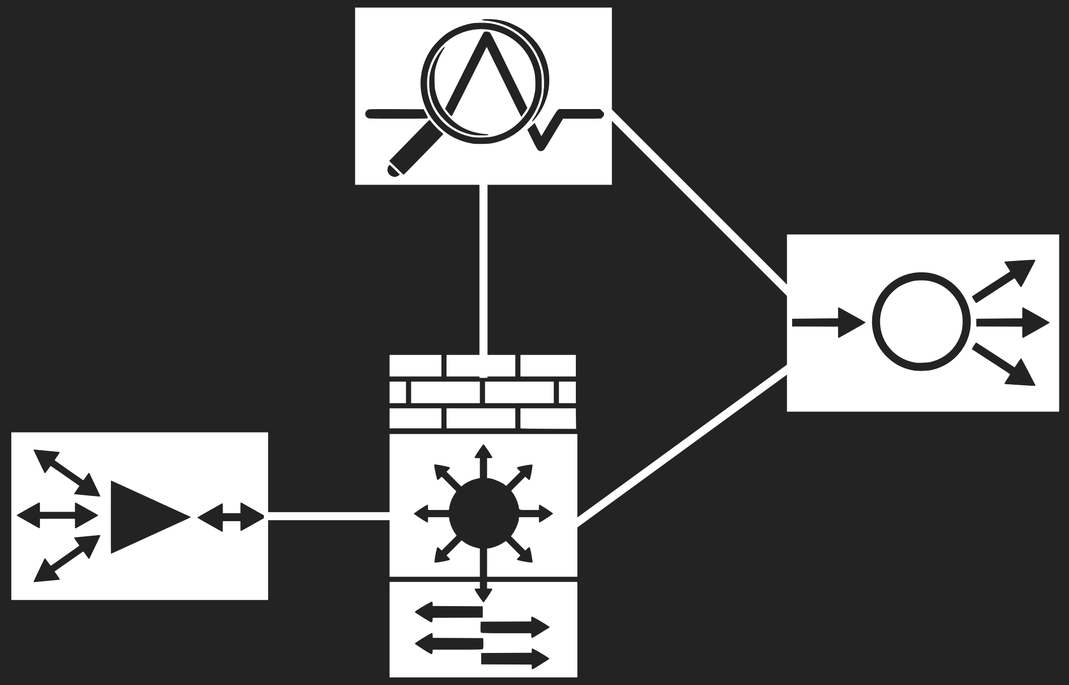
Don’t Yank My Chain

Auditable NF Service Chaining

Guyue Liu, **Hugo Sadok**, Anne Kohlbrenner, Bryan Parno, Vyas Sekar, Justine Sherry

Carnegie Mellon University

Network Function Virtualization (NFV)



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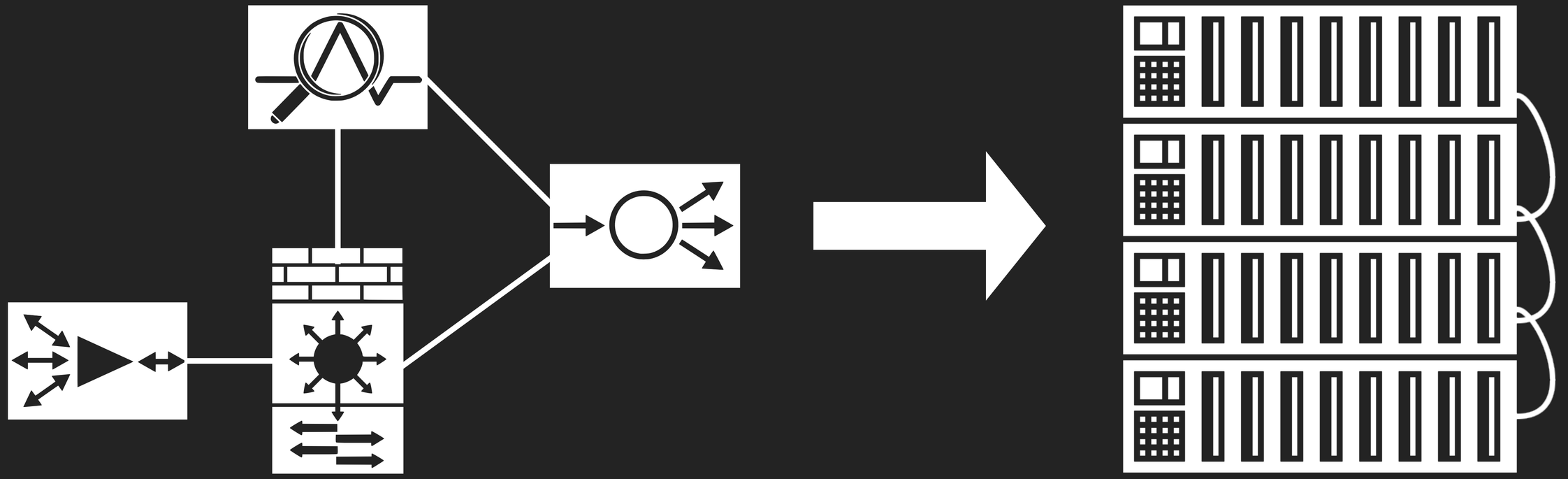

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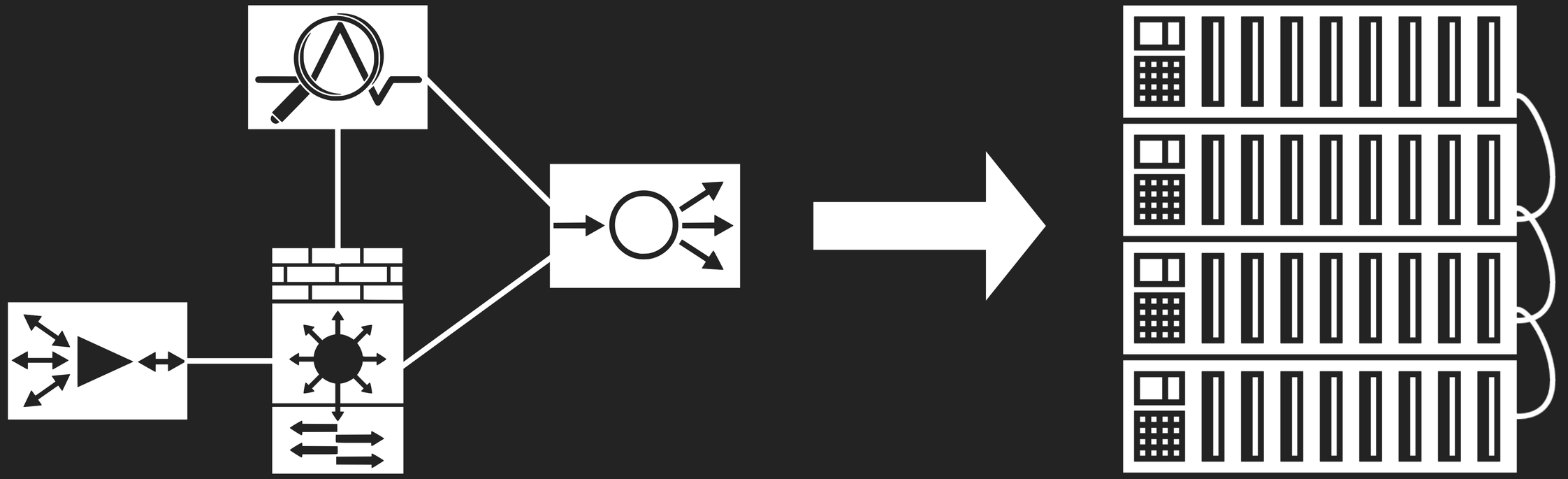
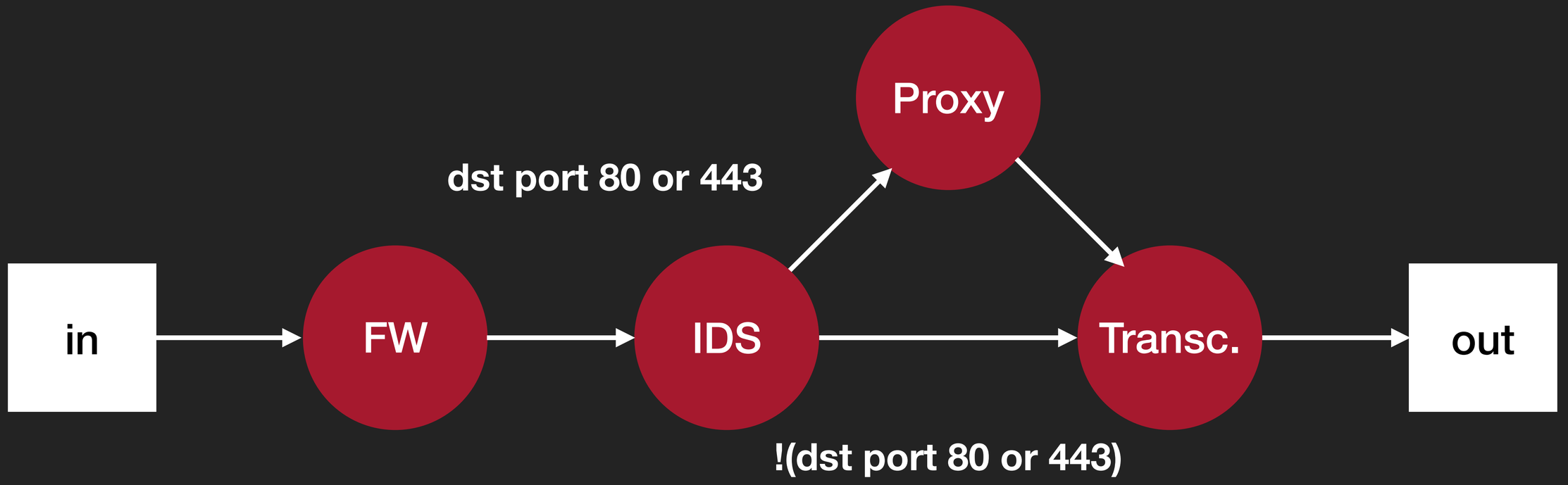


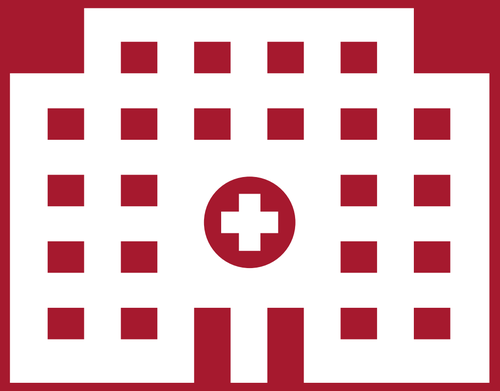
Benefits: ① Cost ② Elasticity ③ Richer Policies

Policies in NFV



Policy Graph

NFs are mandated by legal and policy requirements



HIPPA

PCI

FERPA

Regulatory Compliance (NIST 800-53)*

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Periodically test that the infrastructure is running properly

System must provide **logs** of anomalies and past behavior

Independent auditors must verify that security mechanisms are in place and running correctly

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Auditing Network Function Chains

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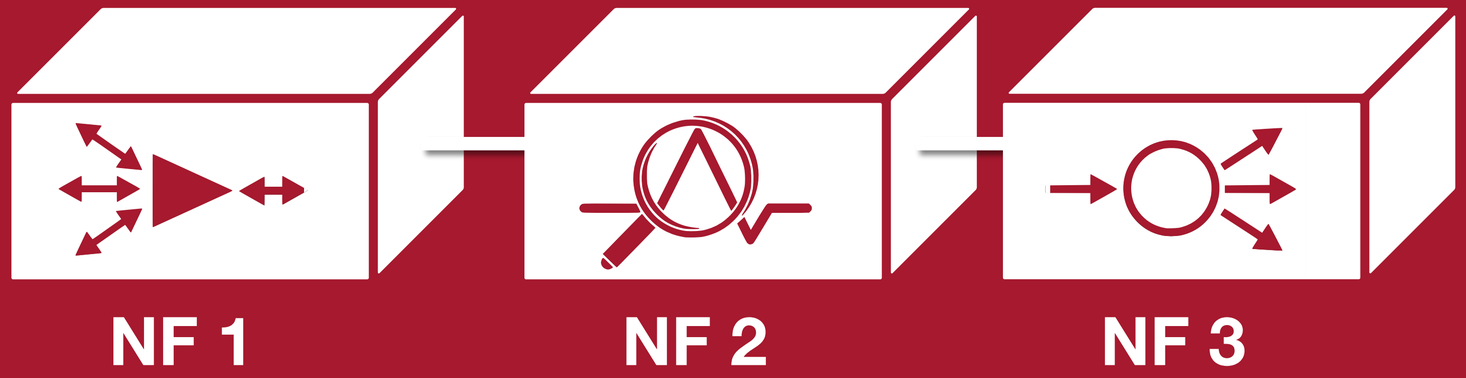

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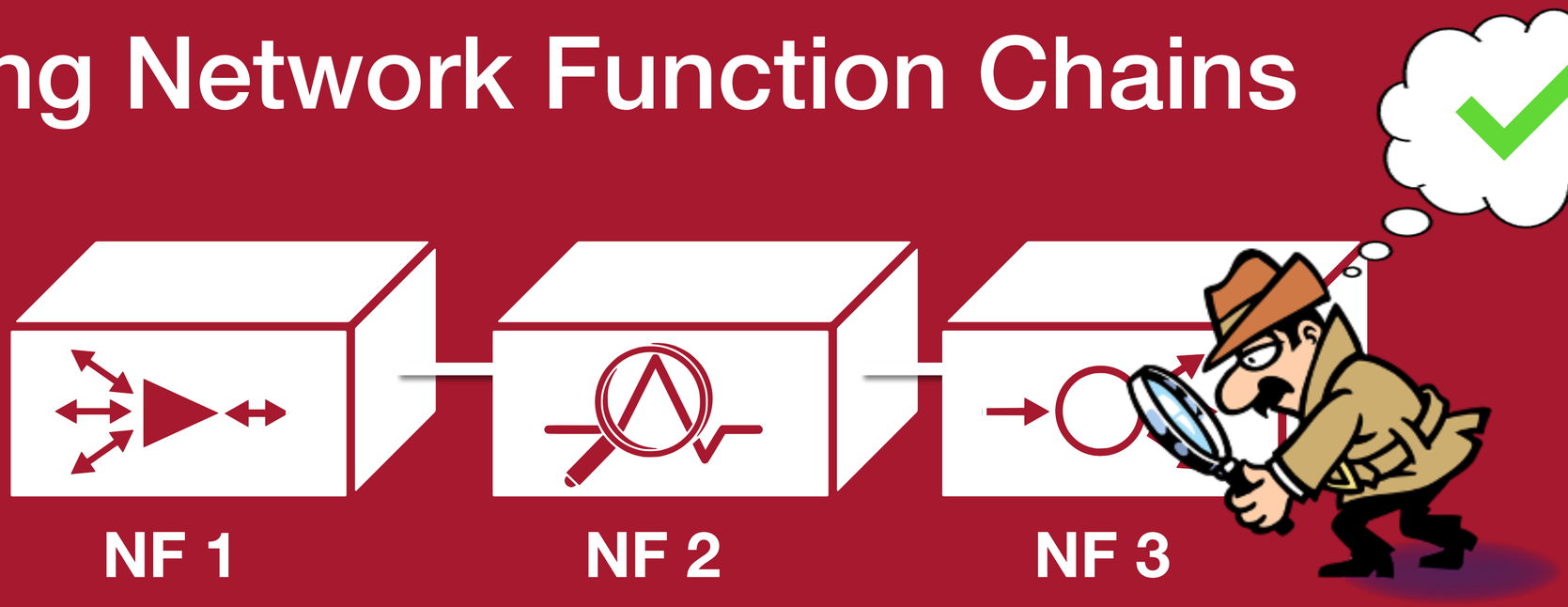

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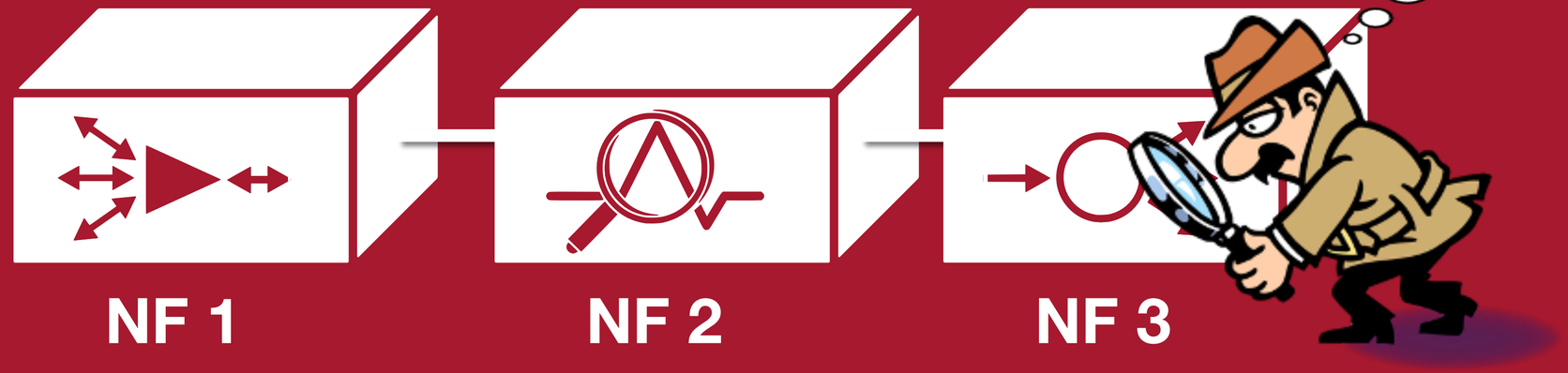

