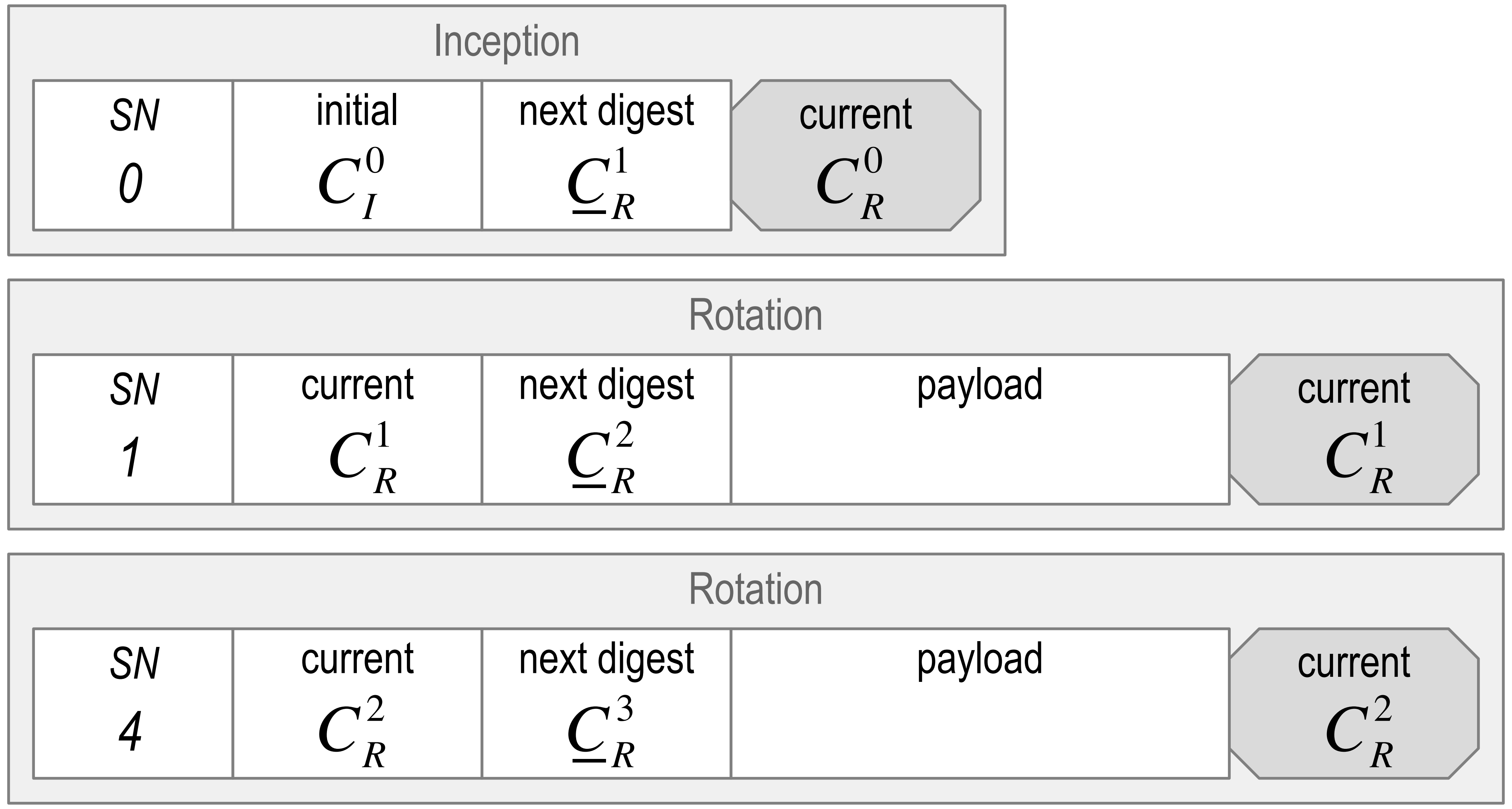


Univalent Key Roles

Repurposed Rotation to Interaction

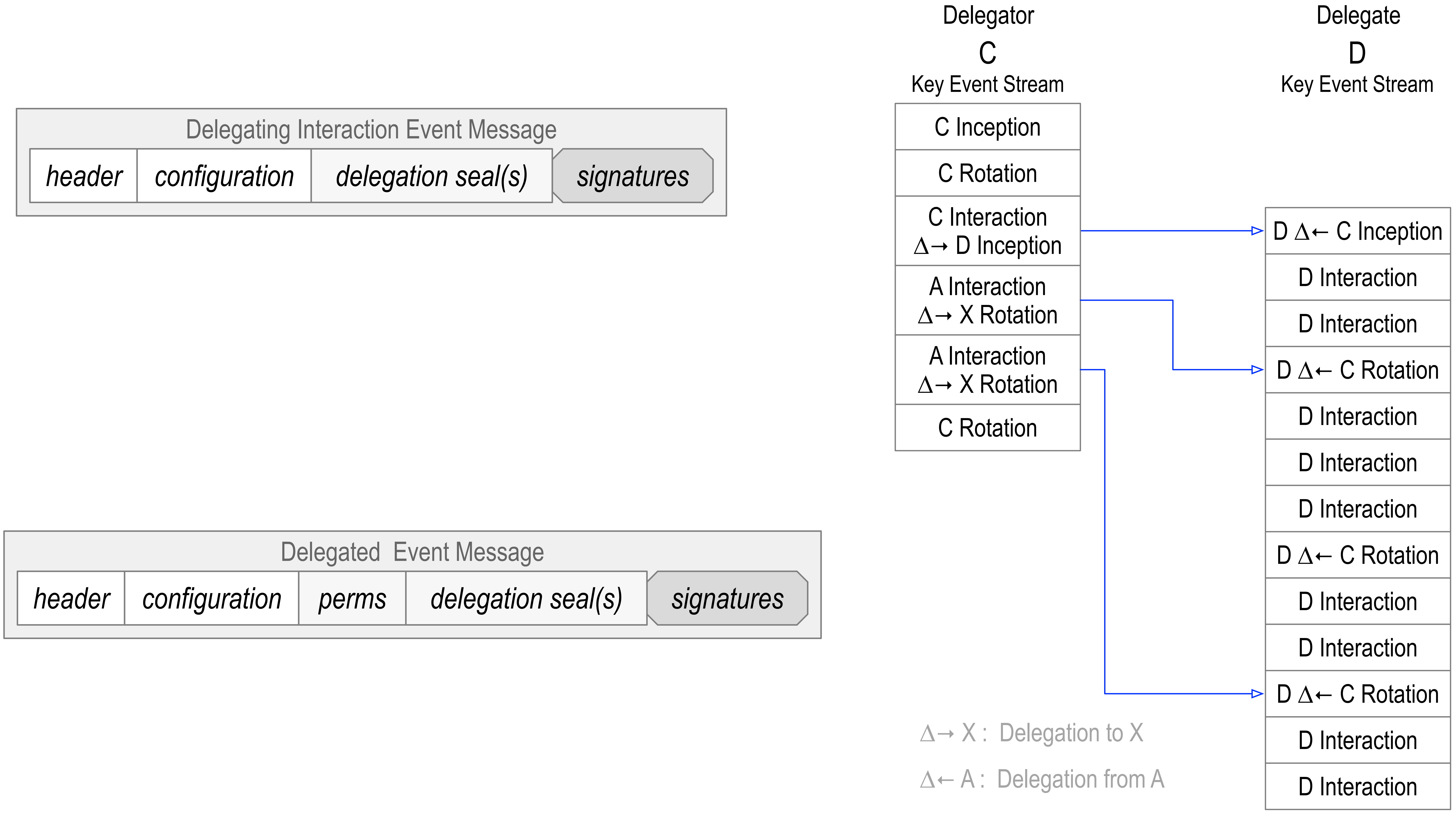


Rotation Only

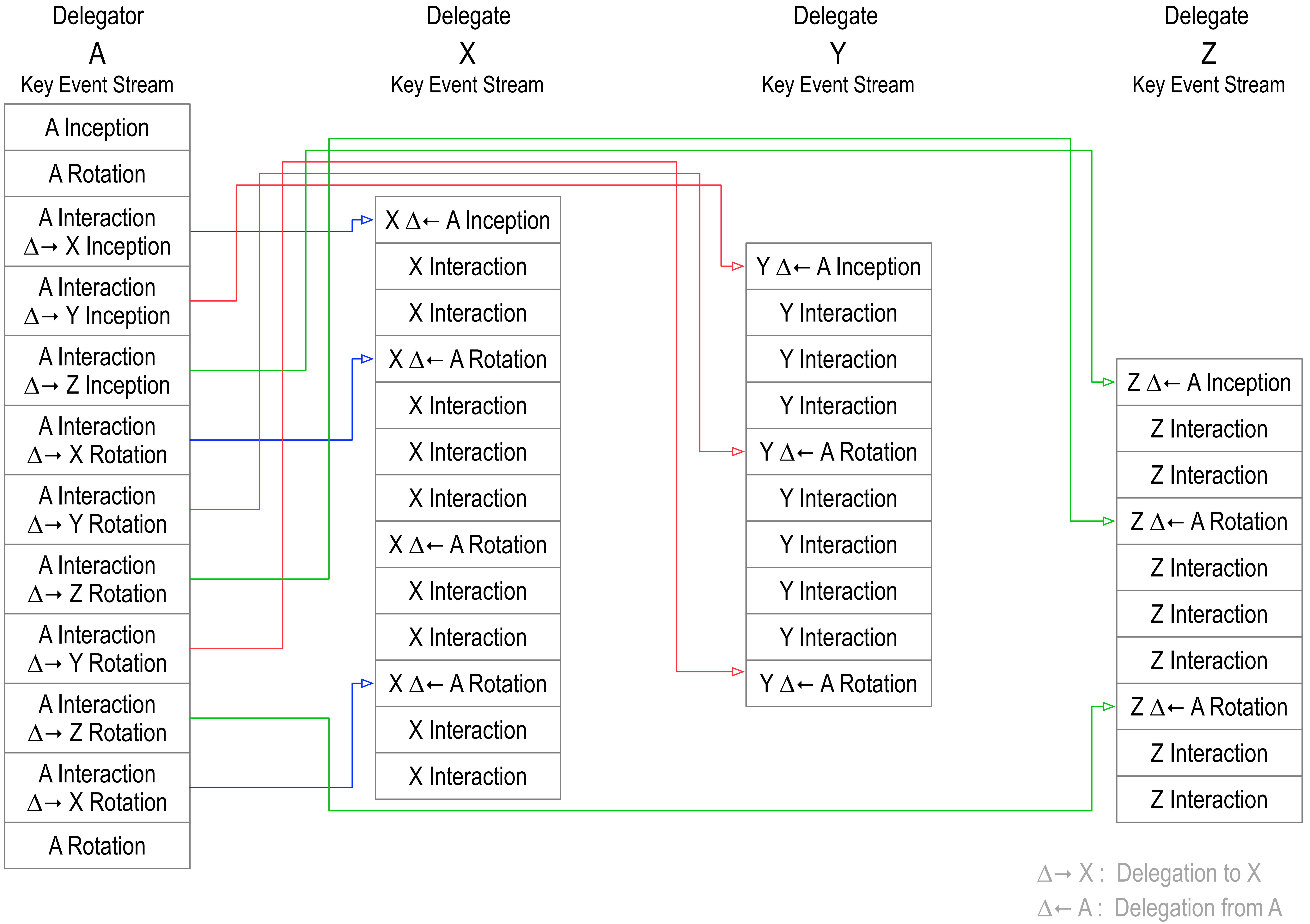


Delegation (Cross Anchor)

