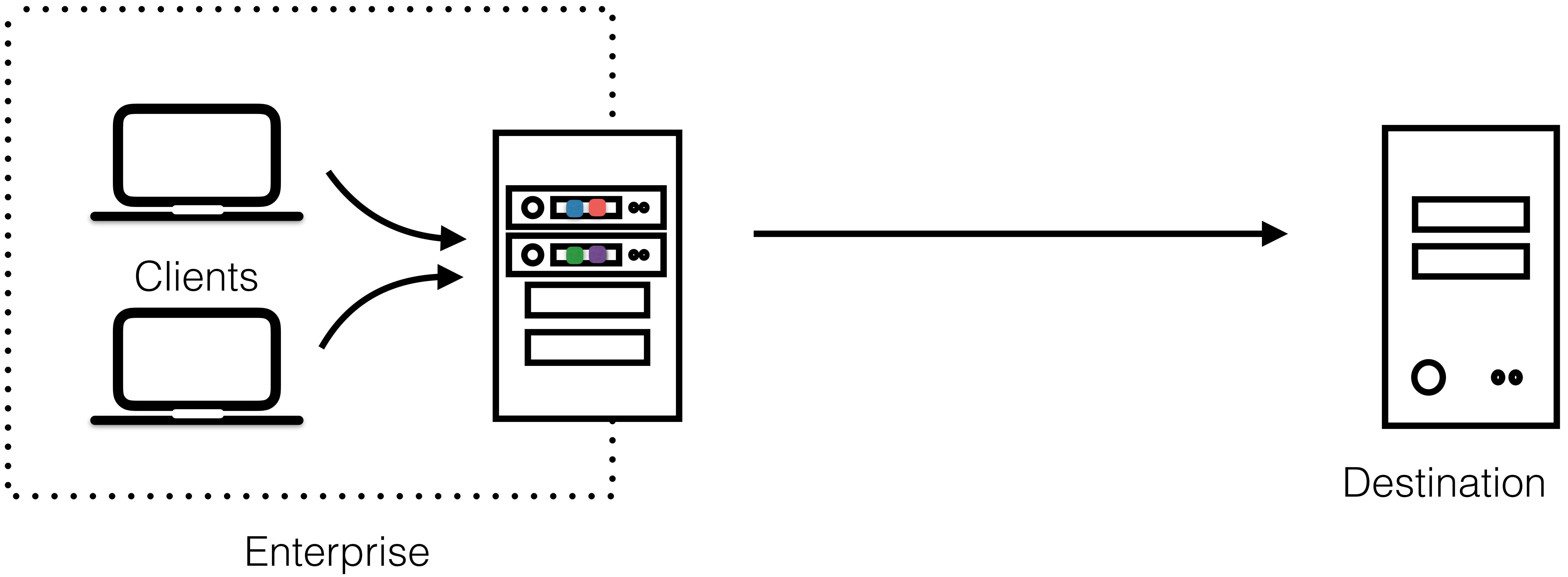
SafeBricks: Shielding Network Functions in the Cloud

Rishabh Poddar, Chang Lan,
Raluca Ada Popa, Sylvia Ratnasamy

UC Berkeley

Network Functions (NFs) in the cloud



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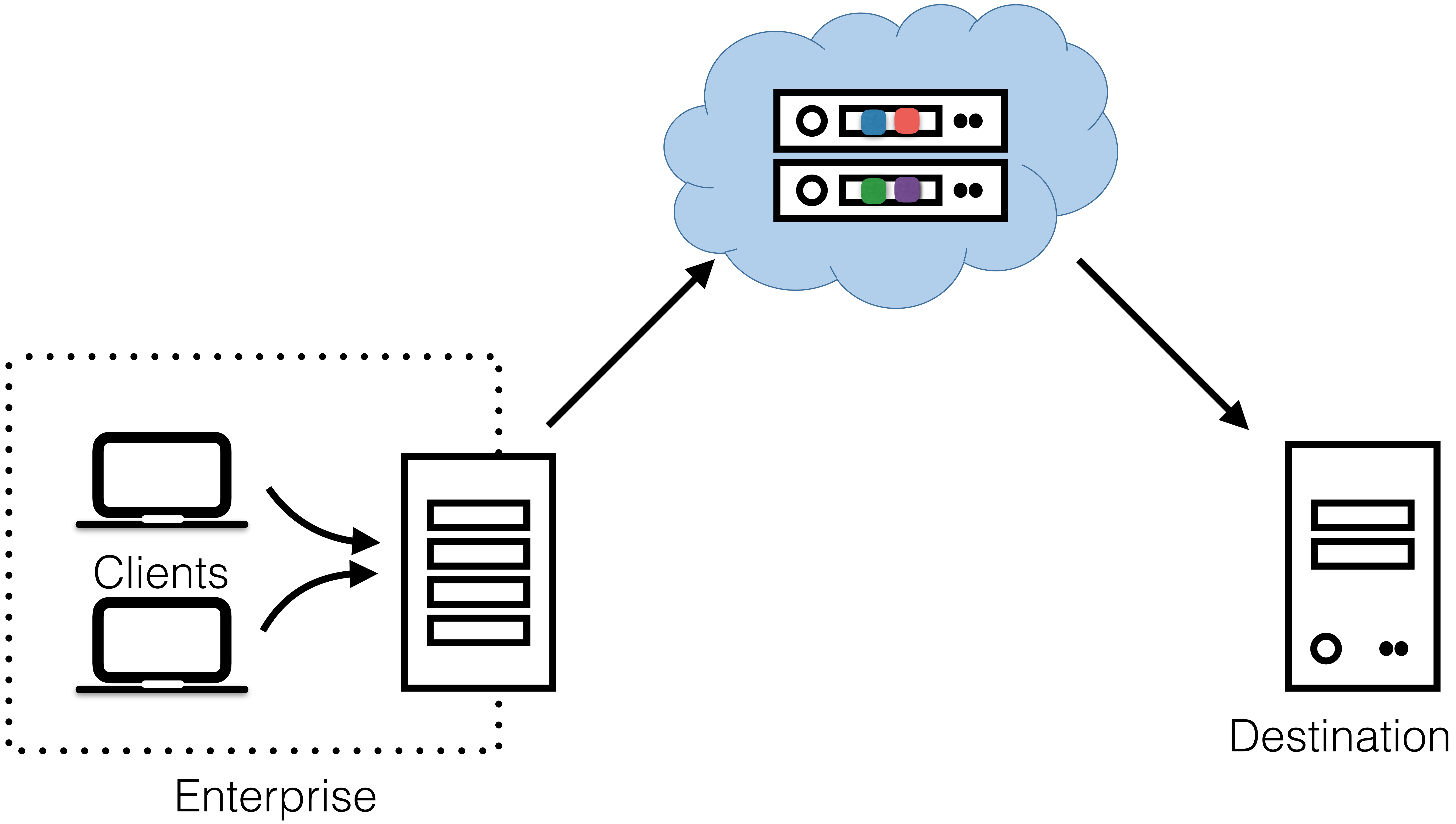

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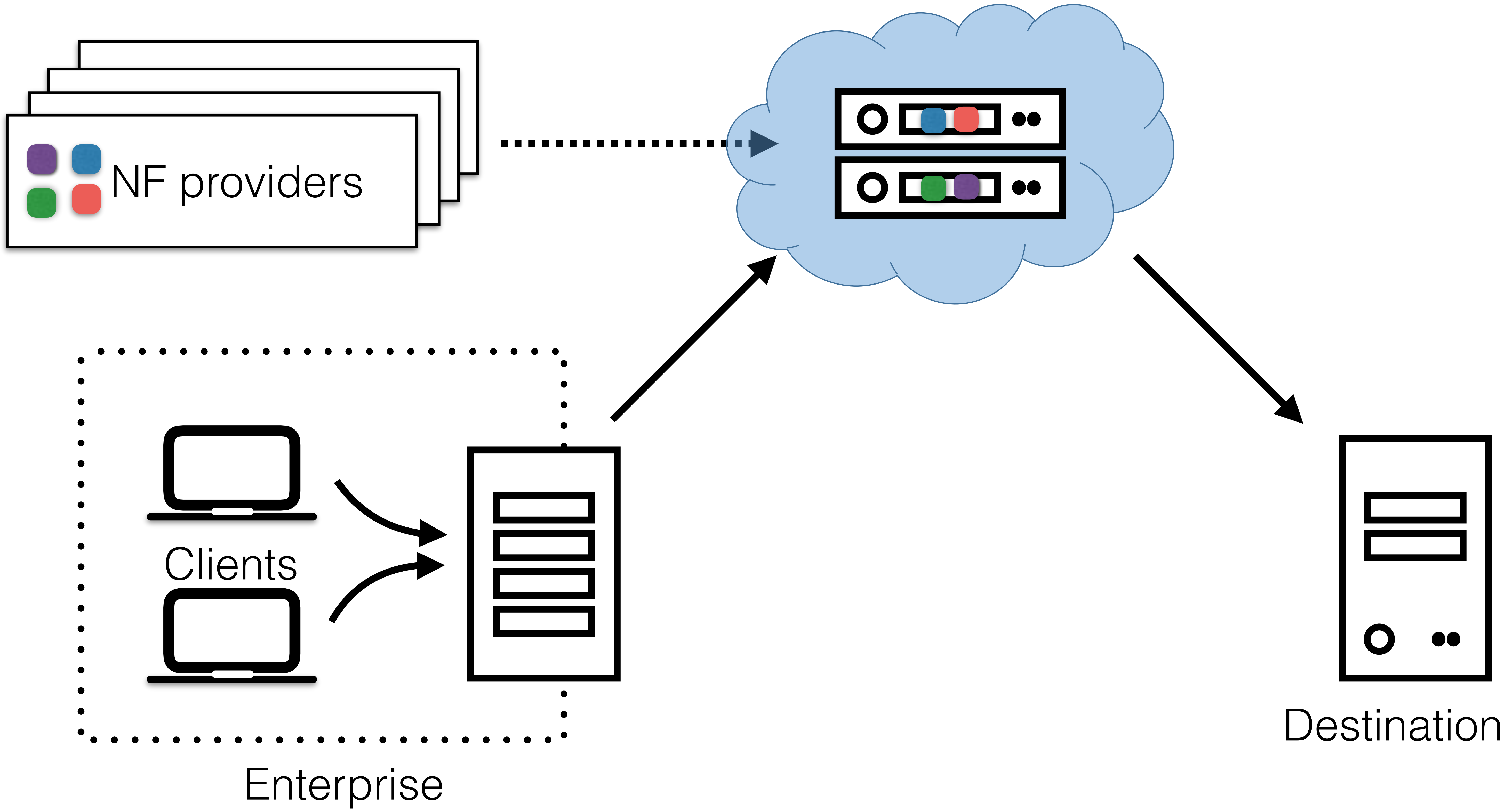
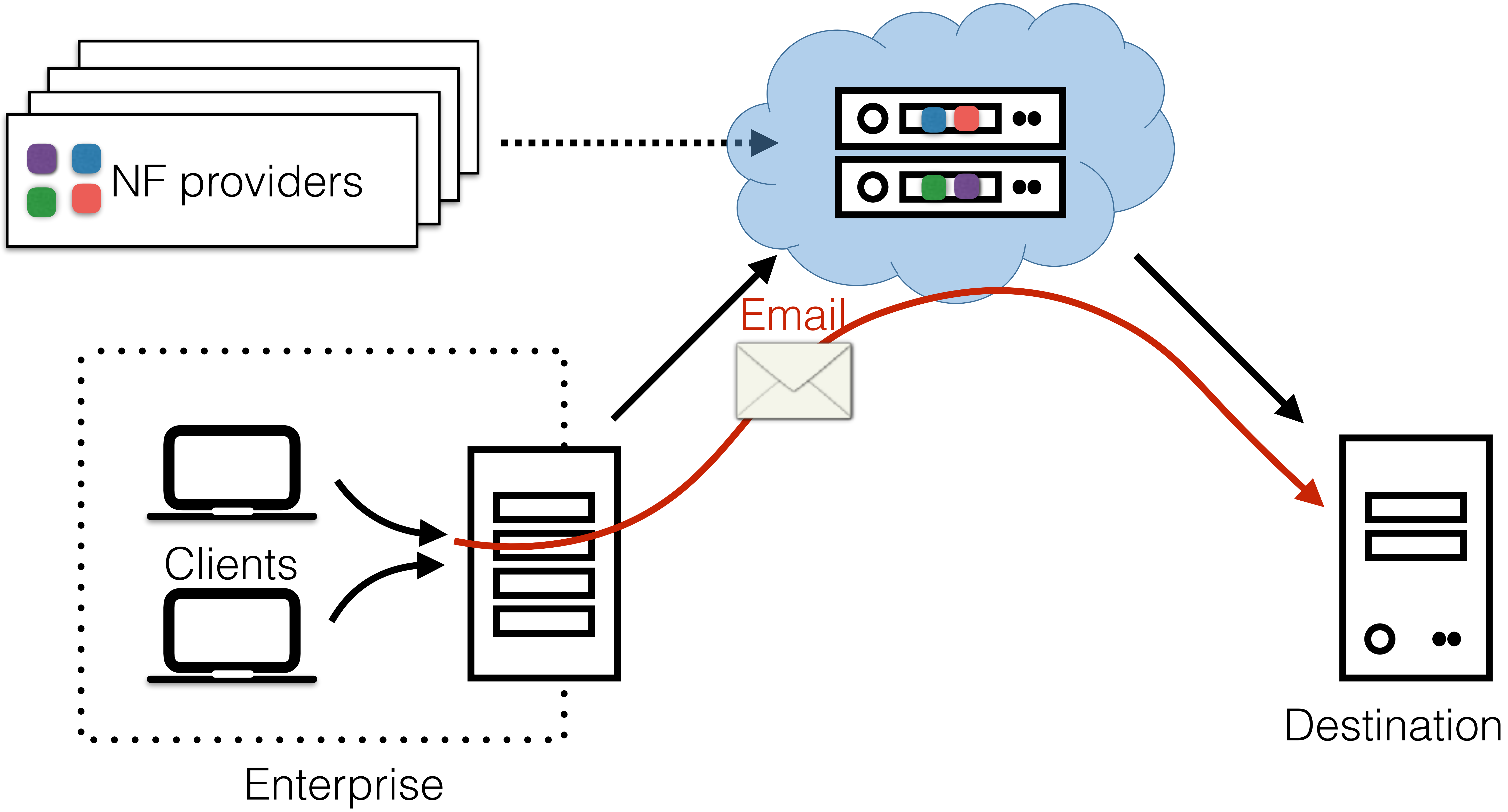
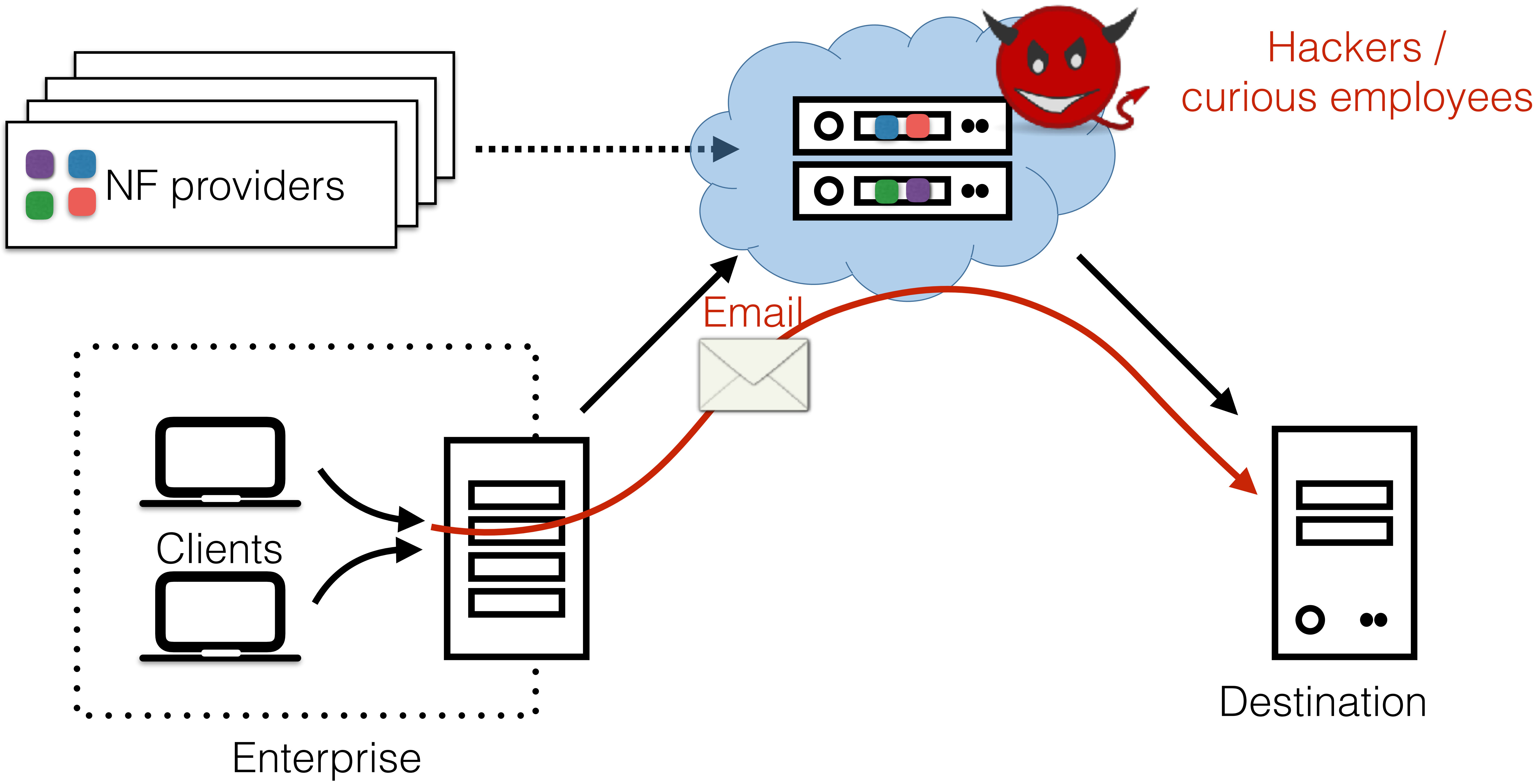