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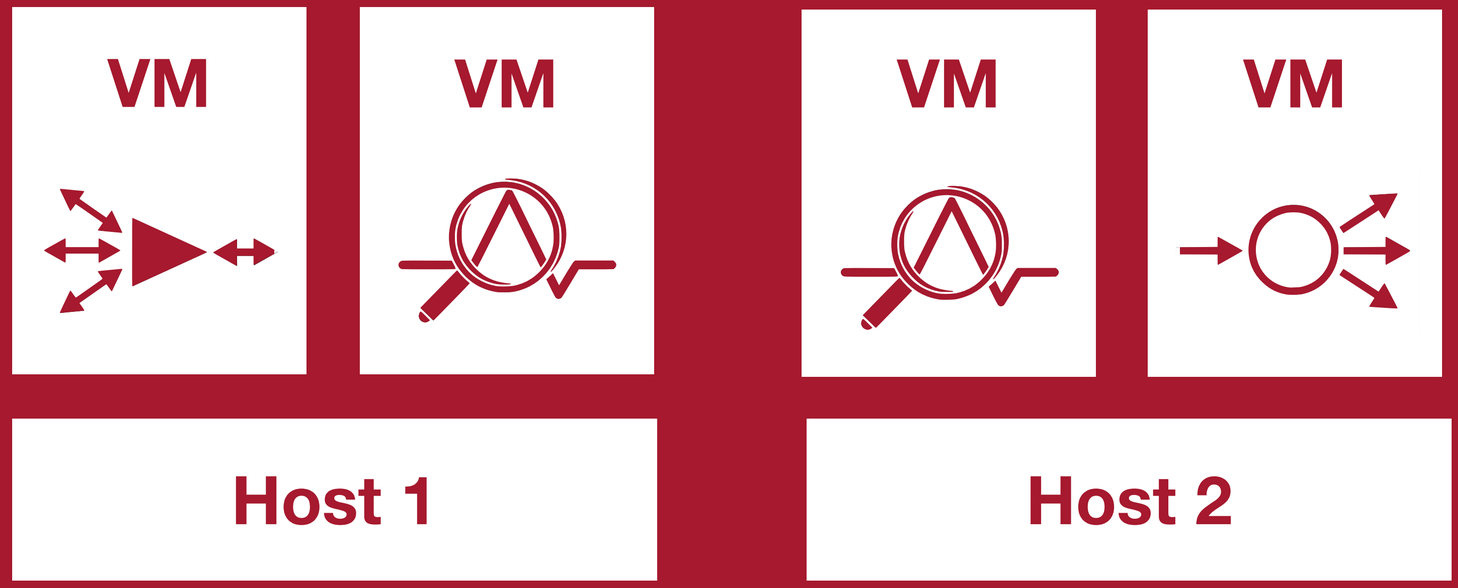

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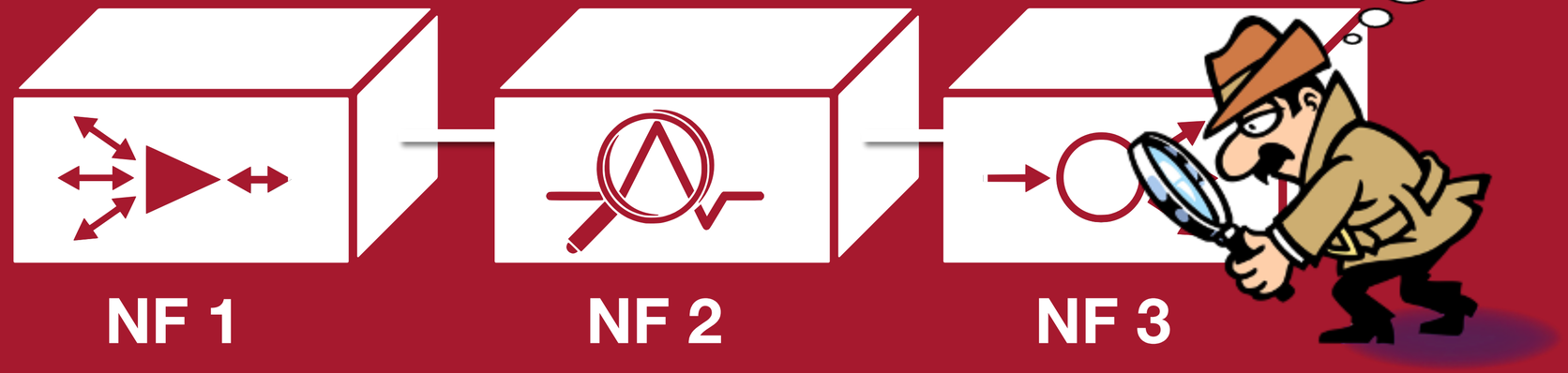

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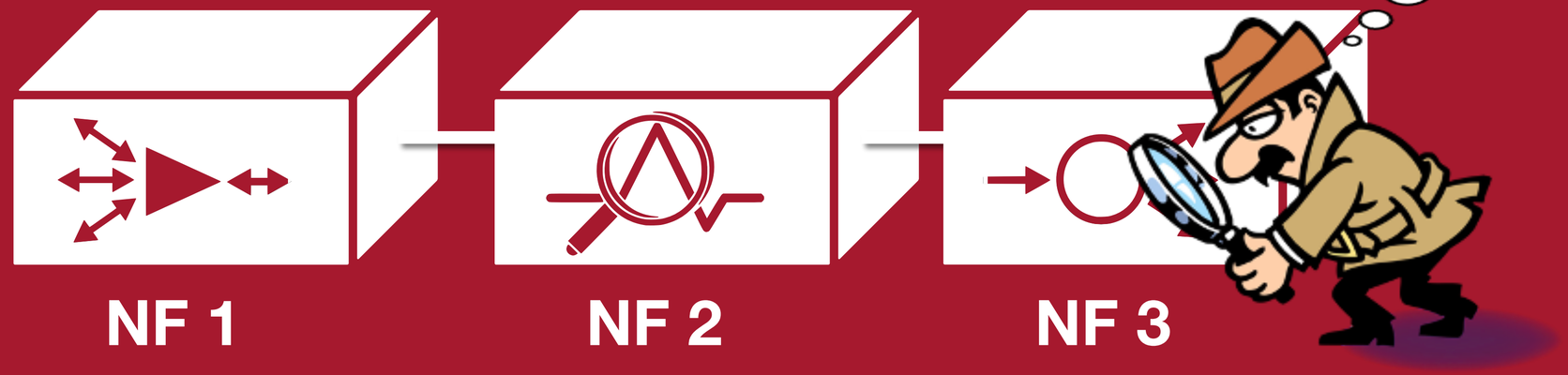

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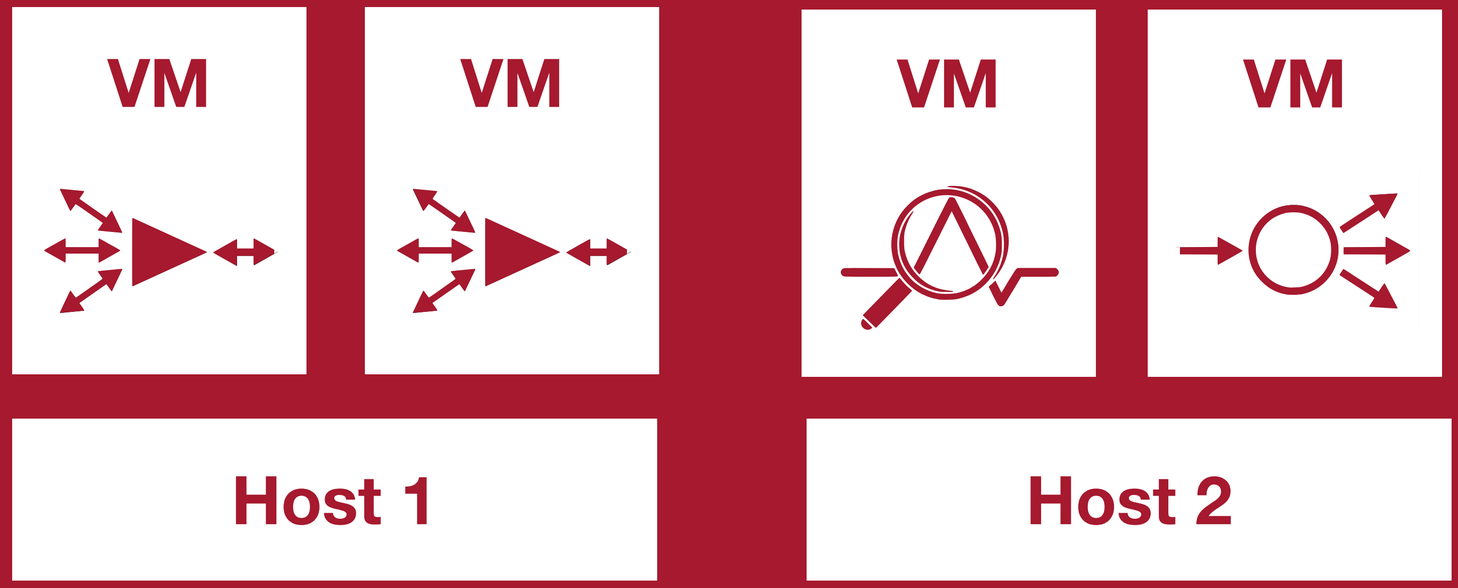

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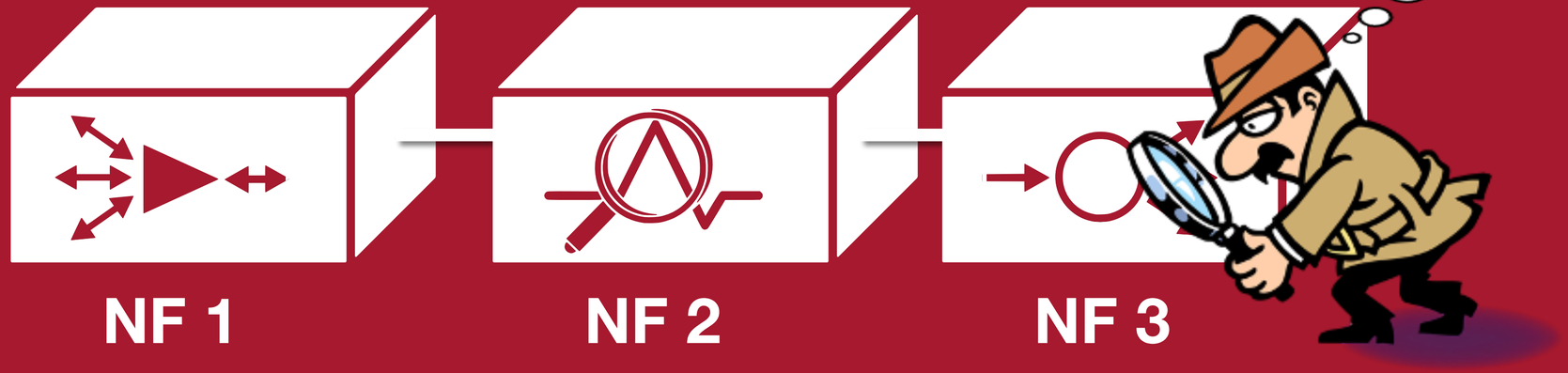

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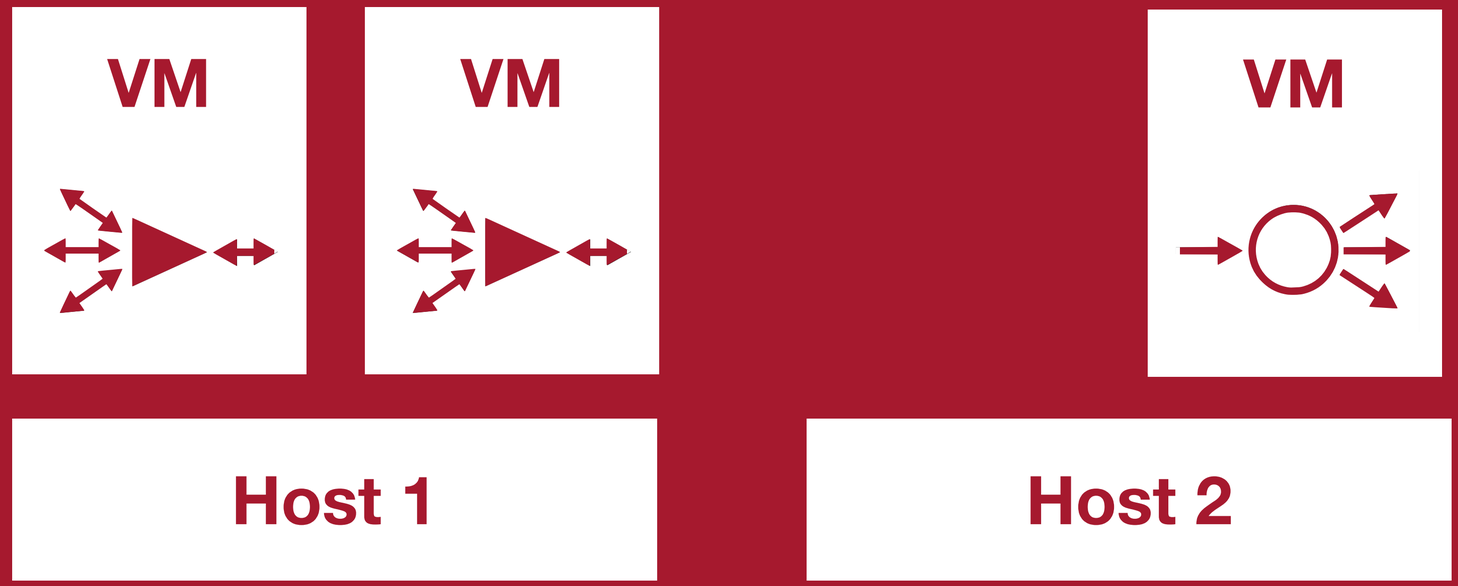

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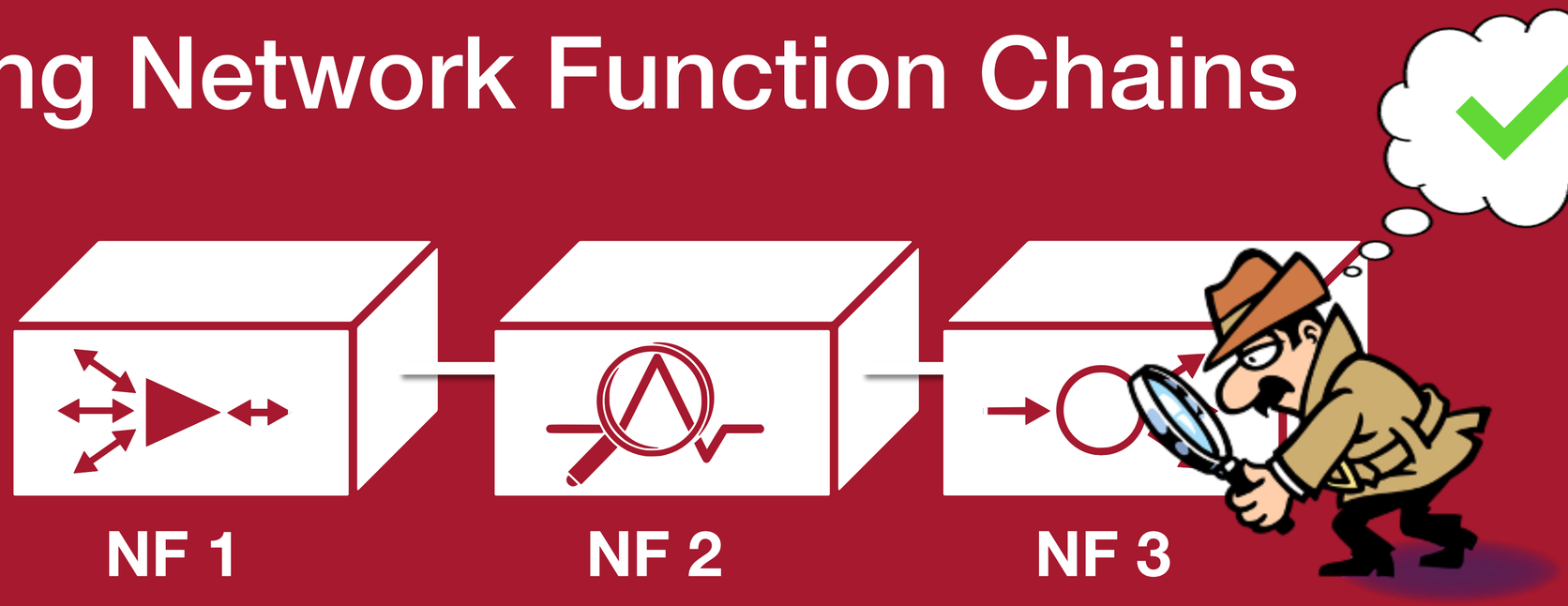