Interaction Delegation



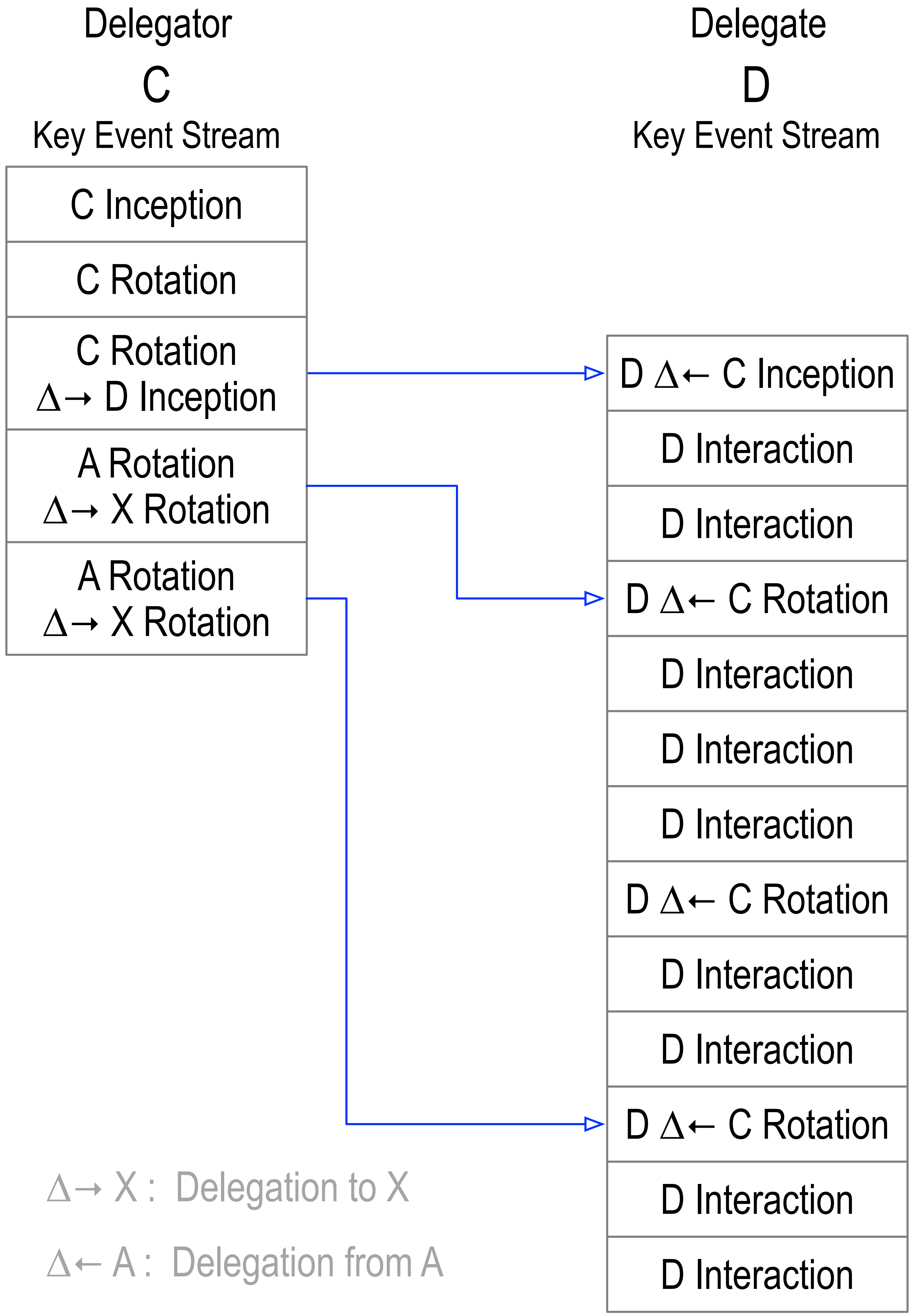
Scaling Delegation via Interaction



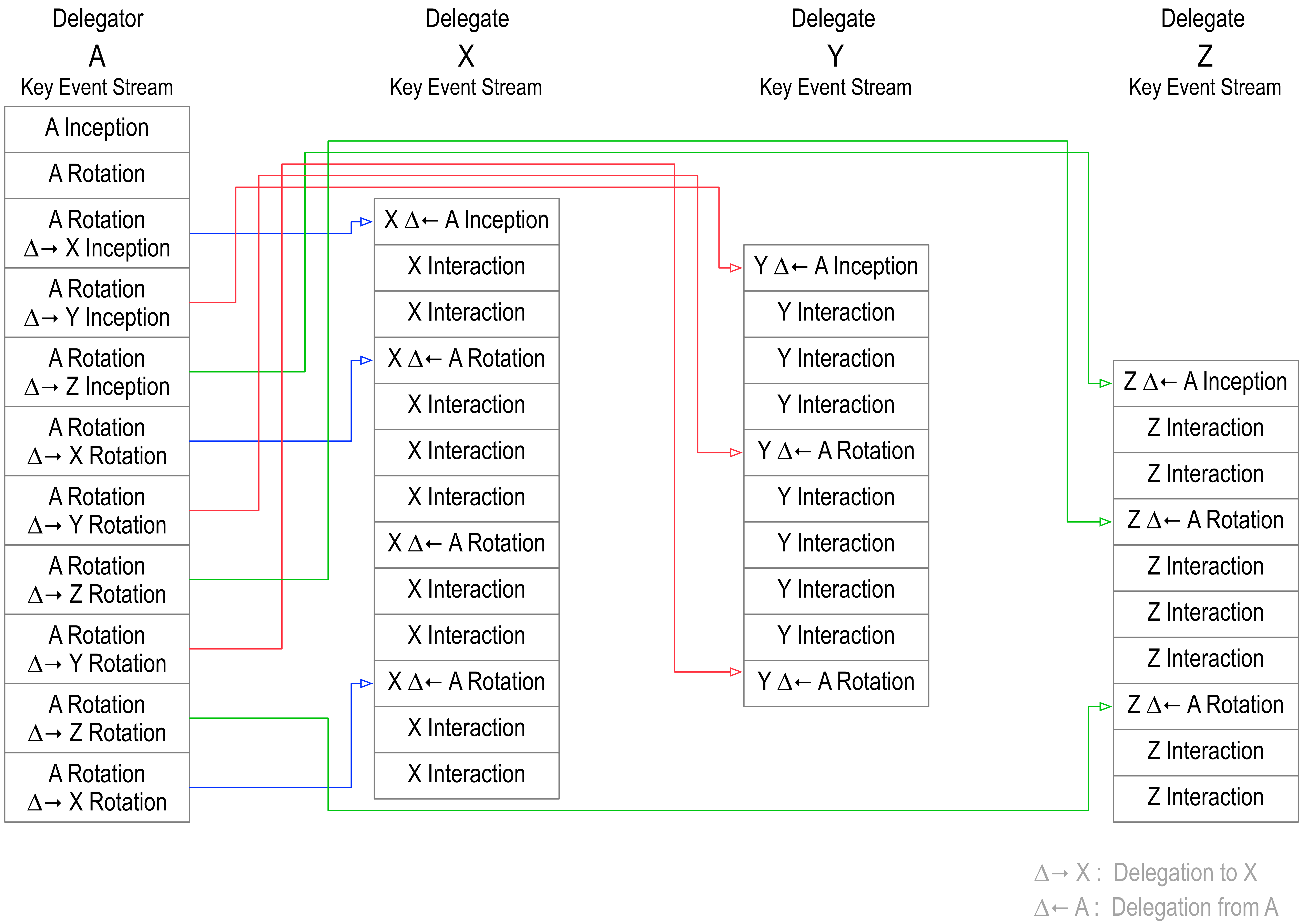
Rotation Delegation

Delegating Rotation Event Message			
header	*configuration*	*delegation seal(s)*	*signatures*

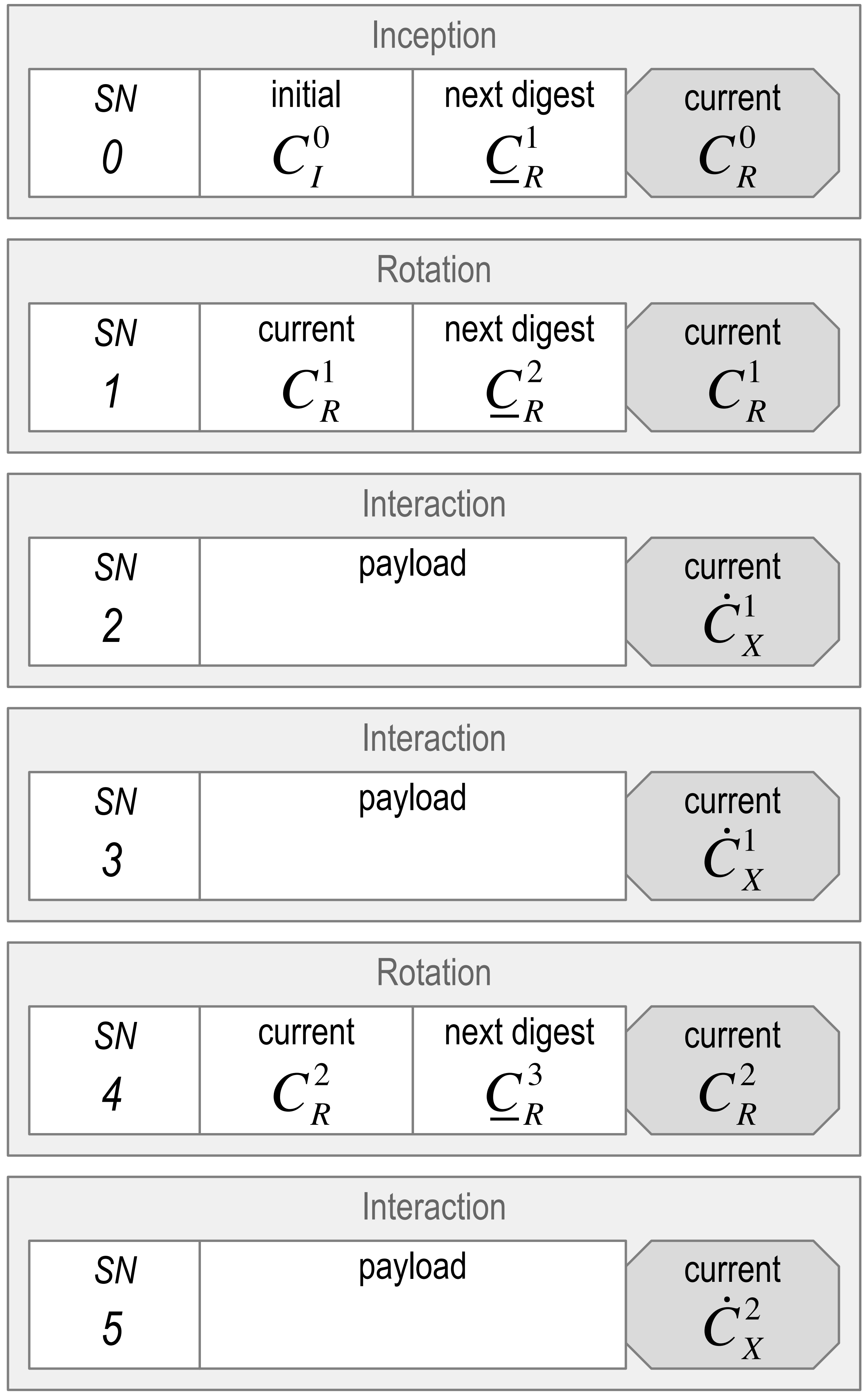
Delegated Event Message				
header	*configuration*	*perms*	*delegation seal(s)*	*signatures*



Scaling Delegation via Rotation

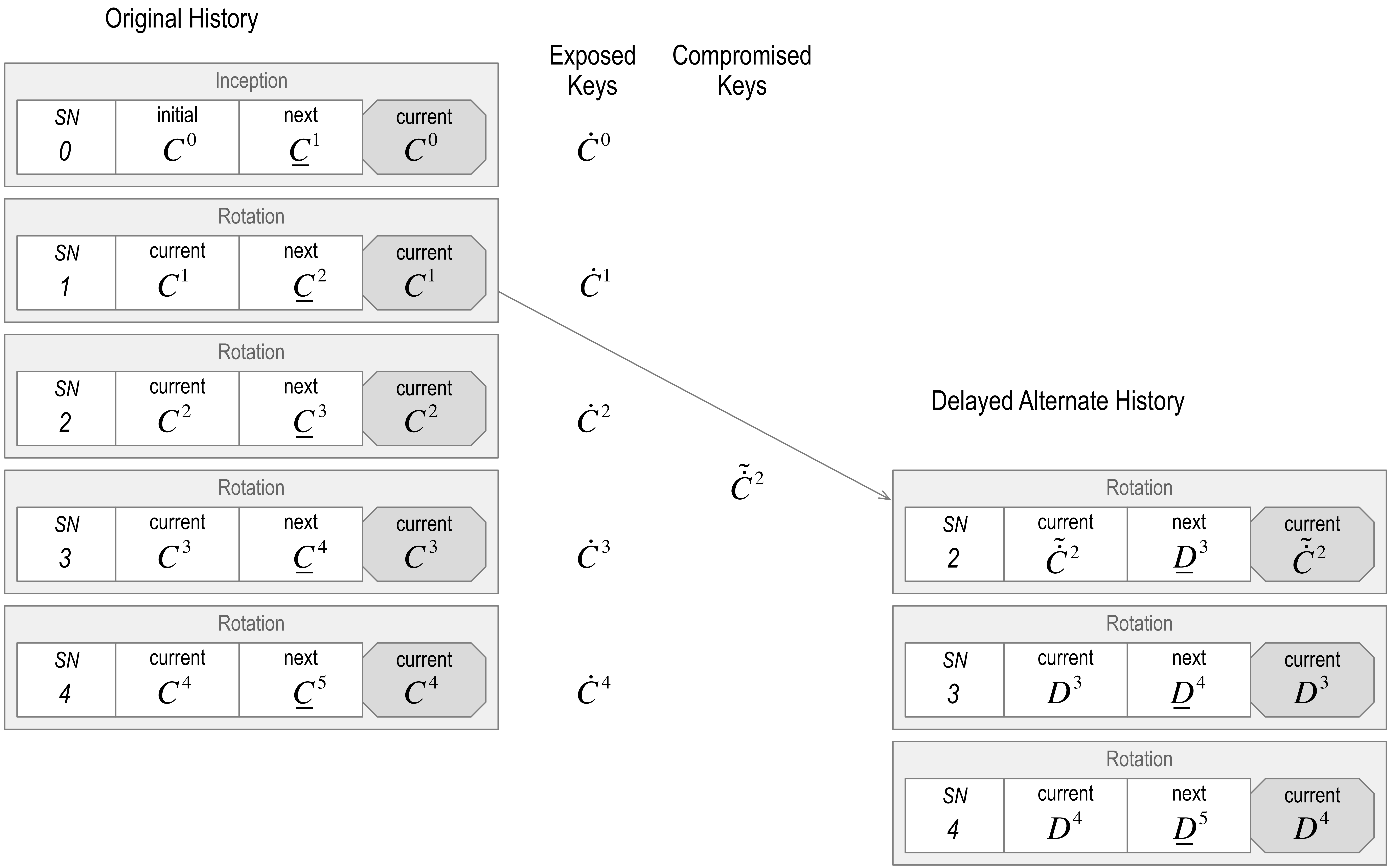


Live Exploit (current signing keys)