Problem: Security



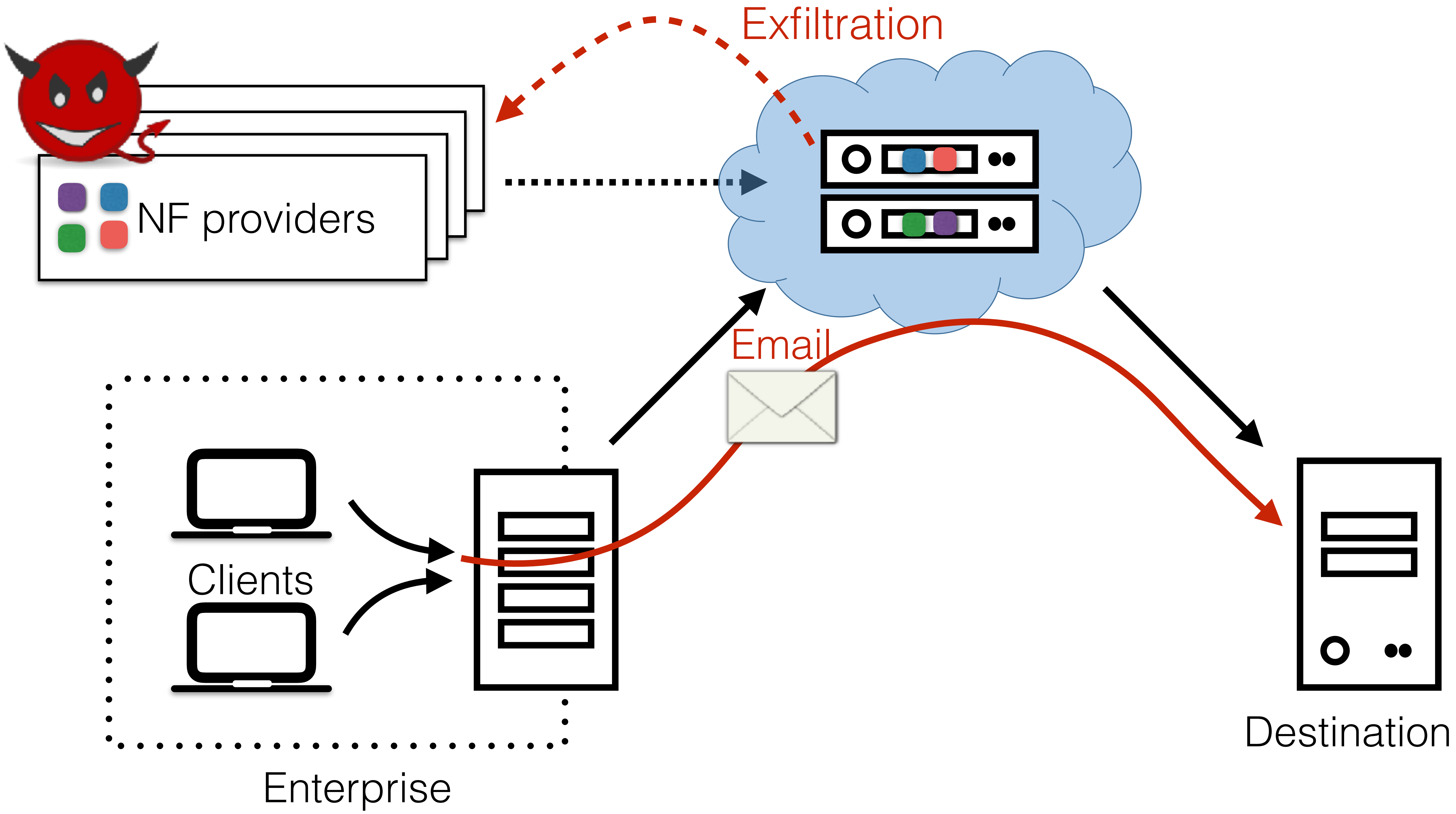
Problem: Security

1 Need to protect **traffic** from the **cloud provider**



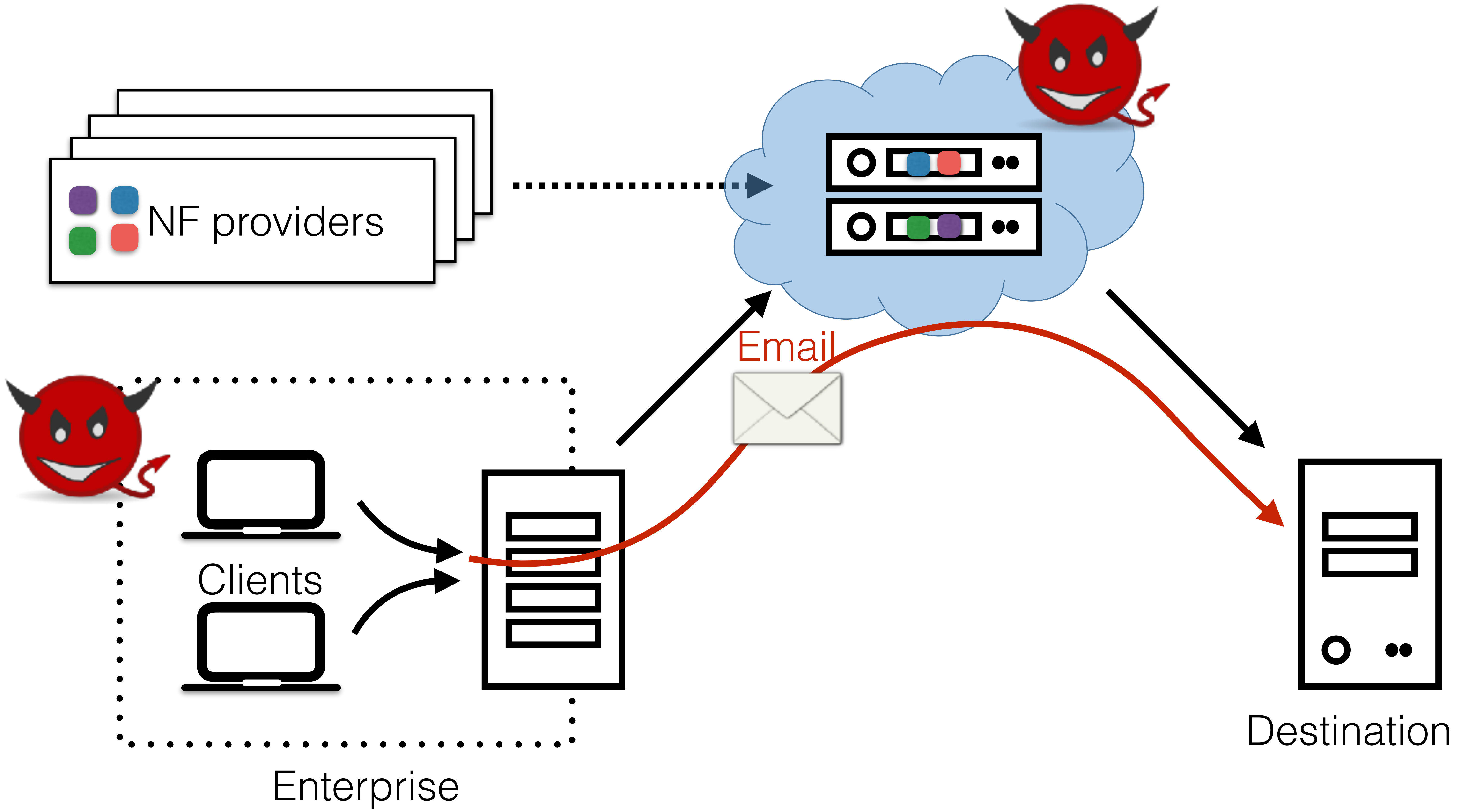
Problem: Security

2 Need to protect **traffic** from the **NF providers**

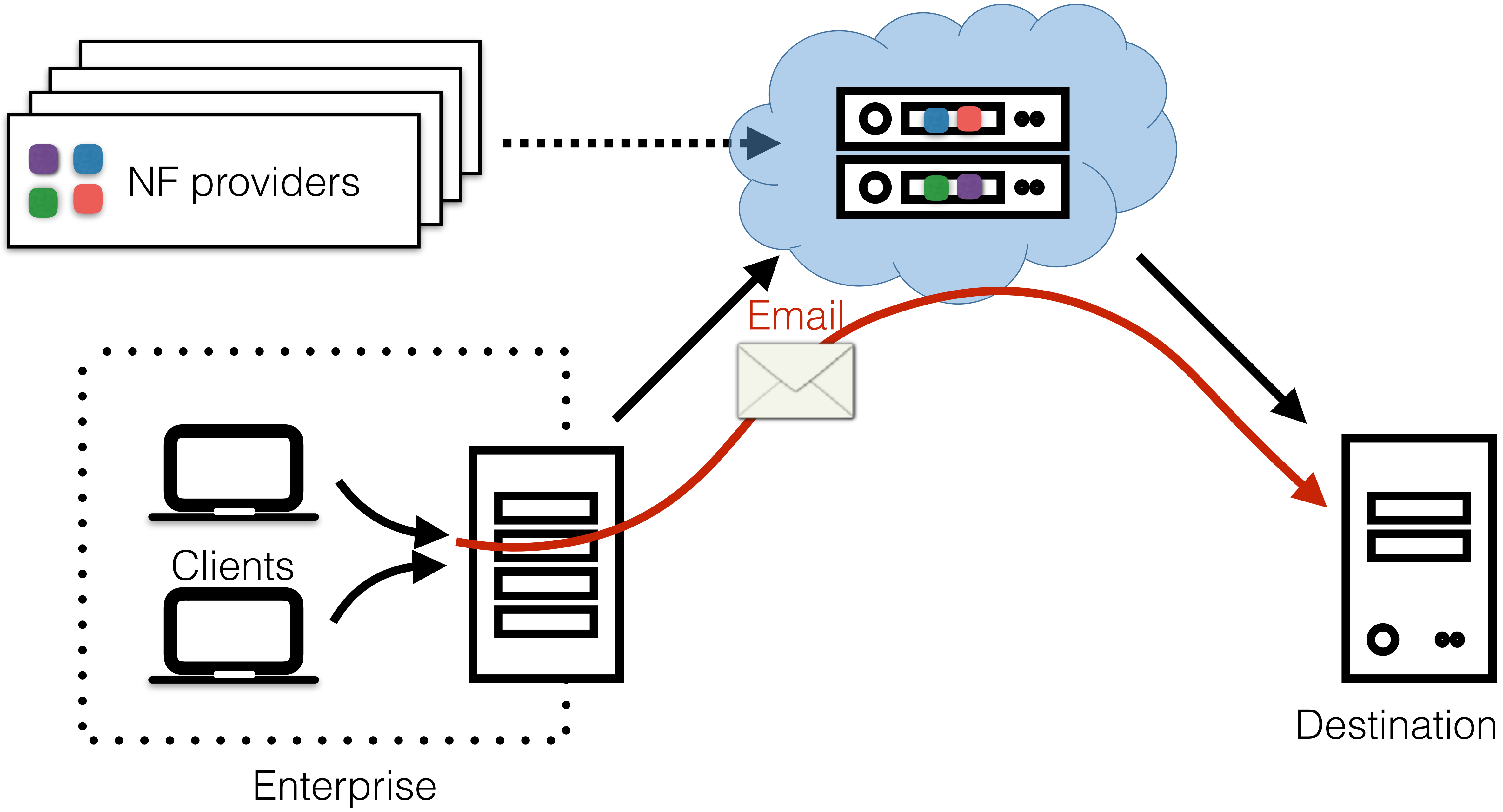


Problem: Security

3 Need to protect **NF code and rulesets** from client enterprise and cloud



Cryptographic solutions do not suffice



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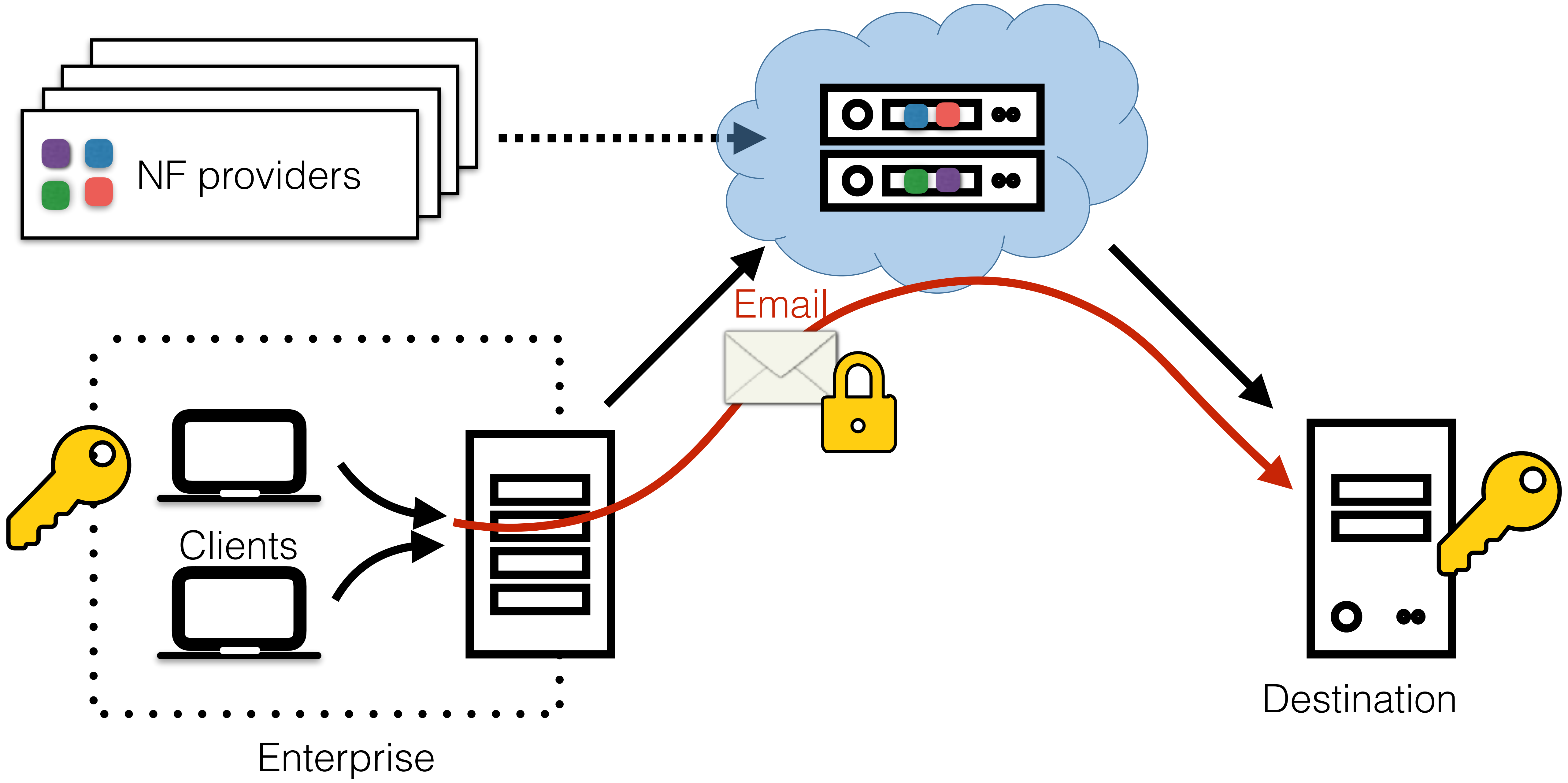

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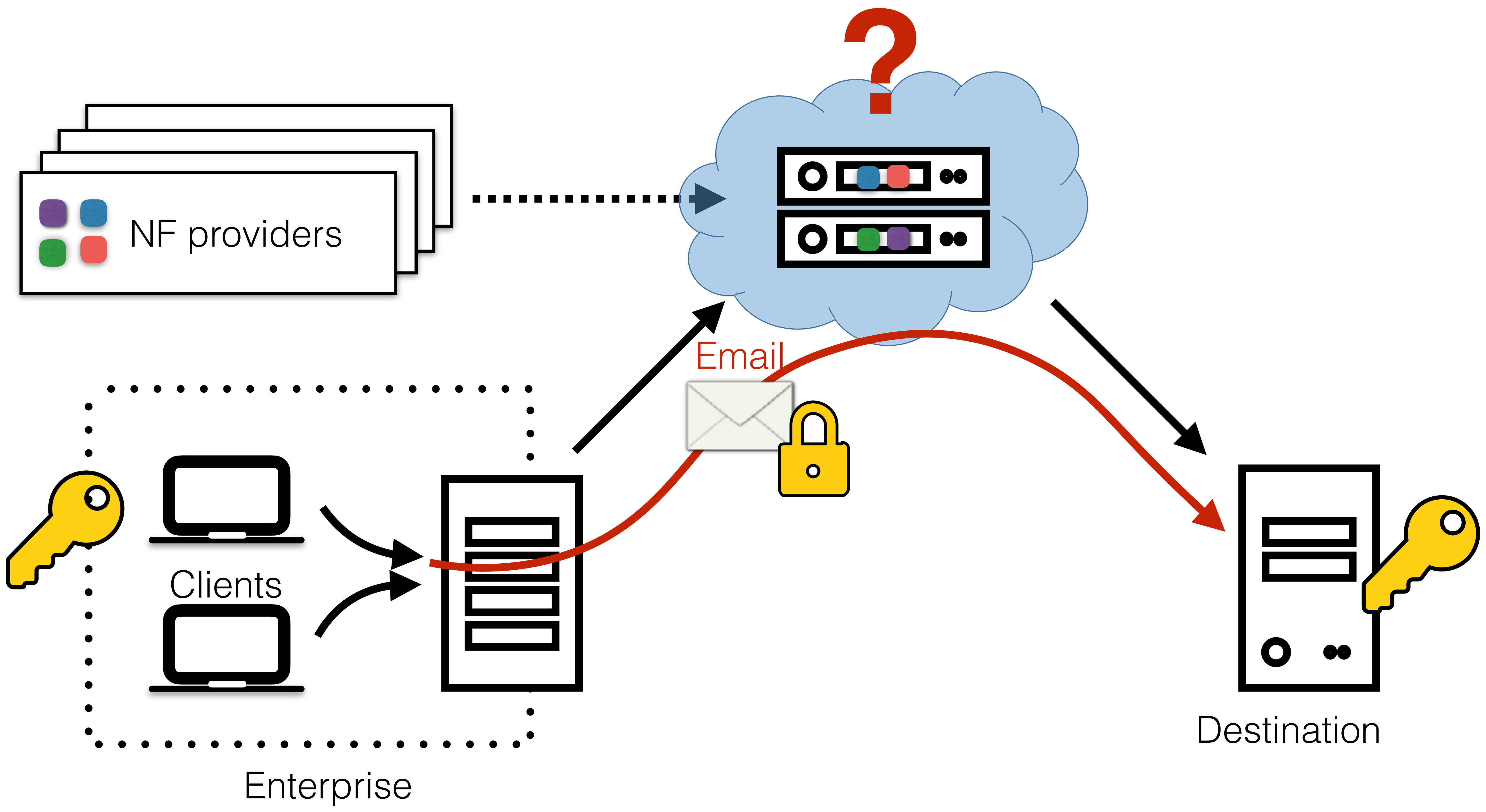
✗ Functionality: Doesn't allow any computation on encrypted payload

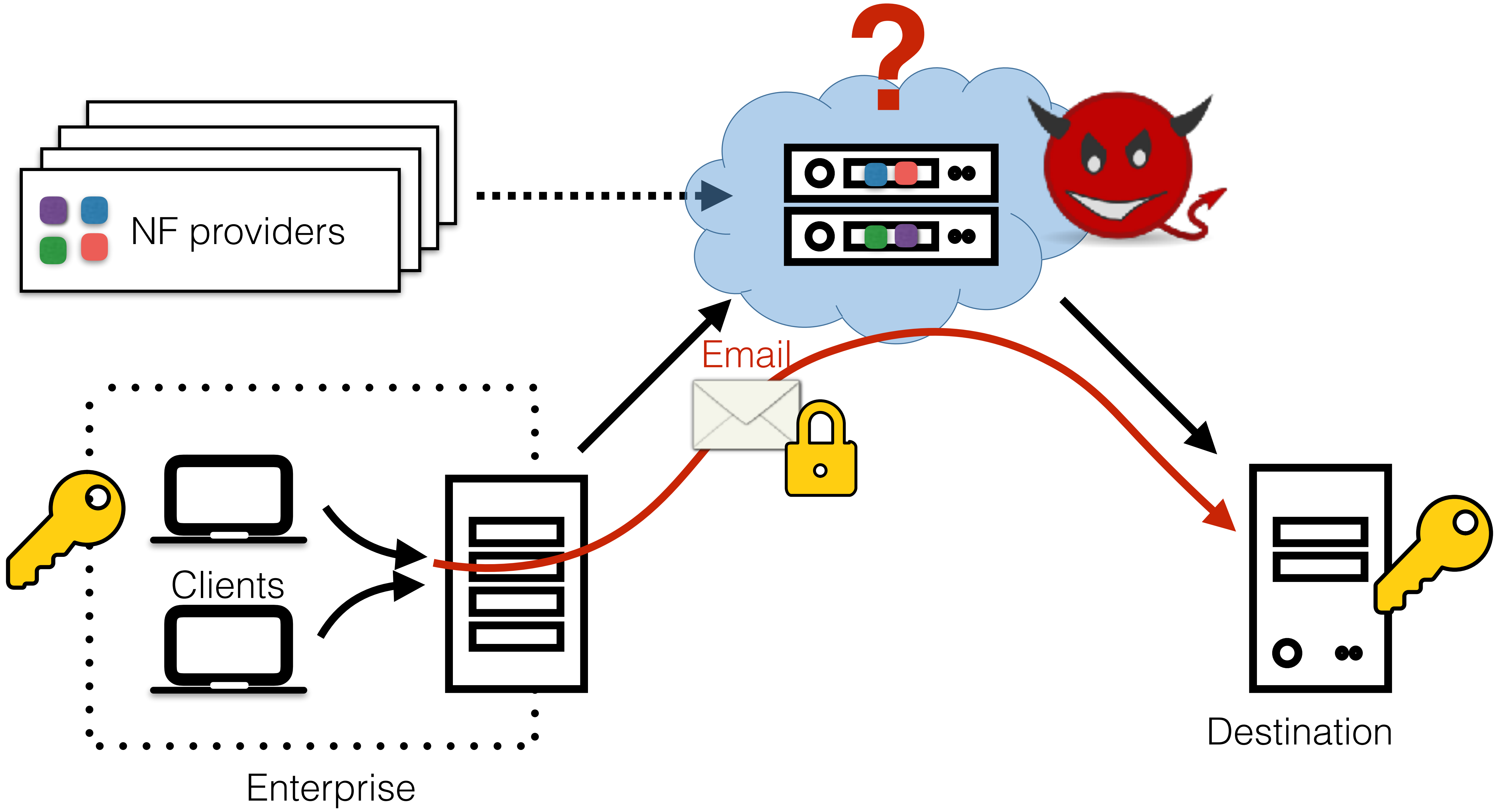


Cryptographic solutions do not suffice

1 **Standard encryption**: e.g. end-to-end TLS

✗ Functionality: Doesn't allow any computation on encrypted payload

✗ Security: Unencrypted fields (e.g. IP headers) still leak information



Cryptographic solutions do not suffice

2 **Specialized encryption**: e.g. BlindBox, Embark

[Sherry et al. (SIGCOMM’15)] [Lan et al. (NSDI’16)]

Cryptographic solutions do not suffice

2 **Specialized encryption**: e.g. BlindBox, Embark

✗ Too limited in functionality!

✓ Header-based comparisons

✓ Keyword matching

✗ Regular expressions

✗ Cross-flow analysis

✗ Statistical computations

How to achieve **full functionality** and

our security goals simultaneously?

SafeBricks

1. Protects **traffic** from the **cloud provider**
2. Protects **traffic** from the **NF providers**
3. Protects **NF source code and rulesets** from client enterprise and cloud

SafeBricks

Hardware enclaves + language-based isolation

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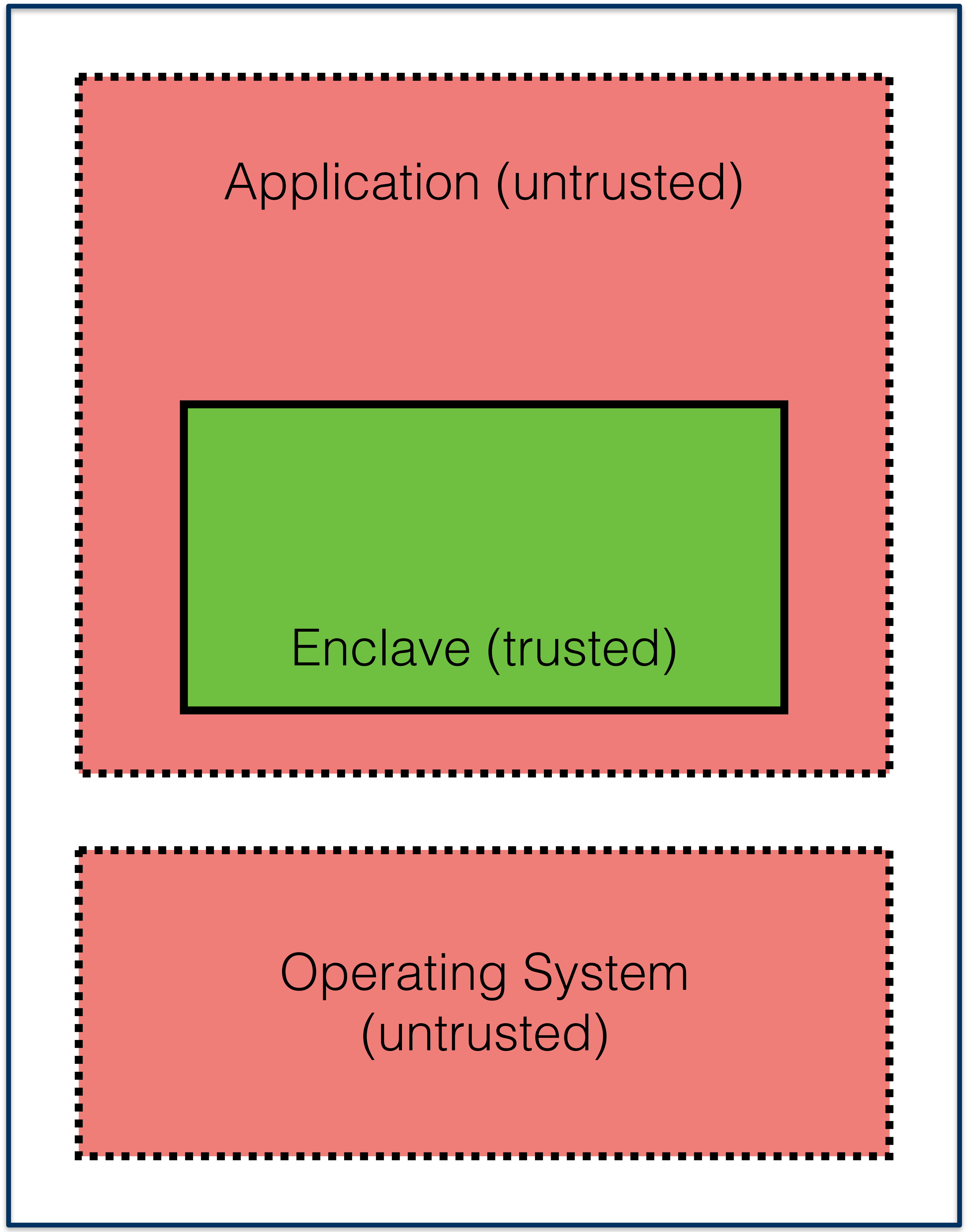
- Secure region of memory (**enclaves**) protected by hardware