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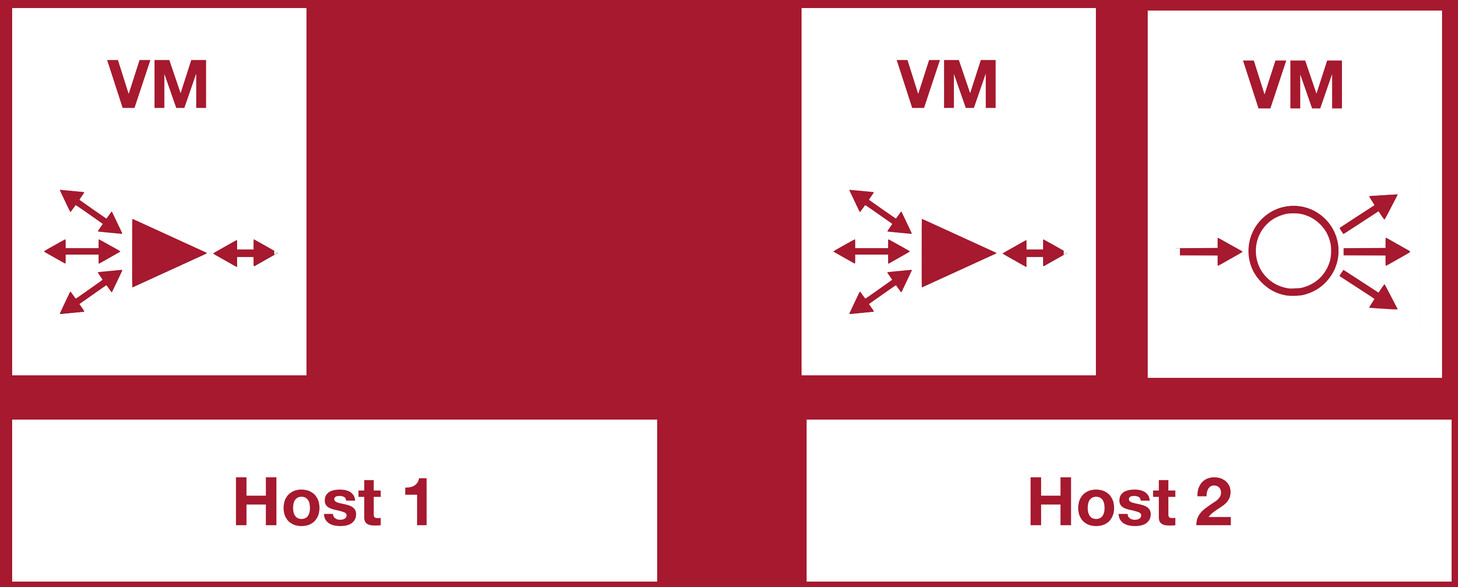

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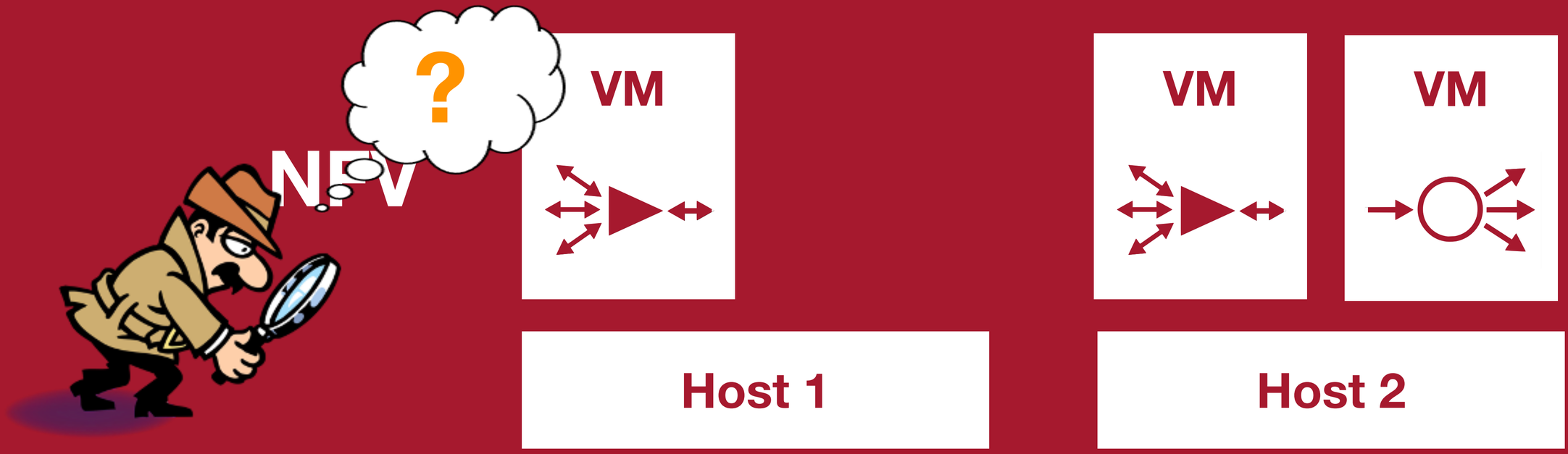

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① Auditors can rely on the network topology to ensure that the correct NF chain is being used

② Auditors can inspect and approve HW boxes

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With AuditBox for NFV, auditors have even stronger auditing guarantees than traditional NF deployments

AuditBox

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Provides auditing capabilities to NFV deployments

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① **NF functionality cannot be modified/manipulated**

② **Traffic is steered between NFs according to the administrator's policy**

③ **Provide logs that attest that the correct policy is being followed**

④ **Good performance**

AuditBox

Key Techniques:

① Secure Enclaves

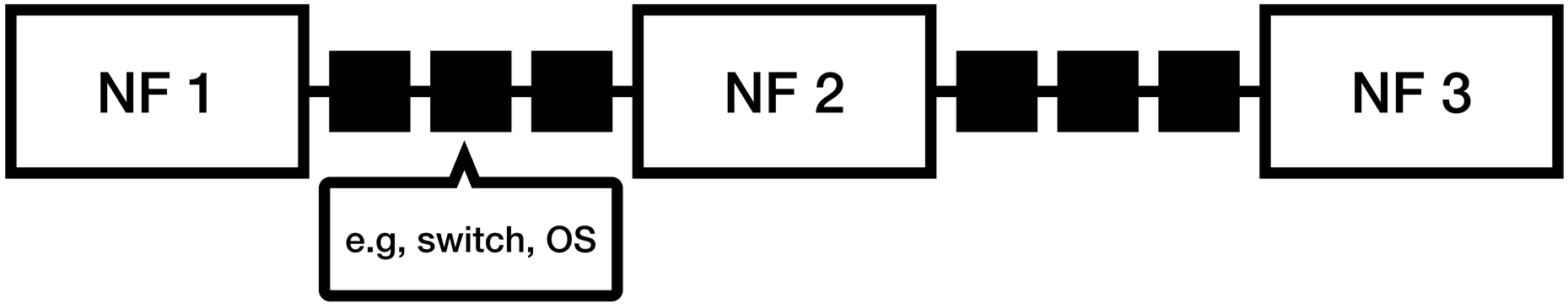
② NF Hop-by-Hop Updated Attestation

③ Secret Logging

④ Efficient Crypto Mechanisms

① Secure Enclaves

Logical view of an NF chain



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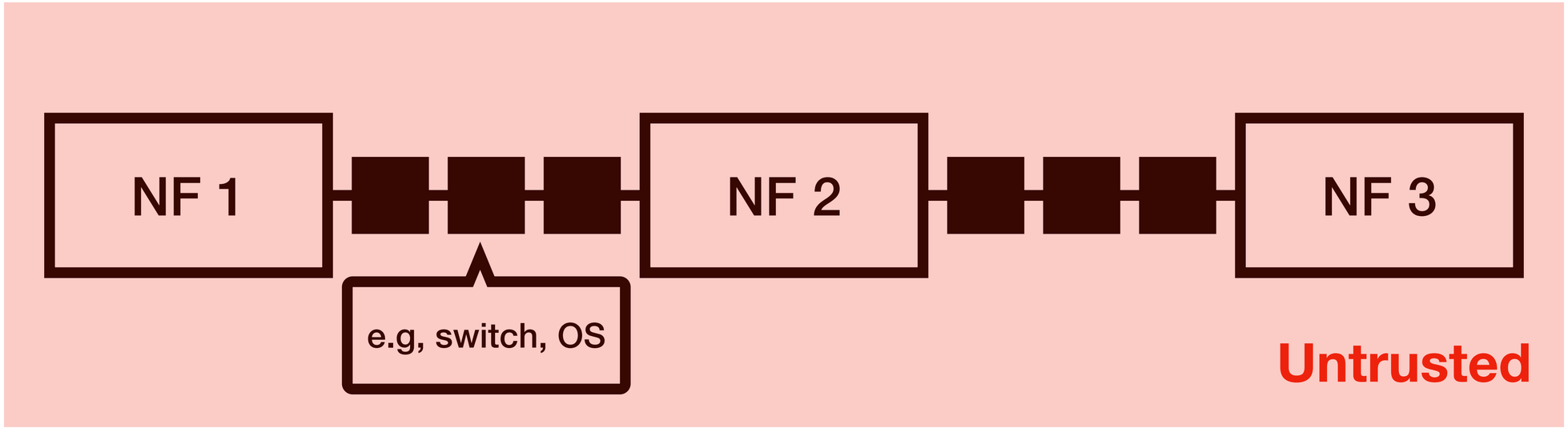

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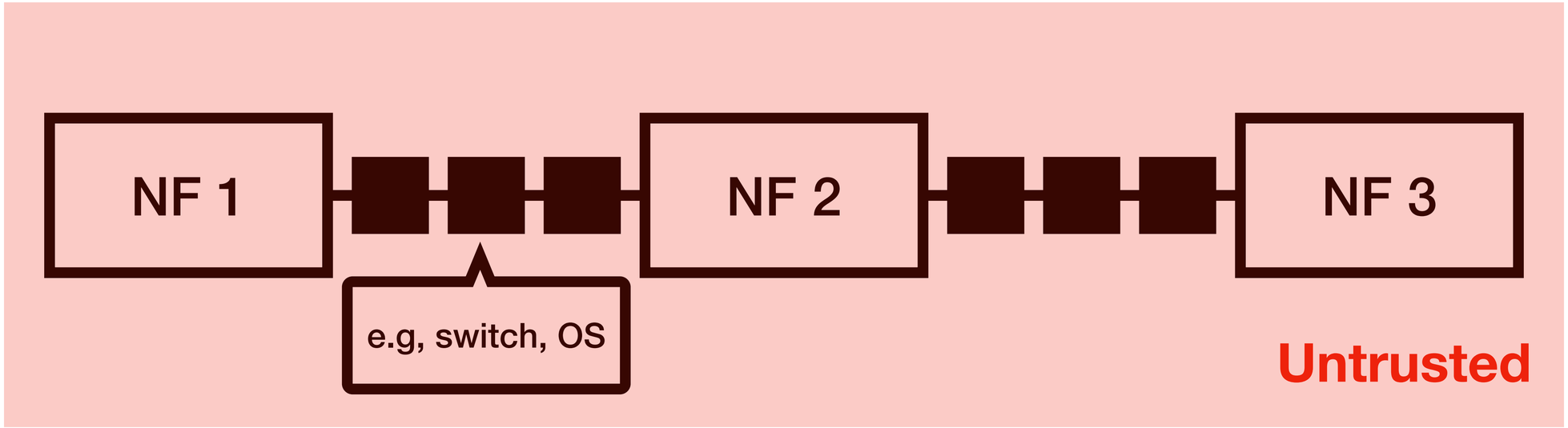
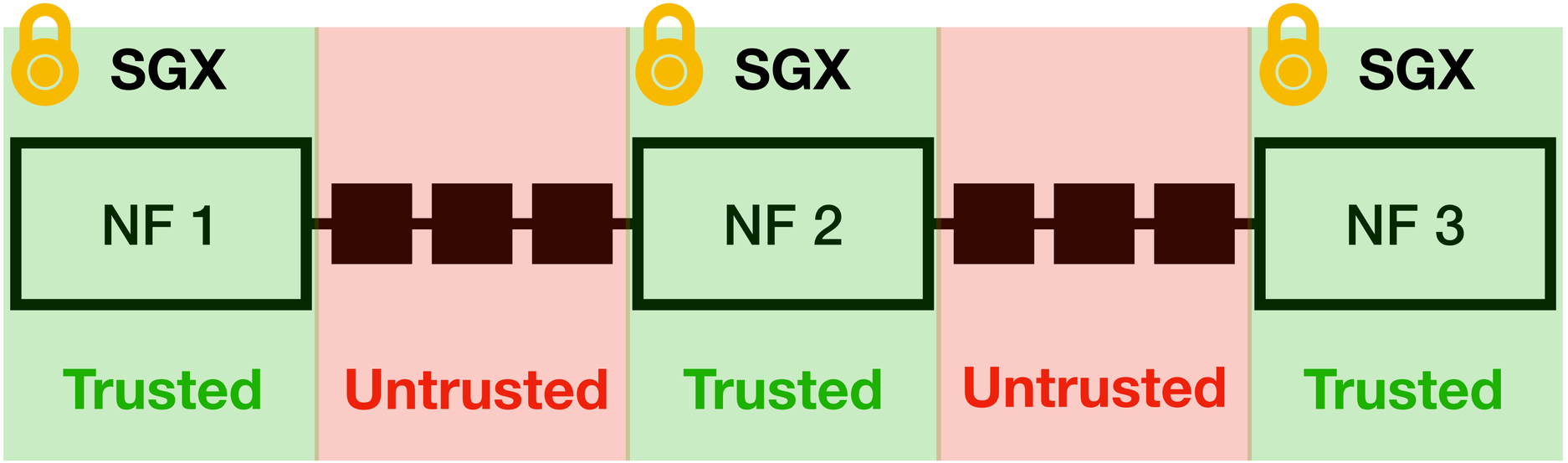


Need to attest that all components in the path are correct

① Secure Enclaves

Run NFs inside secure enclaves (e.g., Intel SGX)



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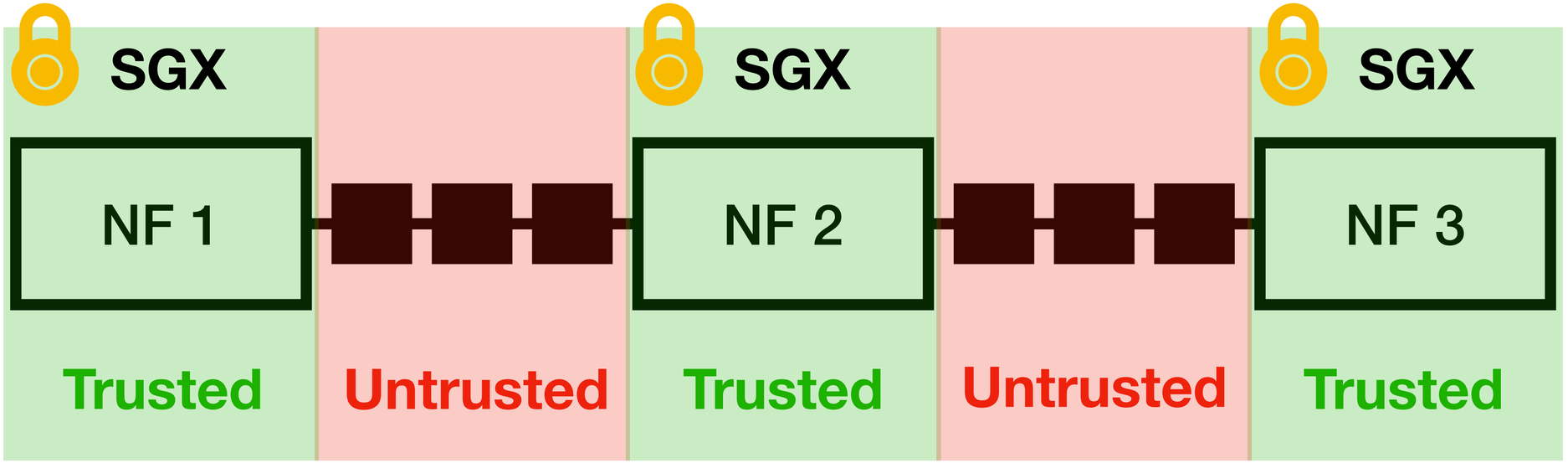