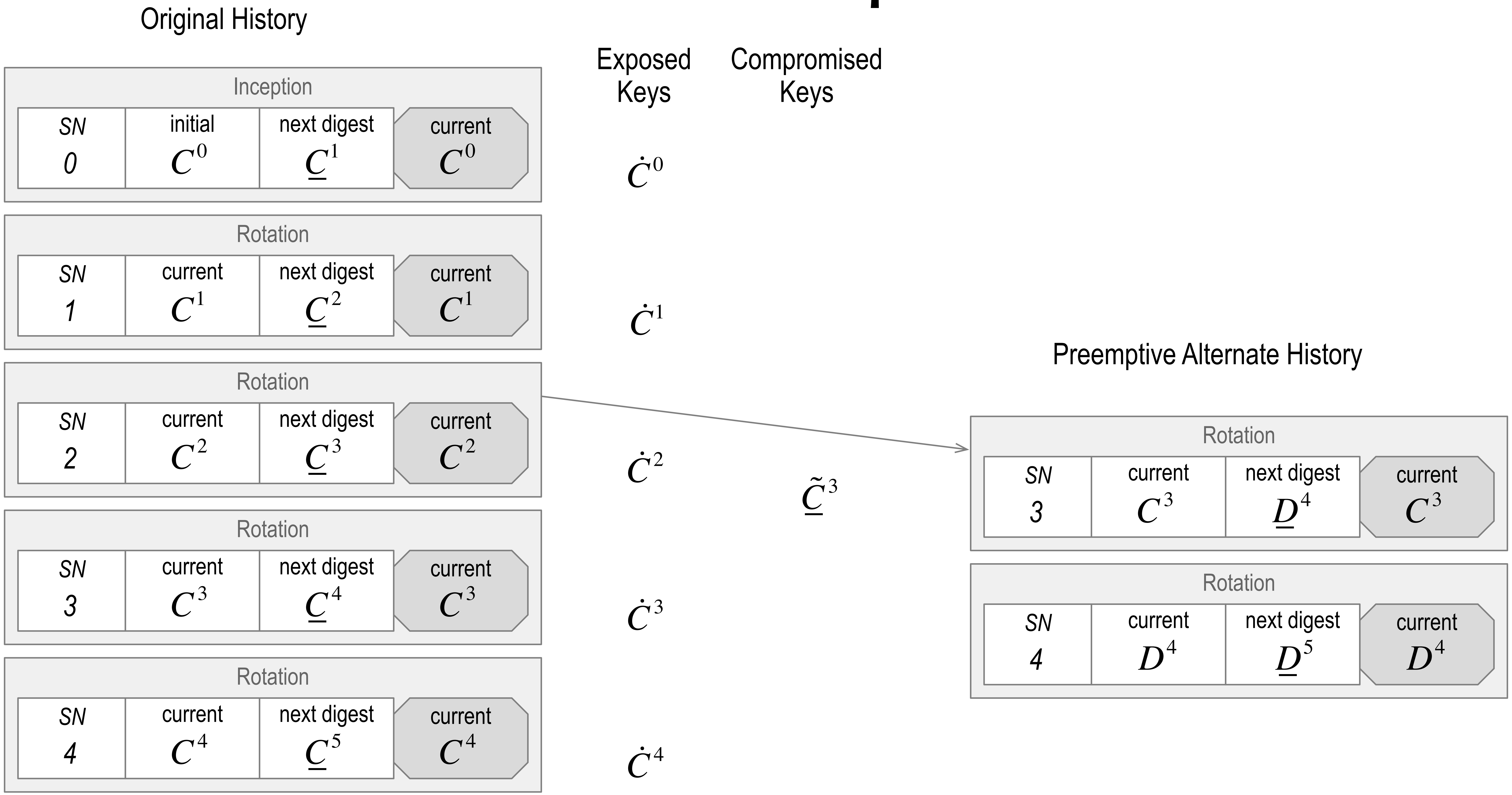
Pre-rotation provides protection from successful *live* exploit of current signing keys.

Dead Exploit (stale next signing keys)



Any copy of original history protects against successful *dead* exploit

Live Exploit (next signing keys)



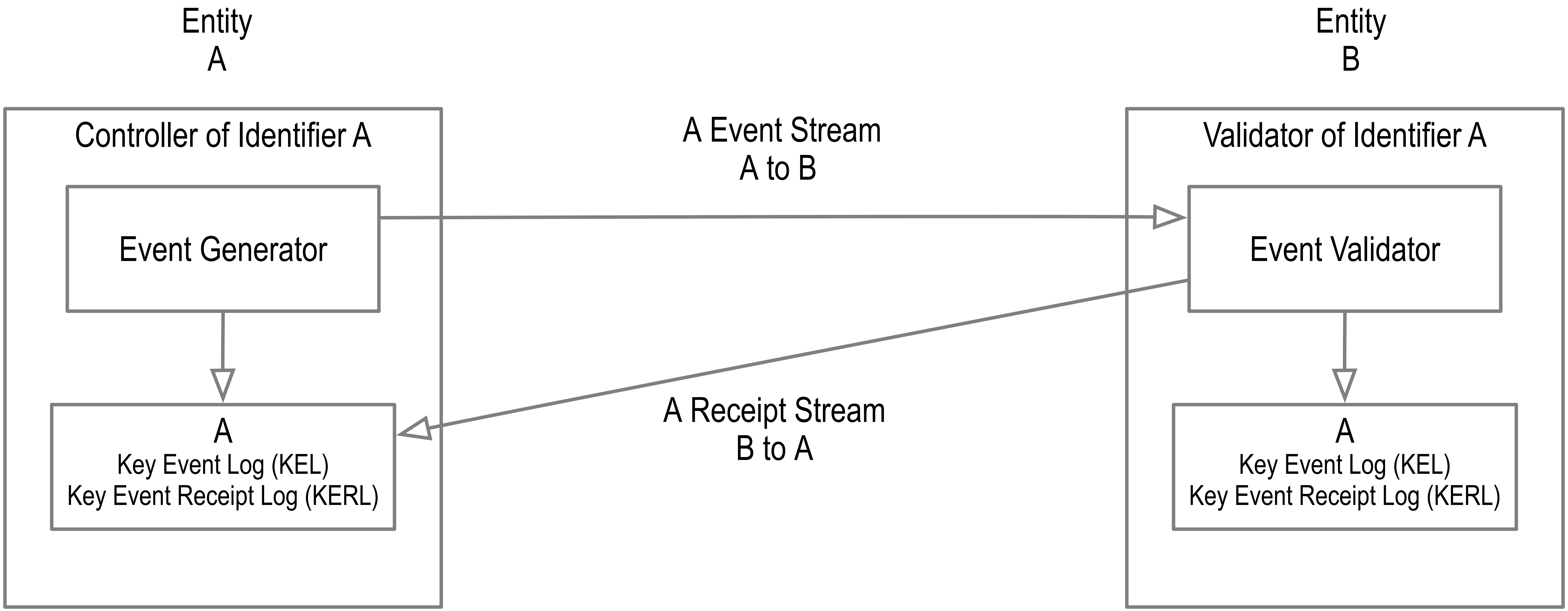
Difficulty of inverting *next* key(s) protects against successful *live* exploit.

Protocol Operational Modes

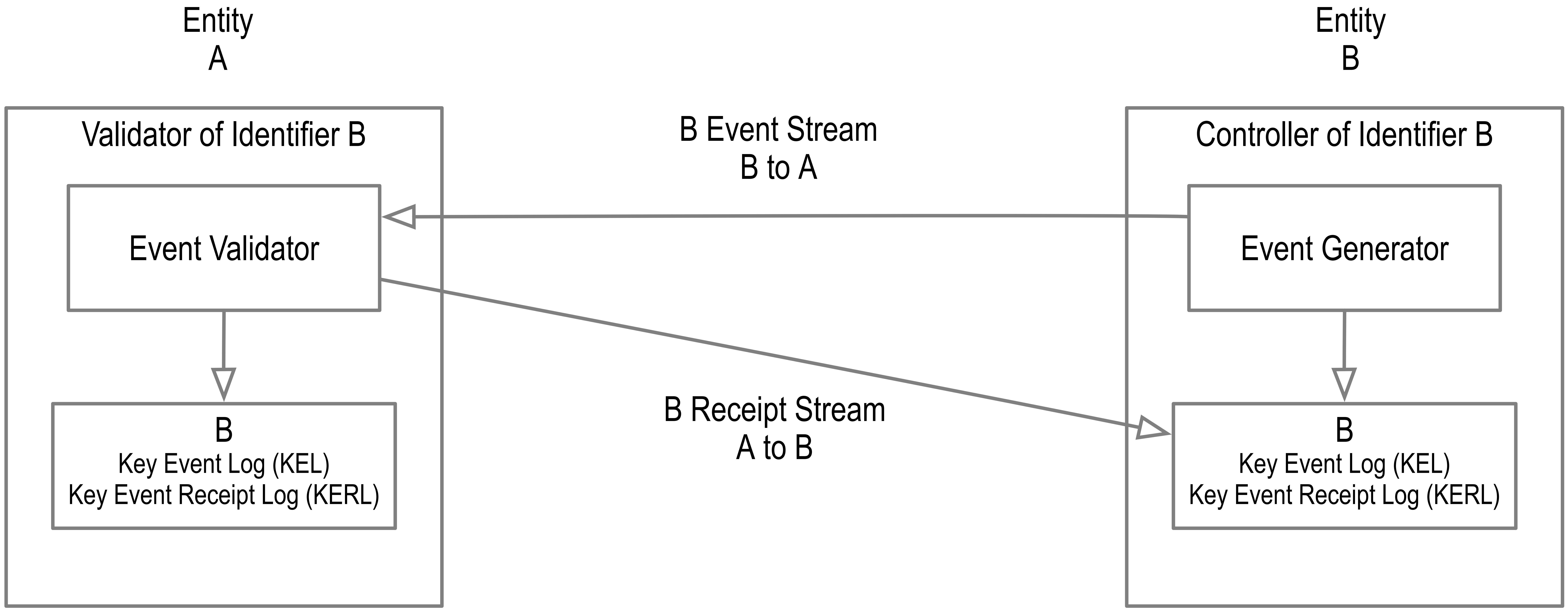
Direct Event Replay Mode (one-to-one)

Indirect Event Replay Mode (one-to-any)