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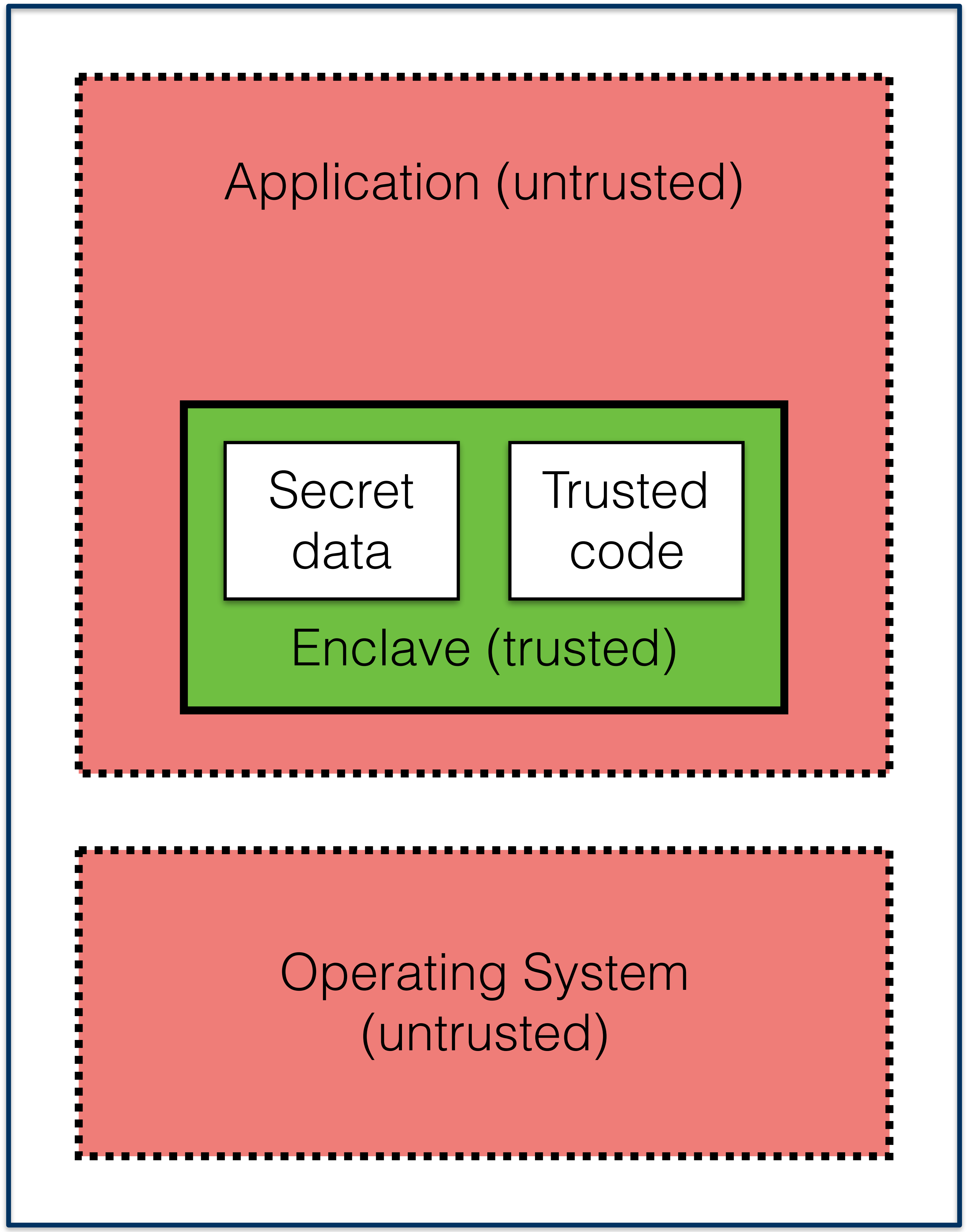

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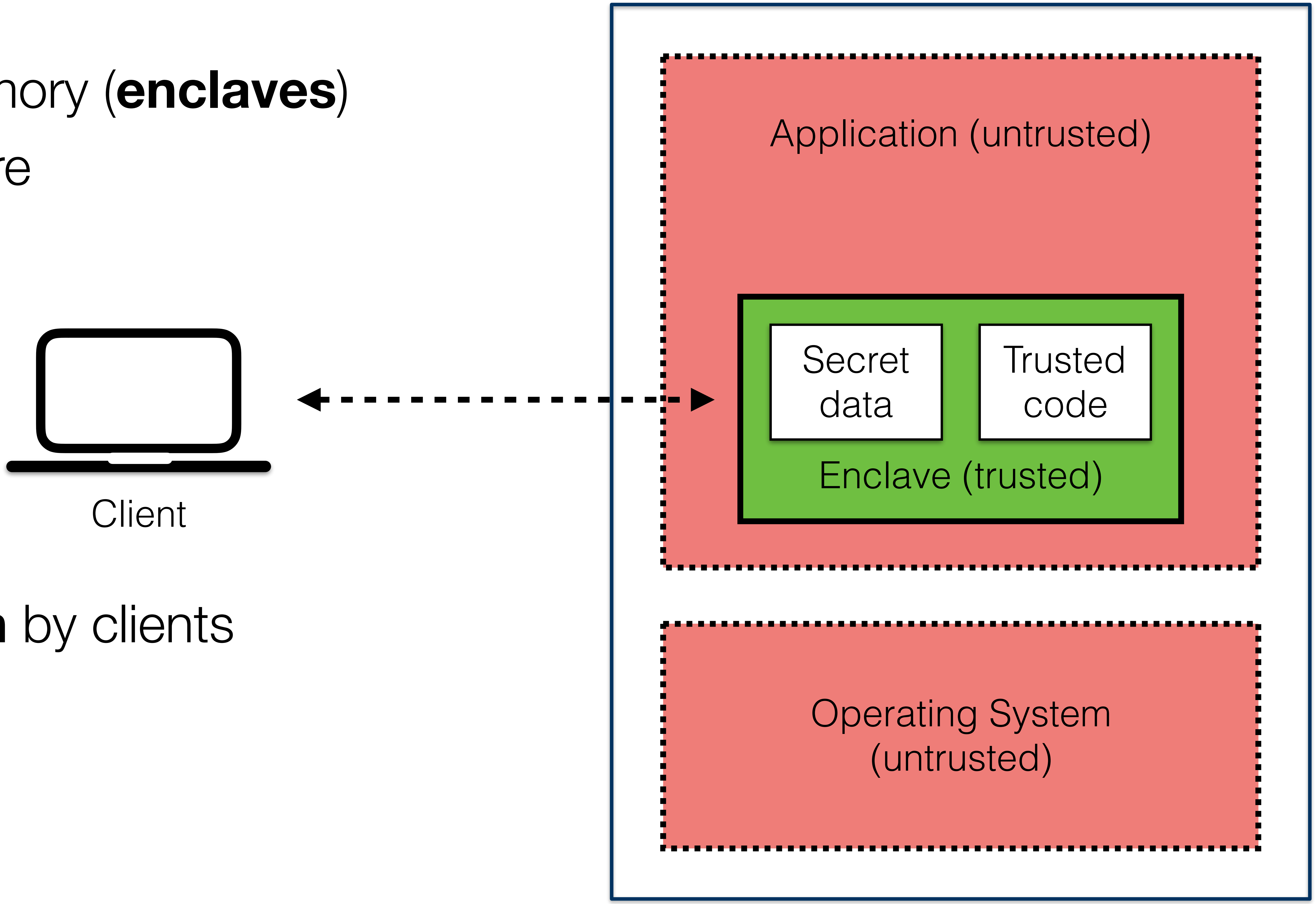

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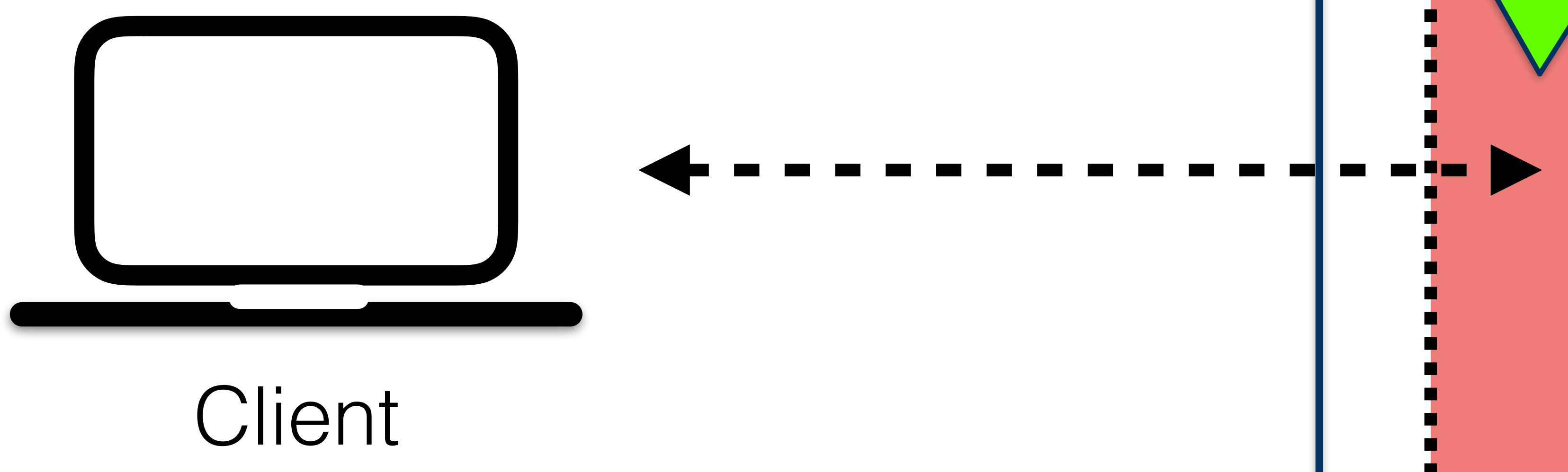

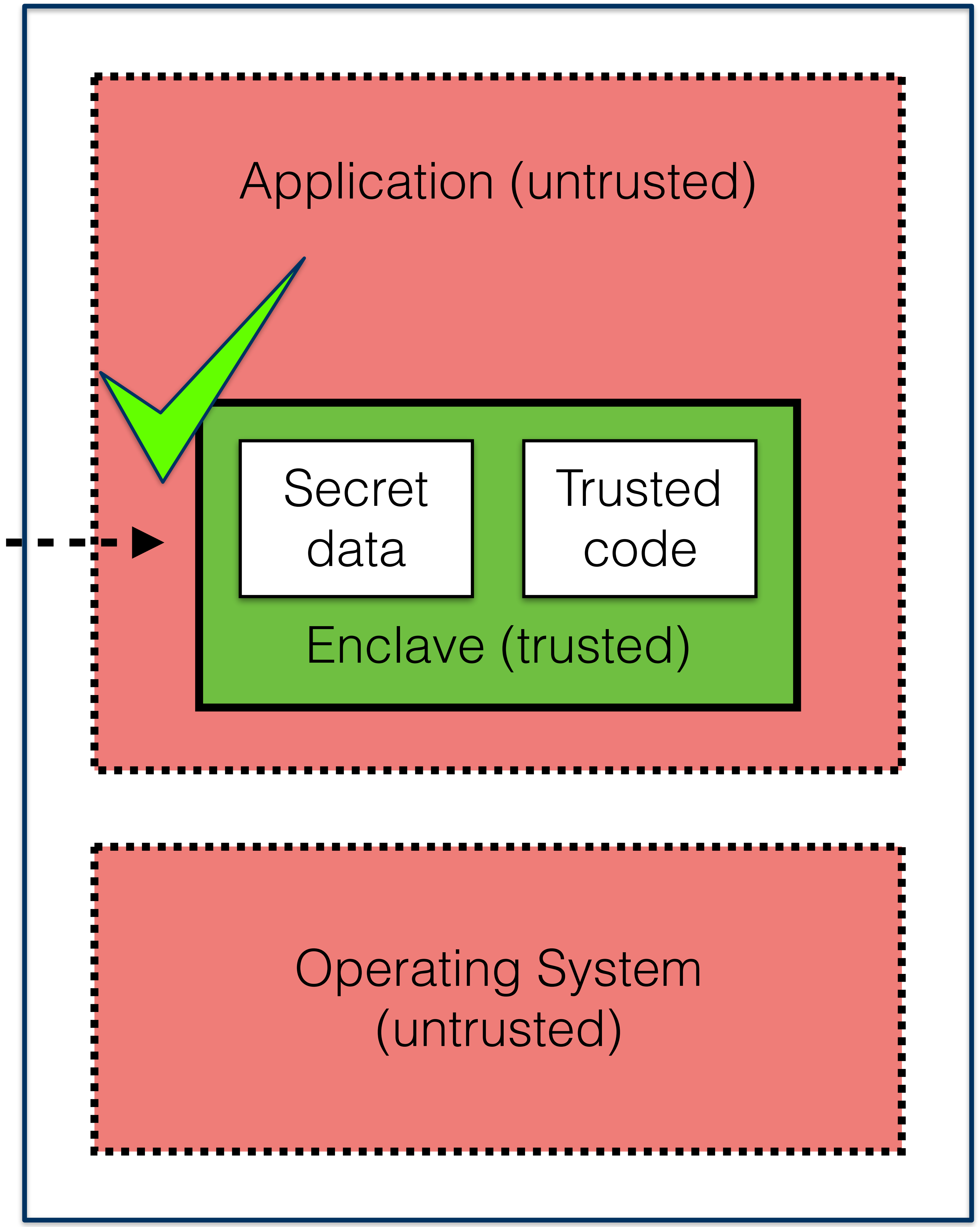

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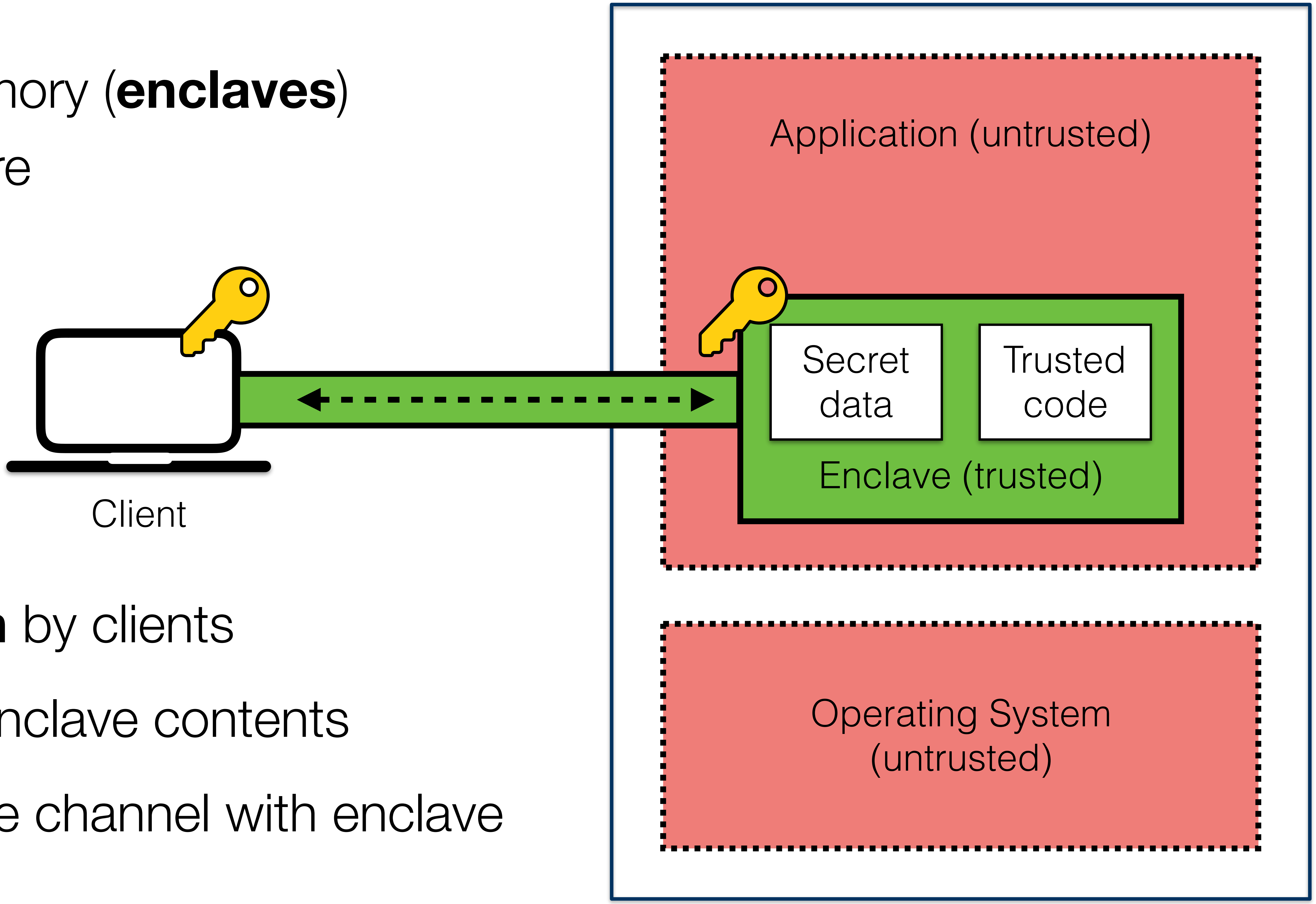
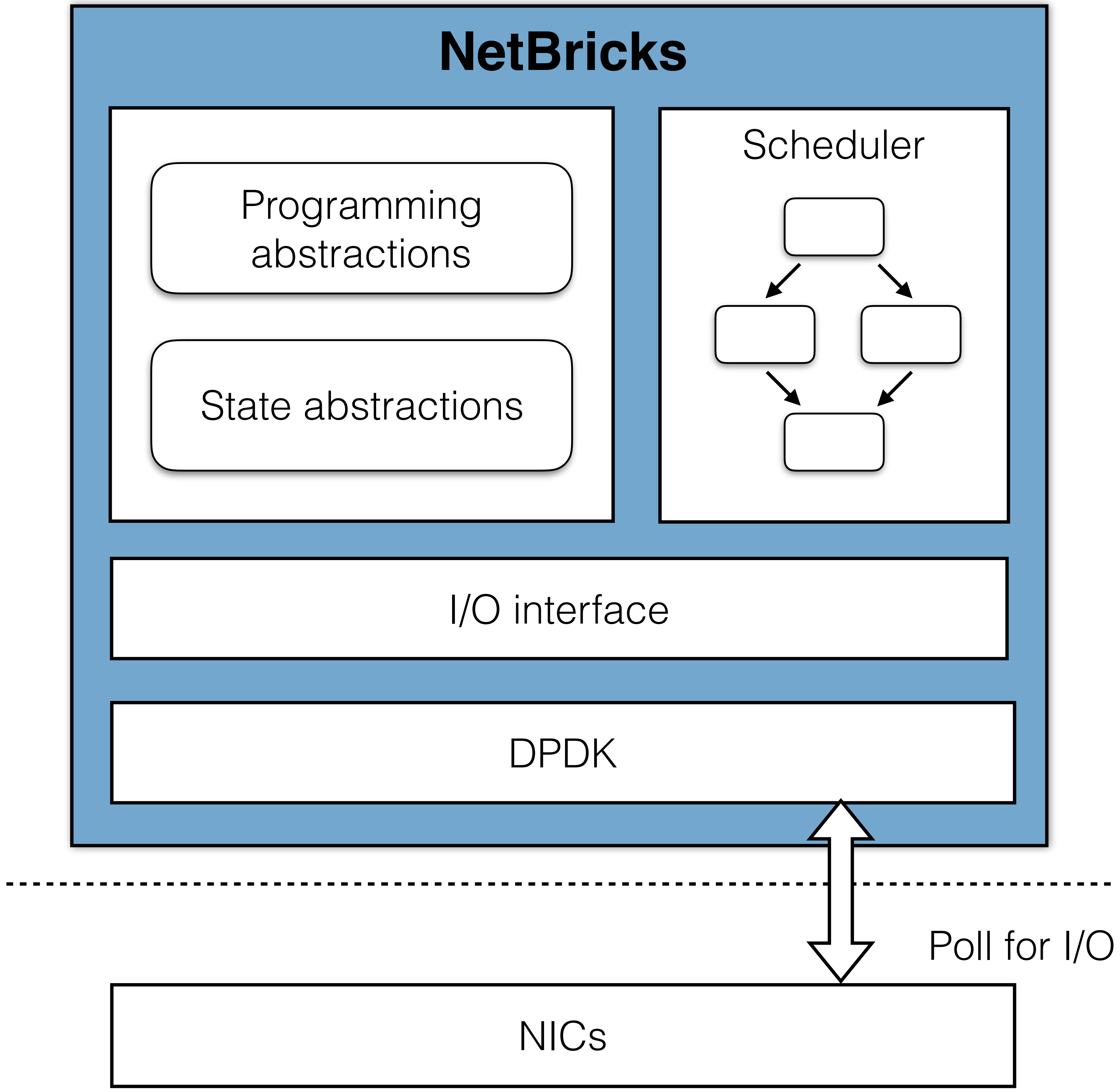


- **Remote attestation** by clients
  - Remotely verify enclave contents
  - Establish a secure channel with enclave

Background: NetBricks

[Panda et al. (OSDI'16)]