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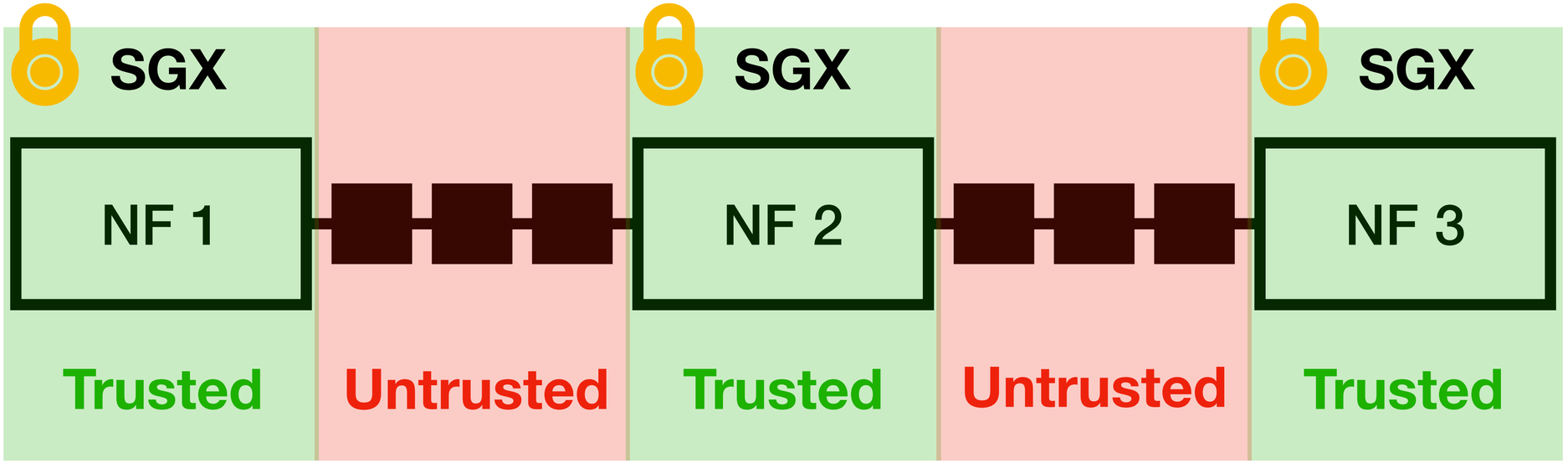

- Auditors have guarantees that the audited NF software is running
- Remaining untrusted functionality is responsible for packet forwarding

Verified Routing Protocols (VRPs)

Examples: EPIC [USENIX '20], OPT [SIGCOMM '14], ICING [CoNEXT ’11]

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VRP Assumptions:

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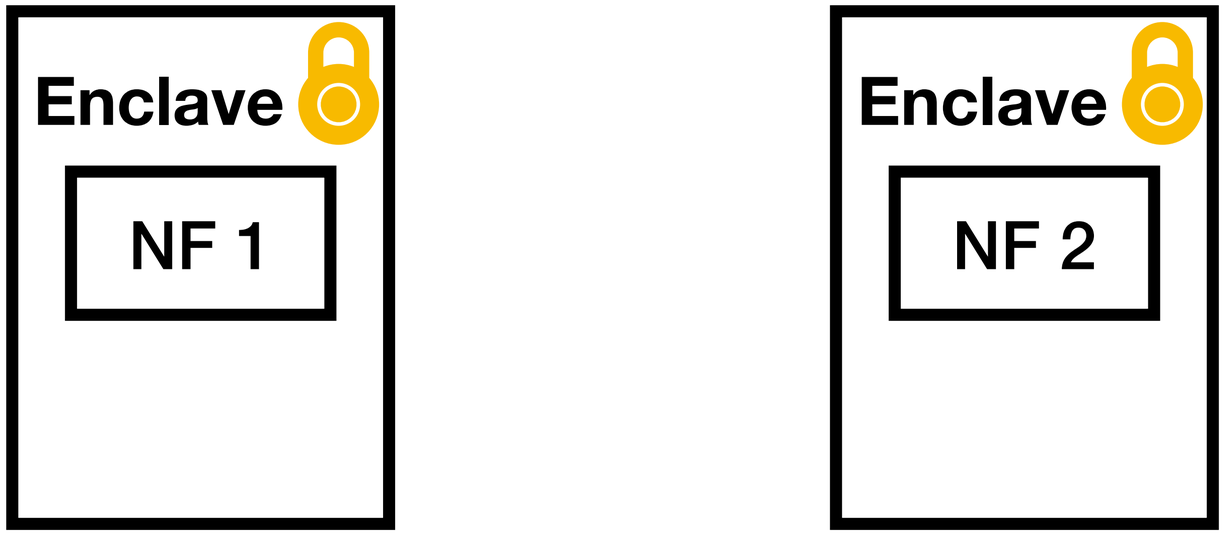
- Dynamic Paths
- Stateful Processing Nodes

② NF Hop-by-Hop Updated Attestation



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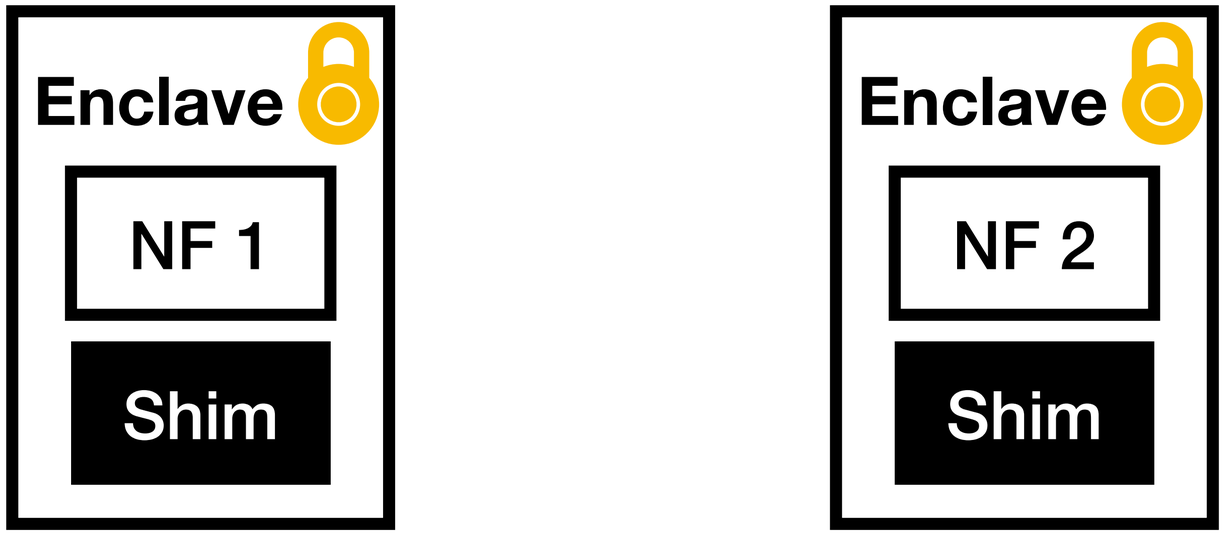

- A **shim** in every enclave mediates all incoming and outgoing packets

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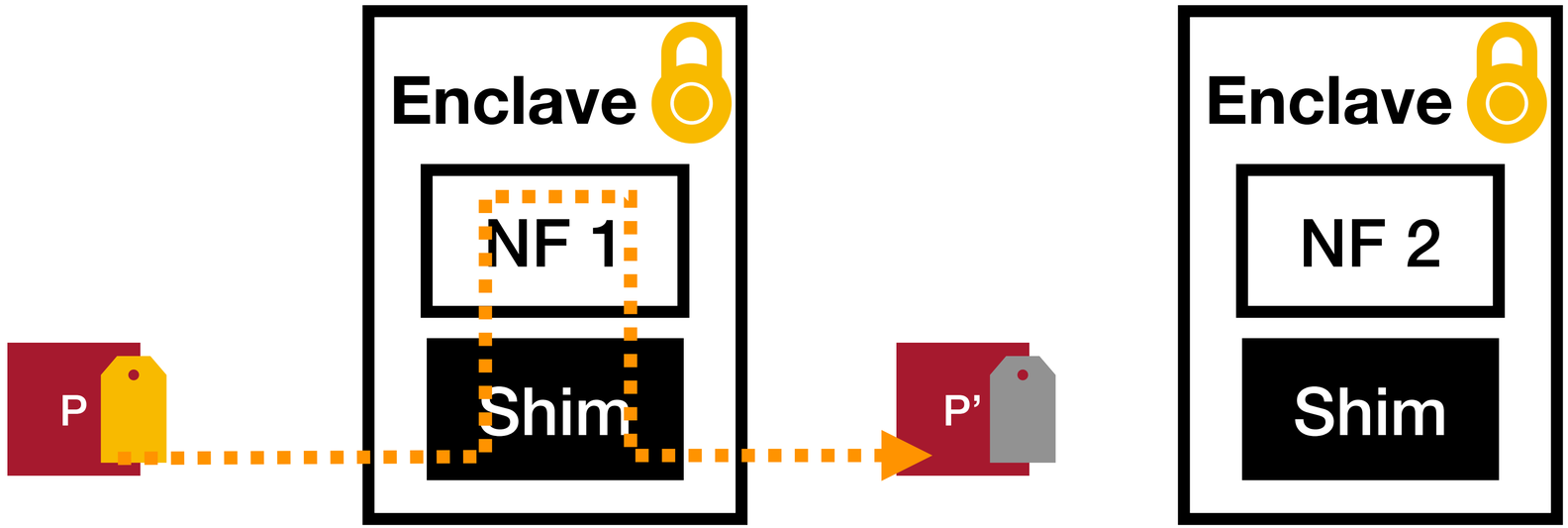

- A **shim** in every enclave mediates all incoming and outgoing packets
- Attestation happens between **pairs of shims**

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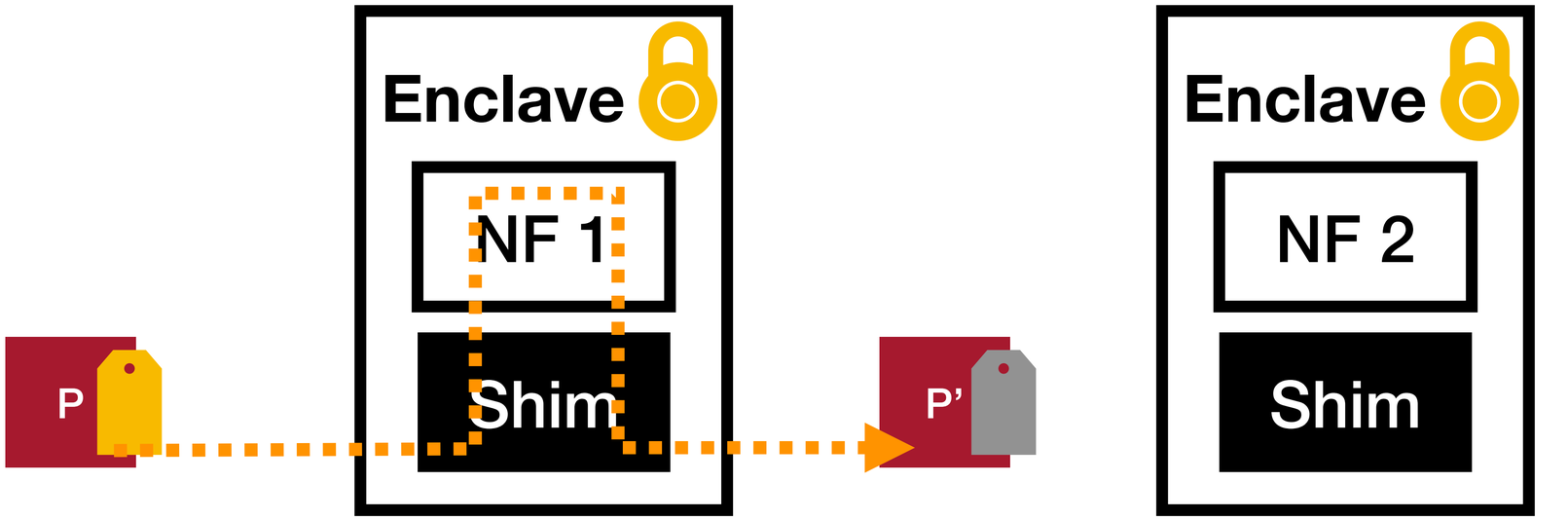

Audit Trailer

Packet ID	SRC NF	DST NF	Tag

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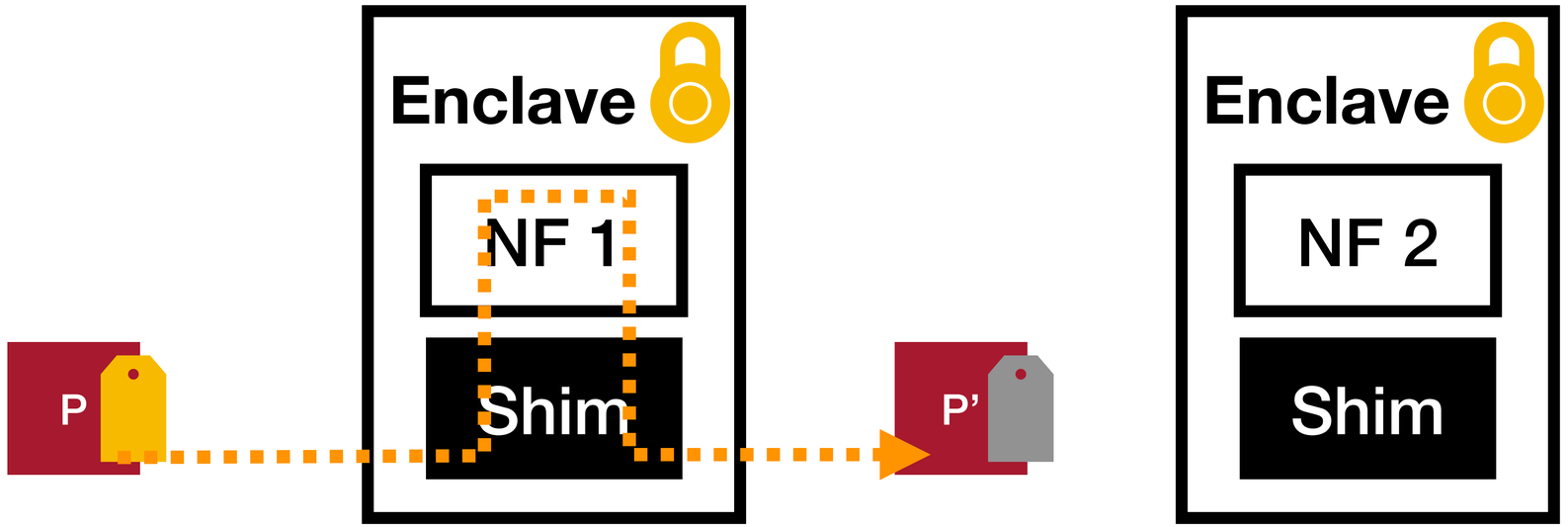

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Tag = GMAC(key, Packet | Packet ID | SRC NF | DST NF)

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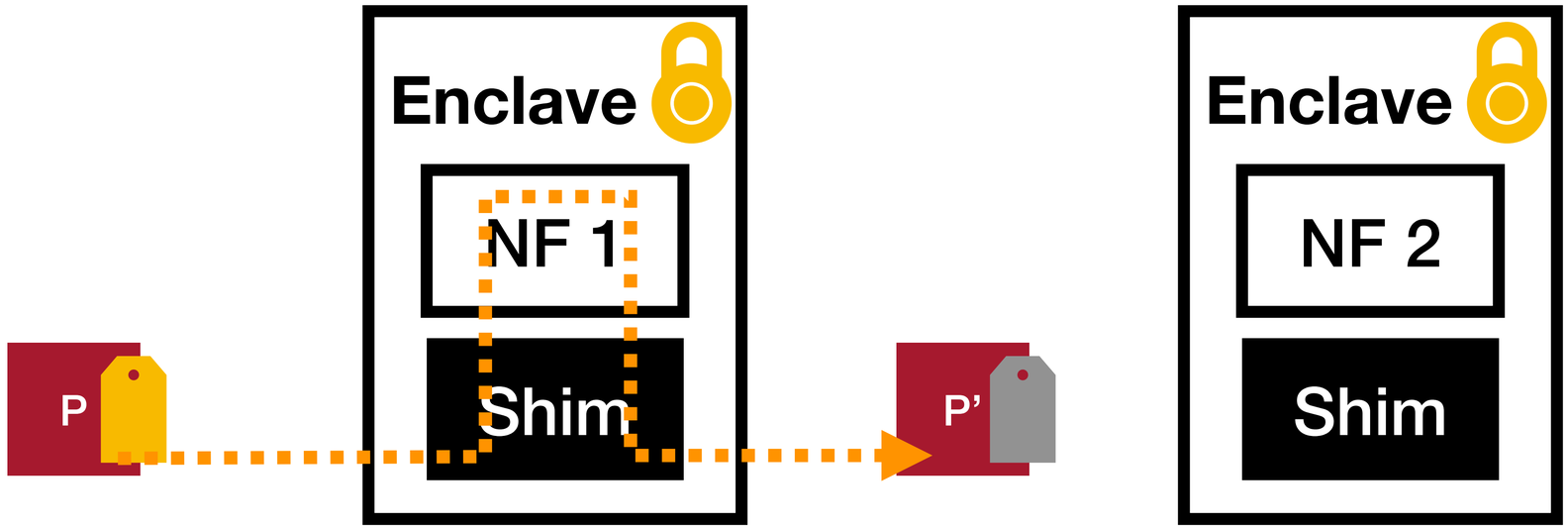