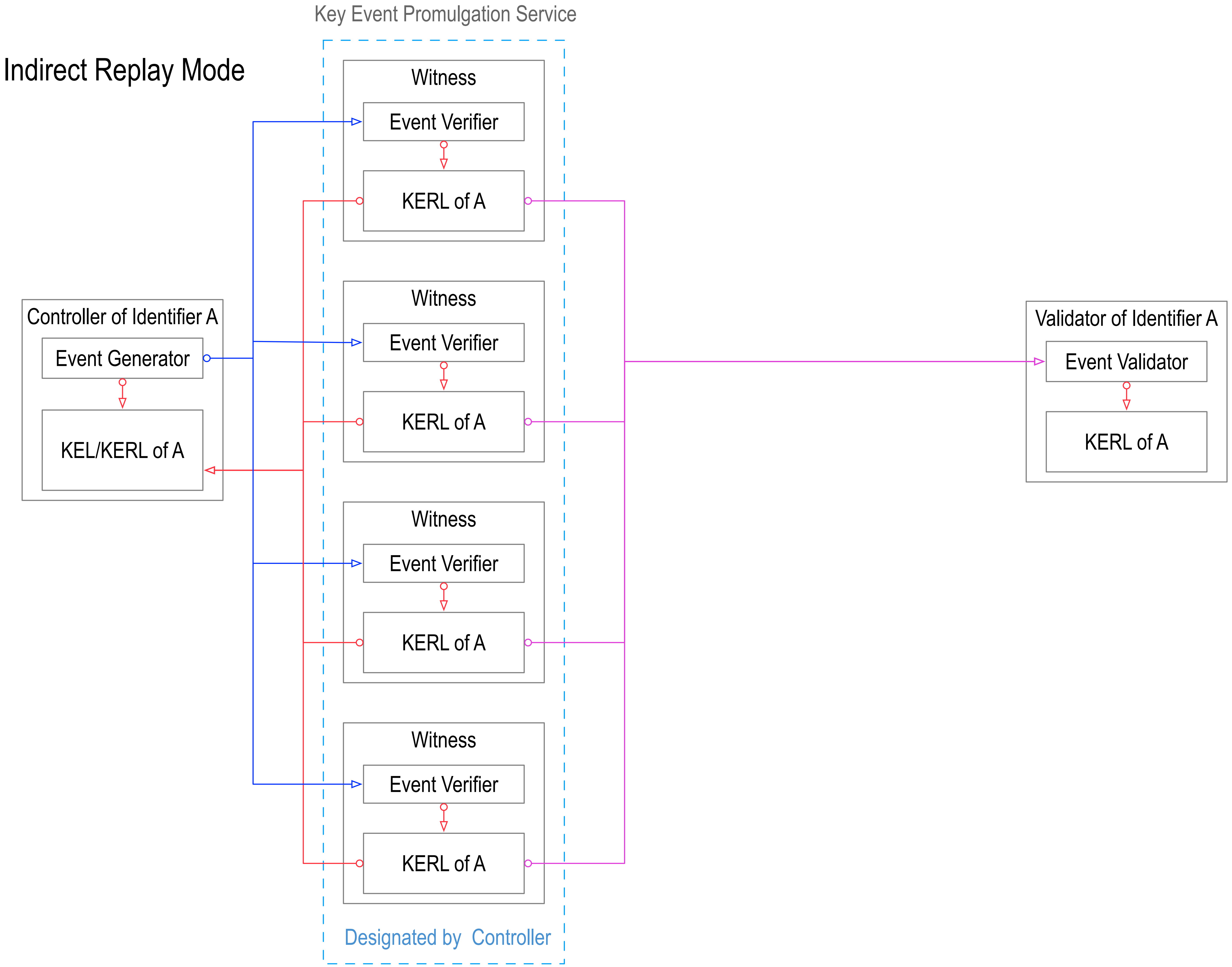
Direct Mode: A to B



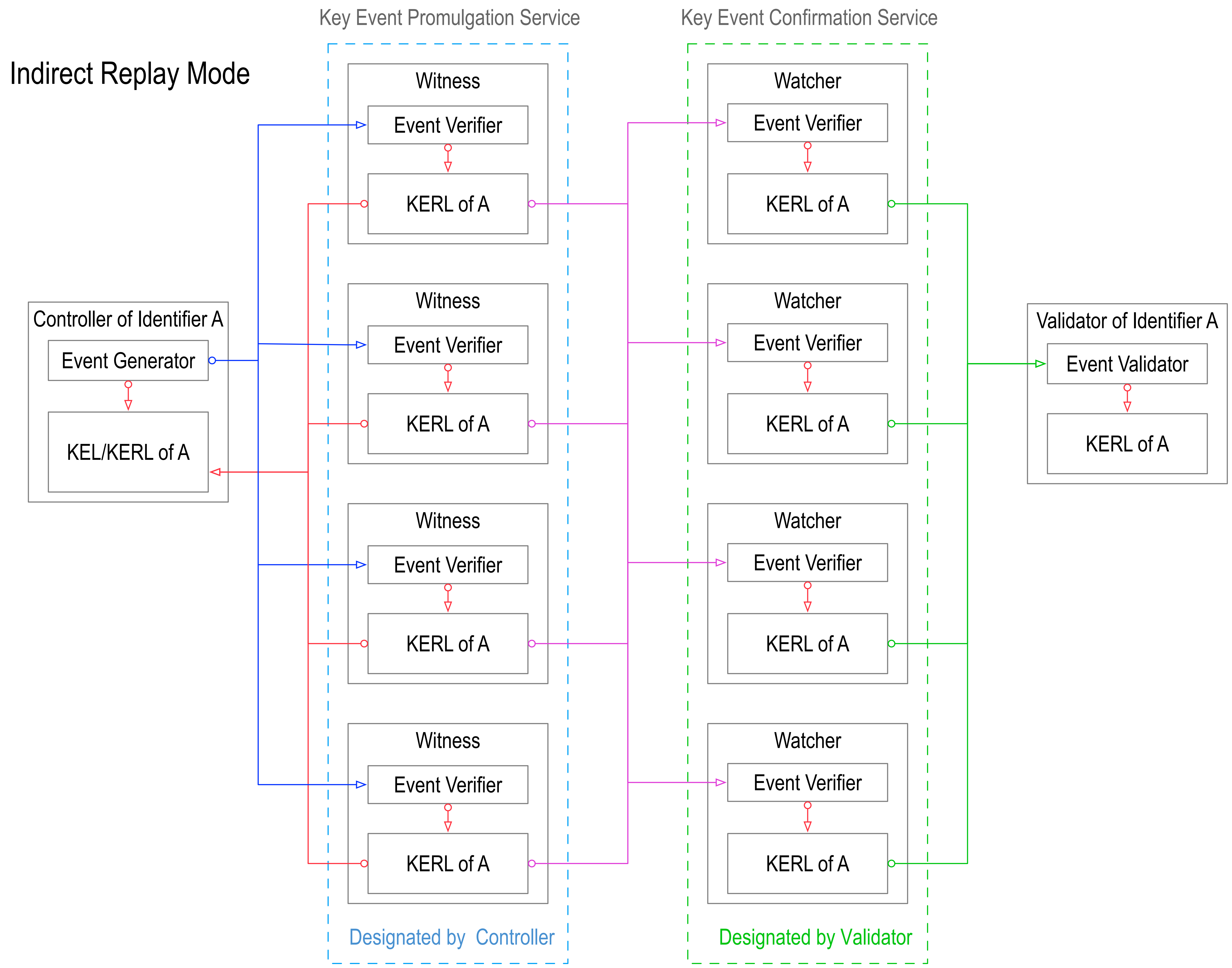
Direct Mode: B to A



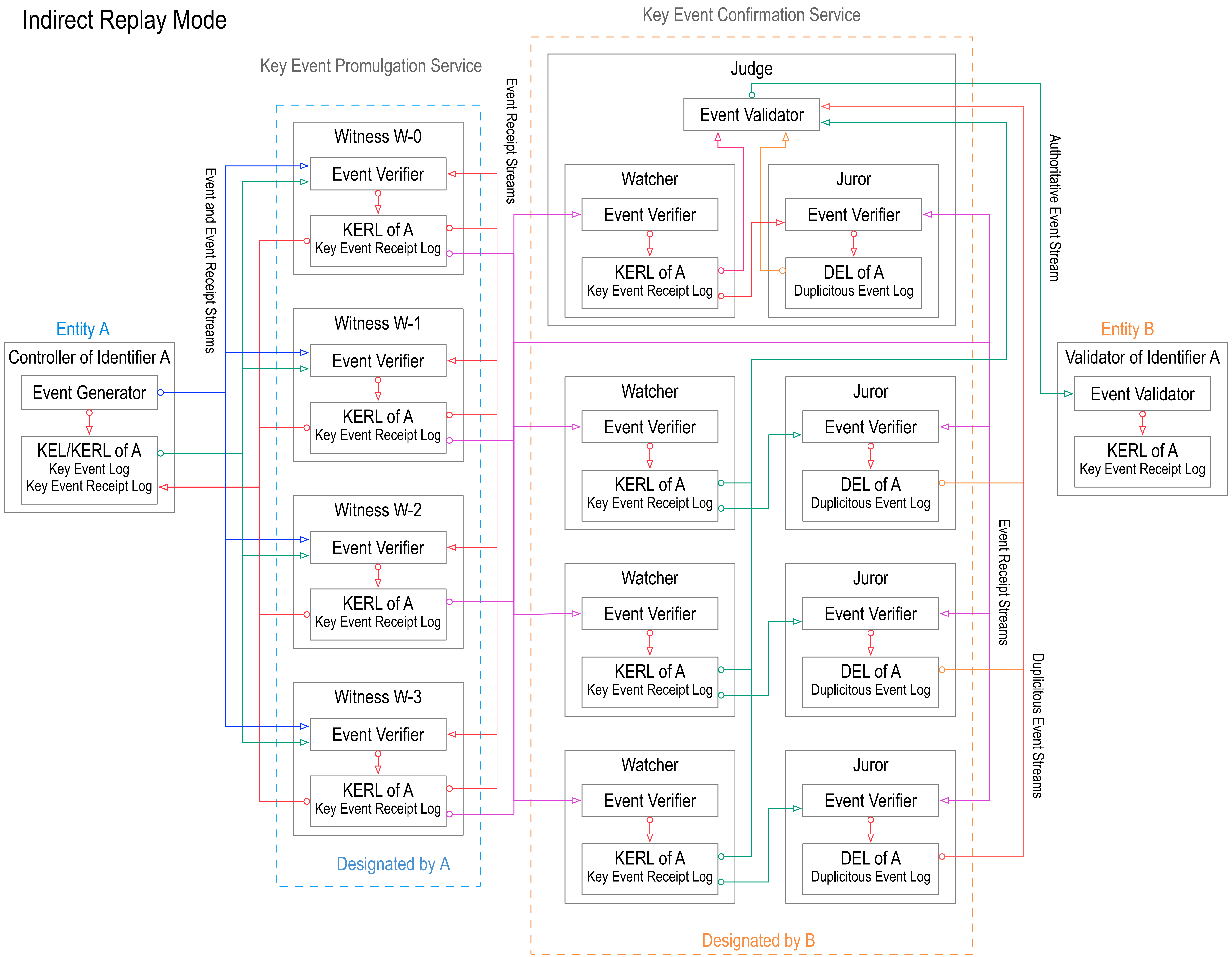
Indirect Mode Promulgation Service



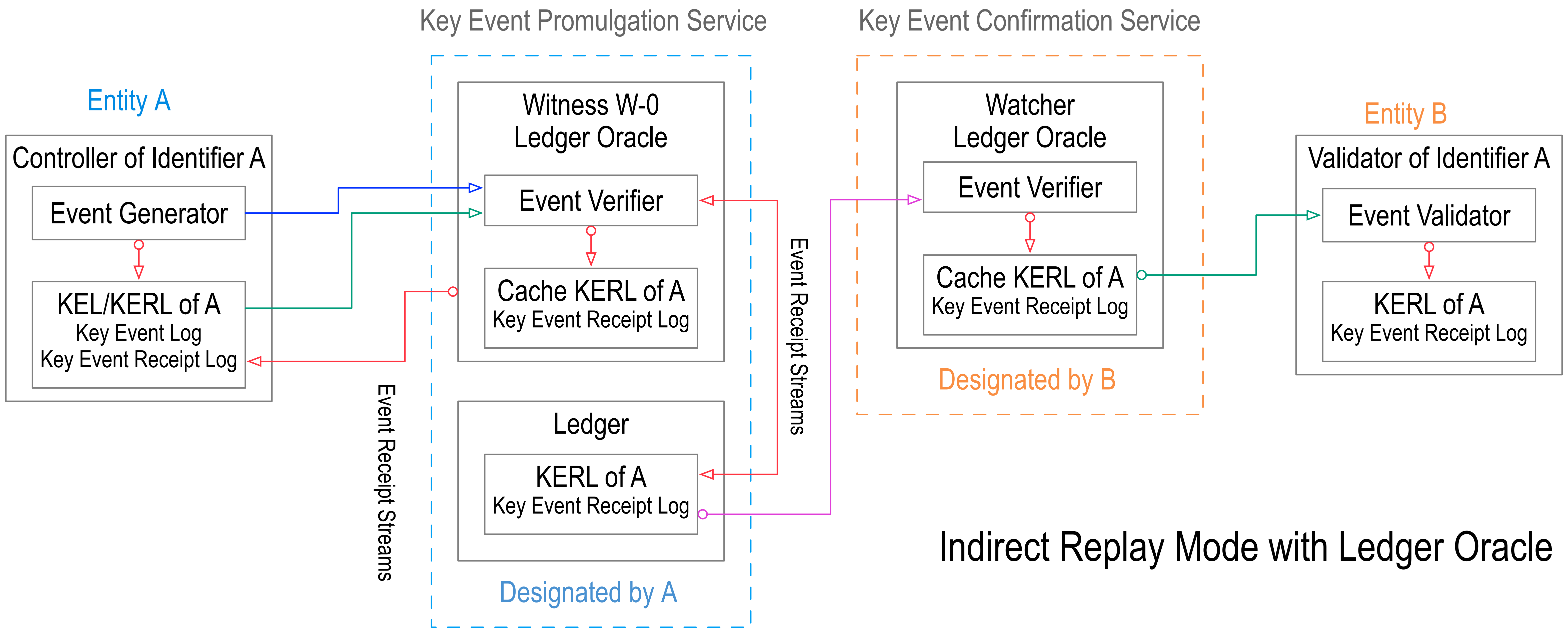
Indirect Mode
Promulgation and Confirmation Services



Indirect Mode Full



Indirect Mode with Ledger Oracles



Indirect Replay Mode with Ledger Oracle

Separation of Control

Shared (permissioned) ledger = *shared control* over *shared data*.

Shared *data* = *good*, shared *control* = *bad*.

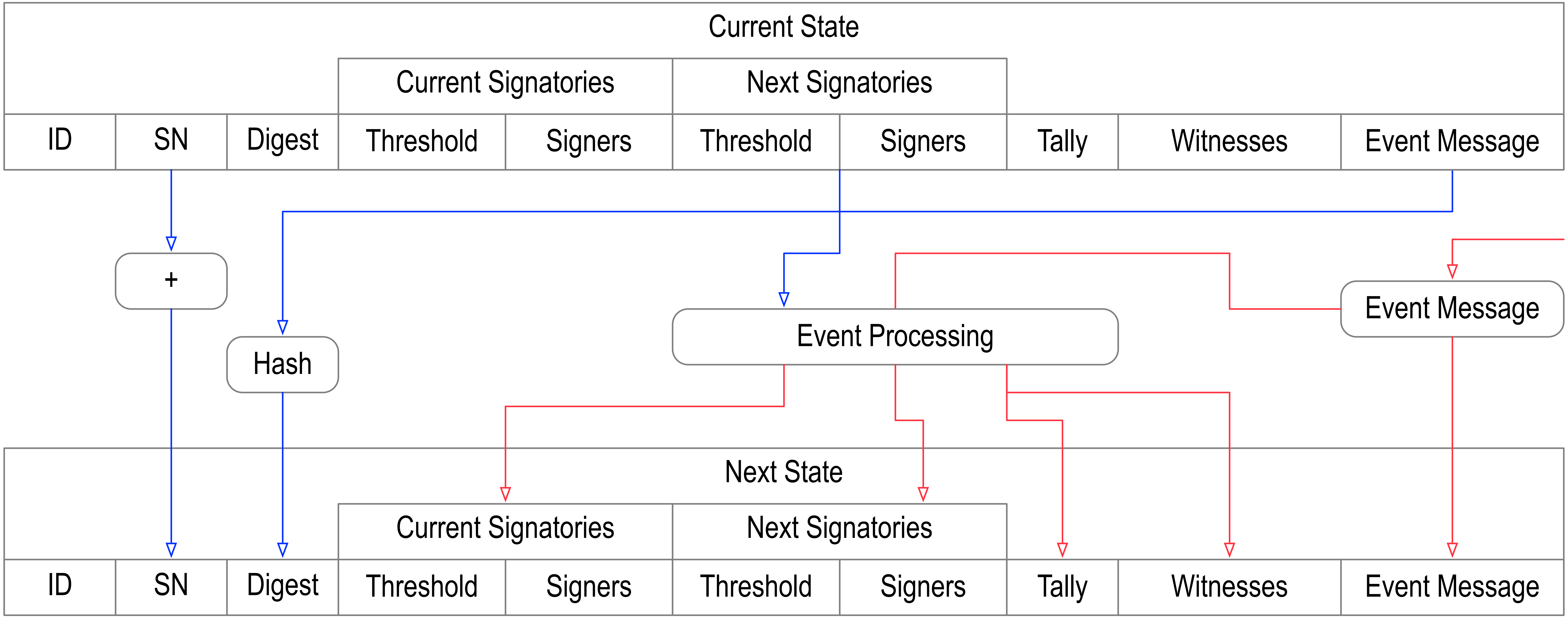
Shared control between controller and validator may be problematic for governance, scalability, and performance.

KERI = *separated control* over *shared data*.

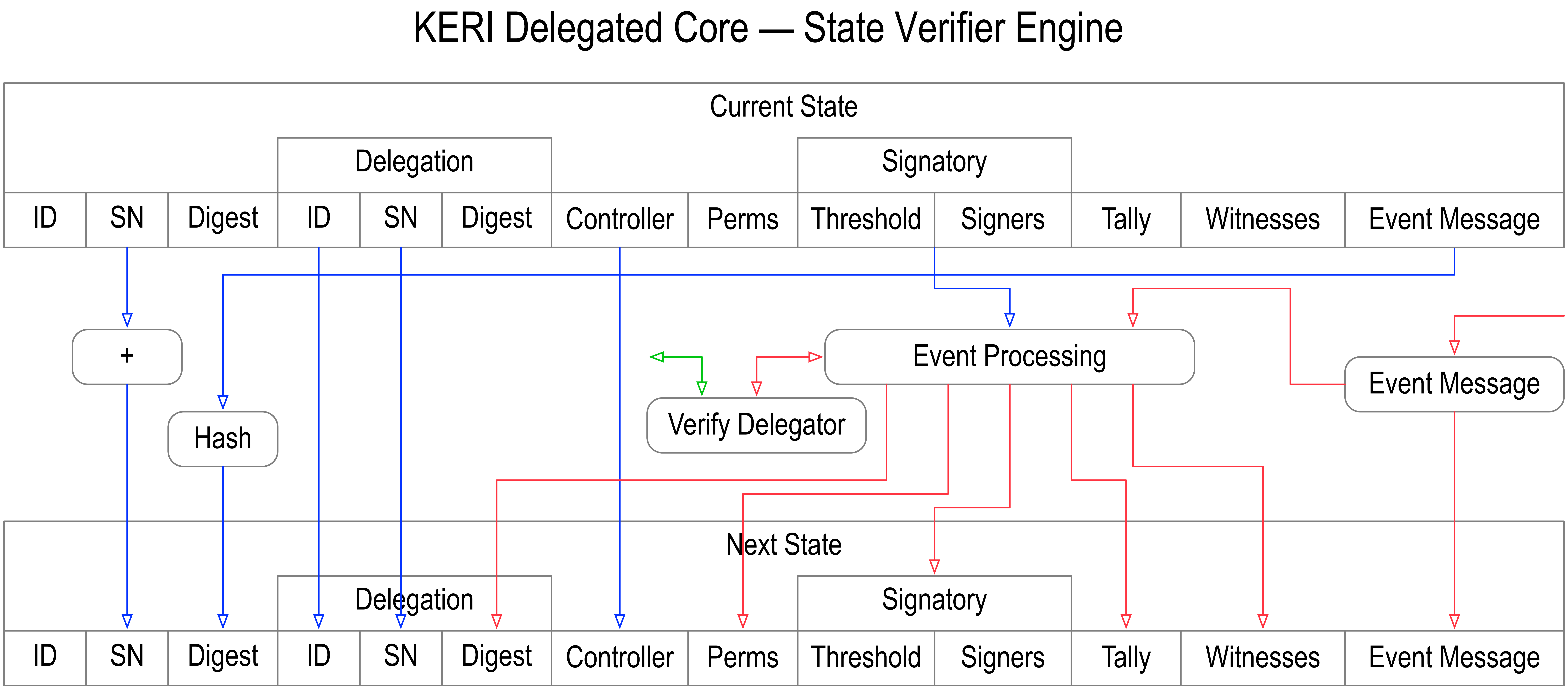
Separated control between controller and validator may provide better decentralization, more flexibility, better scalability, lower cost, higher performance, and more privacy at comparable security.