- Framework for developing **arbitrary NFs**



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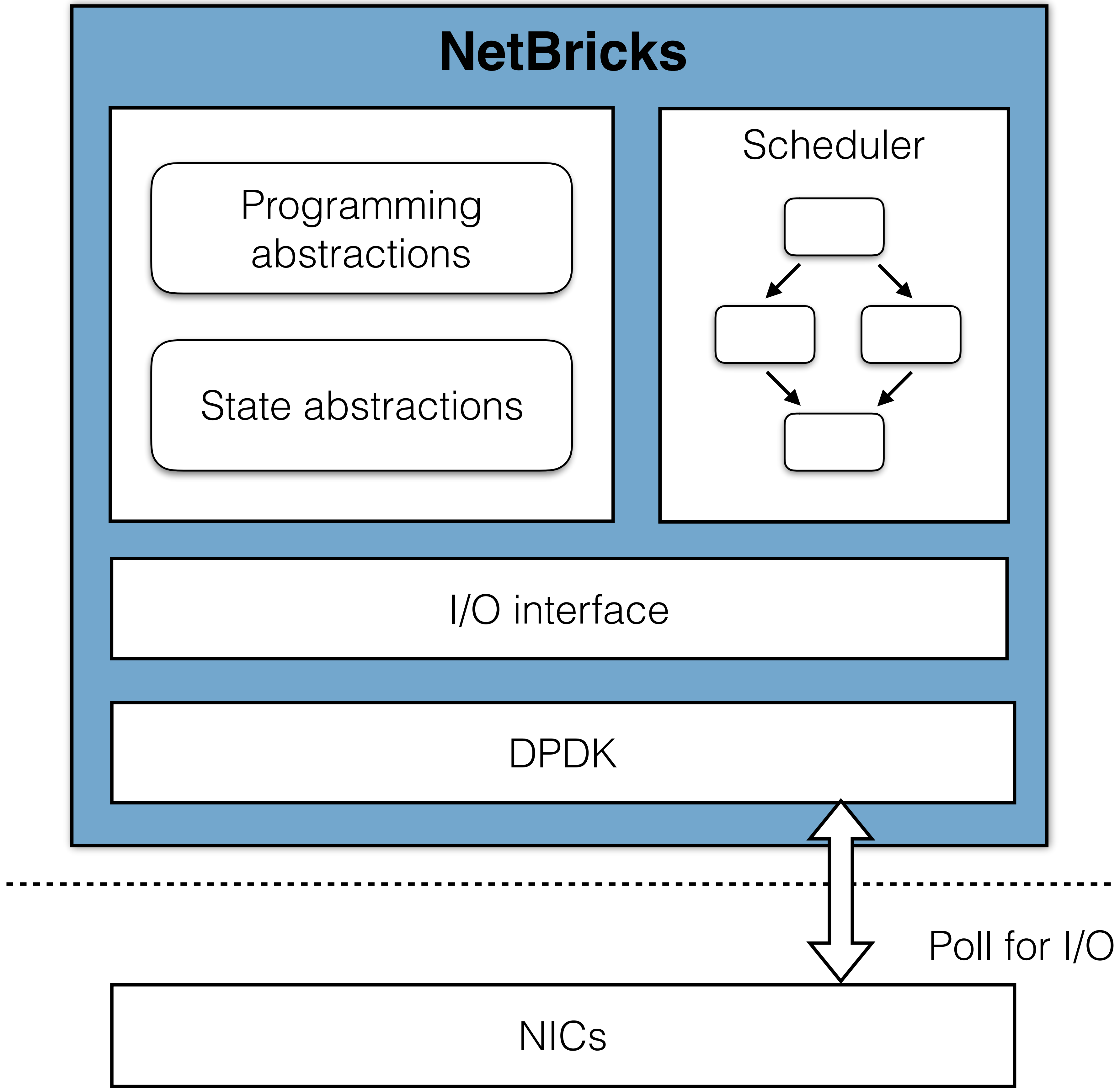

Background: NetBricks

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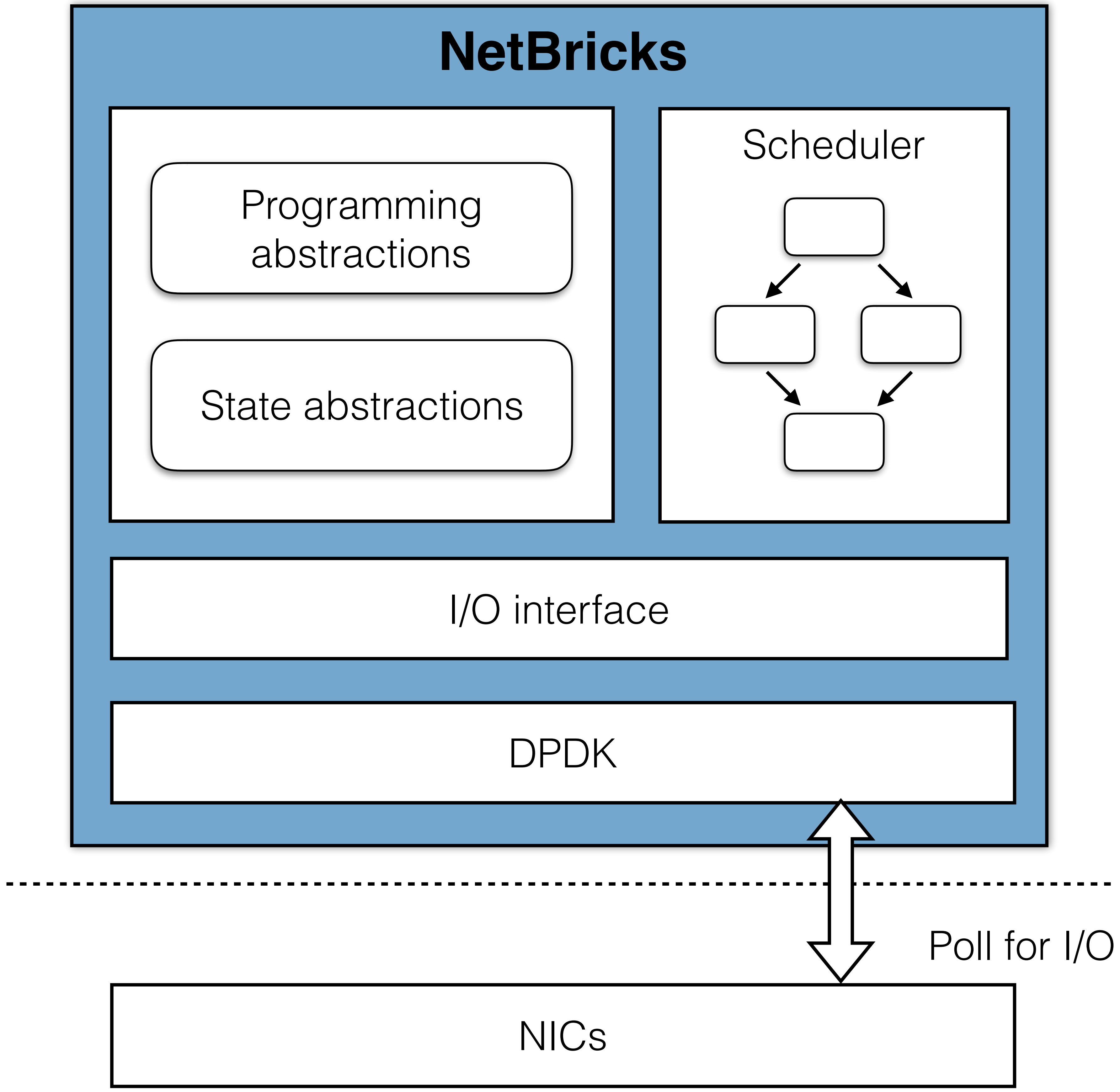
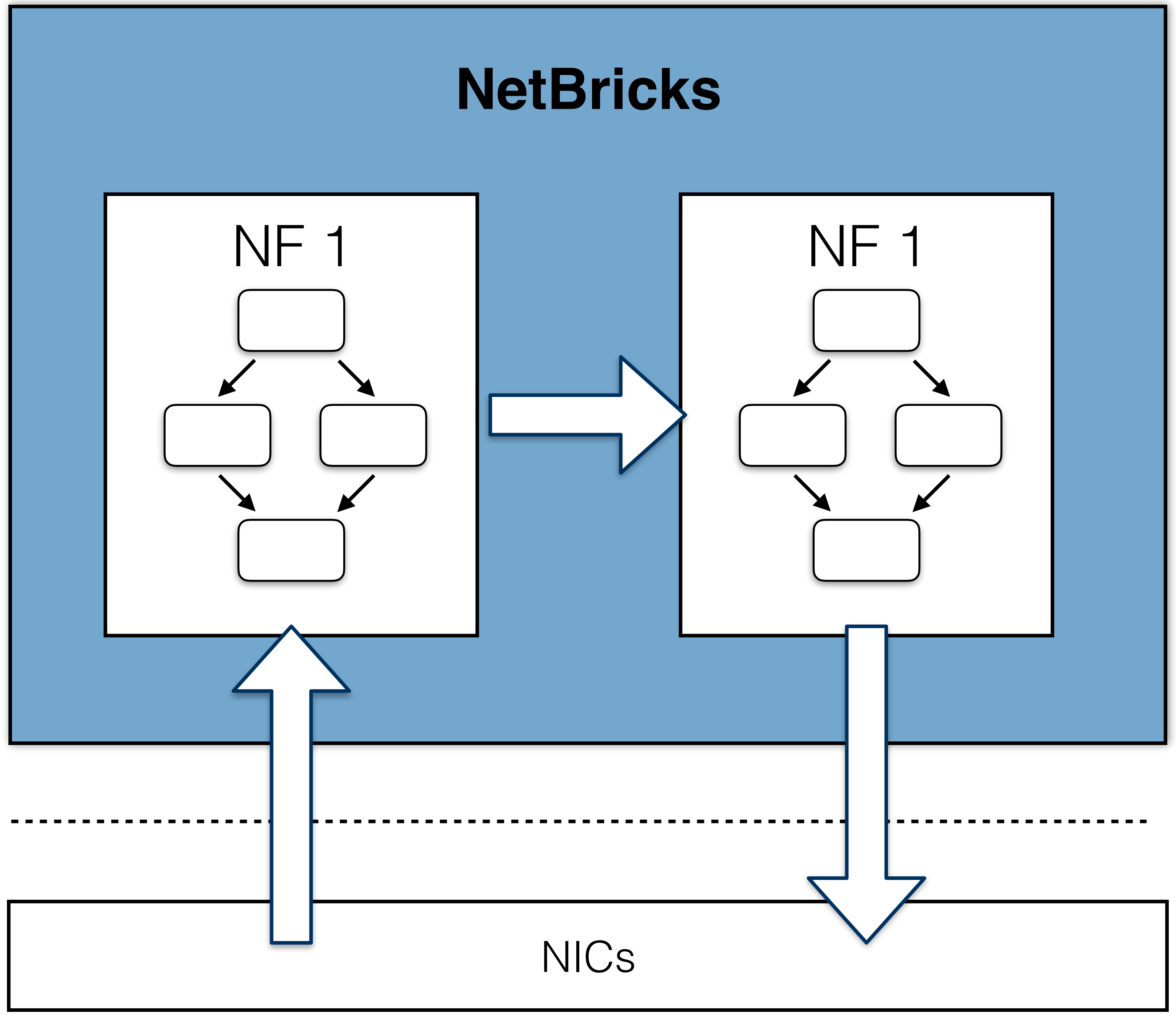
- Framework for developing **arbitrary NFs**
  - MapReduce like programming abstractions (operators) for packet processing
  - NFs represented as a **directed graph** with operators as nodes



Background: NetBricks

- Written in **Rust**
  - Fast, safe, zero-copy semantics
  - **Isolates NFs** deployed in a chain while running them in the same address **space**



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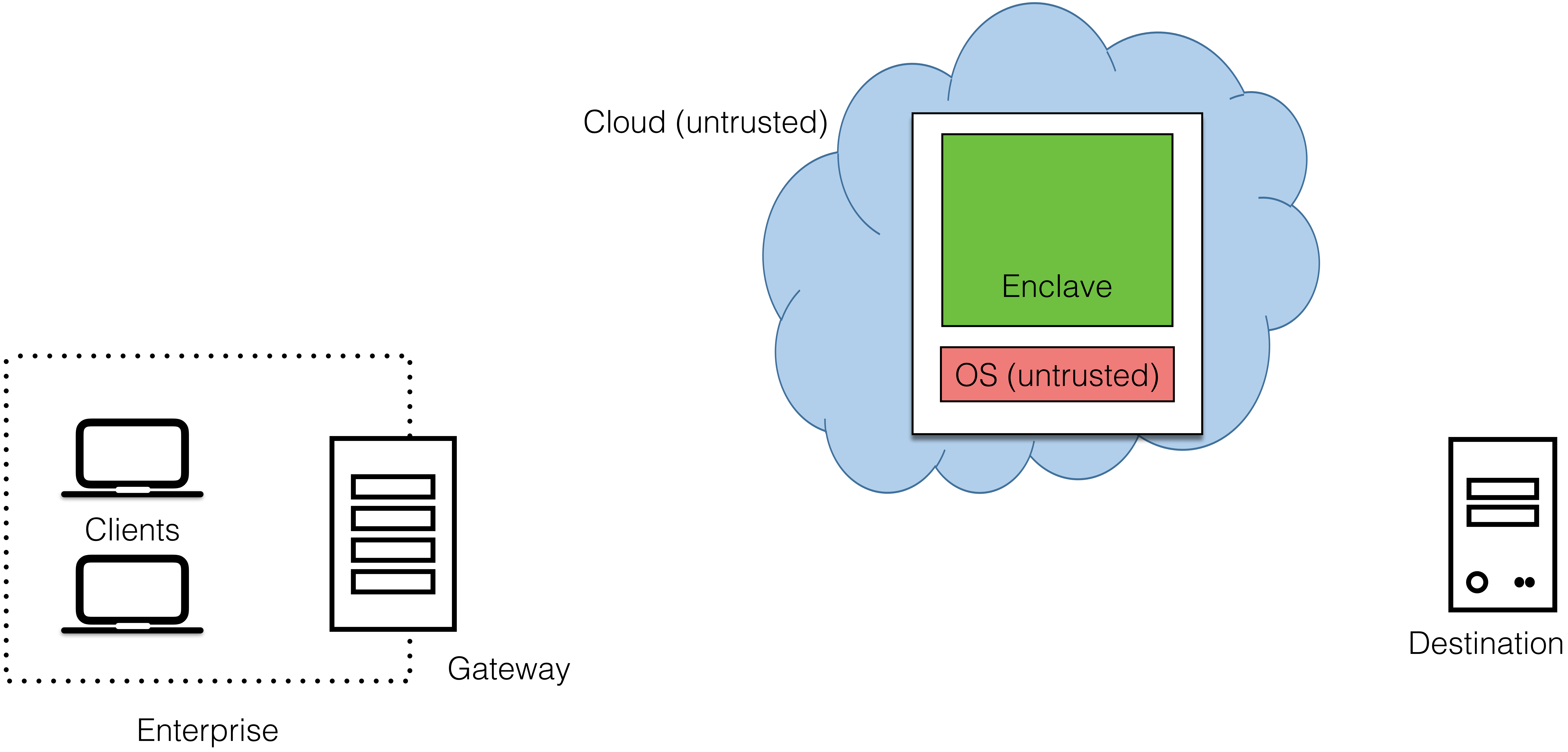
Outsourcing NFs using hardware enclaves



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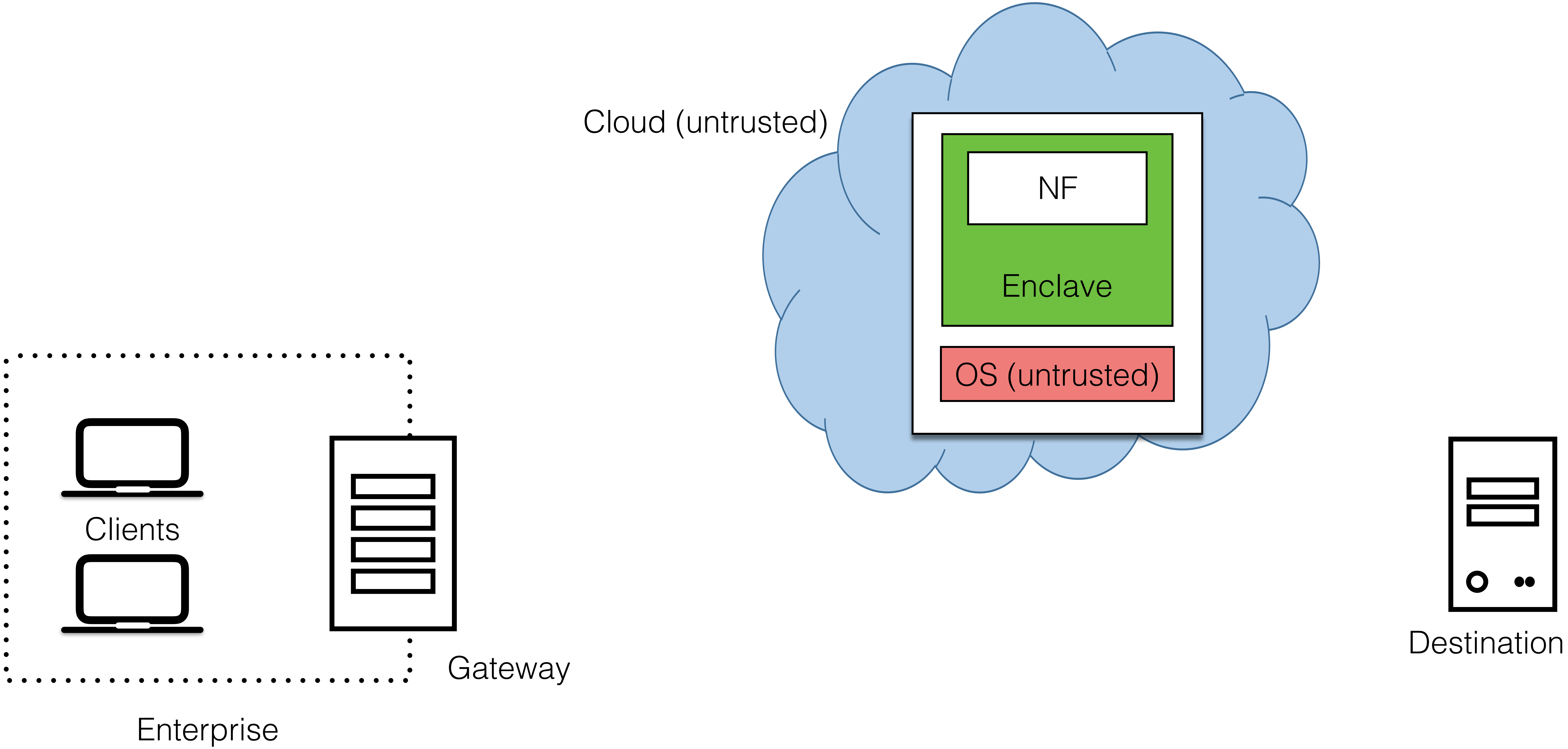

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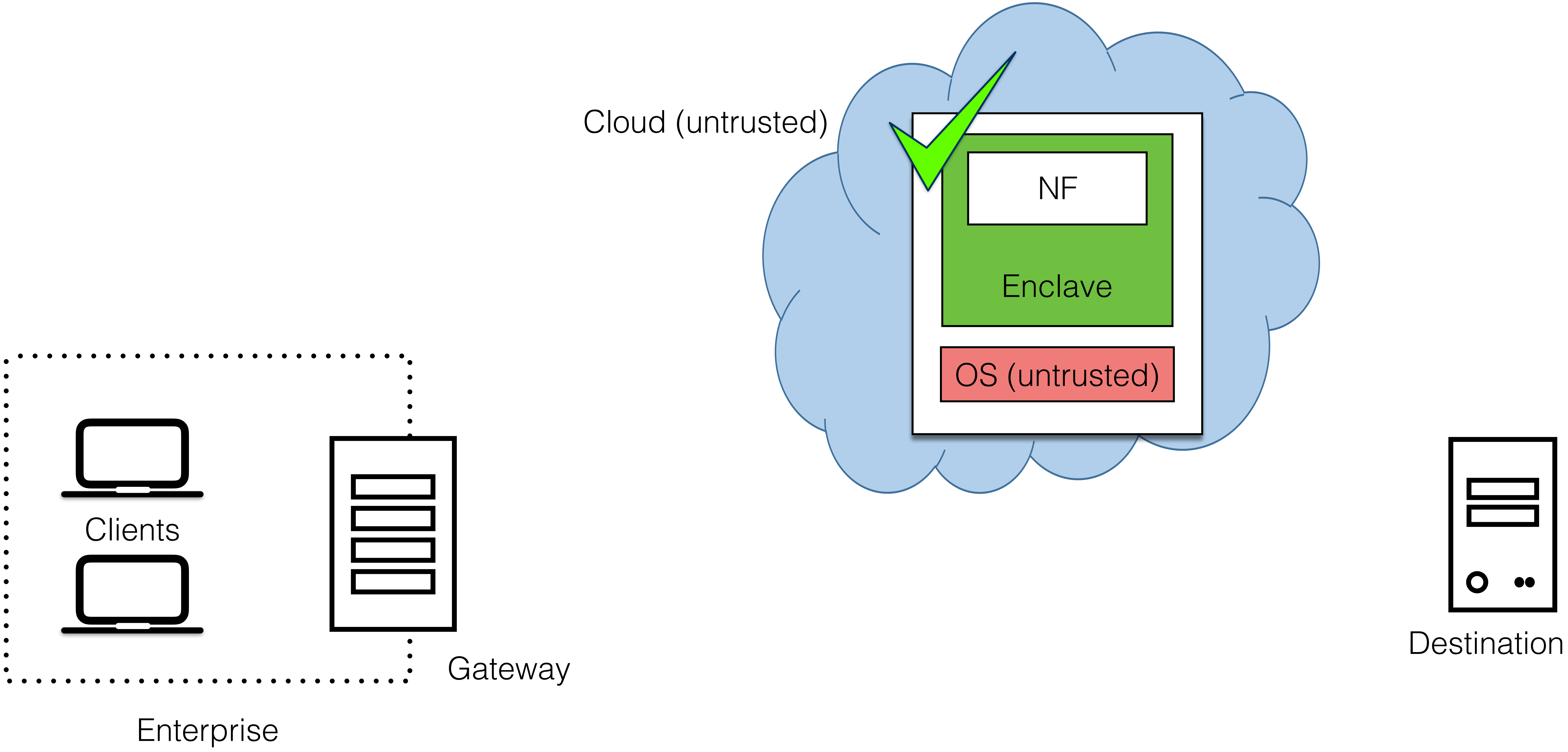