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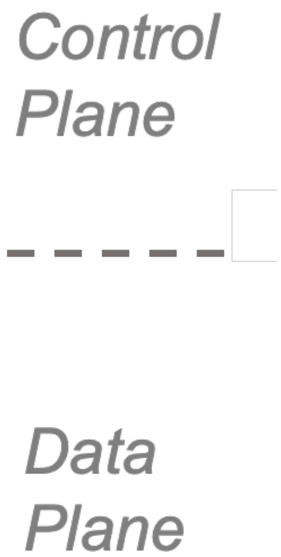
*AuditBox also supports **flow-level correctness** which detects packet duplication, reordering and drops (refer to paper for details)

AuditBox Design Overview



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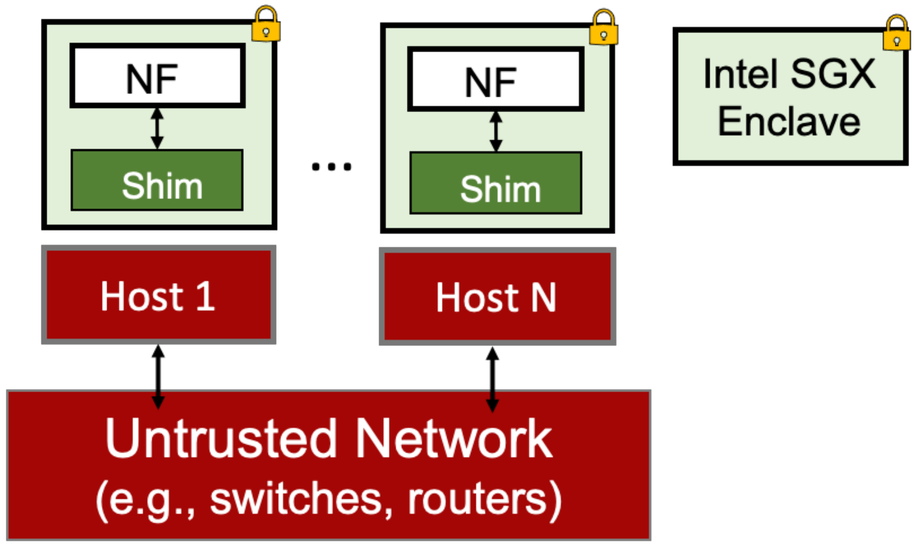
Control Plane

Data Plane



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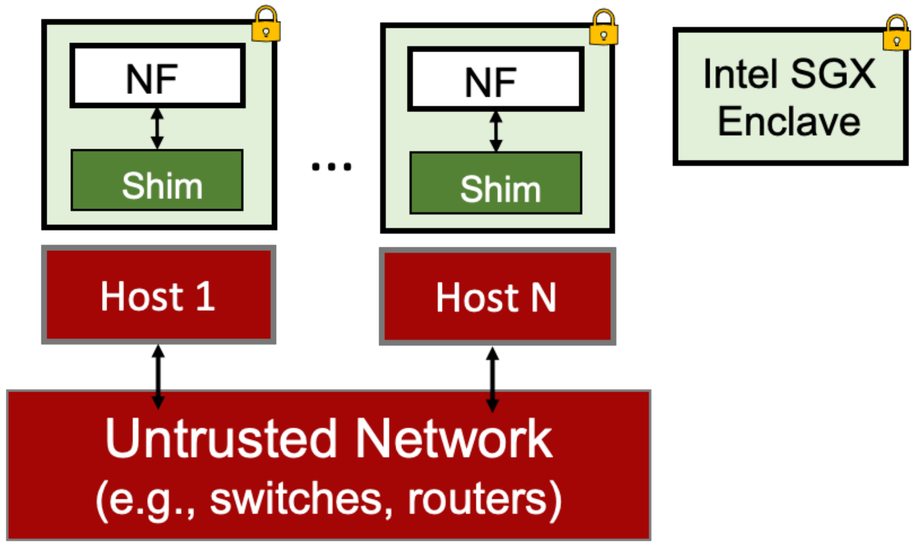

Runtime Correctness

① Secure Enclaves

② Hop-by-hop Verification Protocol

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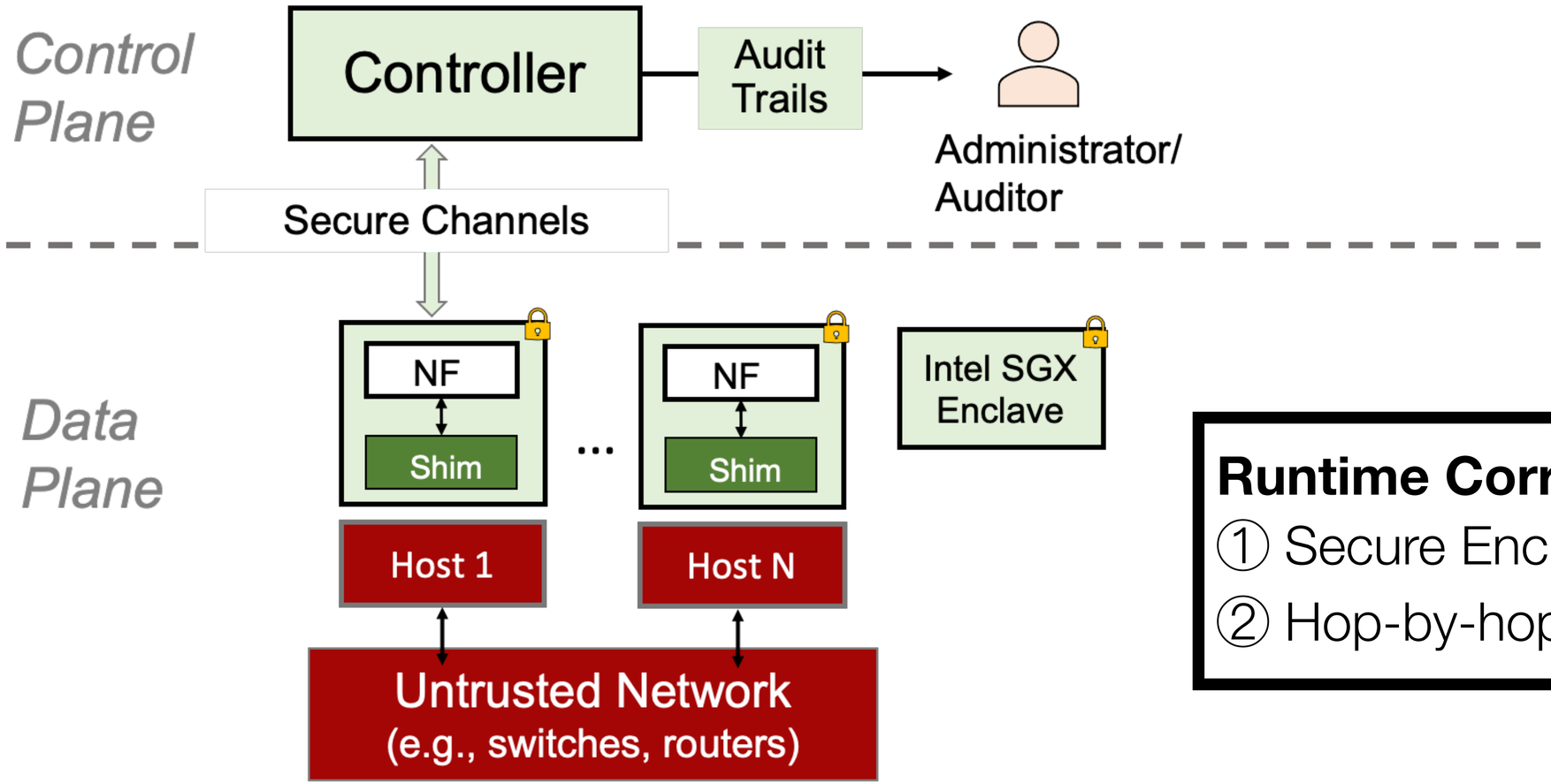

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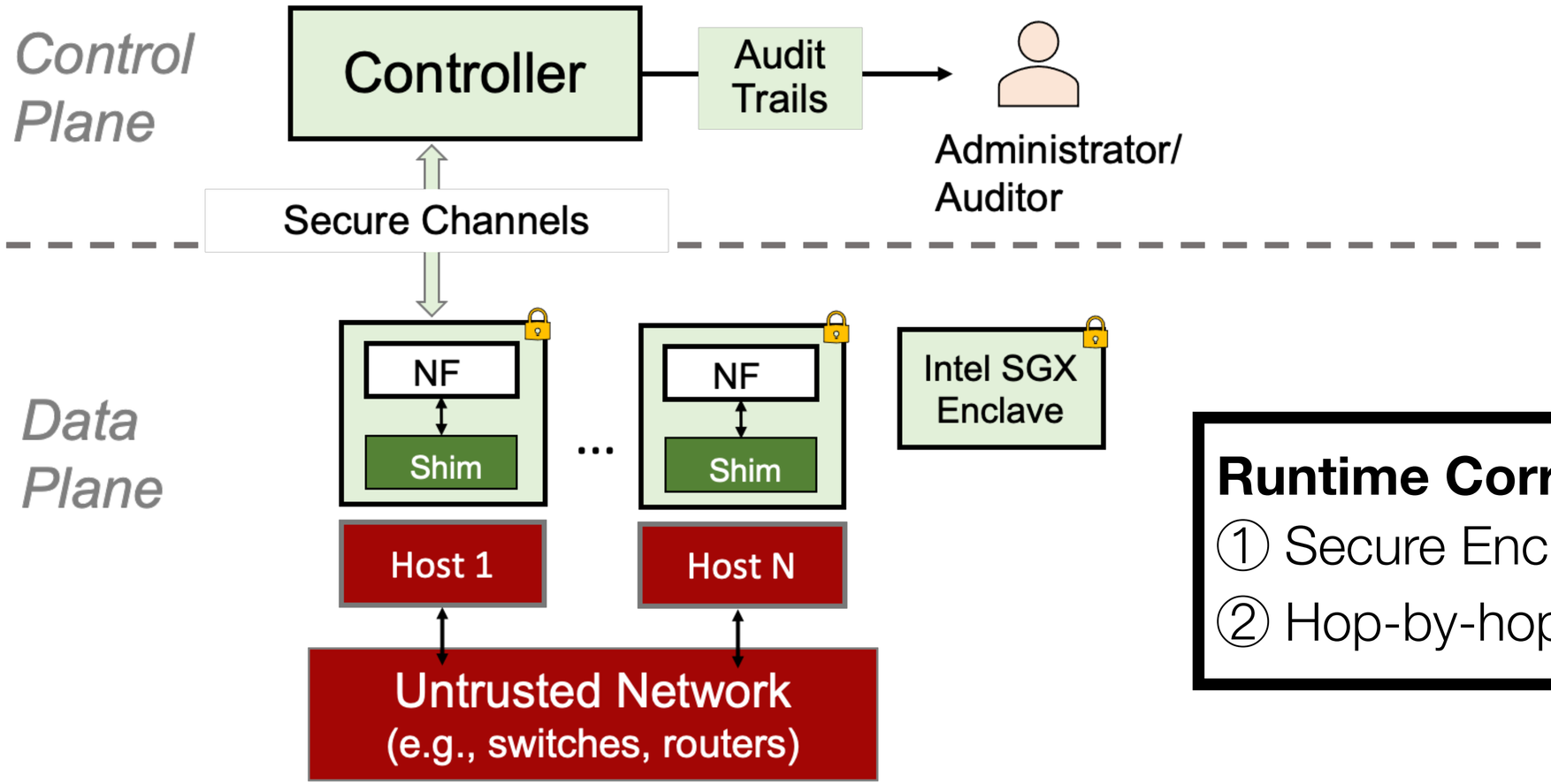

Offline Auditability

③ Secret Logging

Runtime Correctness

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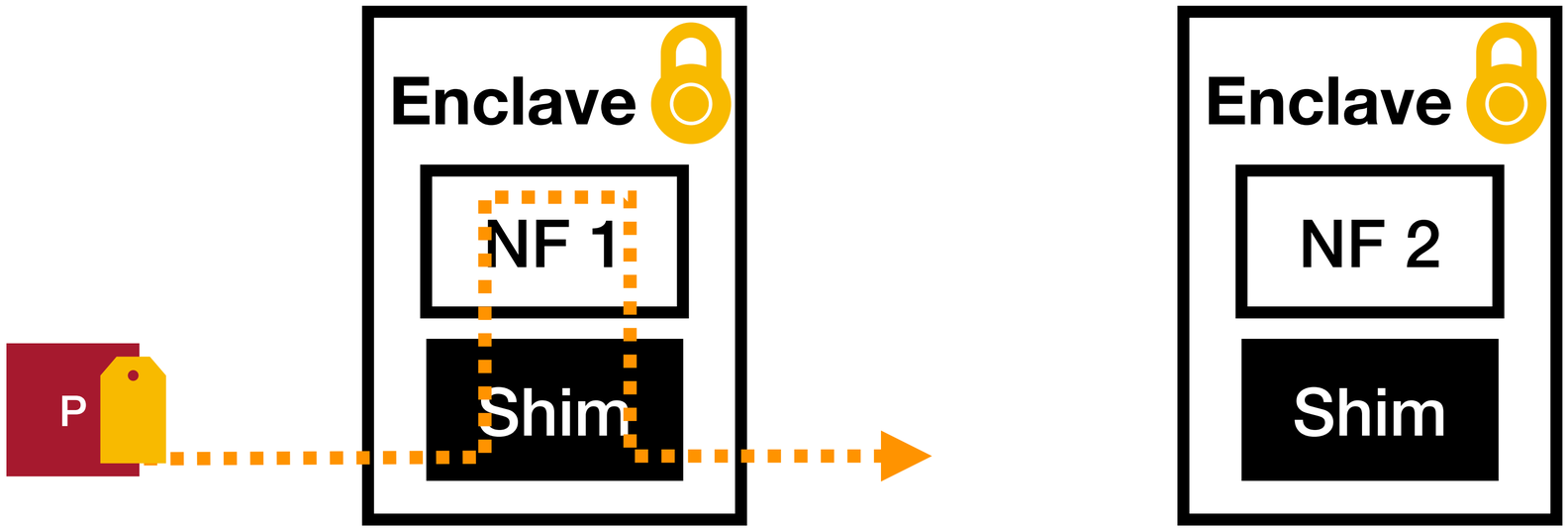
Potentially Crypotographically Expensive



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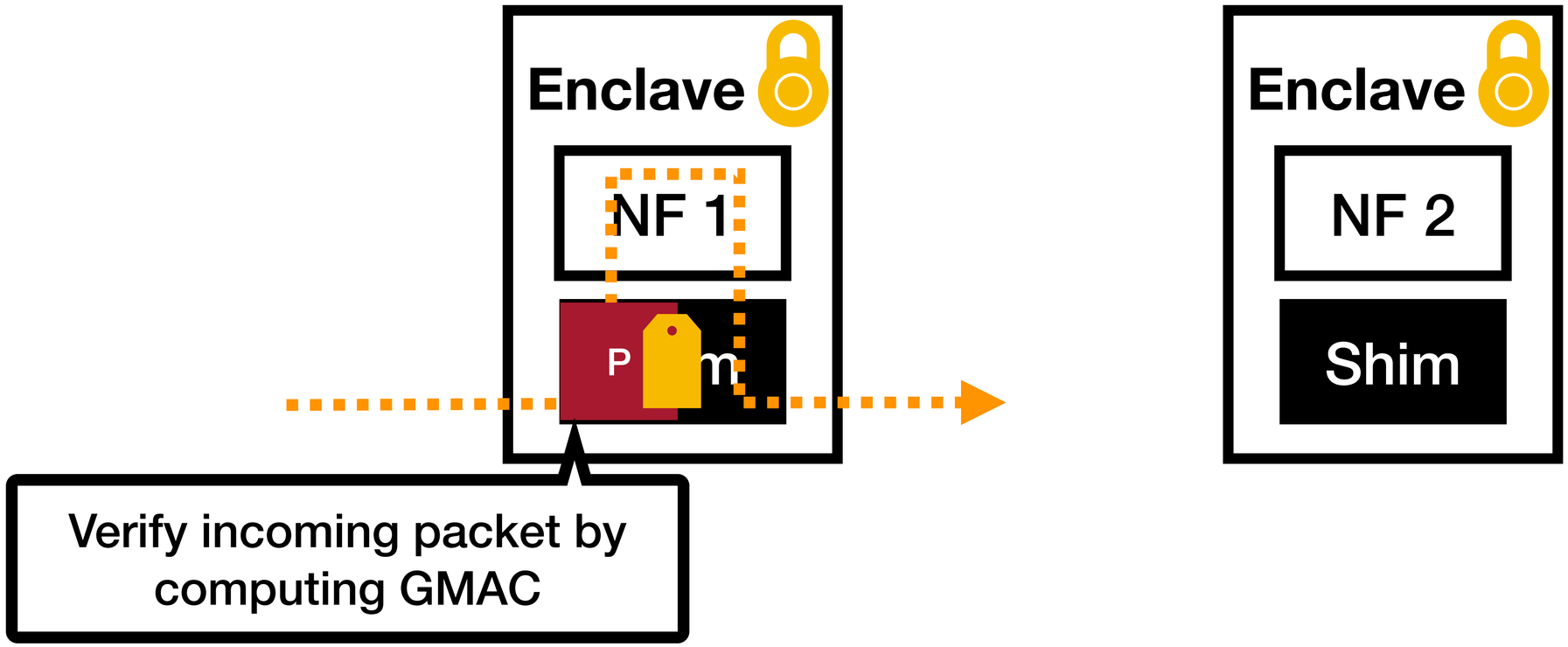