State Verifier Engine

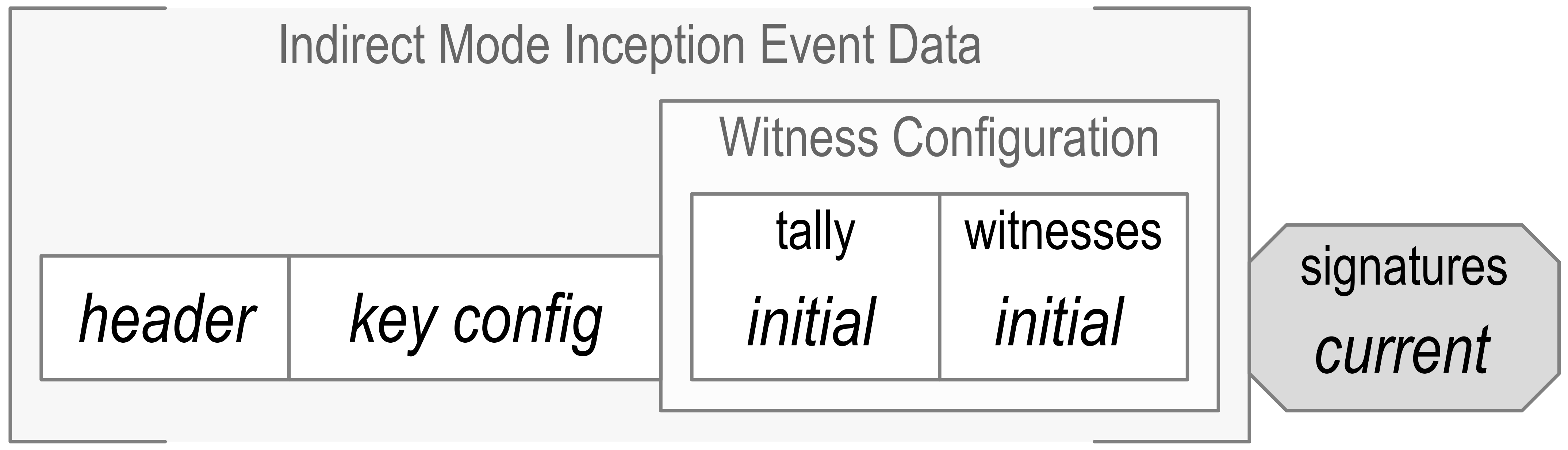
KERI Core — State Verifier Engine

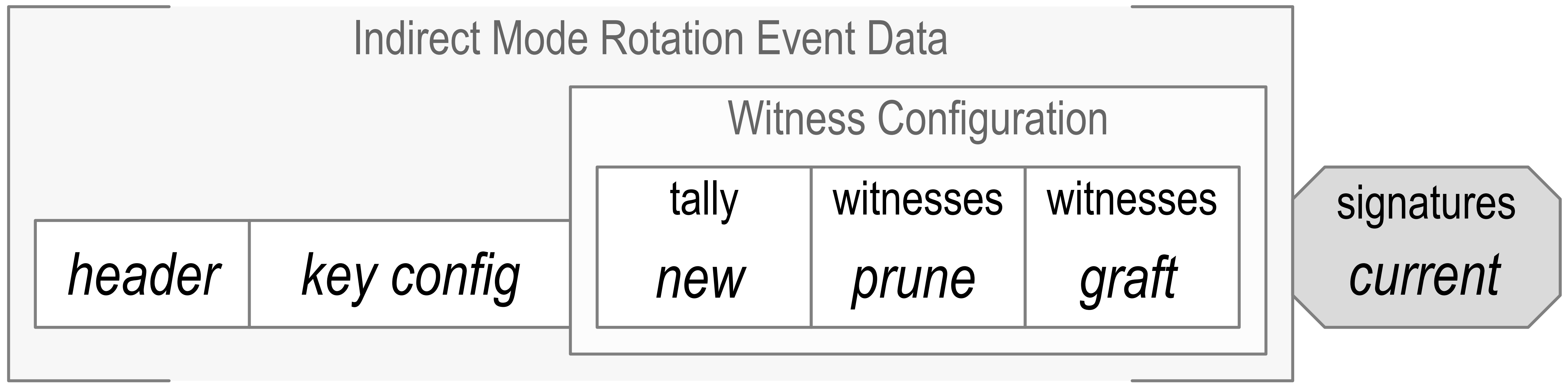


Delegated State Verifier Engine



Witness Designation





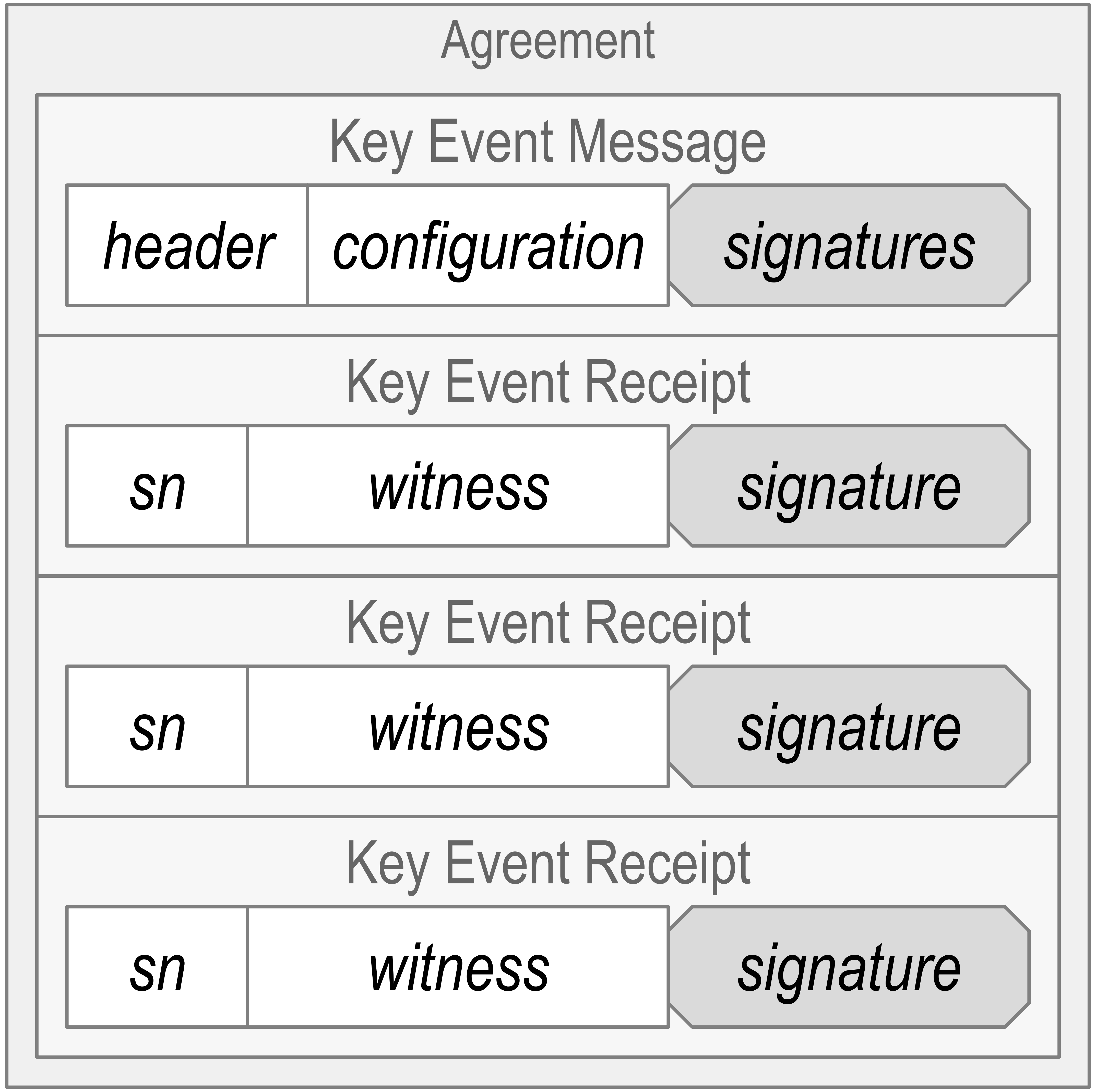
Witnessed Key Event Receipt

Key Event Receipt

version	*prefix*	*sn*	*ilk*	*digest*	*witness*	*signature*

(KA^{2}CE)
Keri's Agreement Algorithm for Control Establishment

Produce Agreements
with Guarantees



Agreement Constraints

Proper Agreement

$$F + 1$$

Sufficient Agreement

$$M > F$$

$$M \le N - F$$

$$F < M \le N - F$$

Intact Agreement

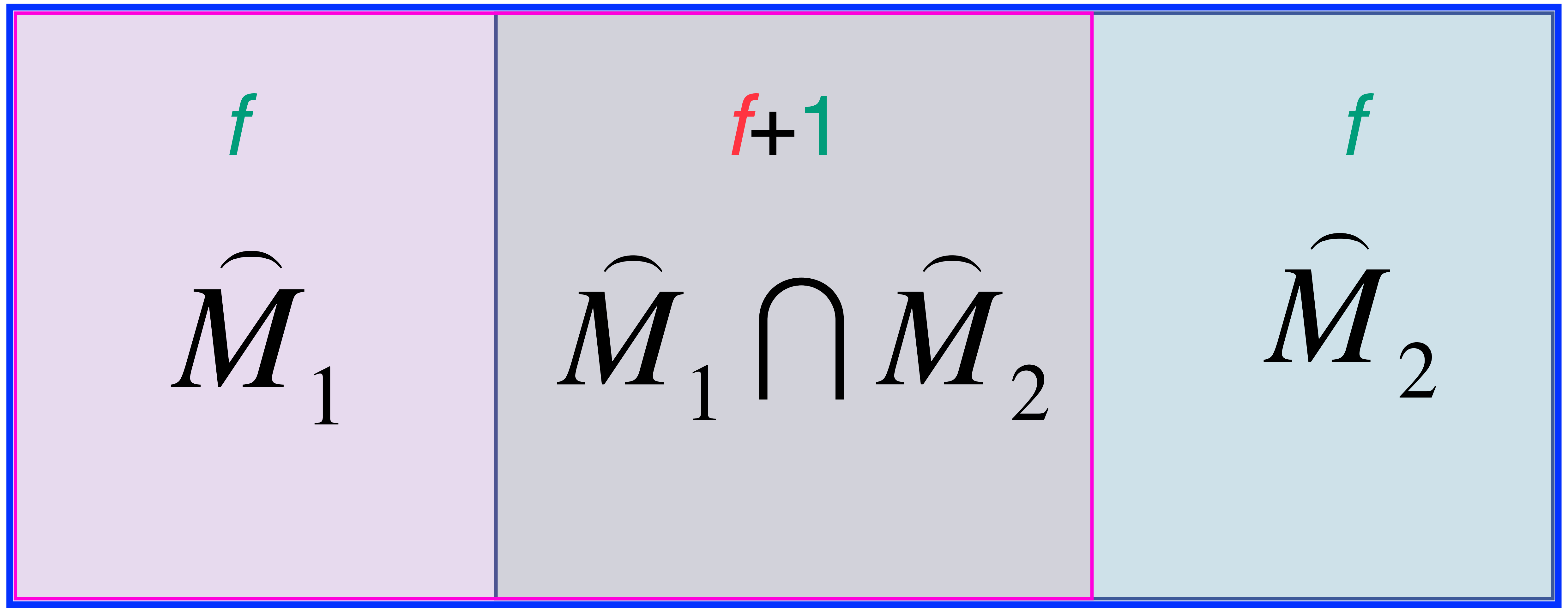
$$N \ge 2F + 1$$

One Agreement or None at All

$$\left|\widehat{N}\right| = N \qquad \left|\widehat{M}_1\right| = \left|\widehat{M}_2\right| = M$$