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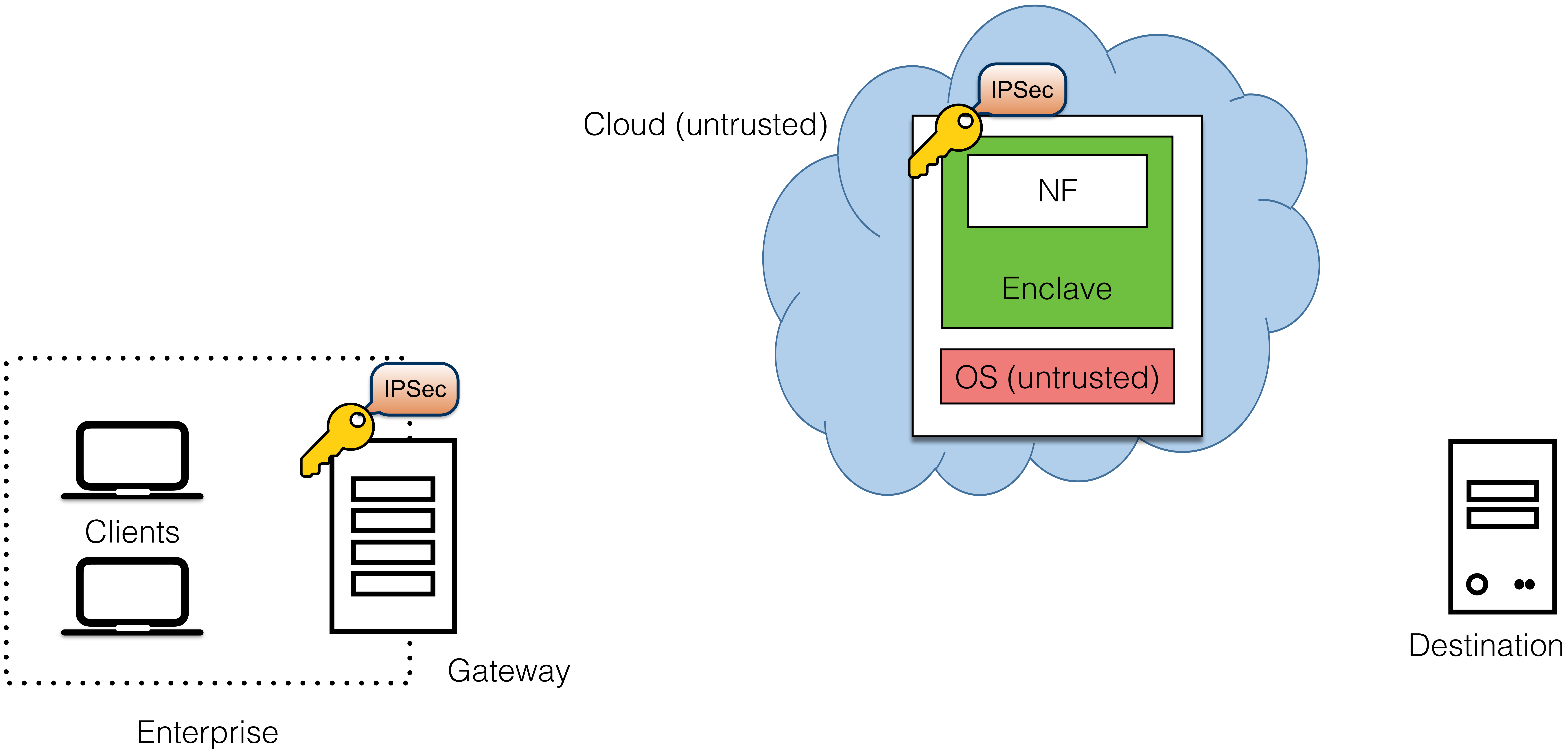

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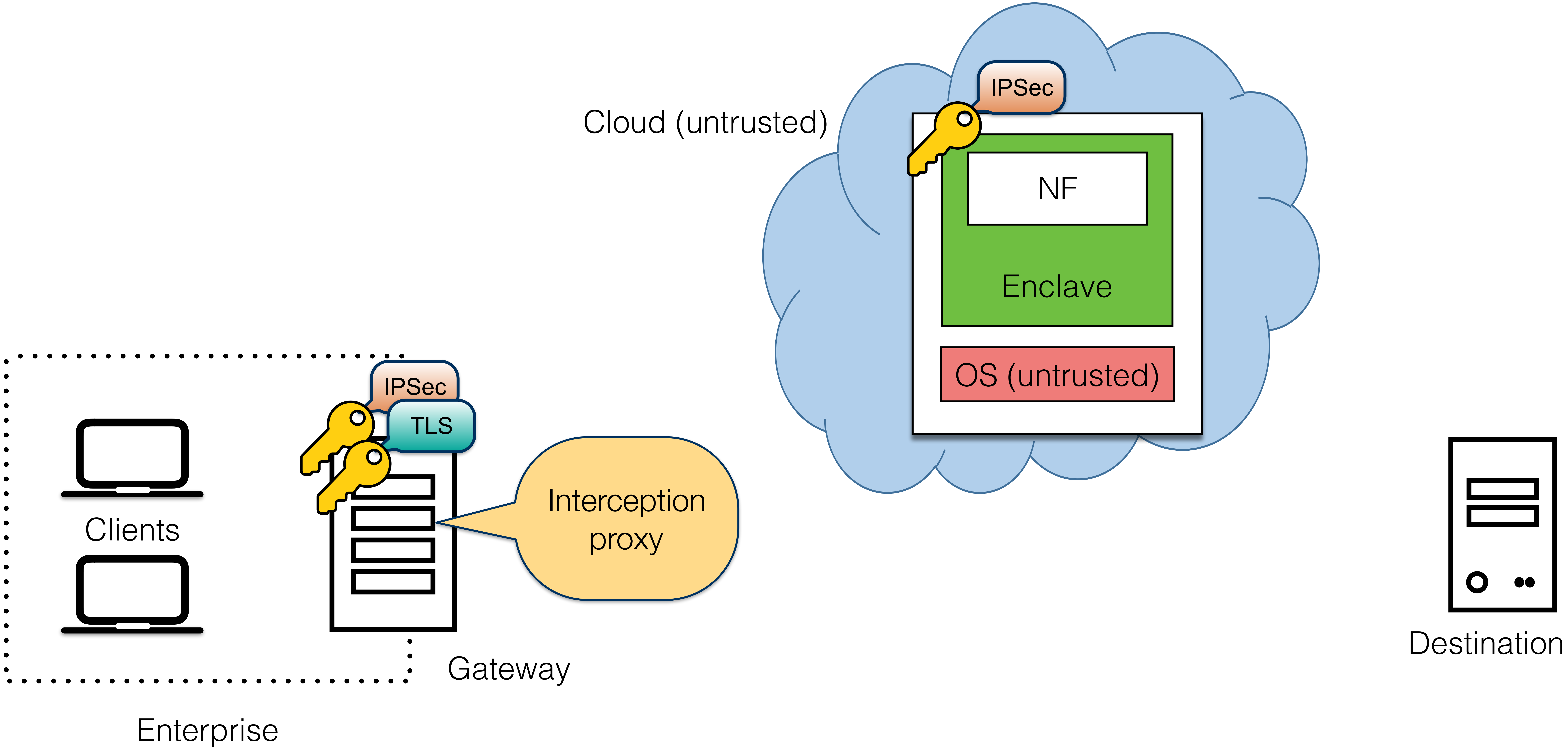

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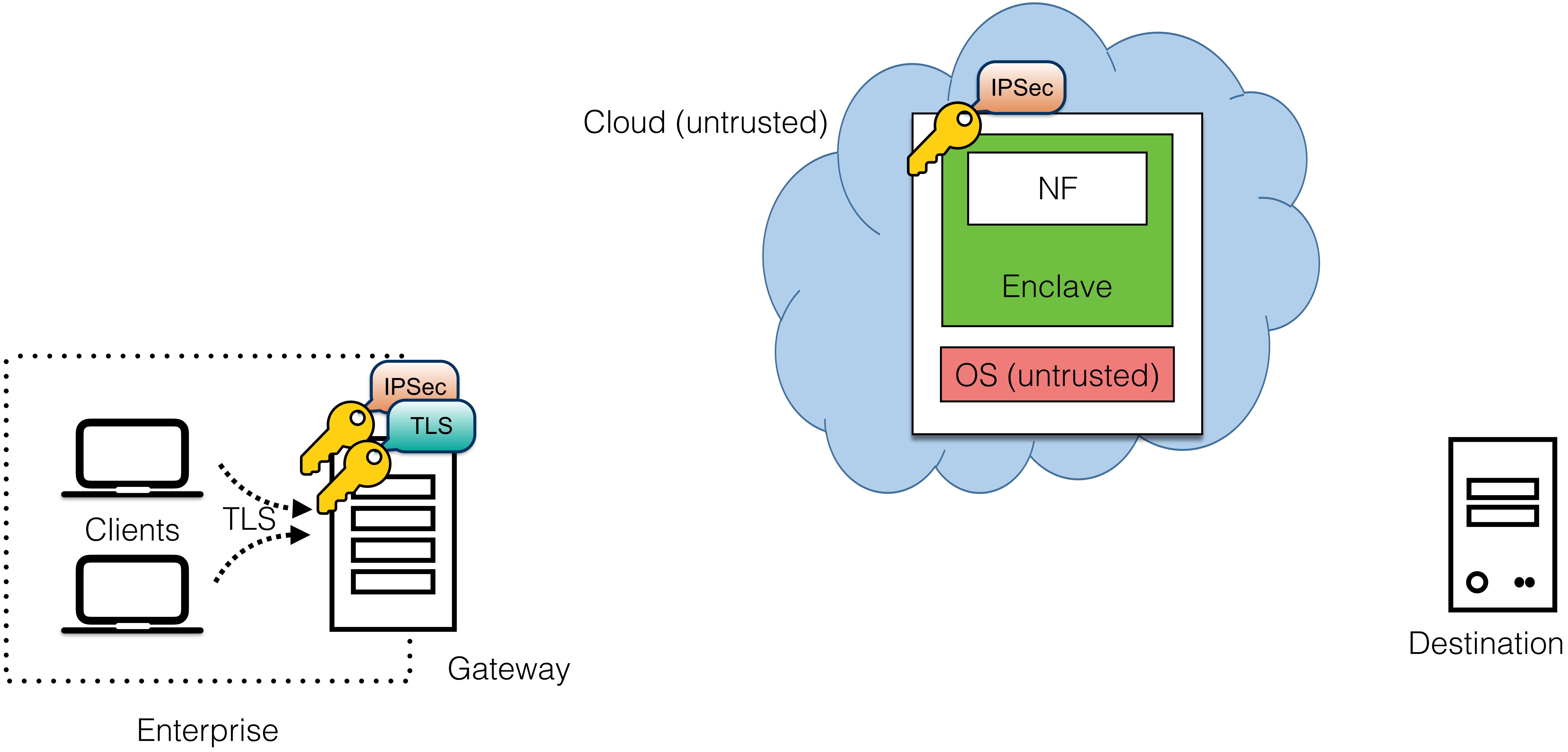

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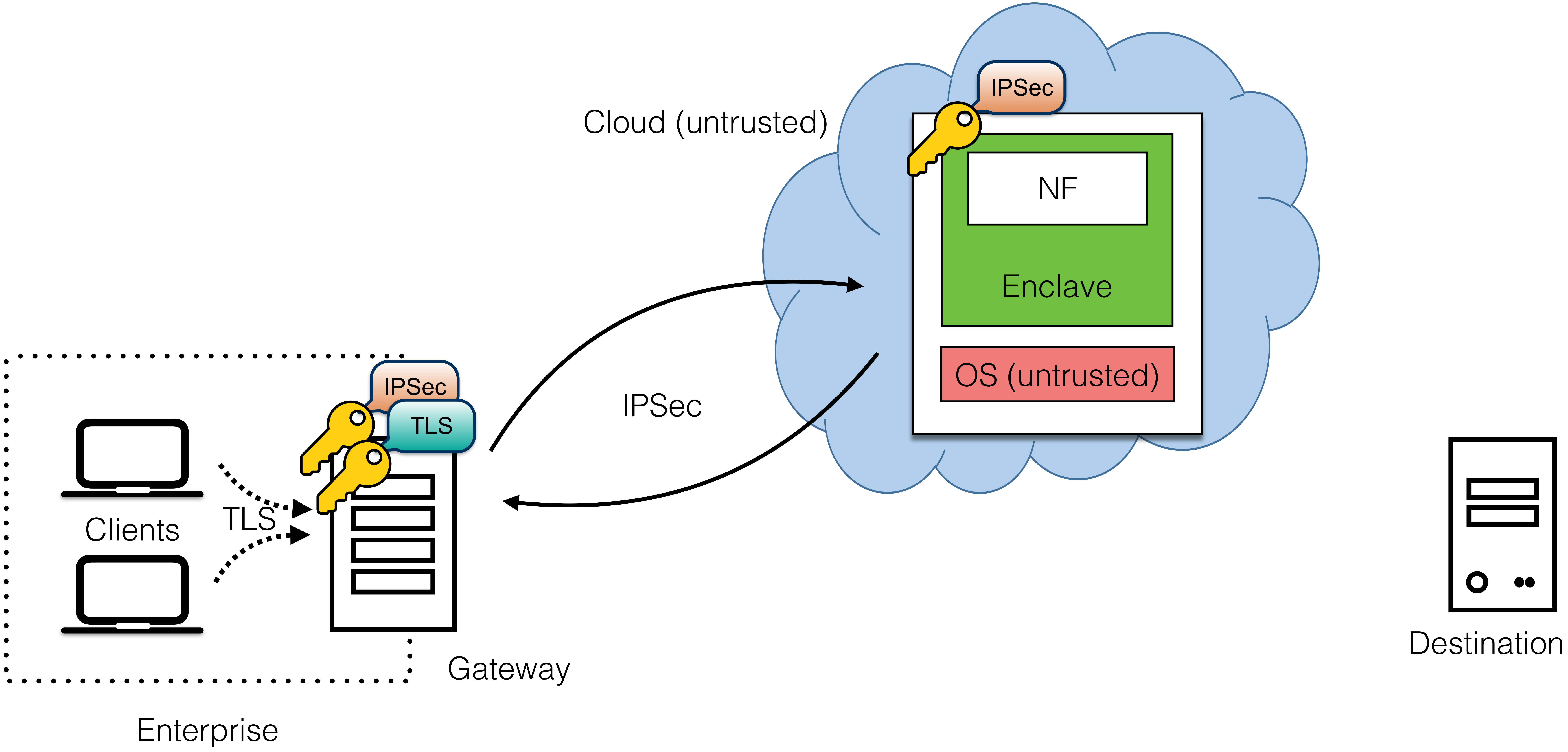

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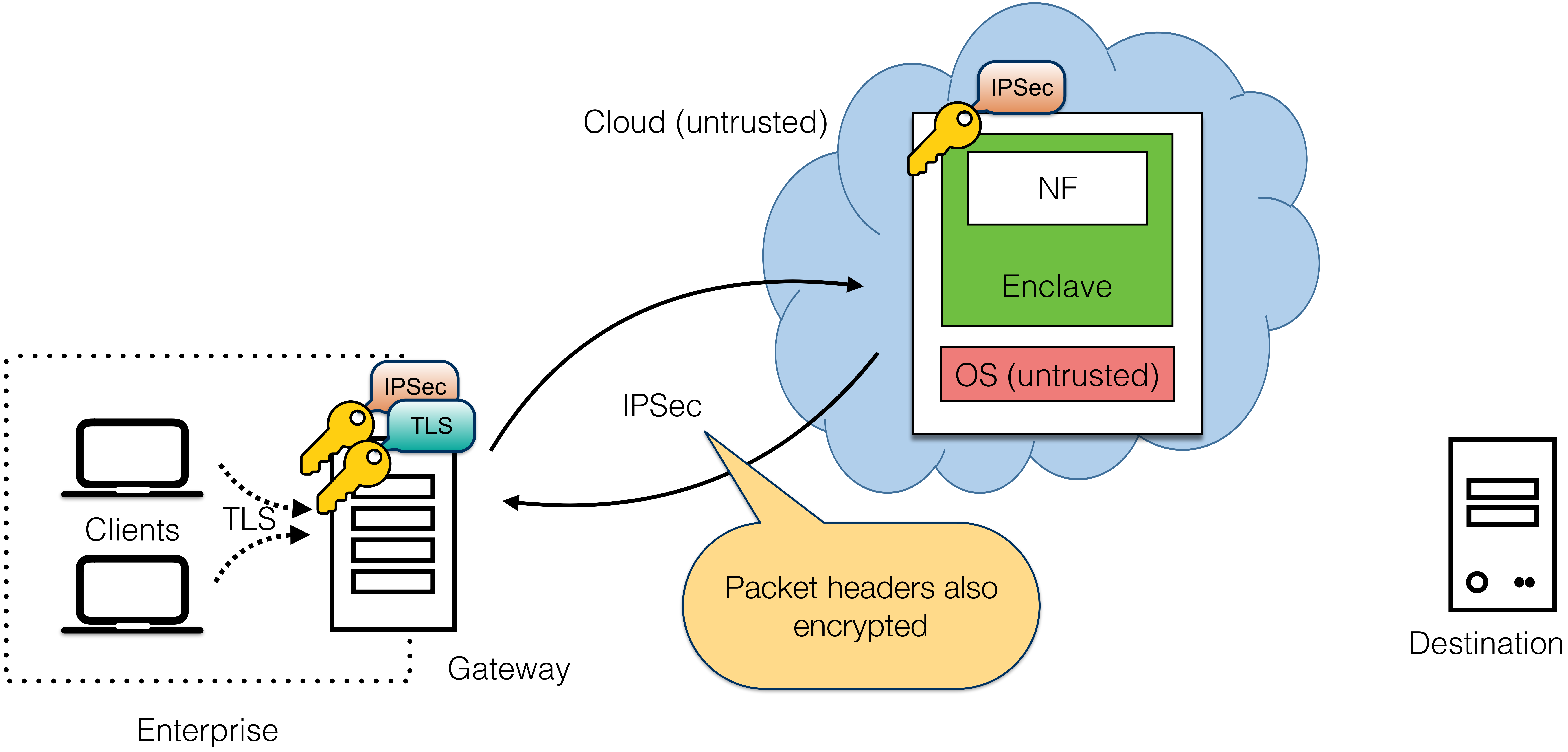
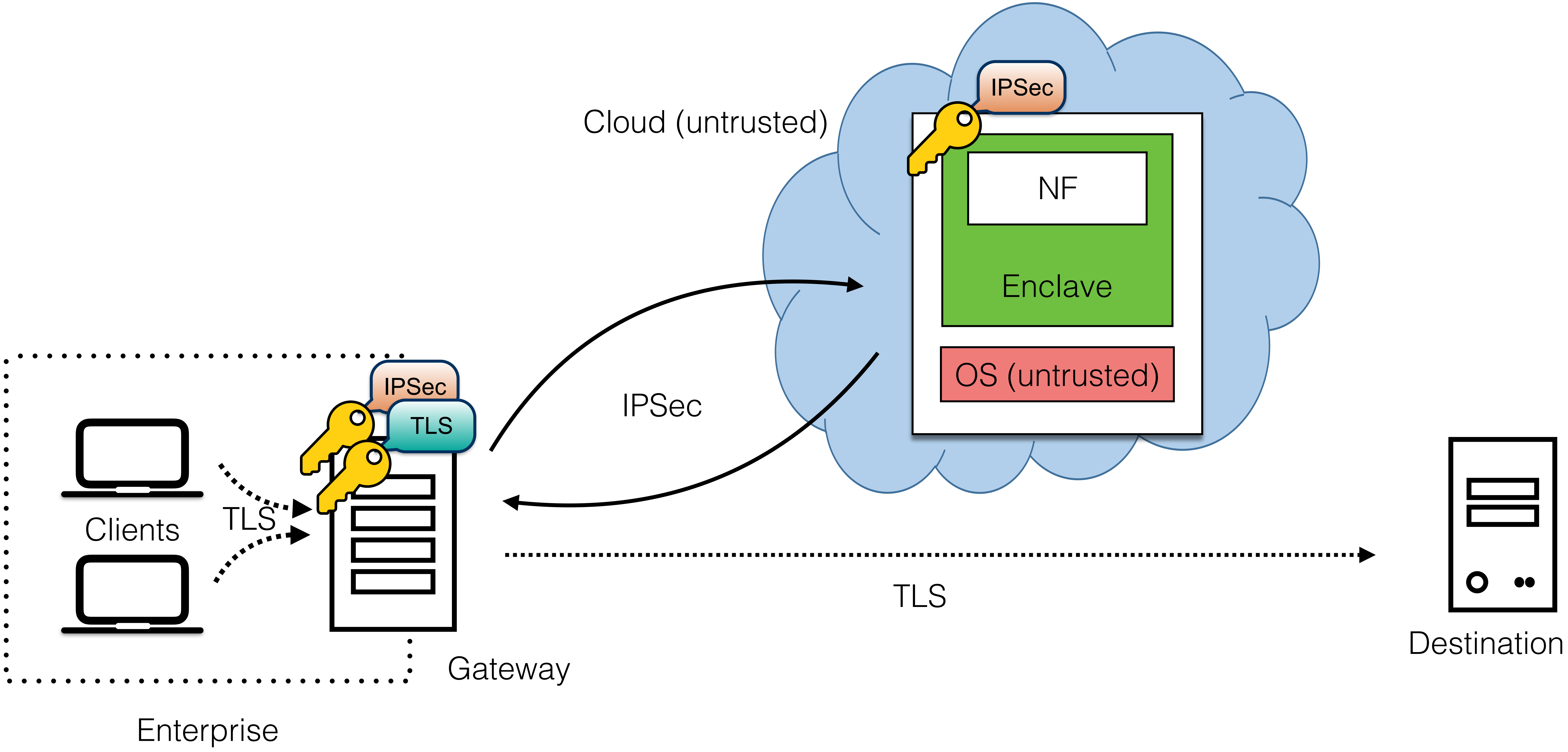