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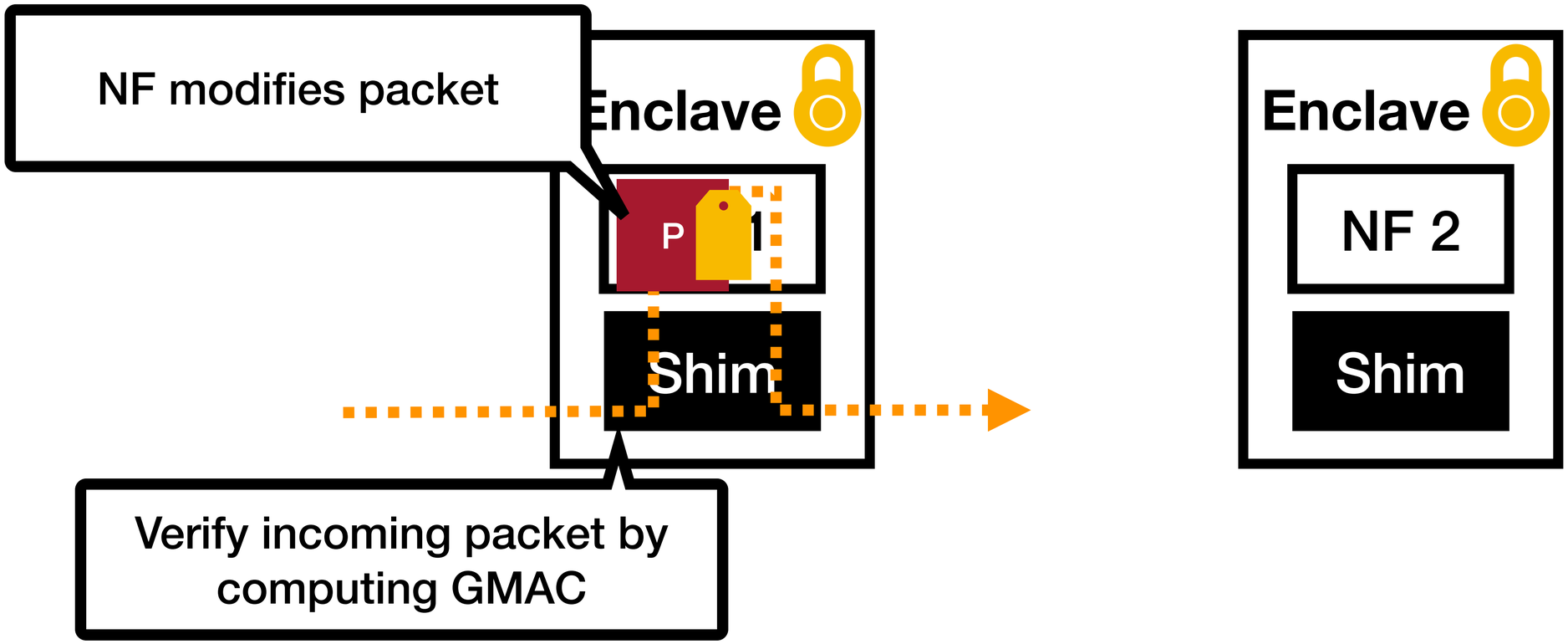

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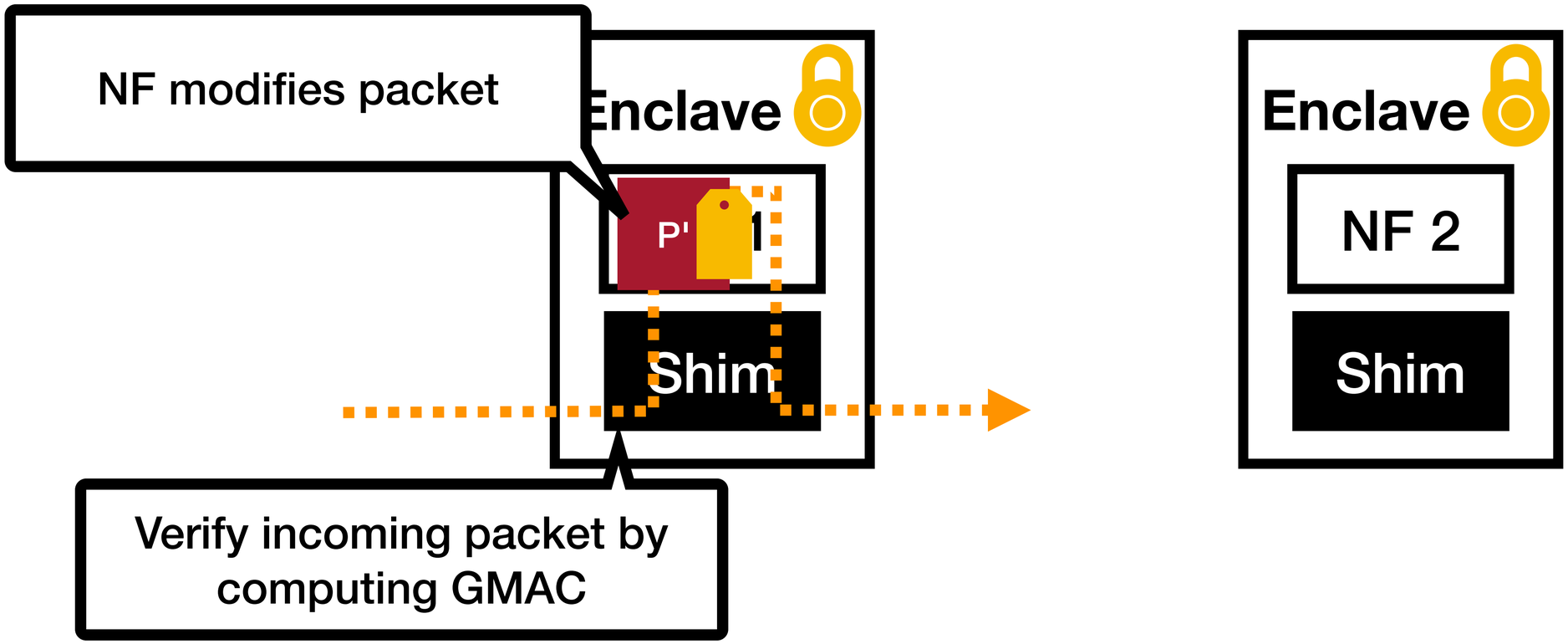

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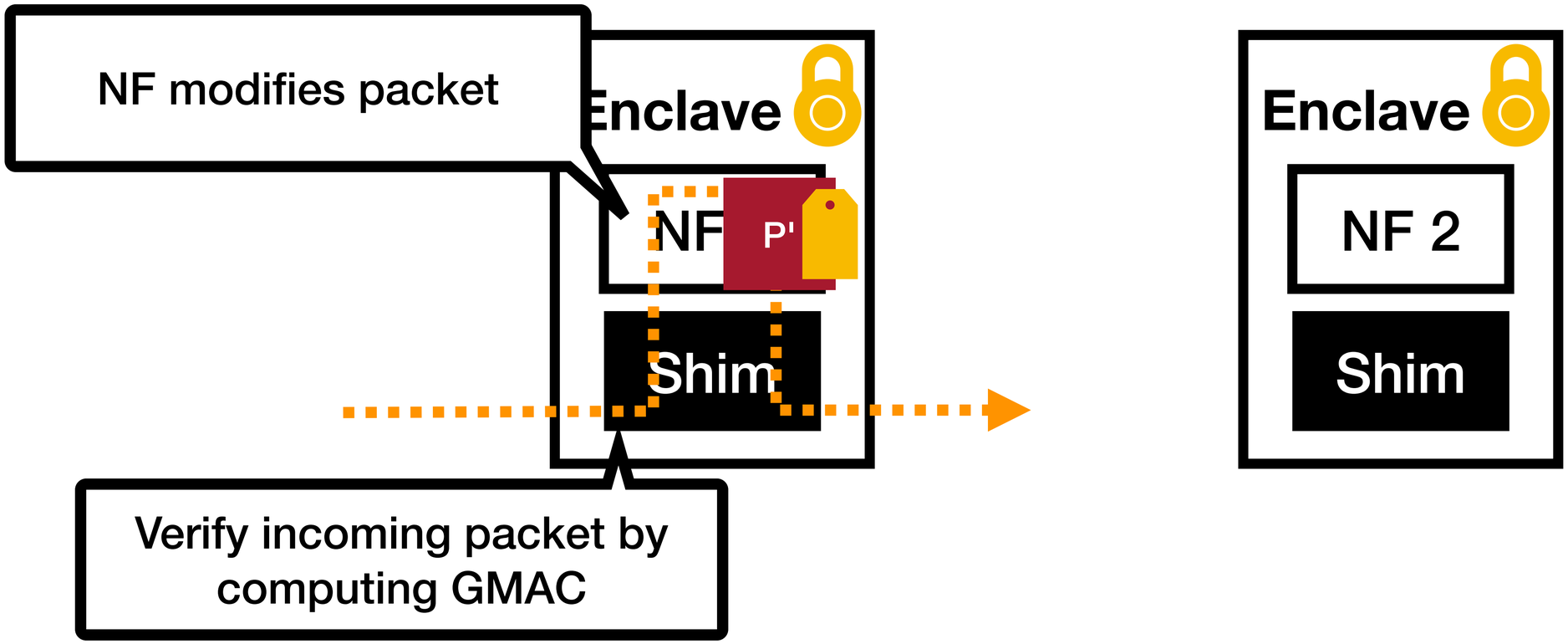

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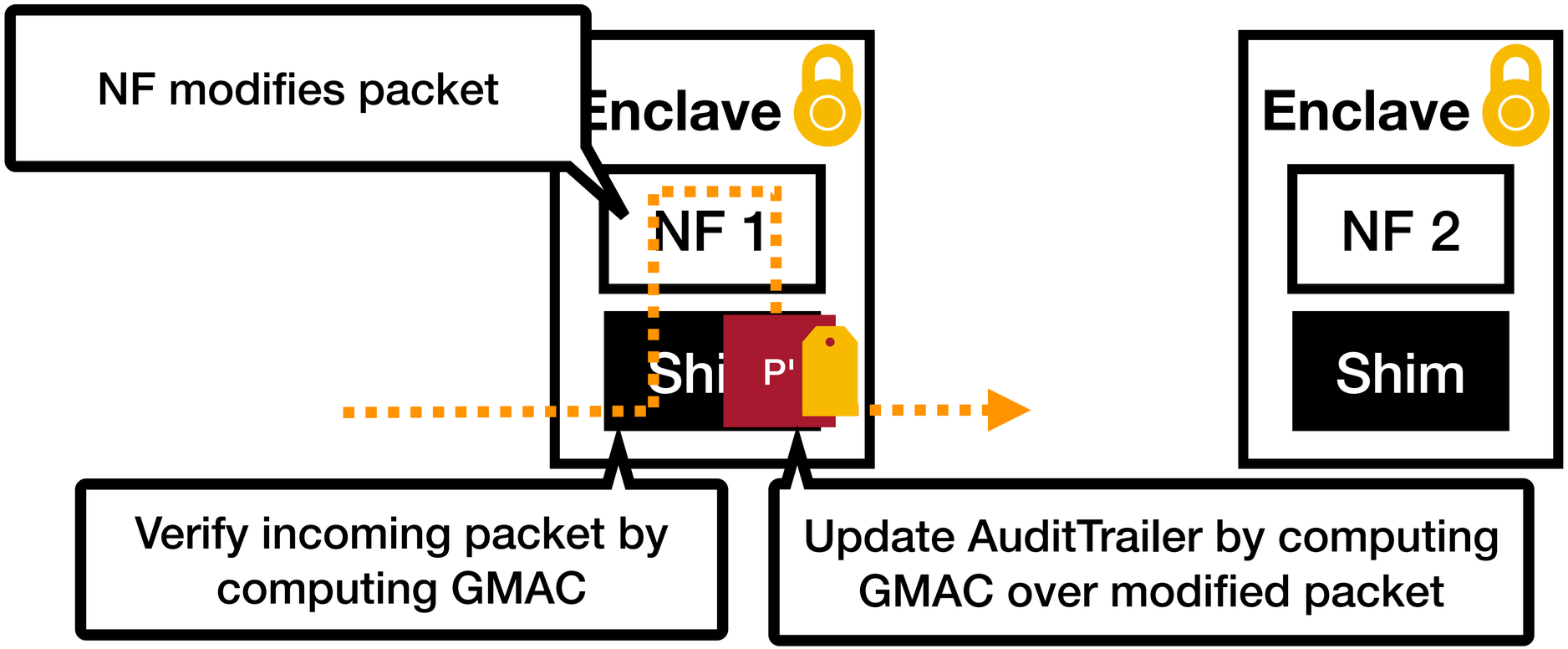

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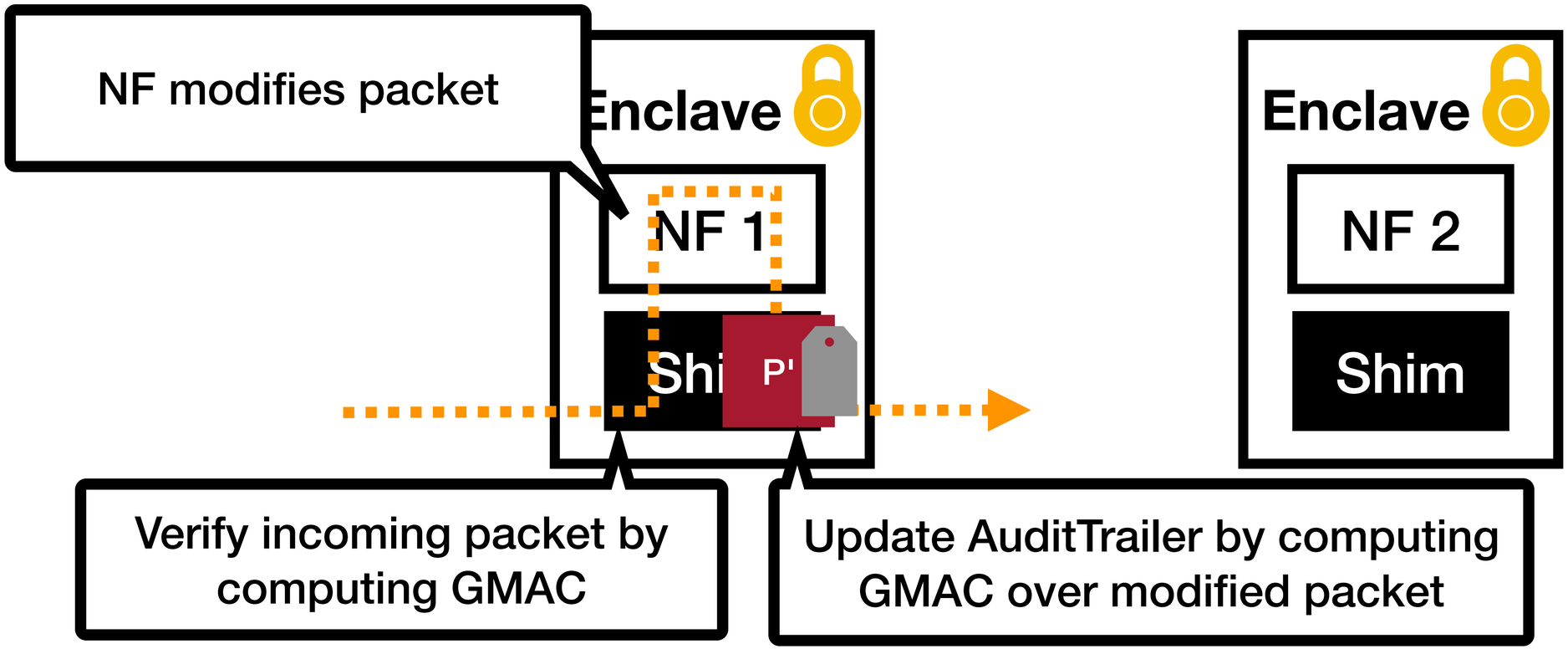