Overlapping Sets

$$\widehat{M}_1 \cup \widehat{M}_2 = \widehat{N}$$



One honest witness if:

$$\left|\widehat{M}_1 \cap \widehat{M}_2\right| \geq F + 1$$

$$\left|\widehat{M}_1 \cup \widehat{M}_2\right| = \left|\widehat{N}\right| = N$$

$$\left|\widehat{M}_1\right| + \left|\widehat{M}_2\right| = \left|\widehat{M}_1 \cup \widehat{M}_2\right| + \left|\widehat{M}_1 \cap \widehat{M}_2\right|$$

$$2M = N + F + 1$$

$$M \geq \left\lceil \frac{N + F + 1}{2} \right\rceil$$

$$M \leq N - F$$

Immune Agreement

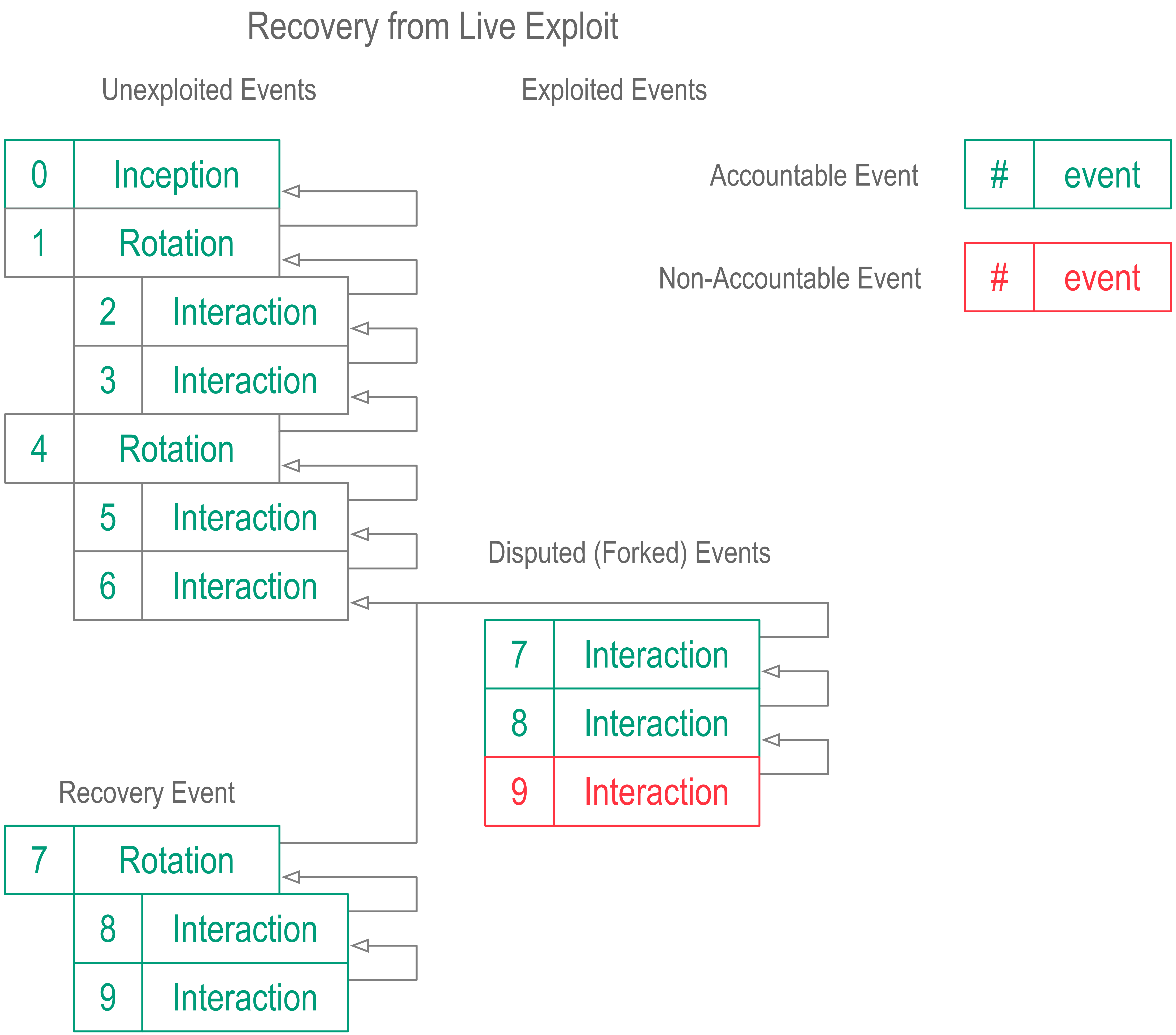
$$\frac{N + F + 1}{2} \leq M \leq N - F$$

Example Values

Immunity

F	N	3F+1	$\left\lceil \frac{N+F+1}{2} \right\rceil$	N-F	M
1	4	4	3	3	3
1	5	4	4	4	4
1	6	4	4	5	4, 5
1	7	4	5	6	5, 6
1	8	4	5	7	5, 6, 7
1	9	4	6	8	6, 7, 8
2	7	7	5	5	5
2	8	7	6	6	6
2	9	7	6	7	6, 7
2	10	7	7	8	7, 8
2	11	7	7	9	7, 8, 9
2	12	7	8	10	8, 9, 10
3	10	10	7	7	7
3	11	10	8	8	8
3	12	10	8	9	8, 9
3	13	10	9	10	9, 10
3	14	10	9	11	9, 10, 11
3	15	10	10	12	10, 11, 12

Recovery from Live Exploit Of Current Signing Keys



Generic Event Formats

Inception Event Data

Header				Key Config			Witness Config		Other Config	
version	*prefix*	*sn*	*ilk*	sith	public keys	threshold key digest	toad	witnesses	cnfg	signatures
`v1`	`C`	`0`	`icp`	*initial*	*initial*	*next*	*initial*	*initial*	*initial*	*initial*

Rotation Event Data

Header					Key Config			Witness Config			Payload	
version	*prefix*	*sn*	*ilk*	*digest*	sith	public keys	threshold key digest	toad	witnesses	witnesses	data	signatures
`v1`	`C`	`1`	`rot`	*prev*	*current*	*current*	*next*	*new*	*prune*	*graft*	*seals*	*current*

Interaction Event Data

Header					Payload	
version	*prefix*	*sn*	*ilk*	*digest*	data	signatures
`v1`	`C`	`2`	`icx`	*prev*	*seals*	*current*

Generic Inception

$$\varepsilon_0^C = \left\langle v_0^C, C, t_0^C, \mathtt{icp}, K_0^C, \widehat{C}_0^C, \eta_0^C\left(\left\langle K_1^C, \widehat{C}_1^C \right\rangle\right), M_0^C, \widehat{W}_0^C, [cnfg] \right\rangle \widehat{\sigma}_0^C$$

$$\widehat{C}_0^C = \left[C^0, \ldots, C^{L_0^C - 1} \right]_0^C$$

$$\widehat{C}_1^C = \left[C^{r_1}, \ldots, C^{r_1 + L_1^C - 1} \right]_1^C$$

$$\widehat{W}_0^C = \left[W_0^C, \ldots, W_{N_0^C - 1}^C \right]_0^C$$

$$\widehat{\sigma}_0^C = \sigma_{C^{s_0}} \ldots \sigma_{C^{s_{S_0^C - 1}}}$$

Generic Rotation

$$\varepsilon_k^C = \left\langle \nu_k^C, C, t_k^C, \eta_k^C\left(\varepsilon_{k-1}^C\right), \texttt{rot}, K_l^C, \widehat{C}_l^C, \eta_l^C\left(\left\langle K_{l+1}^C, \widehat{C}_{l+1}^C \right\rangle\right), M_l^C, \widehat{X}_l^C, \widehat{Y}_l^C, [seals] \right\rangle \widehat{\sigma}_{kl}^C$$

$$\widehat{C}_l^C = \left[C^{r_l^C}, \ldots, C^{r_l^C + L_l^C - 1} \right]_l^C$$

$$\widehat{C}_{l+1}^C = \left[C^{r_{l+1}^C}, \ldots, C^{r_{l+1}^C + L_{l+1}^C - 1} \right]_{l+1}^C$$

$$\widehat{X}_l^C = \left[X_0^C, \ldots, X_{O_l^C - 1}^C \right]_l^C$$

$$\widehat{Y}_l^C = \left[Y_0^C, \ldots, Y_{P_l^C - 1}^C \right]_l^C$$

$$\widehat{\sigma}_{kl}^C = \sigma_{C^{r_l^C + s_0}} \ldots \sigma_{C^{r_l^C + s_{S_{kl}^C - 1}}}$$

Generic Interaction

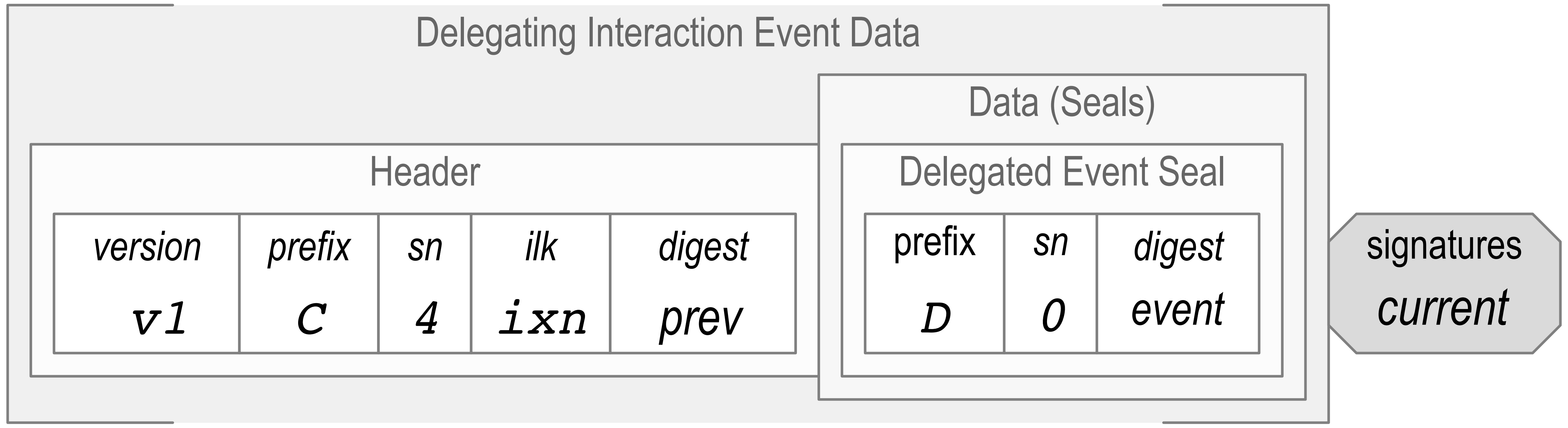
$$\varepsilon_k^C = \left\langle v_k^C, C, t_k^C, \eta_k^C\left(\varepsilon_{k-1}^C\right), \texttt{ixn}, [seals]\right\rangle \widehat{\sigma}_{kl}^C$$

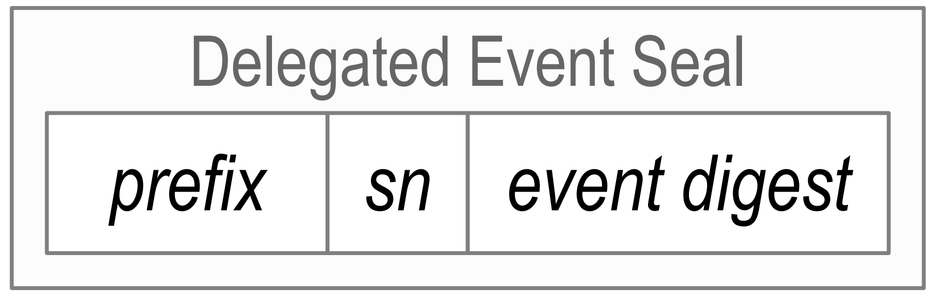
$$K_l^C$$

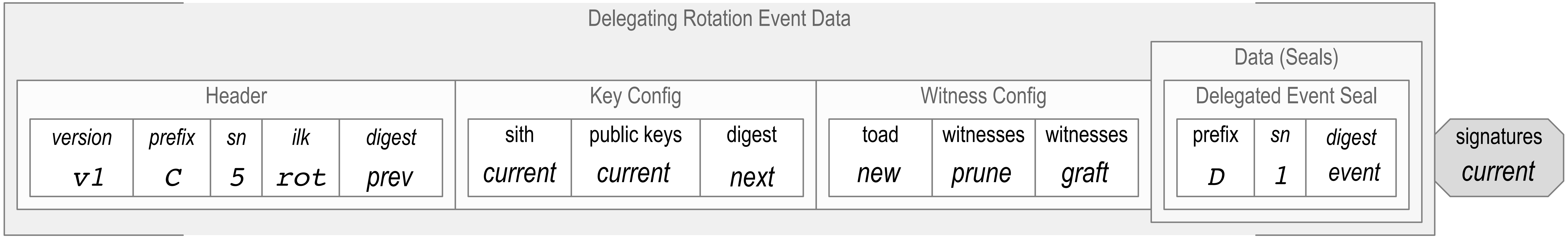
$$\widehat{C}_l^C = \left[C^{r_l^C}, \ldots, C^{r_l^C + L_l^C - 1} \right]_l^C$$

$$\widehat{\sigma}_{kl}^C = \sigma_{C^{r_l^C + s_0}} \ldots \sigma_{C^{r_l^C + s_{S_{kl}^C - 1}}}$$

Generic Delegating Event Formats







Generic Delegated Event Formats

Delegating Location Seal

prefix	sn	ilk	prior digest

Delegated Inception Event Data

Header				Key Config			Witness Config		Perms Config	Delegating Location Seal			
version	prefix	sn	ilk	sith	public keys	digest	toad	witnesses	perms	prefix	sn	ilk	digest
`v1`	*D*	*0*	`dip`	initial	initial	next	initial	initial	data	`C`	*5*	`ixn`	prior event

signatures
initial

Delegated Rotation Event Data

Header					Key Config			Witness Config			Perms Config	Delegating Location Seal			
version	prefix	sn	ilk	digest	sith	public keys	digest	toad	witnesses	witnesses	perms	prefix	sn	ilk	digest
`v1`	*D*	*1*	`drt`	prev	current	current	next	new	prune	graft	data	`C`	*5*	`ixn`	prior event

signatures
current

Delegated Interaction Event Data

Header					Payload Config
version	prefix	sn	ilk	digest	data
`v1`	*D*	*2*	`isn`	prev	seals

signatures
current

Inception Delegation

$$\widehat{\Delta}_0^D = \left\{ D, t_0^D, \eta_k^C \left(\varepsilon_0^D \right) \right\}$$ Delegated Event Seal

$$\varepsilon_0^D = \left\langle v_0^D, D, t_0^D, \mathtt{dip}, K_0^D, \widehat{D}_0^D, M_0^D, \widehat{W}_0^D, \left[perms \right], \widehat{\Delta}_k^C \right\rangle \widehat{\sigma}_0^D$$

$$\widehat{D}_0^D = \left[D^0, \ldots, D^{L_0^D - 1} \right]_0^D$$

$$\widehat{W}_0^C = \left[W_0^C, \ldots, W_{N_0^C - 1}^C \right]_0^C$$

$$\widehat{\Delta}_k^C = \left\{ C, t_k^C, ilk, \eta_k^C \left(\varepsilon_{k-1}^C \right) \right\}$$ Delegating Event Location Seal

$$\widehat{\sigma}_0^D = \sigma_{D^{s_0}} \ldots \sigma_{D^{s_{S_0^D - 1}}}$$

Rotation Delegation

$$\widehat{\Delta}_k^D = \left\{ D, t_k^D, \eta_k^C\left(\varepsilon_k^D\right) \right\}$$ Delegated Event Seal

$$\varepsilon_k^D = \left\langle \nu_k^D, D, t_k^D, \eta_k^D\left(\varepsilon_{k-1}^D\right), \mathtt{drt}, K_l^D, \widehat{D}_l^D, M_l^D, \widehat{X}_l^D, \widehat{Y}_l^D, \left[perms \right], \widehat{\Delta}_k^C \right\rangle \widehat{\sigma}_{kl}^D$$

$$\widehat{D}_l^D = \left[D^{r_l^D}, \ldots, D^{r_l^D + L_l^D - 1} \right]_l^D$$

$$\widehat{X}_l^D = \left[X_0^D, \ldots, X_{O_l^D - 1}^D \right]_l^D$$

$$\widehat{Y}_l^D = \left[Y_0^D, \ldots, Y_{P_l^D - 1}^D \right]_l^D$$

$$\widehat{\Delta}_k^C = \left\{ C, t_k^C, ilk, \eta_k^C\left(\varepsilon_{k-1}^C\right) \right\}$$ Delegating Event Location Seal

$$\widehat{\sigma}_{kl} = \sigma_{C^{+r_l^D + s_0}} \ldots \sigma_{C^{r_l^D + s_{S_{kl}^D - 1}}}$$