Packet headers also encrypted

Outsourcing NFs using hardware enclaves



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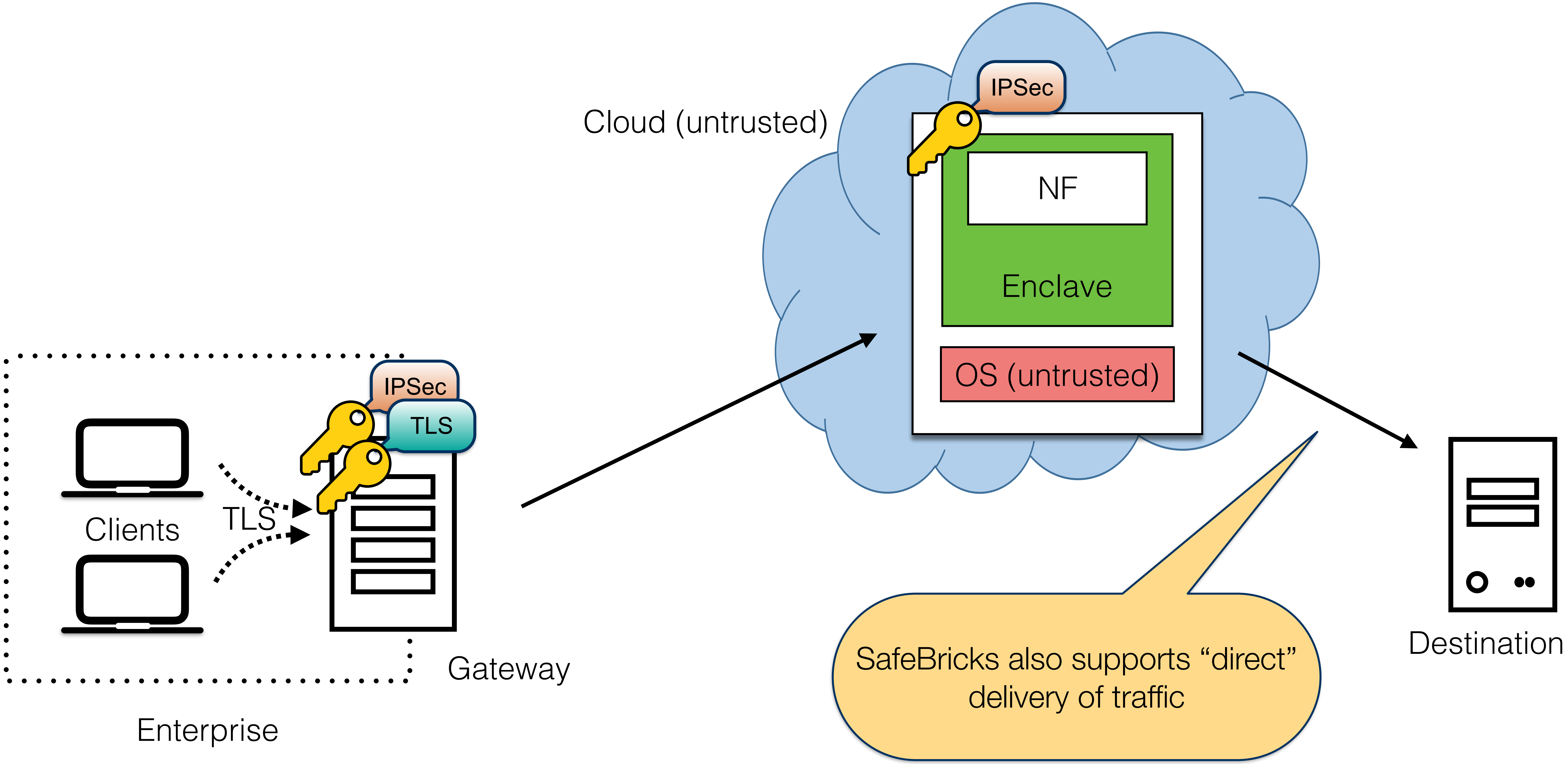
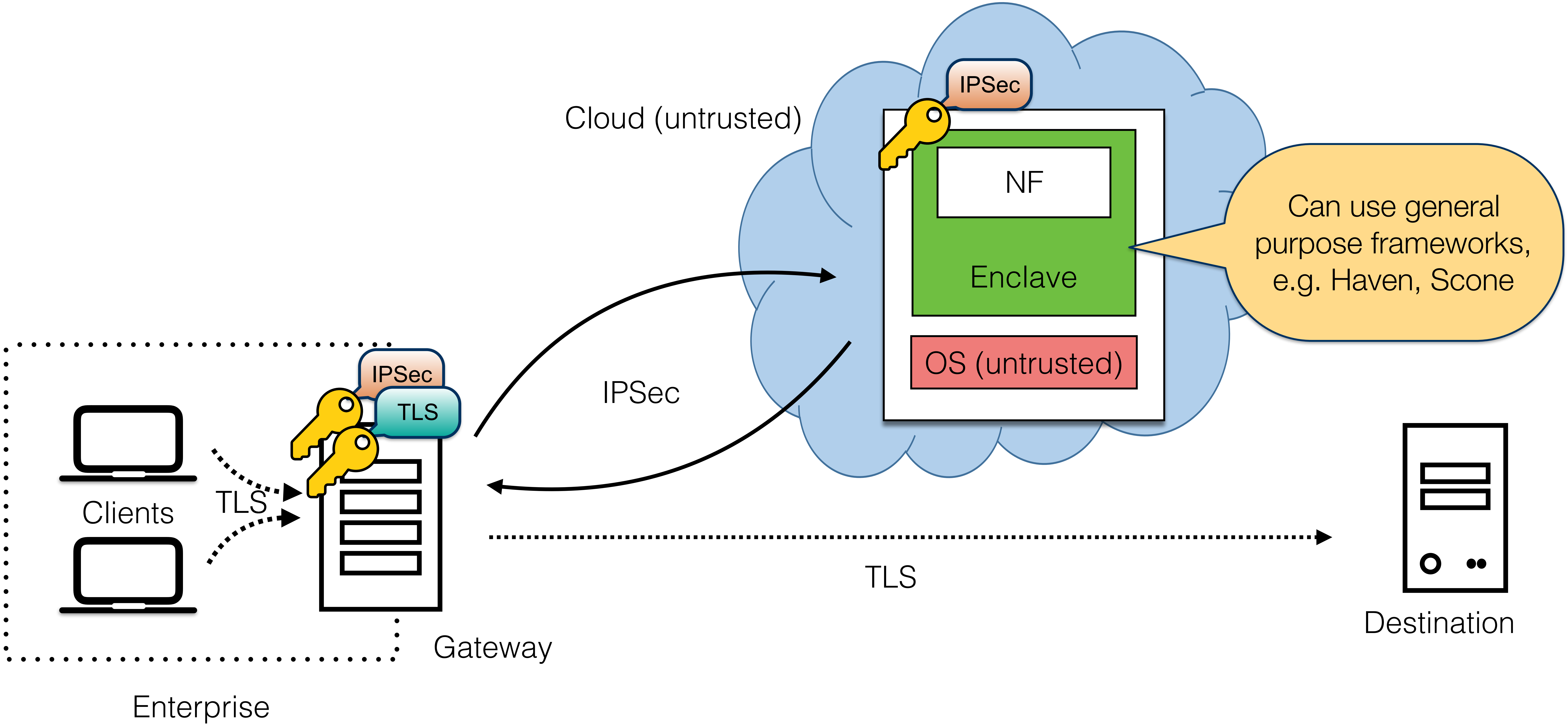


SafeBricks also supports “direct” delivery of traffic

Outsourcing NFs using hardware enclaves



Can use general purpose frameworks, e.g. Haven, Scone

Challenges

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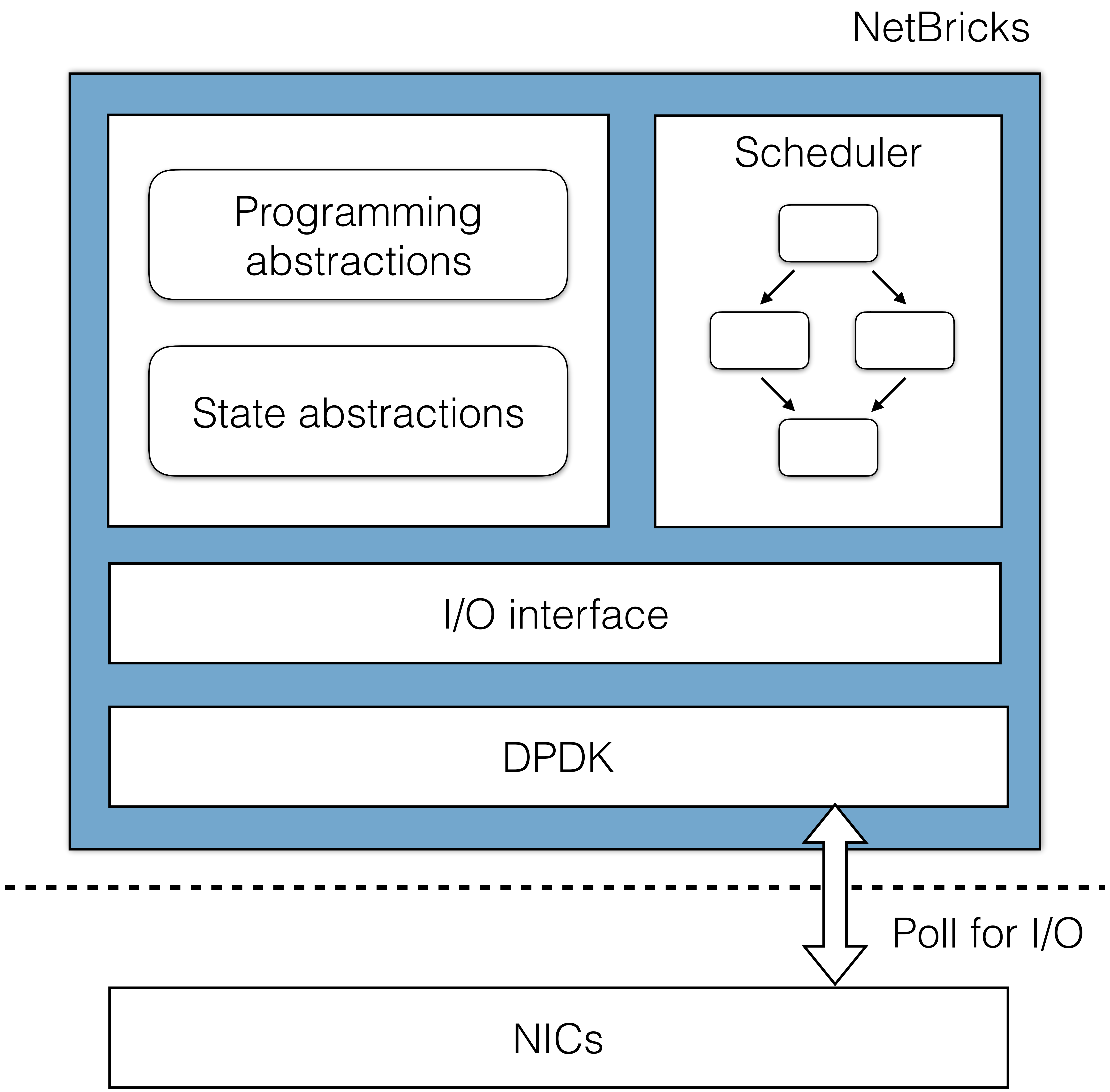
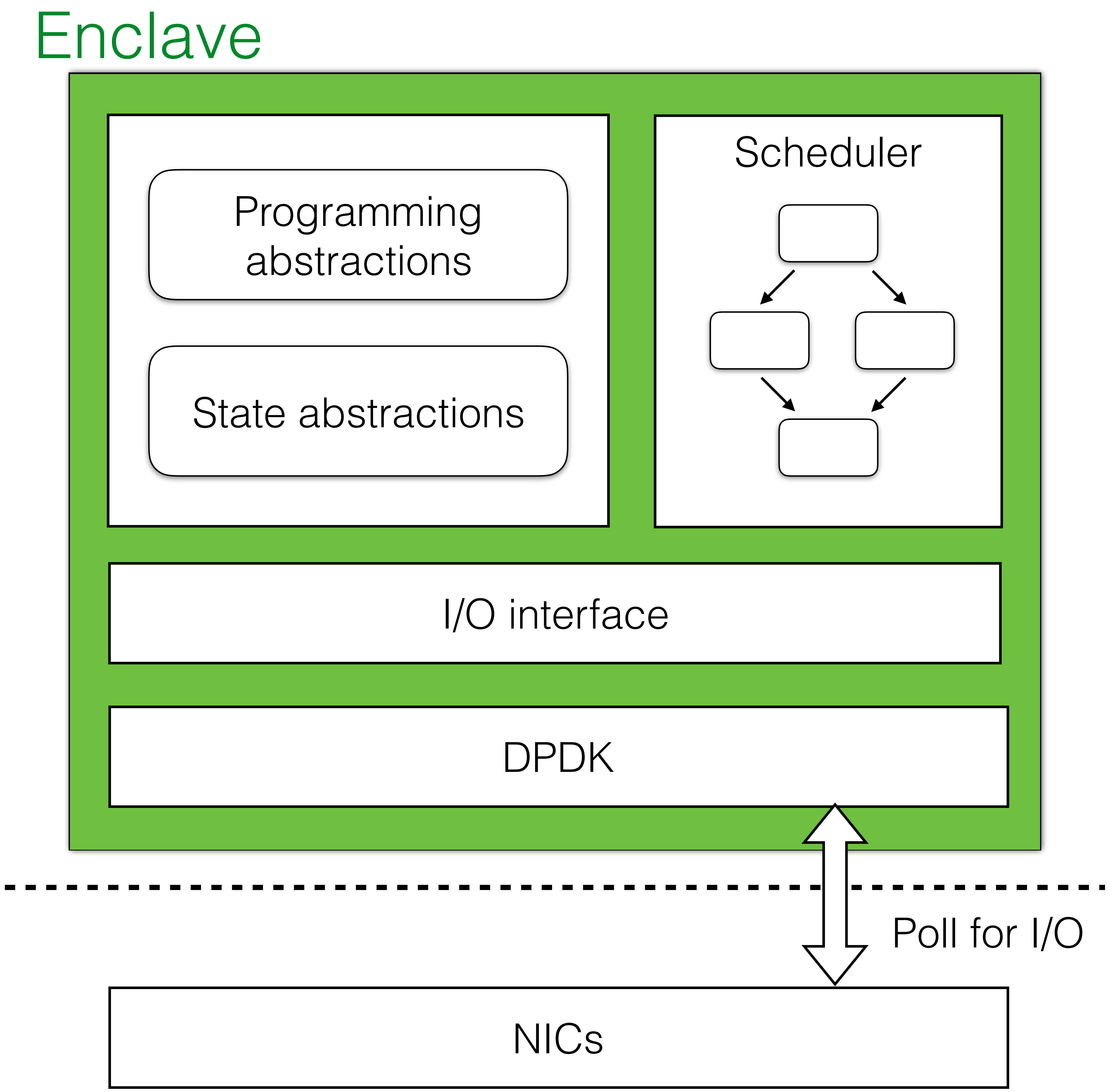
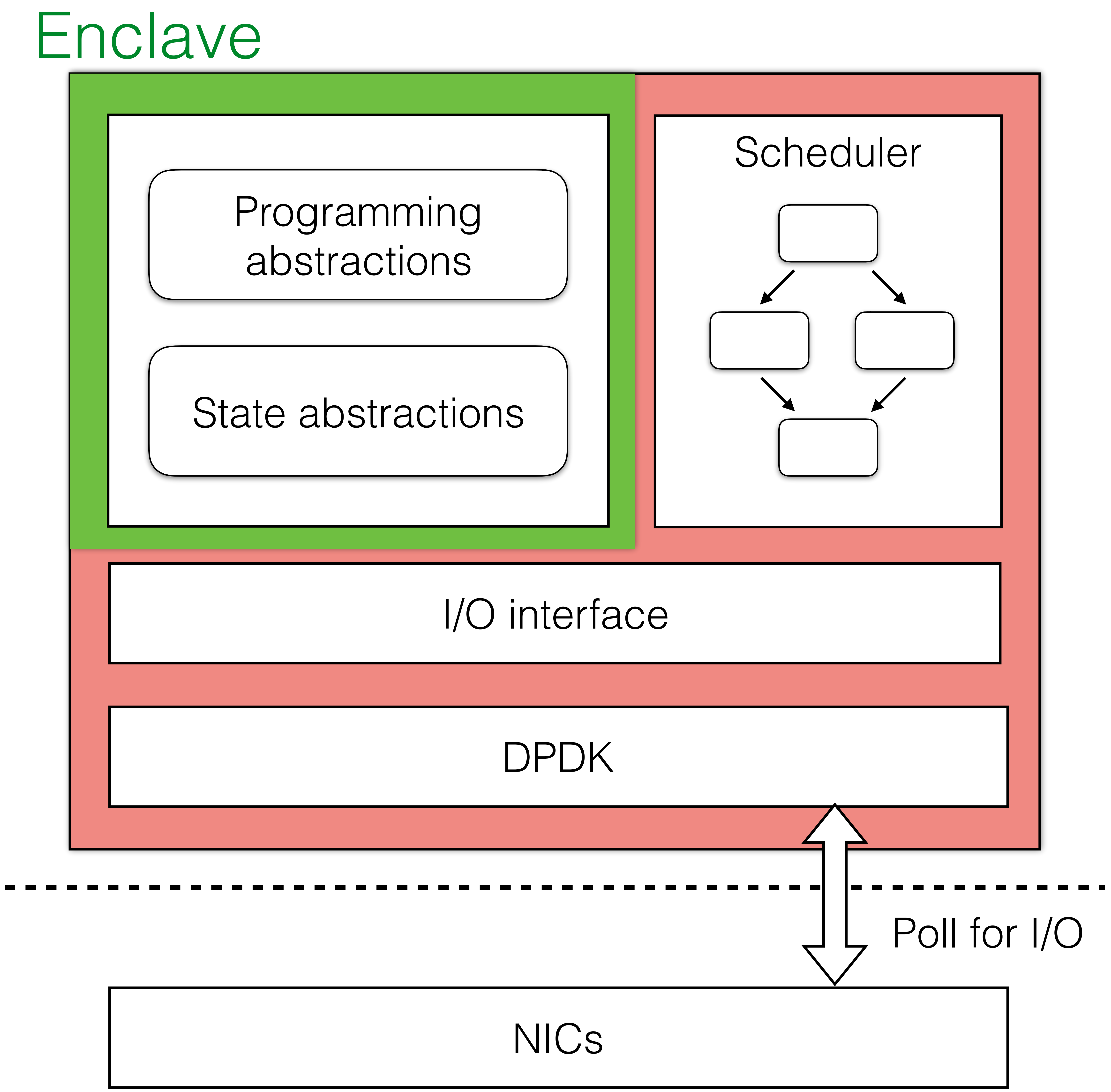

NetBricks
Programming abstractions
State abstractions
Scheduler
I/O interface
DPDK
Poll for I/O
NICs

1



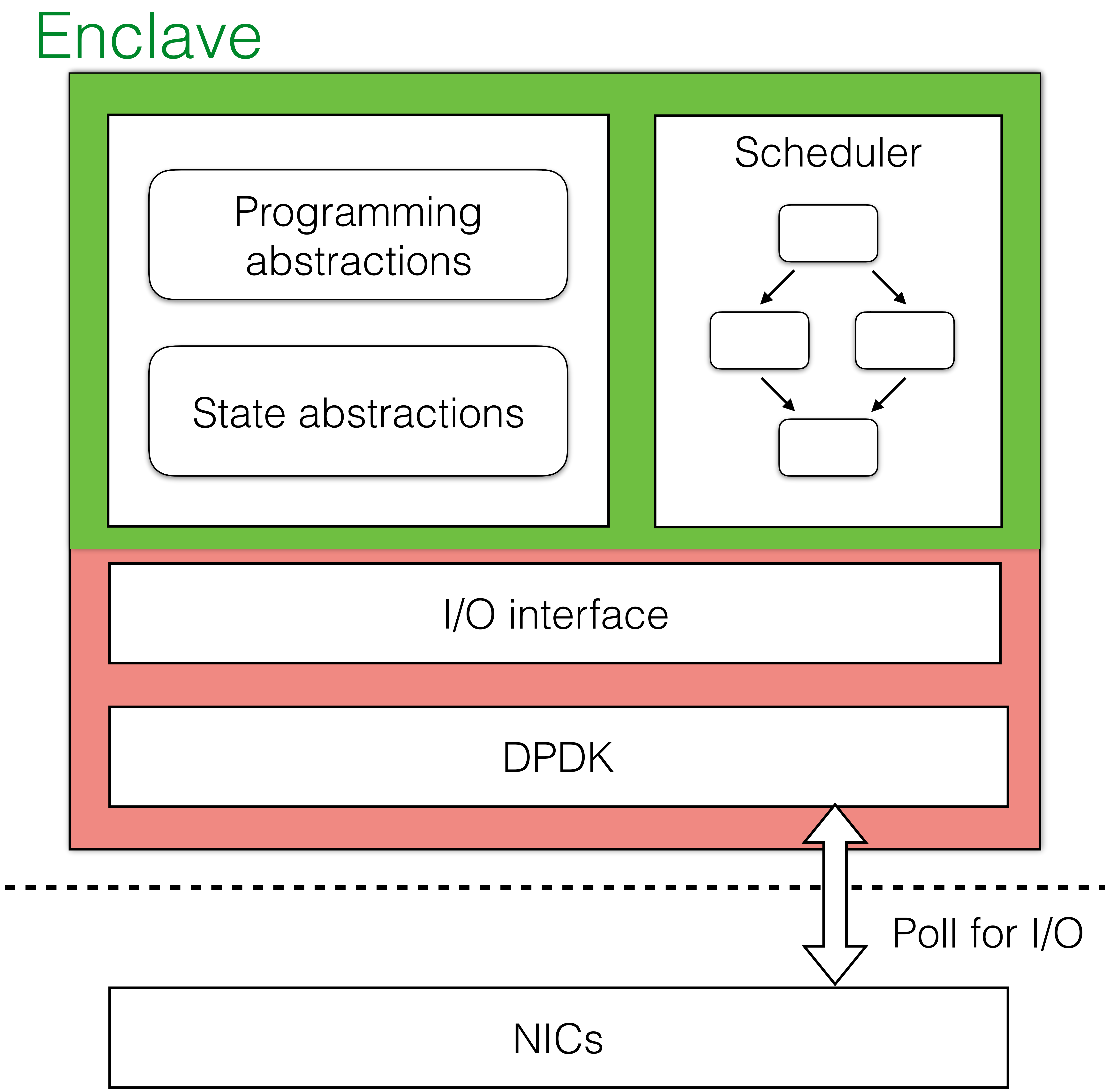
- **Maximal TCB:** NetBricks stack entirely within enclave