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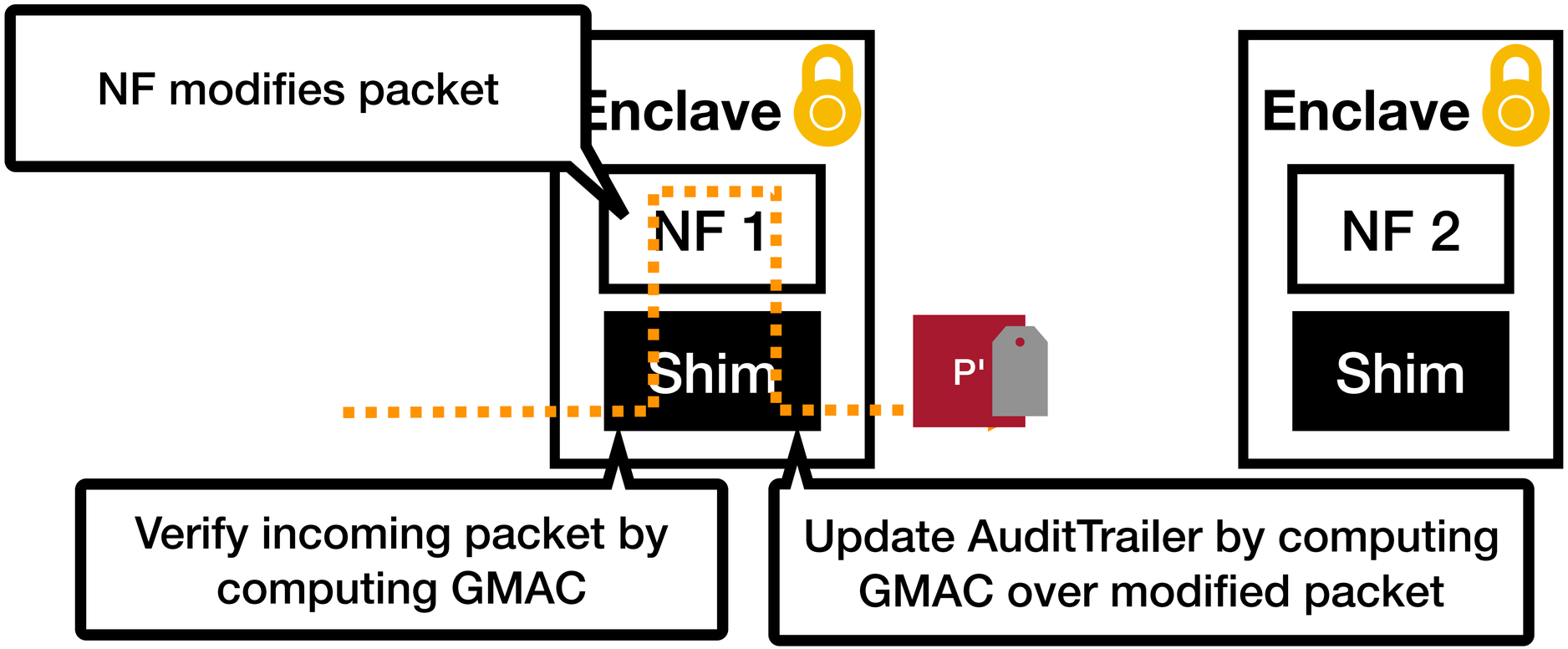

- Asymmetric key at every hop
- 2 GMACs at every hop

④ Efficient Crypto Mechanisms

Audit Trailer

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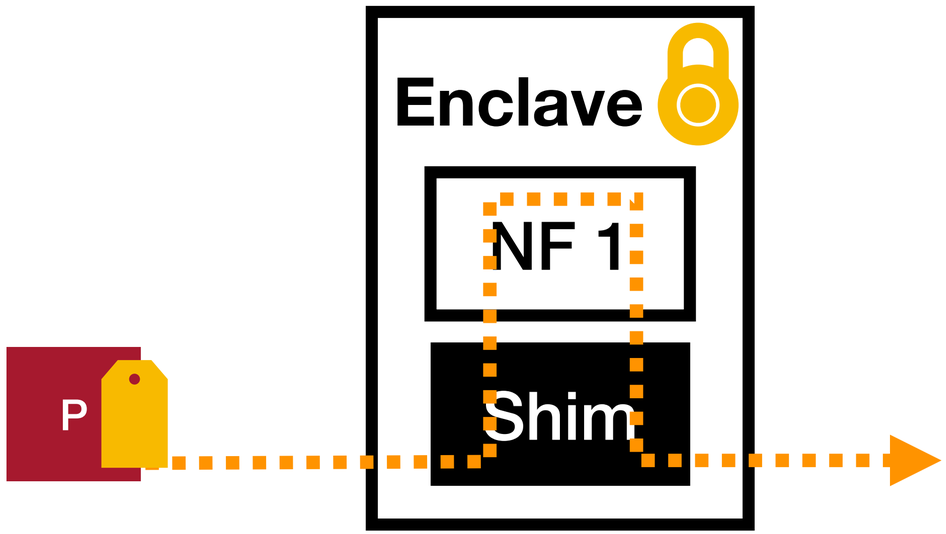
Tag = GMAC(**key**, Packet | Packet ID | SRC NF | DST NF)

One symmetric key for all NFs in the same policy pipelet

④ Efficient Crypto Mechanisms



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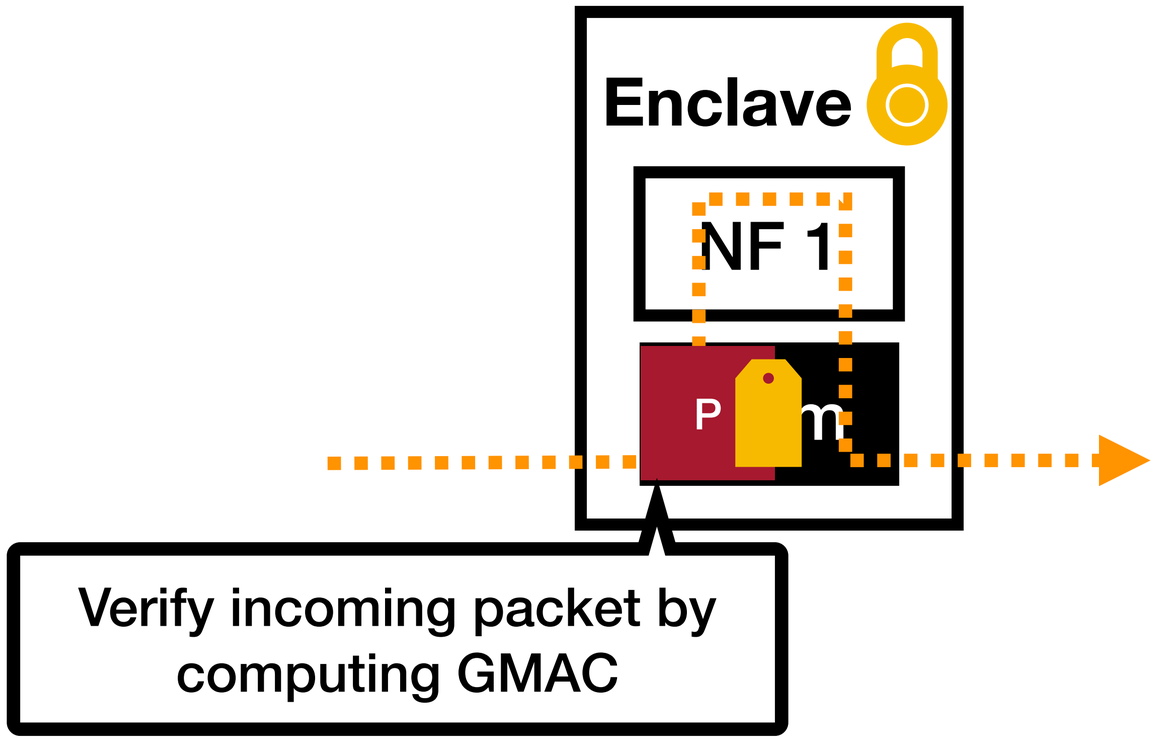

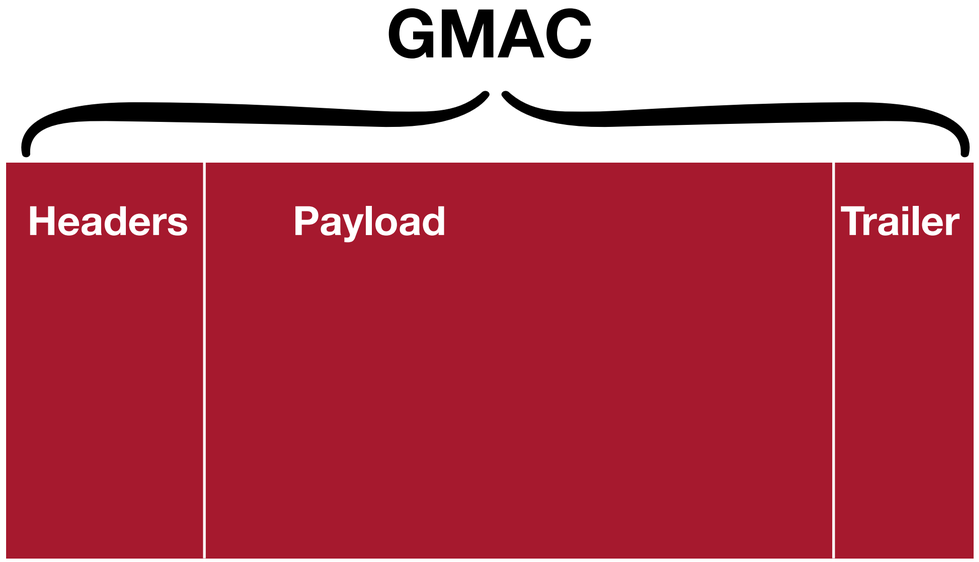

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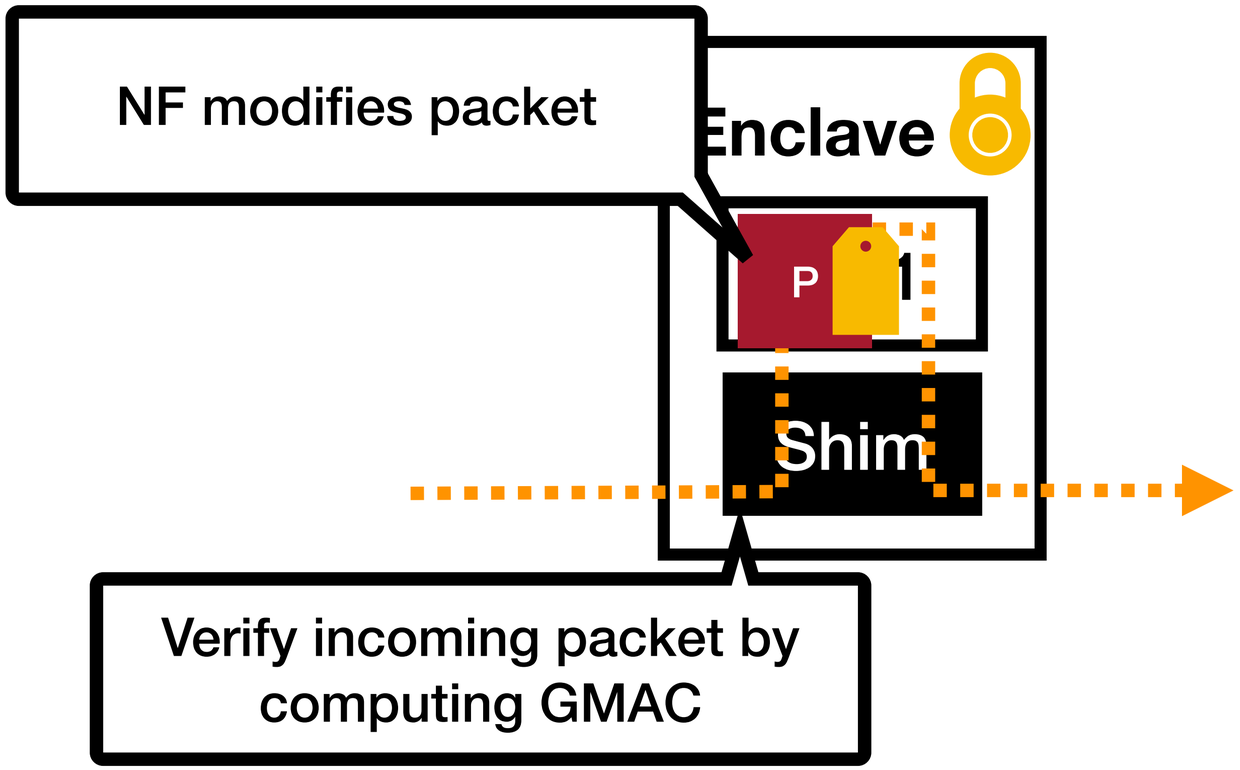
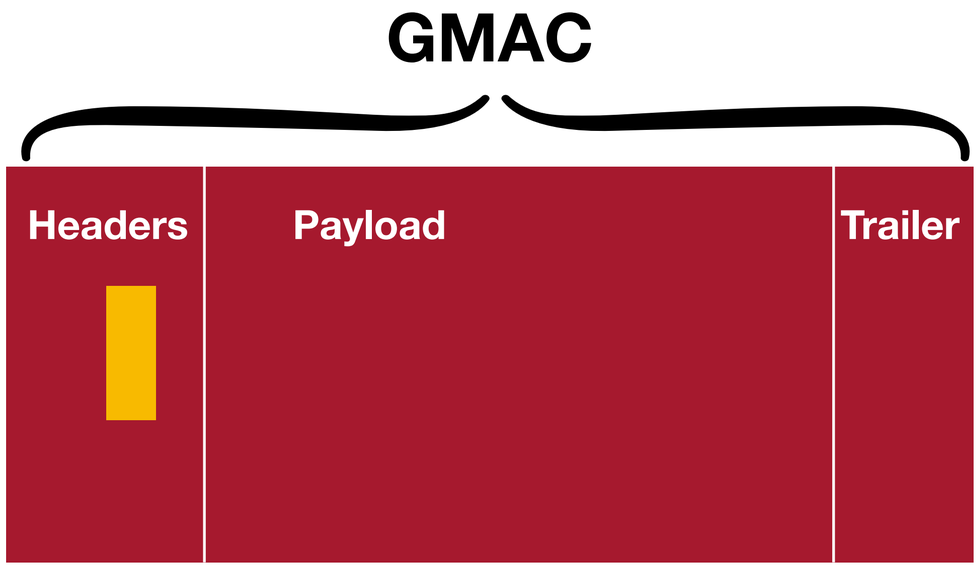
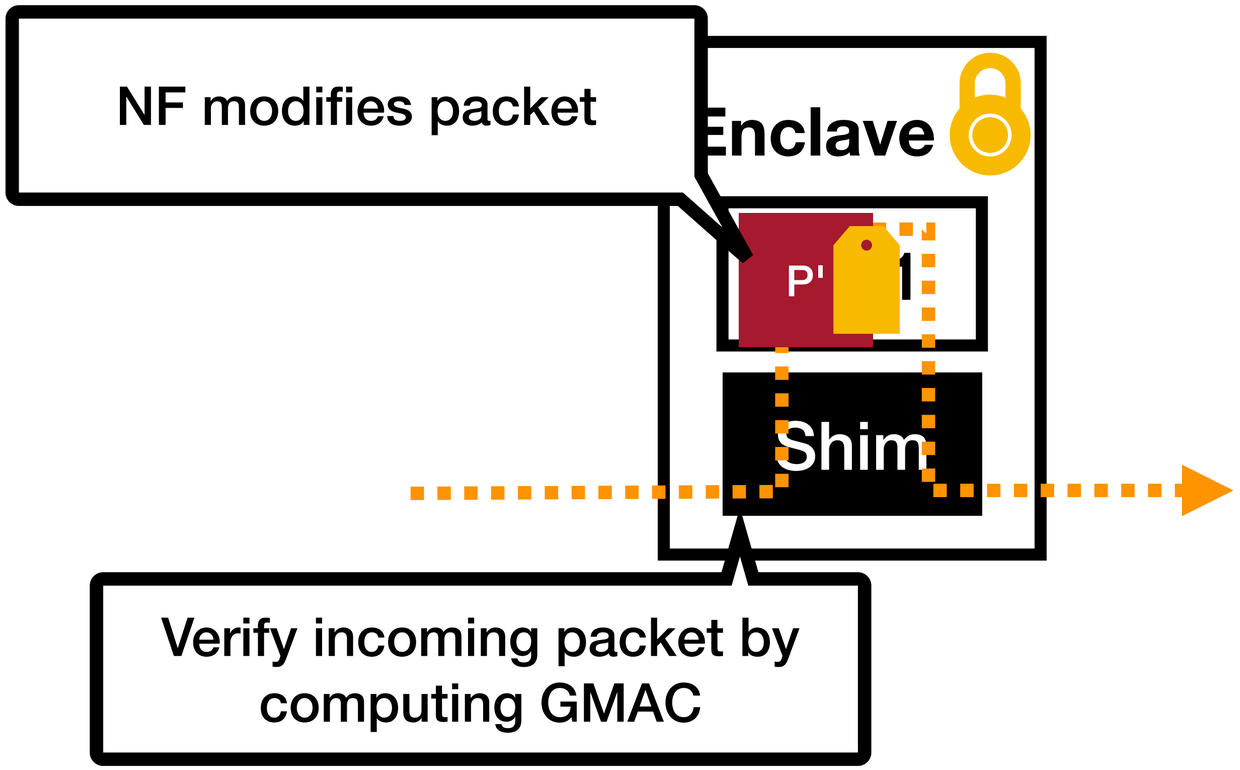
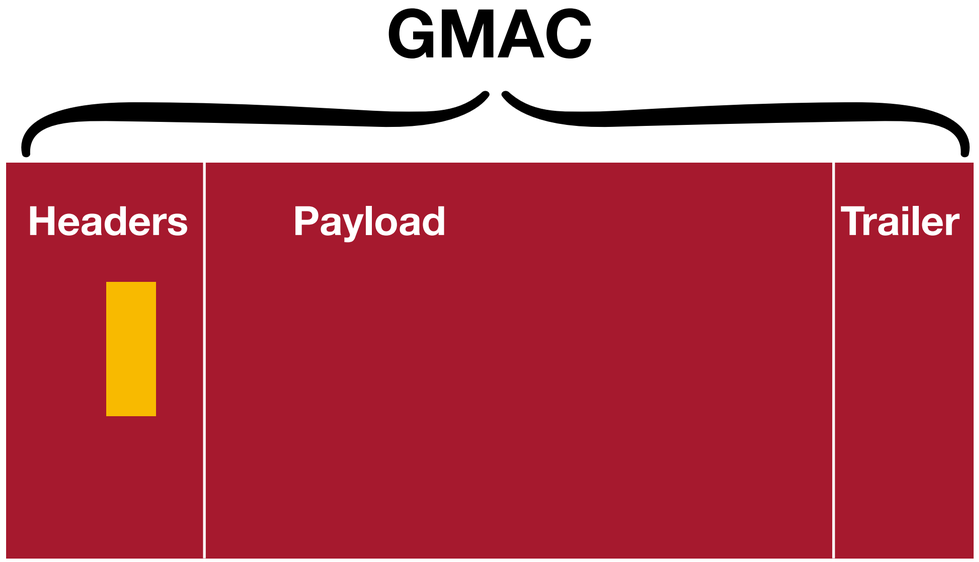