Delegated Interaction

$$\varepsilon_k^D = \left\langle \nu_k^D, D, t_k^D, \eta_k^D\left(\varepsilon_{k-1}^D\right), \texttt{ixn}, \left[seals\right] \right\rangle \widehat{\sigma}_{kl}^D$$

Receipt Messages

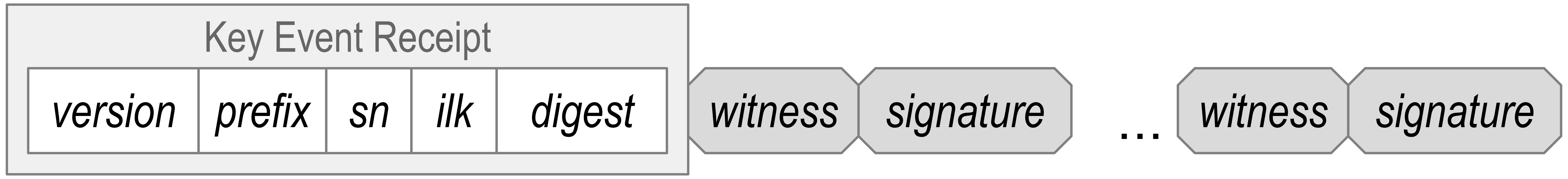
$$\rho_{V}^{C}\left(\varepsilon_{k}^{C}\right)=\left\langle v_{k}^{C}, C, t_{k}^{C}, \texttt{rct}, \eta_{k}^{C}\left(\varepsilon_{k}^{C}\right), V, \sigma_{V}^{C}\right\rangle$$

$$\rho_{W_{li}^{C}}^{C}\left(\varepsilon_{k}^{C}\right)=\left\langle v_{k}^{C}, C, t_{k}^{C}, \texttt{rct}, \eta_{k}^{C}\left(\varepsilon_{k}^{C}\right), W_{li}^{C}, \sigma_{W_{li}^{C}}^{C}\right\rangle$$

$$\rho_{\tilde{W}_{ls}^{C}}^{C}\left(\varepsilon_{k}^{C}\right)=\left\langle v_{k}^{C}, C, t_{k}^{C}, \texttt{rct}, \eta_{k}^{C}\left(\varepsilon_{k}^{C}\right), \tilde{W}_{ls}^{C}, \hat{\sigma}_{\tilde{W}_{ls}^{C}}^{C}\right\rangle$$

$$\tilde{W}_{ls}^{C}=\left[W_{0}^{C}, \ldots, W_{N_{s}^{C}-1}^{C}\right]_{ls}^{C} \qquad \hat{\sigma}_{\tilde{W}_{ls}^{C}}^{C}=\sigma_{W_{l0}^{C}}^{C}, \ldots, \sigma_{W_{N_{s}-1}^{C}}^{C}$$

$$\rho_{\tilde{W}_{ls}^{C}}^{C}\left(\varepsilon_{k}^{C}\right)=\left\langle v_{k}^{C}, C, t_{k}^{C}, \texttt{rct}, \eta_{k}^{C}\left(\varepsilon_{k}^{C}\right)\right\rangle W_{l0}^{C}\sigma_{W_{l0}^{C}}^{C}, \ldots, W_{lN_{s}^{C}-1}^{C}\sigma_{W_{lN_{s}-1}^{C}}^{C}$$



Witness Rotations

$$\widehat{W}_0 = \left[W_0 \ , W_1 \ , \cdots , W_{N-1} \right]$$

$$\widehat{W}_l = \left(\widehat{W}_{l-1} - \widehat{X}_l \right) \bigcap \widehat{Y}_l$$

$$\widehat{X}_l \subseteq \widehat{W}_{l-1} \quad \widehat{Y}_l \not\subset \widehat{W}_{l-1} \quad \widehat{X}_l \not\subset \widehat{W}_l$$

$$N_l = N_{l-1} - O_l + P_l$$

$$M_l \leq N_l$$

$$\left| \widehat{X}_l \right| = O_l \quad \left| \widehat{Y}_l \right| = P_l \quad \left| \widehat{W}_l \right| = N_l$$

$$\widehat{U}_{l-1} \subseteq \widehat{W}_{l-1} \qquad \left| \widehat{U}_{l-1} \right| \geq M_{l-1}$$

$$\widehat{U}_l \subseteq \widehat{W}_l \qquad \left| \widehat{U}_l \right| \geq M_l$$

$$\left| \widehat{U}_{l-1} \bigcup \widehat{U}_l \right| \leq M_{l-1} + M_l$$

Complex Weighted Signing Thresholds

$$\widehat{C}_l = \left[C_l^1, \ldots, C_l^{L_l} \right]_l$$

$$\widehat{K}_l = \left[U_l^1, \ldots, U_l^{L_1} \right]_l$$

$$0 < U_l^j \leq 1$$

$$\widehat{s}_k^l = \left[s_0, \ldots, s_{S_k^l - 1} \right]_k^l$$

$$\bar{U}_l = \sum_{i=s_0}^{s_{S_k-1}} U_l^i \geq 1$$

$$\widehat{C} = \left[C^1, C^2, C^3 \right]$$

$$U_l^j = {}^1\!/_{K_l}$$

$$\widehat{K} = \left[{}^1\!/_2, {}^1\!/_2, {}^1\!/_2 \right]$$

$$\widehat{K}_l = \left[{}^1\!/_2, {}^1\!/_2, {}^1\!/_4, {}^1\!/_4, {}^1\!/_4, {}^1\!/_4 \right]_l$$

$$\widehat{K}_l = \left[\left[{}^1\!/_2, {}^1\!/_2, {}^1\!/_4, {}^1\!/_4, {}^1\!/_4, {}^1\!/_4 \right], \left[{}^1\!/_2, {}^1\!/_2, {}^1\!/_2, {}^1\!/_2 \right], \left[1, 1, 1, 1 \right] \right]$$

BACKGROUND

Cryptographic Material Derivation Code Tables

Length of crypt material determines number of pad characters. One character table for one pad char. Two character table for two pad char.

One Character KERI Base64 Prefix Derivation Code Selector

Derivation Code	Prefix Description
0	Two character derivation code. Use two character table.
1	Four character derivation code. Use four character table.
2	Five character derivation code. Use five character table.
3	Six character derivation code. Use six character table.
4	Eight character derivation code. Use eight character table.
5	Nine character derivation code. Use nine character table.
6	Ten character derivation code. Use ten character table.
-	Count code for attached receipts. Use receipt count code table(s)

Four Character KERI Base64 Count Code for Attached Receipt Couplets

Derivation Code	Prefix Description	Data Length Bytes	Pad Length	Count Code Length	Qual Length Base64	Code Length Bytes
-A*XX*	Count of Attached Qualified Base64 Receipt Couplets	0	0	4	4	3
-B*XX*	Count of Attached Qualified Base2 Receipt Couplets	0	0	4	4	3

One Character KERI Base64 Prefix Derivation Code

Derivation Code	Prefix Description	Data Length Bytes	Pad Length	Derivation Code Length	Prefix Length Base64	Prefix Length Bytes
A	Non-transferable prefix using Ed25519 public signing verification key. Basic derivation.	32	1	1	44	33
B	X25519 public encryption key. May be converted from Ed25519 public signing verification key.	32	1	1	44	33
C	Ed25519 public signing verification key. Basic derivation.	32	1	1	44	33
D	Blake3-256 Digest. Self-addressing derivation.	32	1	1	44	33
E	Blake2b-256 Digest. Self-addressing derivation.	32	1	1	44	33
F	Blake2s-256 Digest. Self-addressing derivation.	32	1	1	44	33
G	Non-transferable prefix using ECDSA secp256k1 public singing verification key. Basic derivation.	32	1	1	44	33
H	ECDSA secp256k1 public signing verification key. Basic derivation.	32	1	1	44	33
I	SHA3-256 Digest. Self-addressing derivation.	32	1	1	44	33
J	SHA2-256 Digest. Self-addressing derivation.	32	1	1	44	33

Two Character KERI Base64 Prefix Derivation Code

Derivation Code	Prefix Description	Data Length Bytes	Pad Length	Derivation Code Length	Prefix Length Base64	Prefix Length Bytes
0A	Ed25519 signature. Self-signing derivation.	64	2	2	88	66
0B	ECDSA secp256k1 signature. Self-signing derivation.	64	2	2	88	66
0C	Blake3-512 Digest. Self-addressing derivation.	64	2	2	88	66
0D	SHA3-512 Digest. Self-addressing derivation.	64	2	2	88	66
0E	Blake2b-512 Digest. Self-addressing derivation.	64	2	2	88	66
0F	SHA2-512 Digest. Self-addressing derivation.	64	2	2	88	66

Attached Signature Derivation Code Tables

Length of crypt material determines number of pad characters. One character table for one pad char. Two character table for two pad char.

Two Character KERI Base64 Attached Signature Selection Code

Derivation Code	Selector Description	Data Length Bytes	Pad Length	Derivation Code Length	Prefix Length Base64	Prefix Length Bytes
0	Four character attached signature code. Use four character table					
1	Five character attached signature code. Use five character table					
2	Six character attached signature code. Use six character table					
-	Count code for attached signatures. Use attached signature count code table(s)					

Two Character KERI Base64 Attached Signature Derivation Code

Derivation Code	Prefix Description	Data Length Bytes	Pad Length	Derivation Code Length	Prefix Length Base64	Prefix Length Bytes
A*X*	Ed25519 signature	64	2	2	88	66
B*X*	ECDSA secp256k1 signature	64	2	2	88	66

Four Character KERI Base64 Attached Signature Derivation Code

Derivation Code	Prefix Description	Data Length Bytes	Pad Length	Derivation Code Length	Prefix Length Base64	Prefix Length Bytes
0A*XX*	Ed448 signature	114	0	4	156	117
OB*XX*						
0C*XX*						

Four Character KERI Base64 Count Code for Attached Signatures

Derivation Code	Prefix Description	Data Length Bytes	Pad Length	Count Code Length	Qual Length Base64	Code Length Bytes
-A*XX*	Count of Attached Qualified Base64 Signatures	0	0	4	4	3
-B*XX*	Count of Attached Qualified Base2 Signatures	0	0	4	4	3

Base64

Base64 Decode ASCII to Binary

Base64 Binary Decoding from ASCII

ASCII Char	Base64 Index Decimal	Base64 Index Hex	Base64 Index 6 bit Binary	ASCII Char	Base64 Index Decimal	Base64 Index Hex	Base64 Index 6 bit Binary	ASCII Char	Base64 Index Decimal	Base64 Index Hex	Base64 Index 6 bit Binary	ASCII Char	Base64 Index Decimal	Base64 Index Hex	Base64 Index 6 bit Binary
A	0	00	000000	Q	16	10	010000	g	32	20	100000	w	48	30	110000
B	1	01	000001	R	17	11	010001	h	33	21	100001	x	49	31	110001
C	2	02	000010	S	18	12	010010	i	34	22	100010	y	50	32	110010
D	3	03	000011	T	19	13	010011	j	35	23	100011	z	51	33	110011
E	4	04	000100	U	20	14	010100	k	36	24	100100	0	52	34	110100
F	5	05	000101	V	21	15	010101	l	37	25	100101	1	53	35	110101
G	6	06	000110	W	22	16	010110	m	38	26	100110	2	54	36	110110
H	7	07	000111	X	23	17	010111	n	39	27	100111	3	55	37	110111
I	8	08	001000	Y	24	18	011000	o	40	28	101000	4	56	38	111000
J	9	09	001001	Z	25	19	011001	p	41	29	101001	5	57	39	111001
K	10	0A	001010	a	26	1A	011010	q	42	2A	101010	6	58	3A	111010
L	11	0B	001011	b	27	1B	011011	r	43	2B	101011	7	59	3B	111011
M	12	0C	001100	c	28	1C	011100	s	44	2C	101100	8	60	3C	111100
N	13	0D	001101	d	29	1D	011101	t	45	2D	101101	9	61	3D	111101
O	14	0E	001110	e	30	1E	011110	u	46	2E	101110	-	62	3E	111110
P	15	0F	001111	f	31	1F	011111	v	47	2F	101111	_	63	3F	111111