1

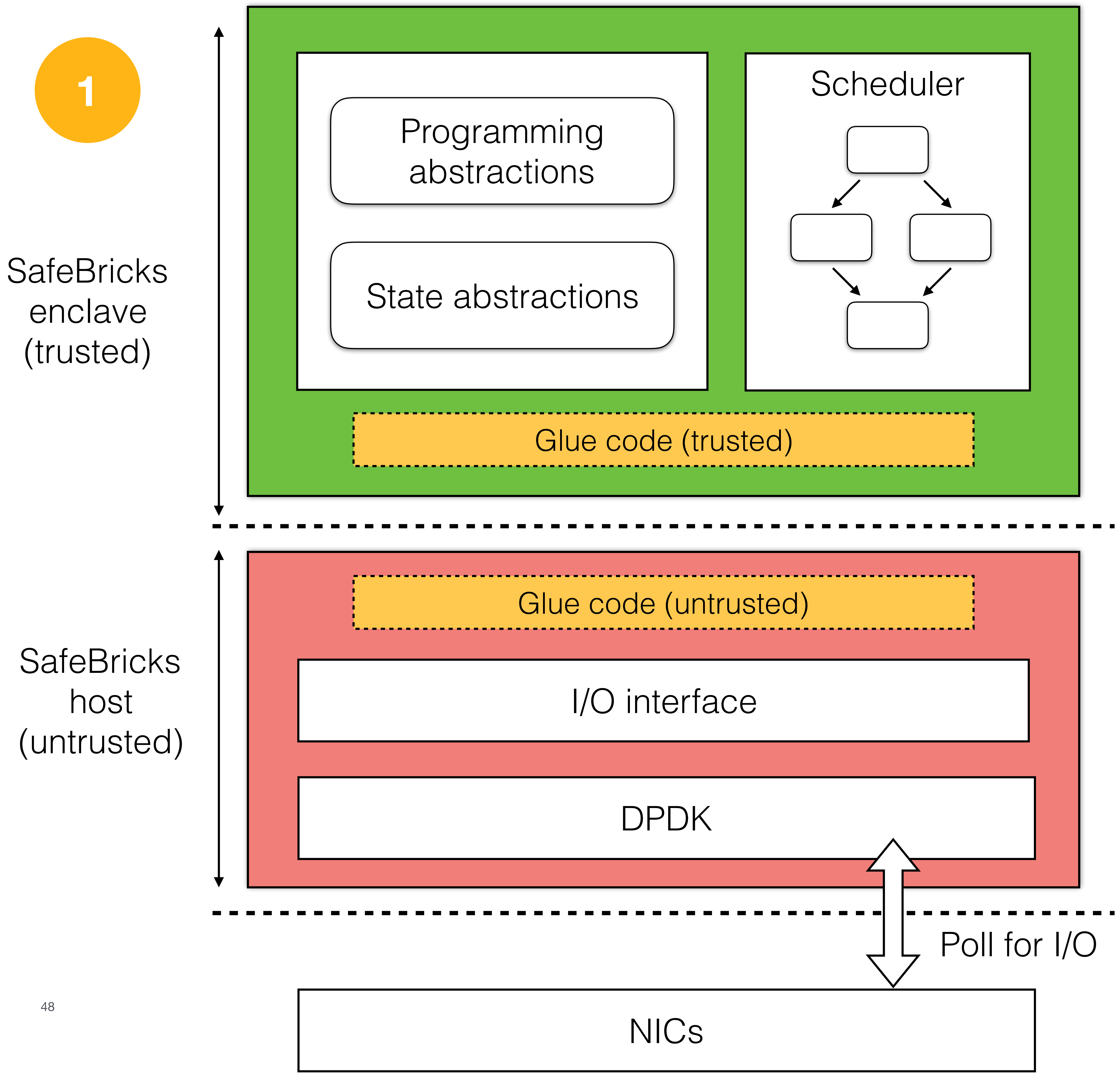


- **Minimal TCB:** Only security-critical components within enclave
- One enclave transition **per node per packet batch**

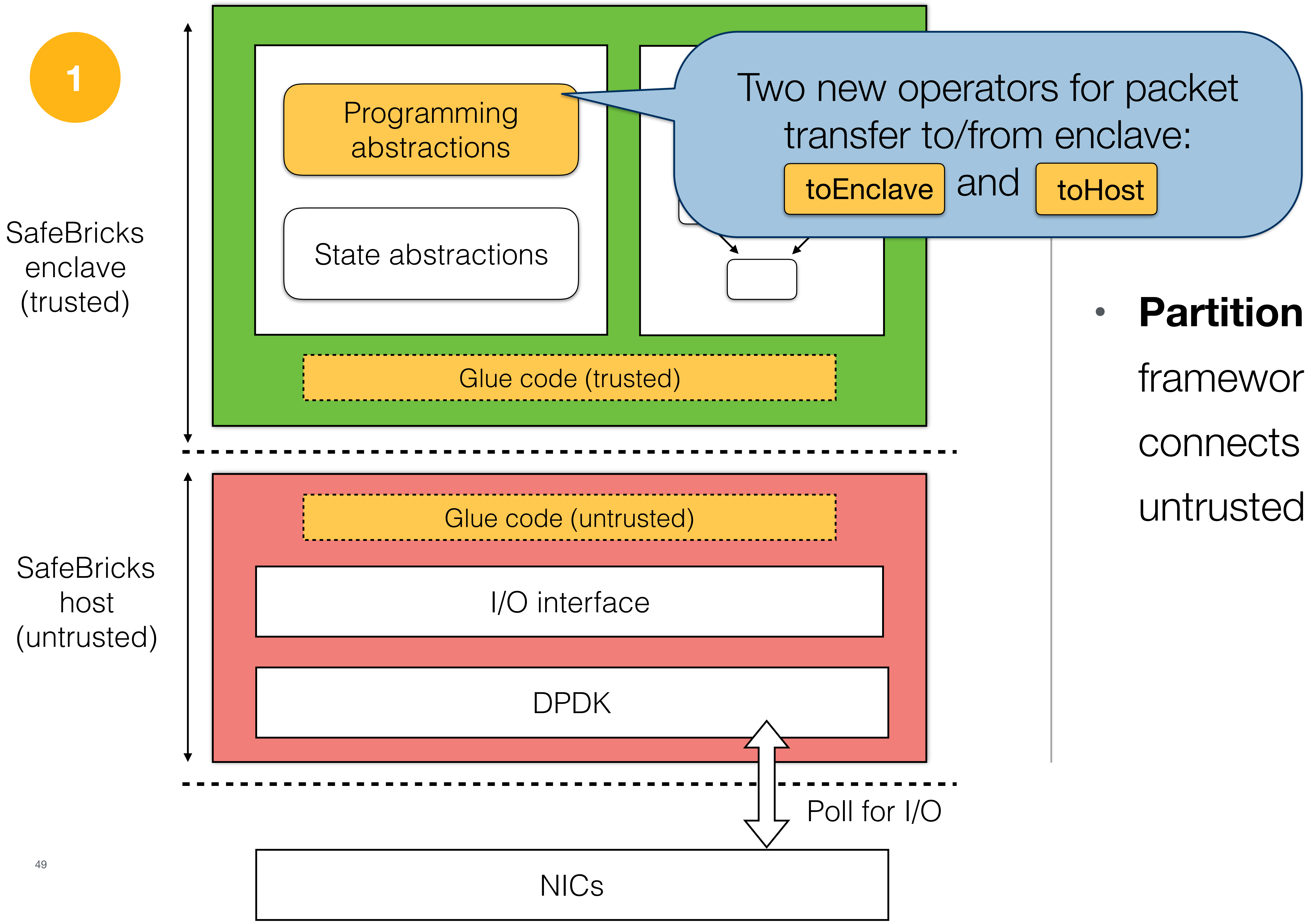
1



- **Intermediate** TCB
- One enclave **transition per packet batch**



- **Partitioned** NetBricks framework; glue code connects trusted and untrusted code



Two new operators for packet transfer to/from enclave: toEnclave and toHost

- **Partitioned** NetBricks framework; glue code connects trusted and untrusted code

Challenges

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3. **Illegal enclave instructions** — SGX does not support system calls or instructions that lead to a `VMEXIT`

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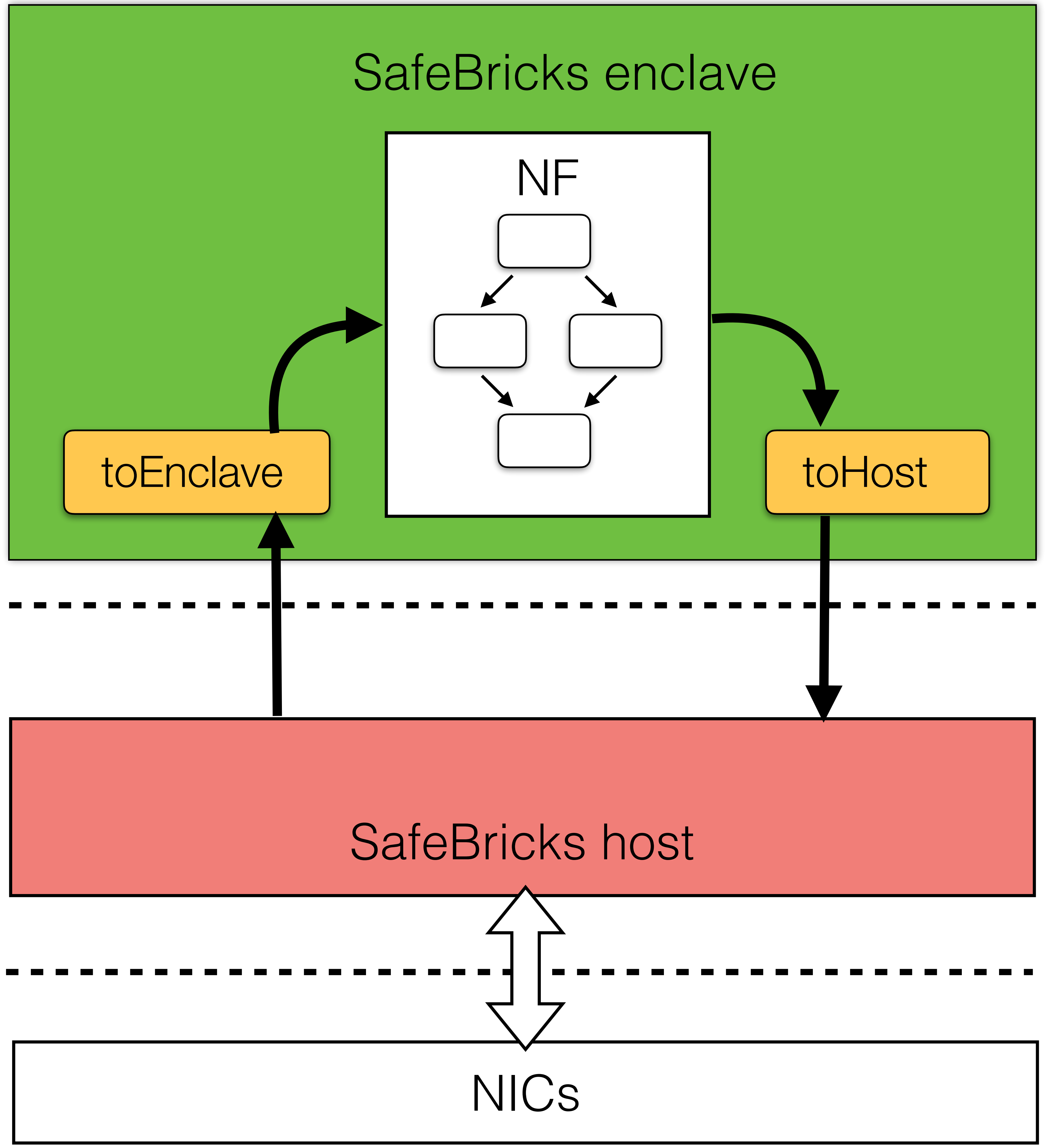

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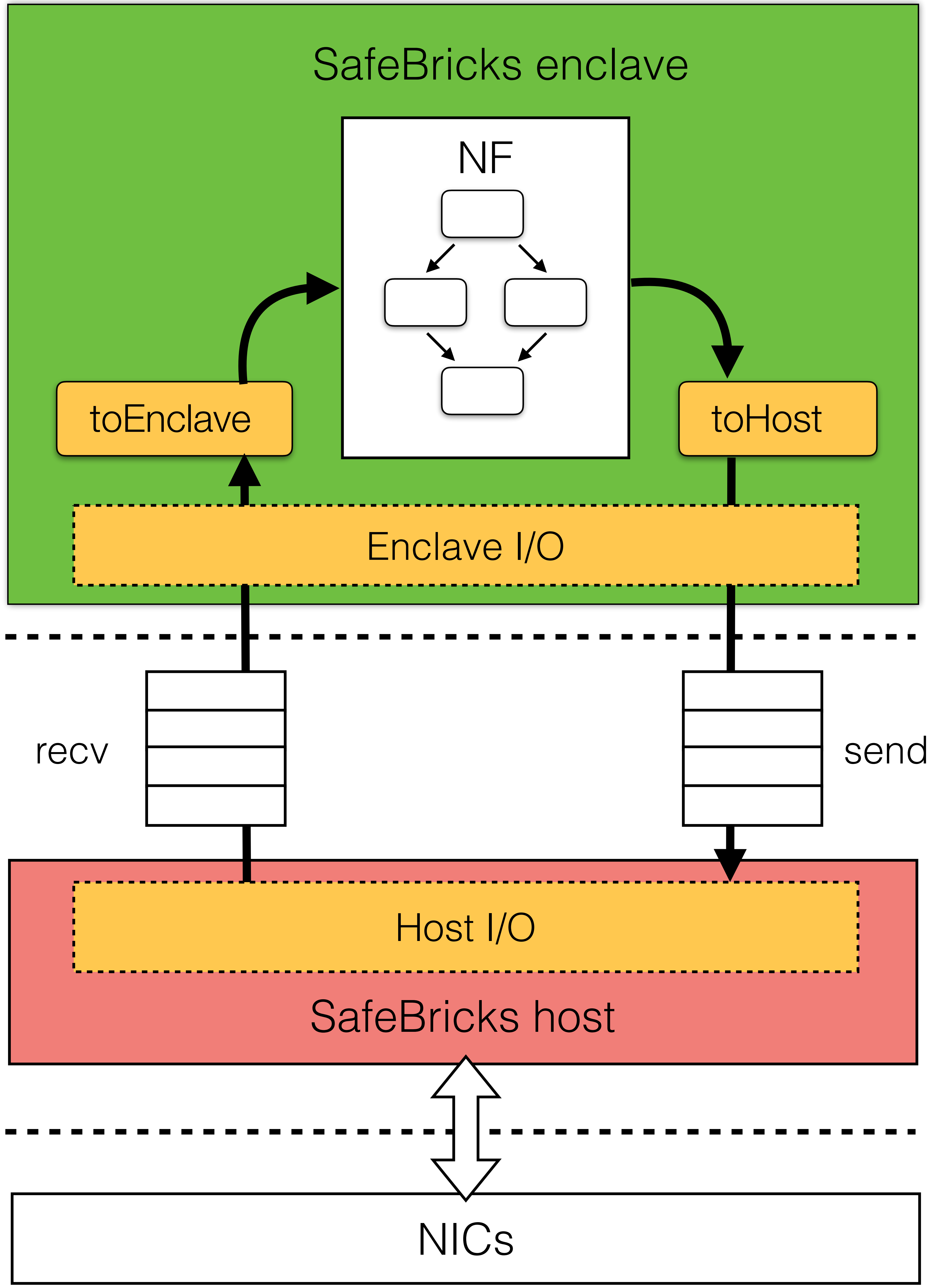

- **Shared queues** in non-enclave heap
- Separate enclave and host threads
- Access queues without exiting enclave — **zero enclave transitions**

Challenges

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2 **High performance** — Transitioning into / out of enclaves is expensive!

3 **Illegal enclave instructions** — SGX does not support system calls or instructions that lead to a `VMEXIT`

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Observation: NFs in general do not require support for system calls / instructions that lead to VMEXITs

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SafeBricks designs **custom solutions** for these operations without enclave transitions

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Problem: Malicious NFs within enclaves

⚠ **Malicious NFs** inside the enclave can exfiltrate or tamper with packets!

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IP addresses; TCP ports; HTTP payload

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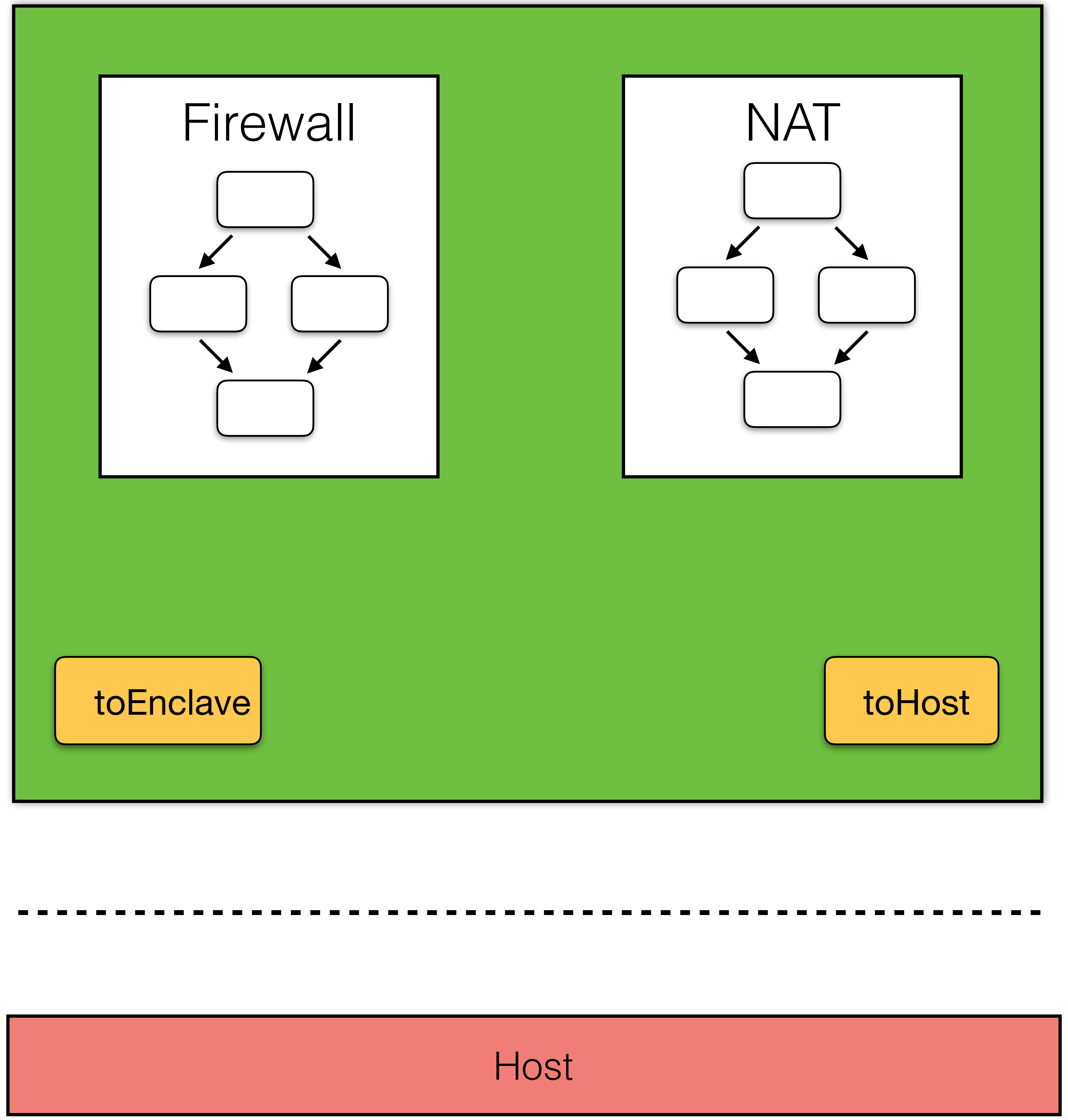
SafeBricks enforces **least privilege** across NFs within the enclave

Least privilege enforcement

Run NFs within the **same** enclave



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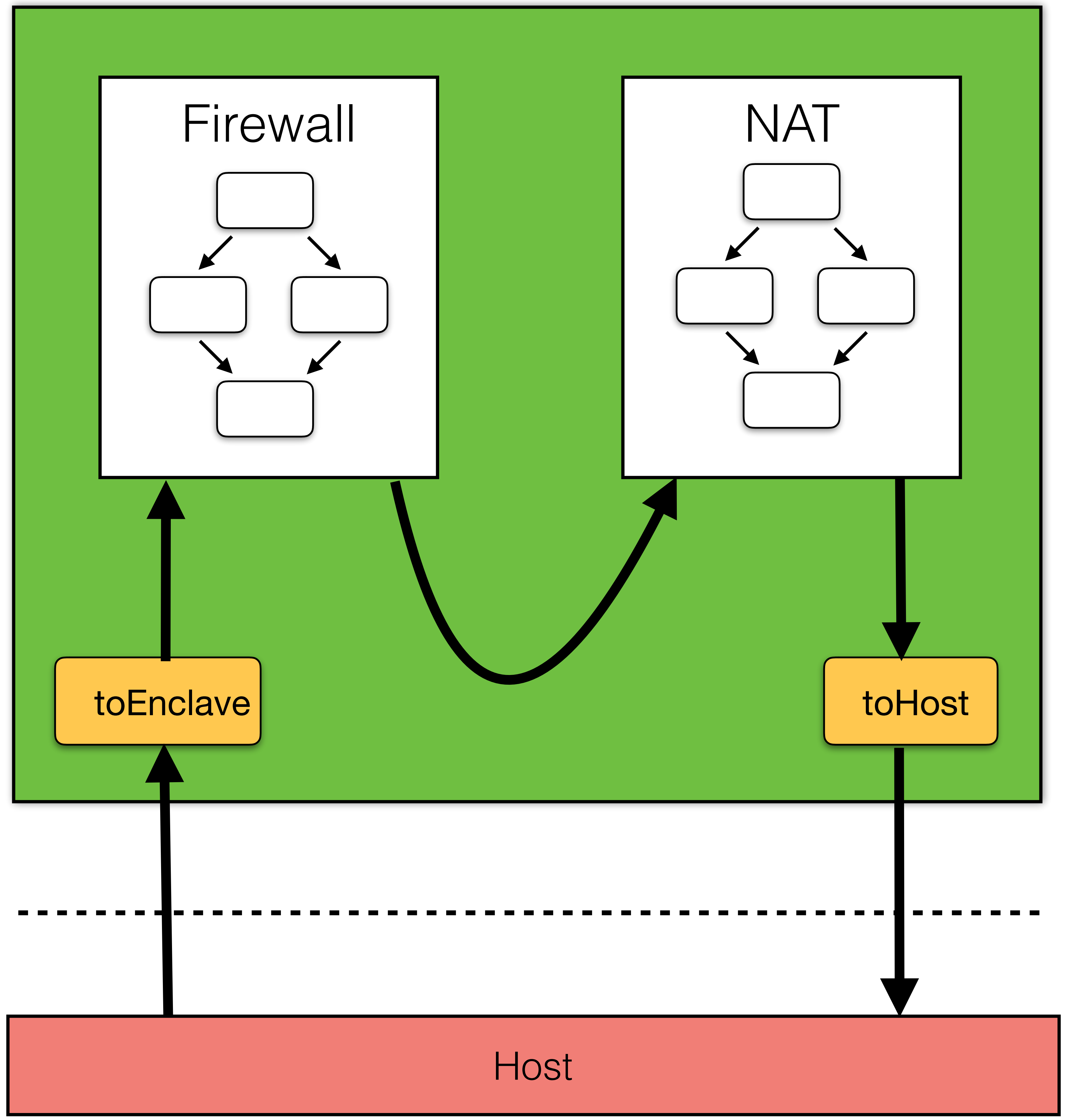
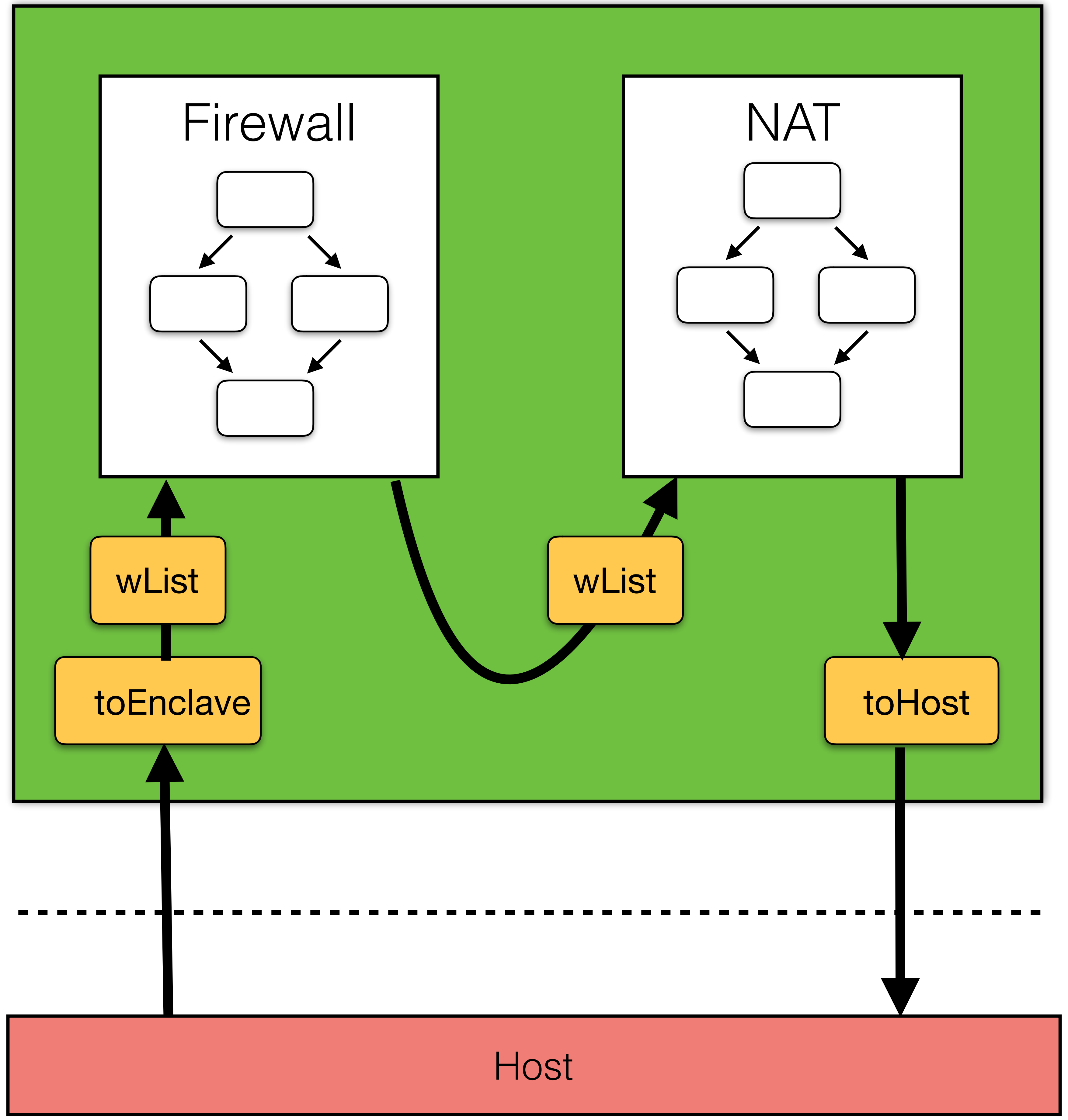