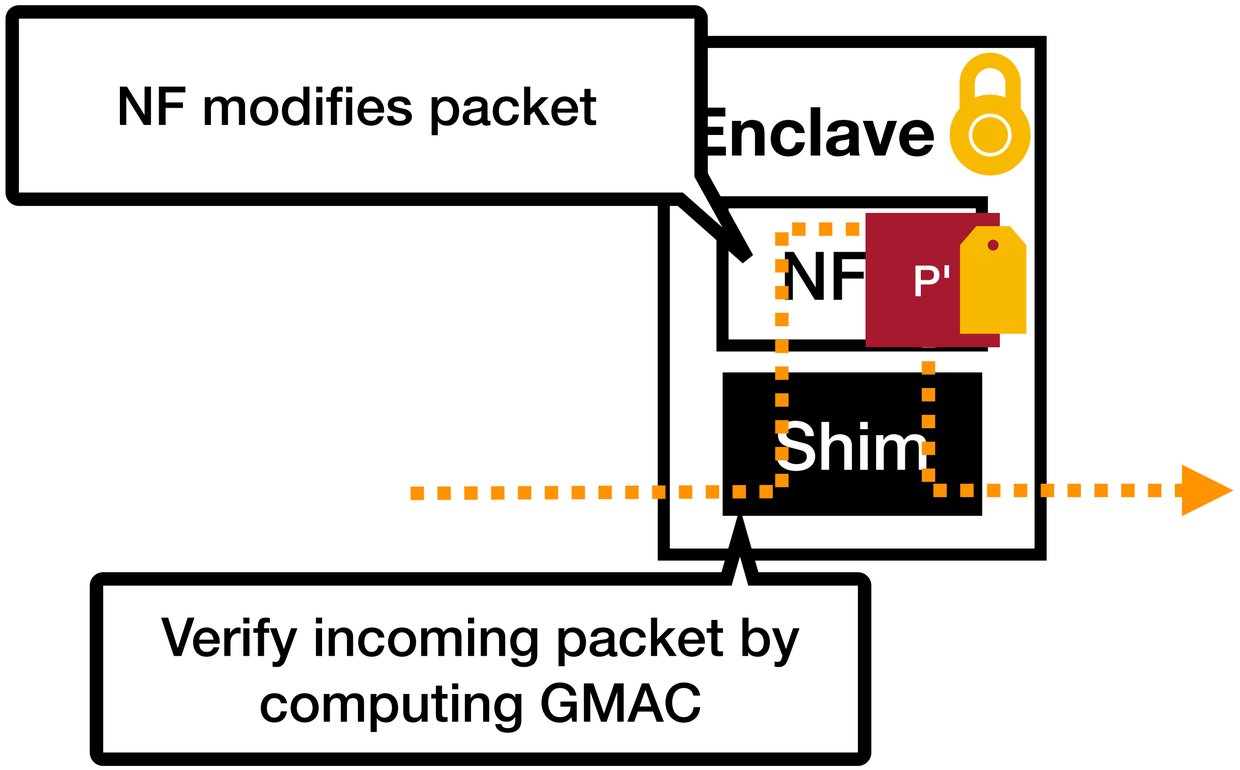


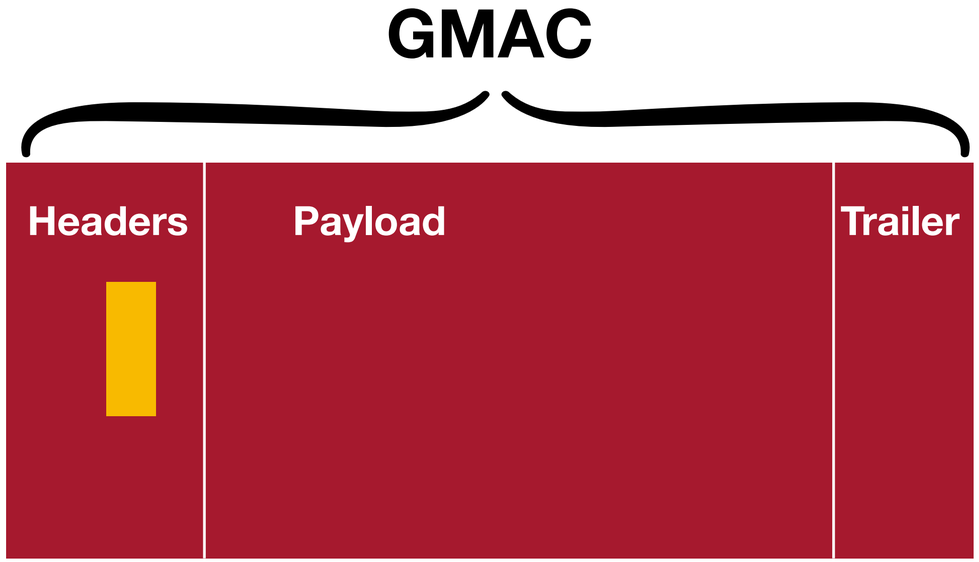
④ Efficient Crypto Mechanisms



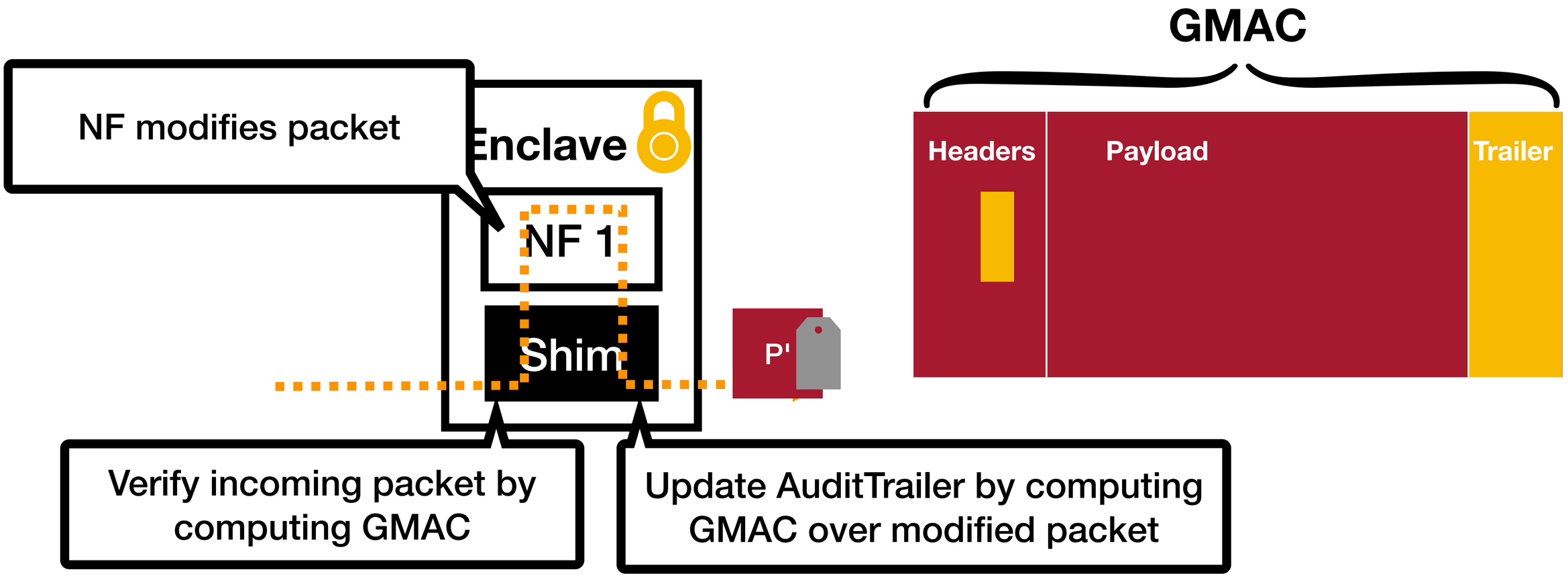


④ Efficient Crypto Mechanisms



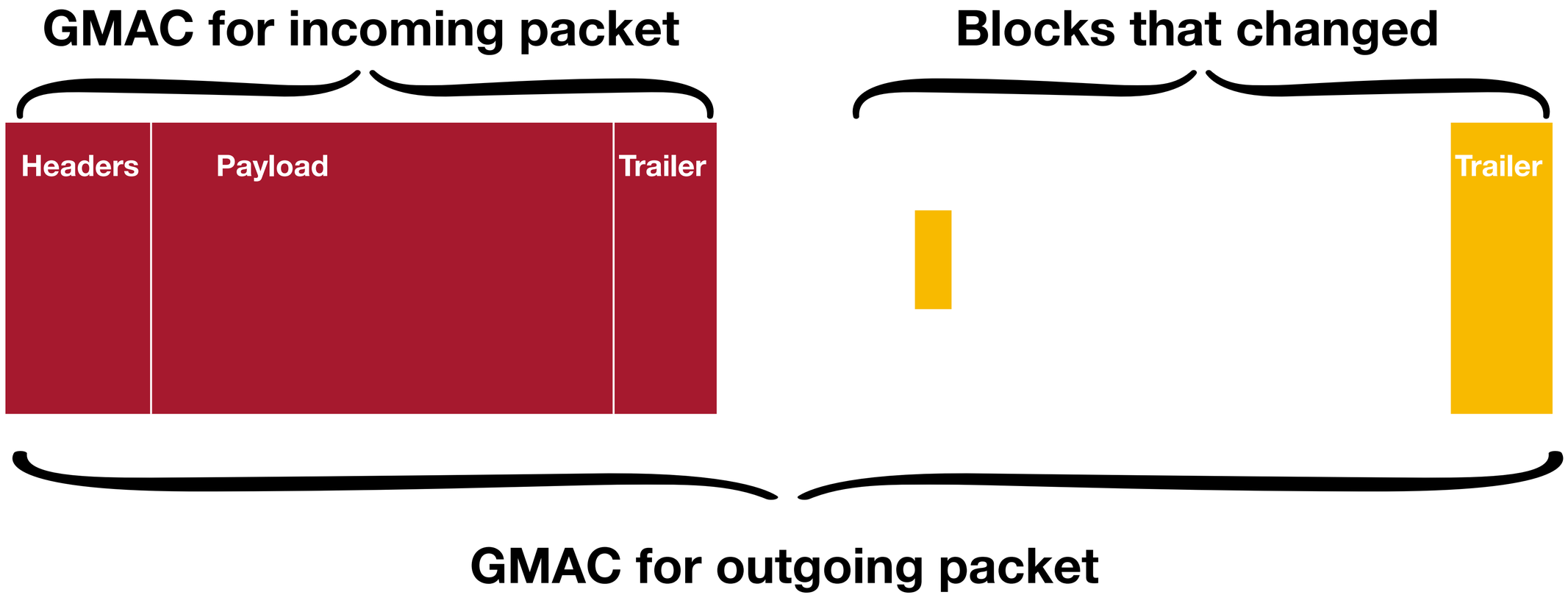


④ Efficient Crypto Mechanisms



④ Efficient Crypto Mechanisms

Updatable GMAC [1]: Reuse first GMAC when computing the second GMAC



[1] D. McGrew. Efficient authentication of large, dynamic data sets using Galois/counter mode (GCM). In Security in Storage Workshop. IEEE, 2005.

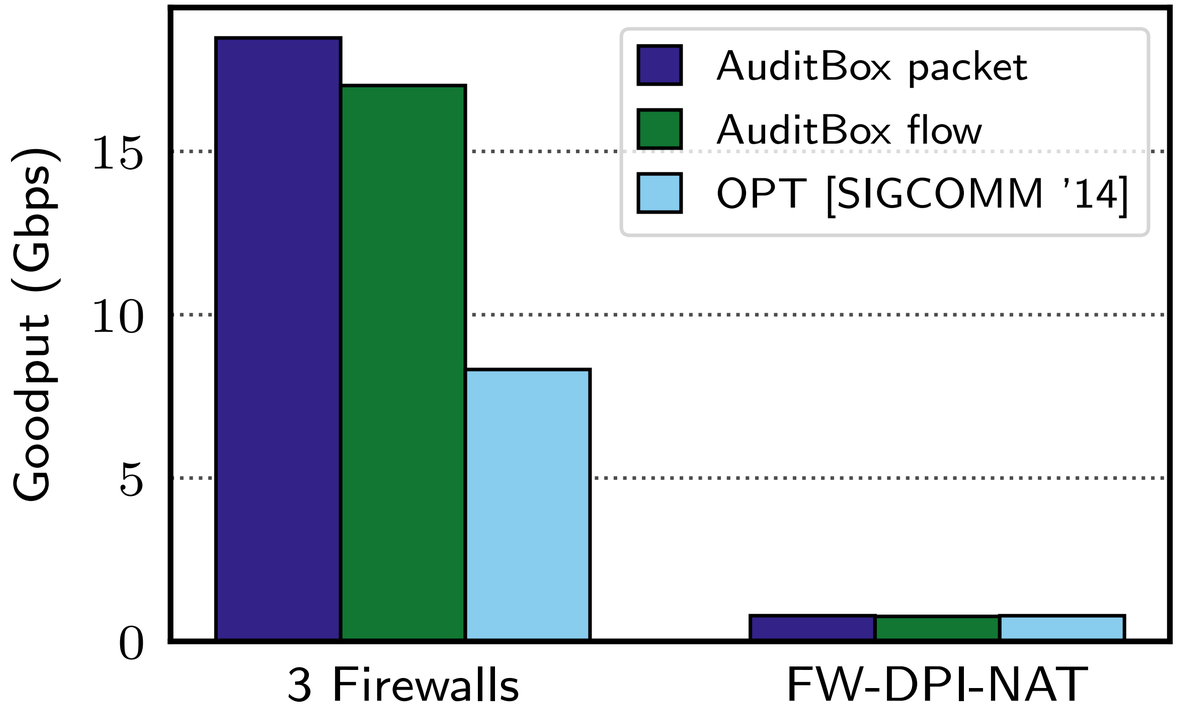
Evaluation

① **Proofs:** We provide security proofs that AuditBox can achieve both runtime correctness and offline auditability

② **Functionality Evaluation:** AuditBox correctly detects a broad class of policy violations

③ **Performance Evaluation:** AuditBox enables auditing for unmodified NFs with low overhead

Evaluation: NF Chain Goodput



Achieves 18 Gbps for a simple NF chain

Summary

AuditBox is the first NFV auditing system. It leverages **trusted execution environments** to provide:

- Runtime correctness
- Offline auditability
- While still achieving good performance

Don't Yank My Chain: Auditable NF Service Chaining

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