Base64 Encode Binary to ASCII

Base64 Binary Encoding to ASCII

Base64 Index Decimal	ASCII Char	ASCII Decimal	ASCII Hex	ASCII 8 bit Binary	Base64 Index Decimal	ASCII Char	ASCII Decimal	ASCII Hex	ASCII 8 bit Binary	Base64 Index Decimal	ASCII Char	ASCII Decimal	ASCII Hex	ASCII 8 bit Binary	Base64 Index Decimal	ASCII Char	ASCII Decimal	ASCII Hex	ASCII 8 bit Binary
0	A	65	41	01000001	**16**	Q	81	51	01010001	**32**	g	103	67	01100111	**48**	w	119	77	01110111
1	B	66	42	01000010	**17**	R	82	52	01010010	**33**	h	104	68	01101000	**49**	x	120	78	01111000
2	C	67	43	01000011	**18**	S	83	53	01010011	**34**	i	105	69	01101001	**50**	y	121	79	01111001
3	D	68	44	01000100	**19**	T	84	54	01010100	**35**	j	106	6A	01101010	**51**	z	122	7A	01111010
4	E	69	45	01000101	**20**	U	85	55	01010101	**36**	k	107	6B	01101011	**52**	0	48	30	00110000
5	F	70	46	01000110	**21**	V	86	56	01010110	**37**	l	108	6C	01101100	**53**	1	49	31	00110001
6	G	71	47	01000111	**22**	W	87	57	01010111	**38**	m	109	6D	01101101	**54**	2	50	32	00110010
7	H	72	48	01001000	**23**	X	88	58	01011000	**39**	n	110	6E	01101110	**55**	3	51	33	00110011
8	I	73	49	01001001	**24**	Y	89	59	01011001	**40**	o	111	6F	01101111	**56**	4	52	34	00110100
9	J	74	4A	01001010	**25**	Z	90	5A	01011010	**41**	p	112	70	01110000	**57**	5	53	35	00110101
10	K	75	4B	01001011	**26**	a	97	61	01100001	**42**	q	113	71	01110001	**58**	6	54	36	00110110
11	L	76	4C	01001100	**27**	b	98	62	01100010	**43**	r	114	72	01110010	**59**	7	55	37	00110111
12	M	77	4D	01001101	**28**	c	99	63	01100011	**44**	s	115	73	01110011	**60**	8	56	38	00111000
13	N	78	4E	01001110	**29**	d	100	64	01100100	**45**	t	116	74	01110100	**61**	9	57	39	00111001
14	O	79	4F	01001111	**30**	e	101	65	01100101	**46**	u	117	75	01110101	**62**	-	45	2D	00101101
15	P	80	50	01010000	**31**	f	102	66	01100110	**47**	v	118	76	01110110	**63**	_	95	5F	01011111

Certificate Transparency Problem

"The solution the computer world has relied on for many years is to introduce into the system trusted third parties (CAs) that vouch for the binding between the domain name and the private key. The problem is that we've managed to bless several hundred of these supposedly trusted parties, any of which can vouch for any domain name. Every now and then, one of them gets it wrong, sometimes spectacularly."

Pinning inadequate
Notaries inadequate
DNSSec inadequate
All require trust in 3rd party compute infrastructure that is inherently vulnerable

Certificate Transparency: (related EFF SSL Observatory)
Public end-verifiable append-only event log with consistency and inclusion proofs
End-verifiable duplicity detection = Ambient verifiability of duplicity
Event log is third party infrastructure but zero trust because it is verifiable.
Sparse Merkle Trees for revocation of certificates

Certificate Transparency Solution

Public end-verifiable append-only event log with consistency and inclusion proofs
End-verifiable duplicity detection = ambient verifiability of duplicity
Event log is third party infrastructure but it is not trusted because logs are verifiable.
Sparse Merkle trees for revocation of certificates
(related EFF SSL Observatory)

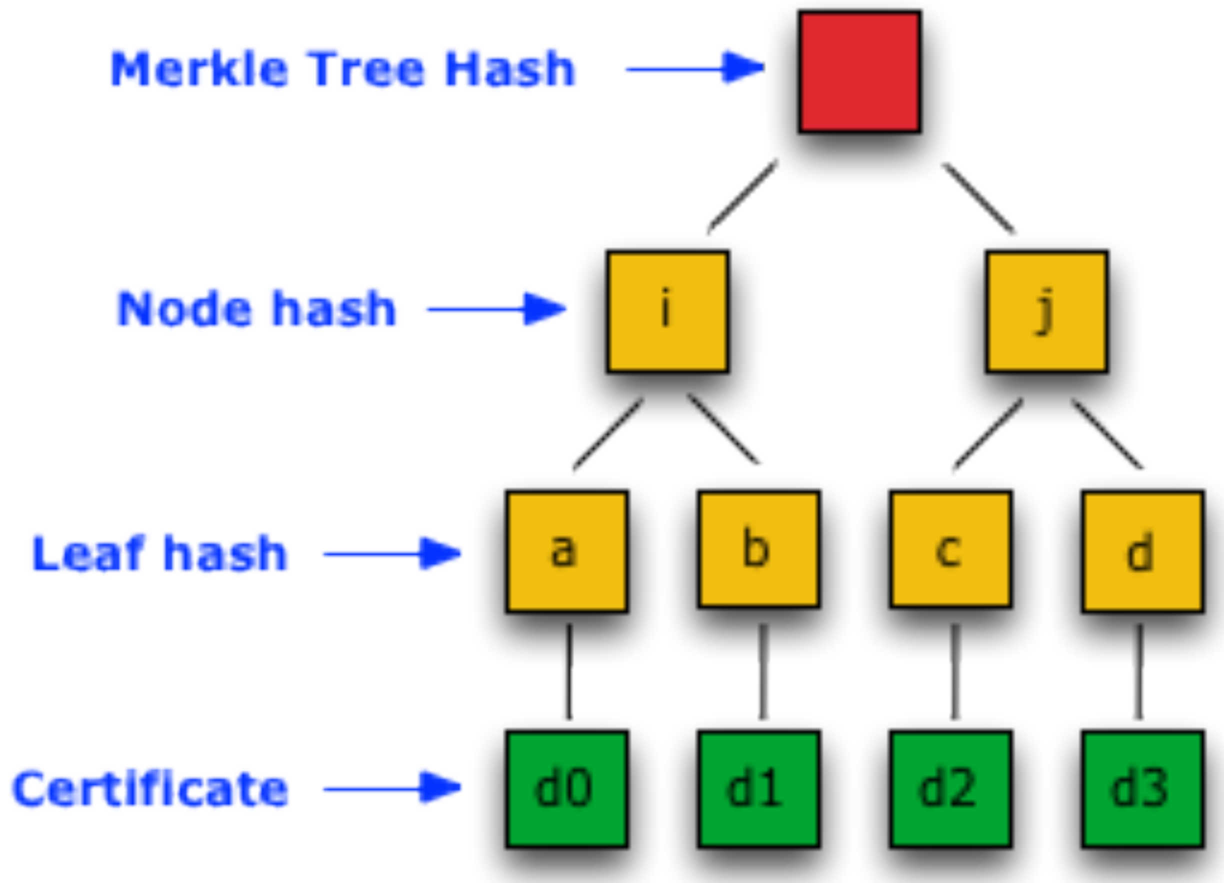


Figure 1

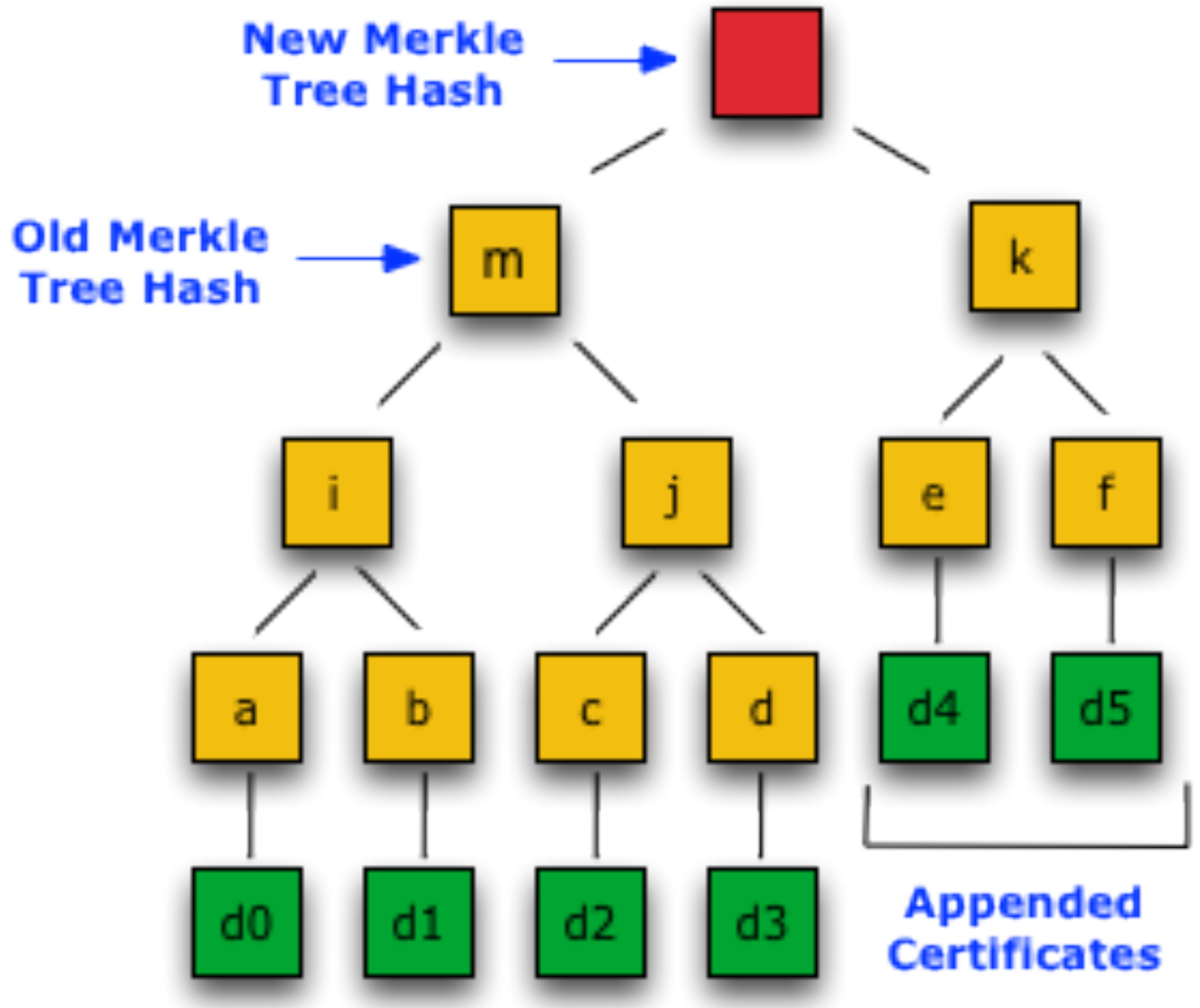


Figure 2

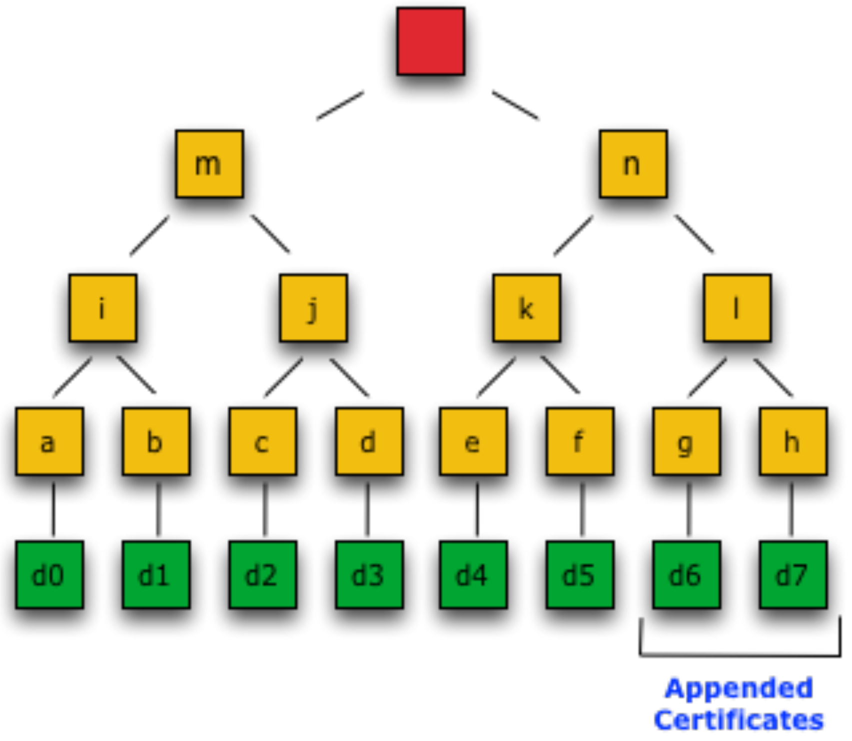


Figure 3

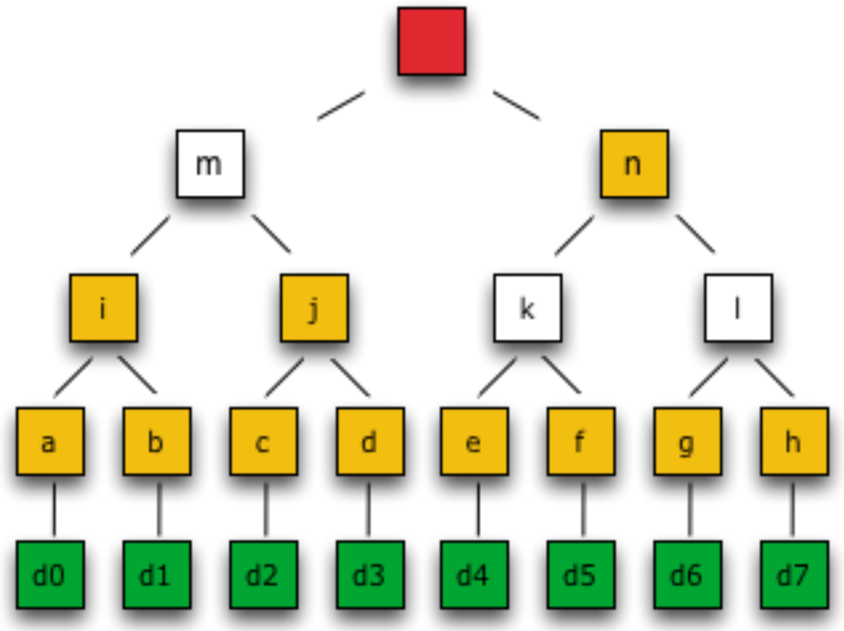


Figure 4