Least privilege enforcement

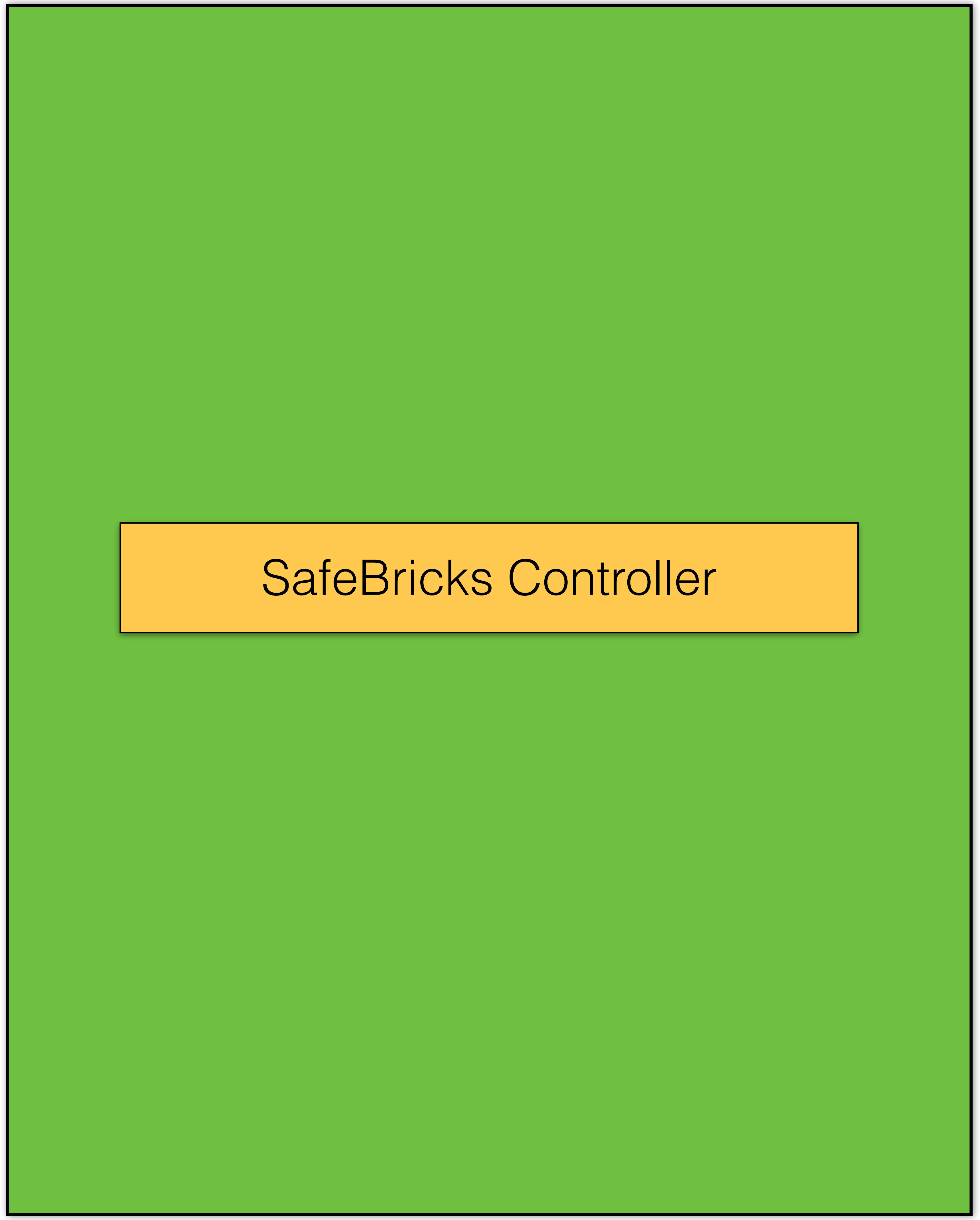
Run NFs within the **same** enclave

- Stitch NFs together interspersed with an operator (wList) that embeds a **vector of permissions** in packets — two bits per packet field



Least privilege enforcement

Enforce permissions by **mediating** access to packets using Rust's **ownership model**



SafeBricks Controller

Least privilege enforcement

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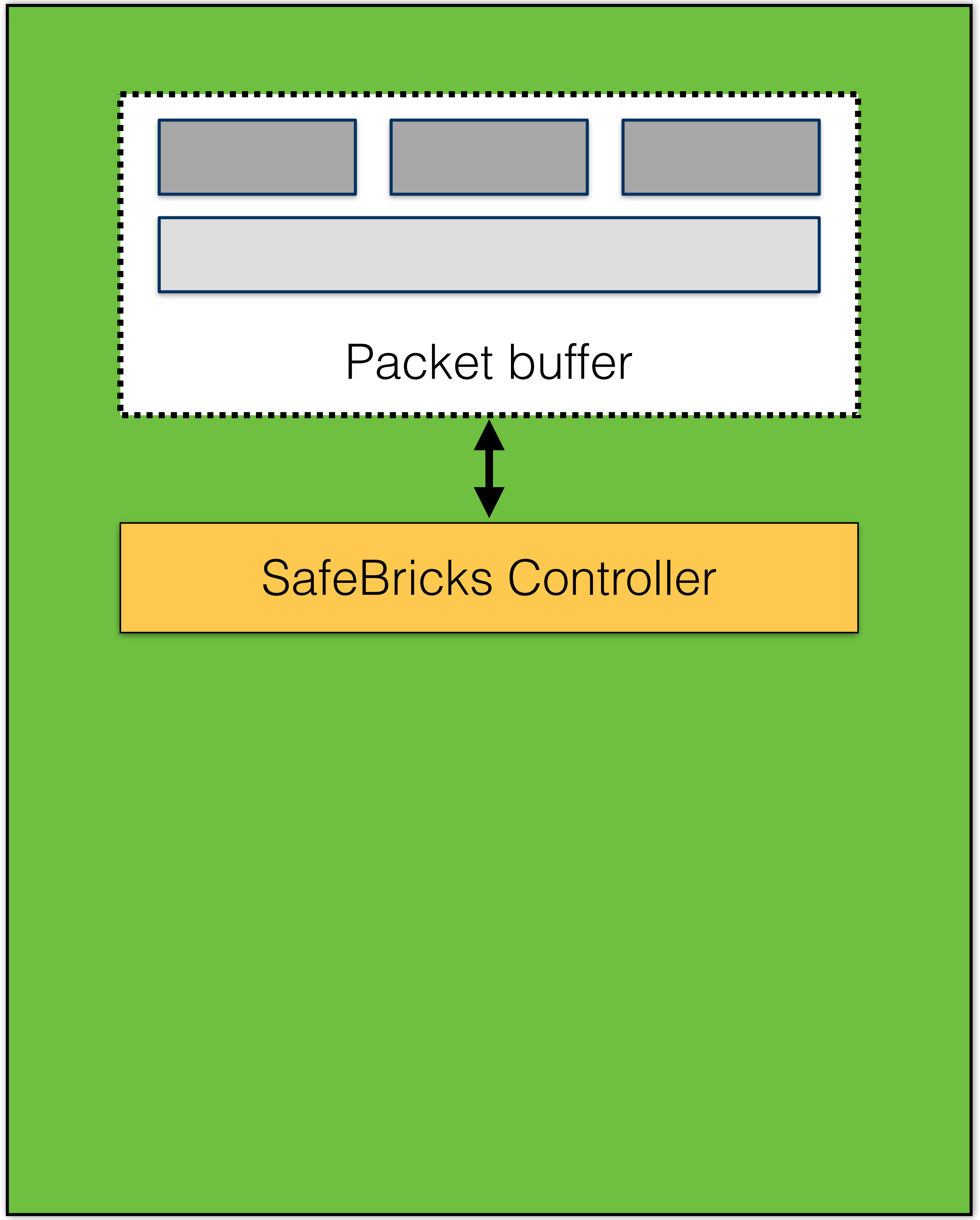
- Controller module holds ownership of packet buffers



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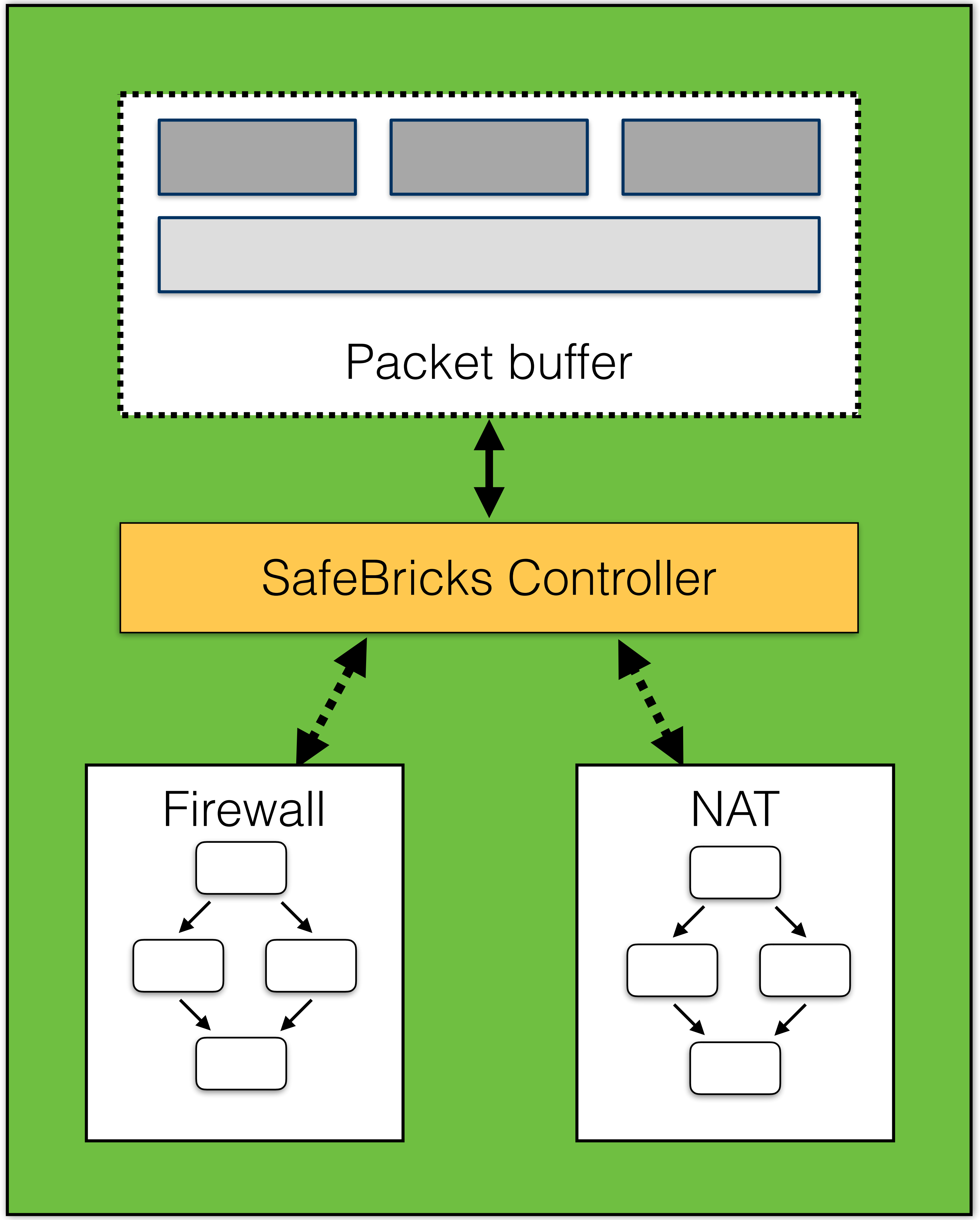

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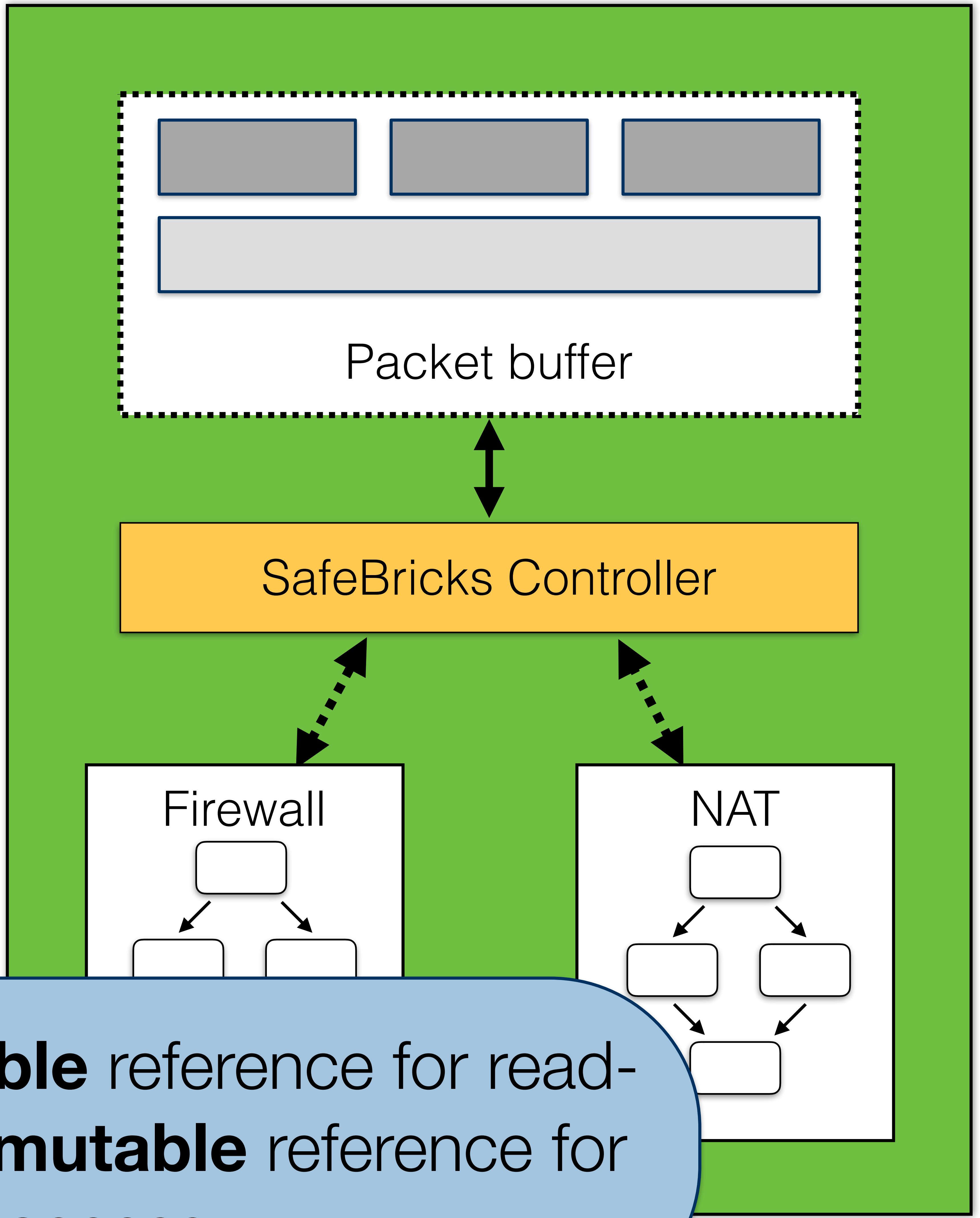

Returns an **immutable** reference for read-only access, and a **mutable** reference for write access

Assumption: Trusted compilation of NFs

Least privilege guarantees only hold if NFs are built using a **compiler that prohibits *unsafe* operations!**

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E.g. Check array bounds, no pointer arithmetic, no unsafe type casts

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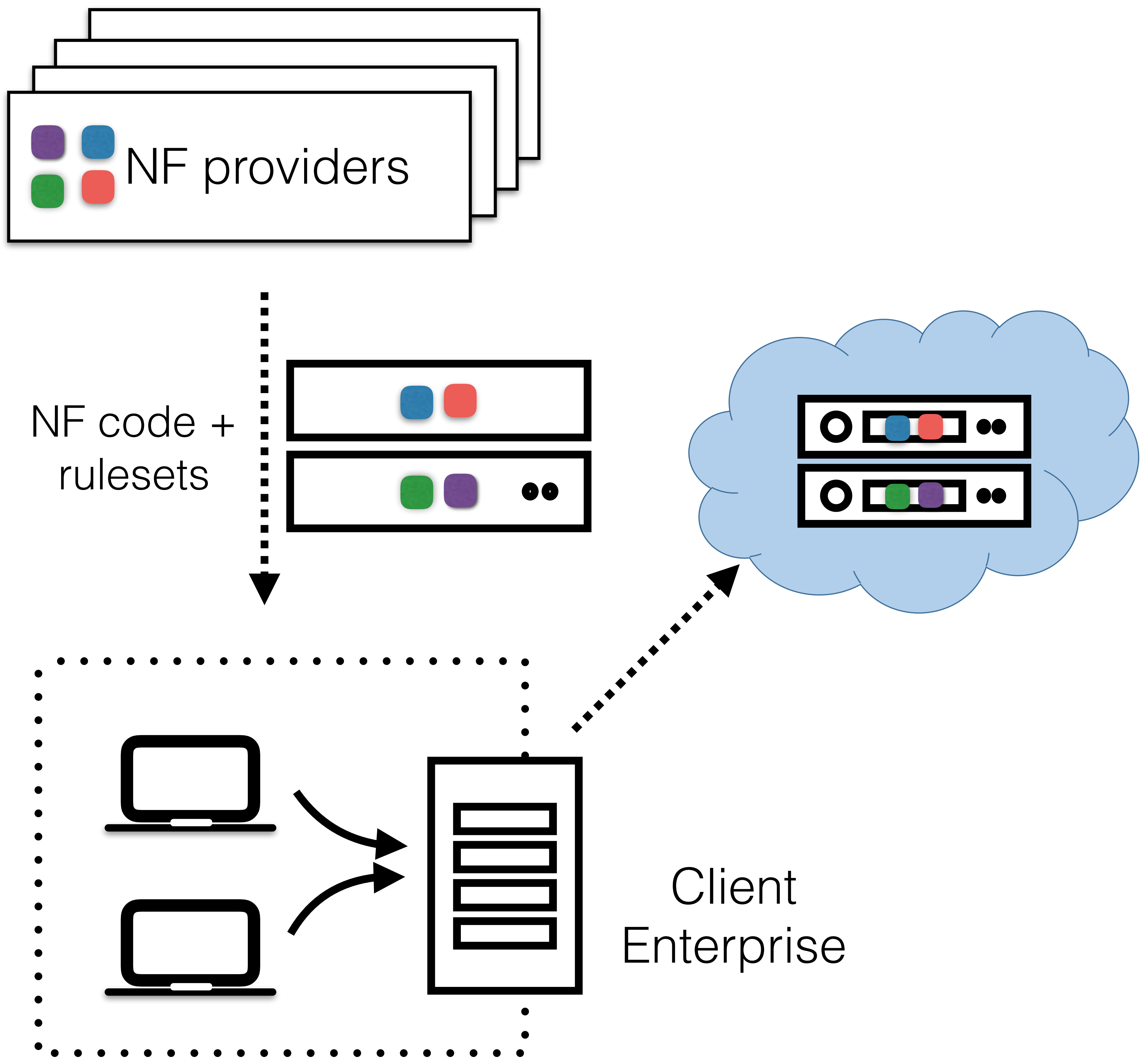
- Possible solution: Client obtains NF source codes from providers and assembles them locally



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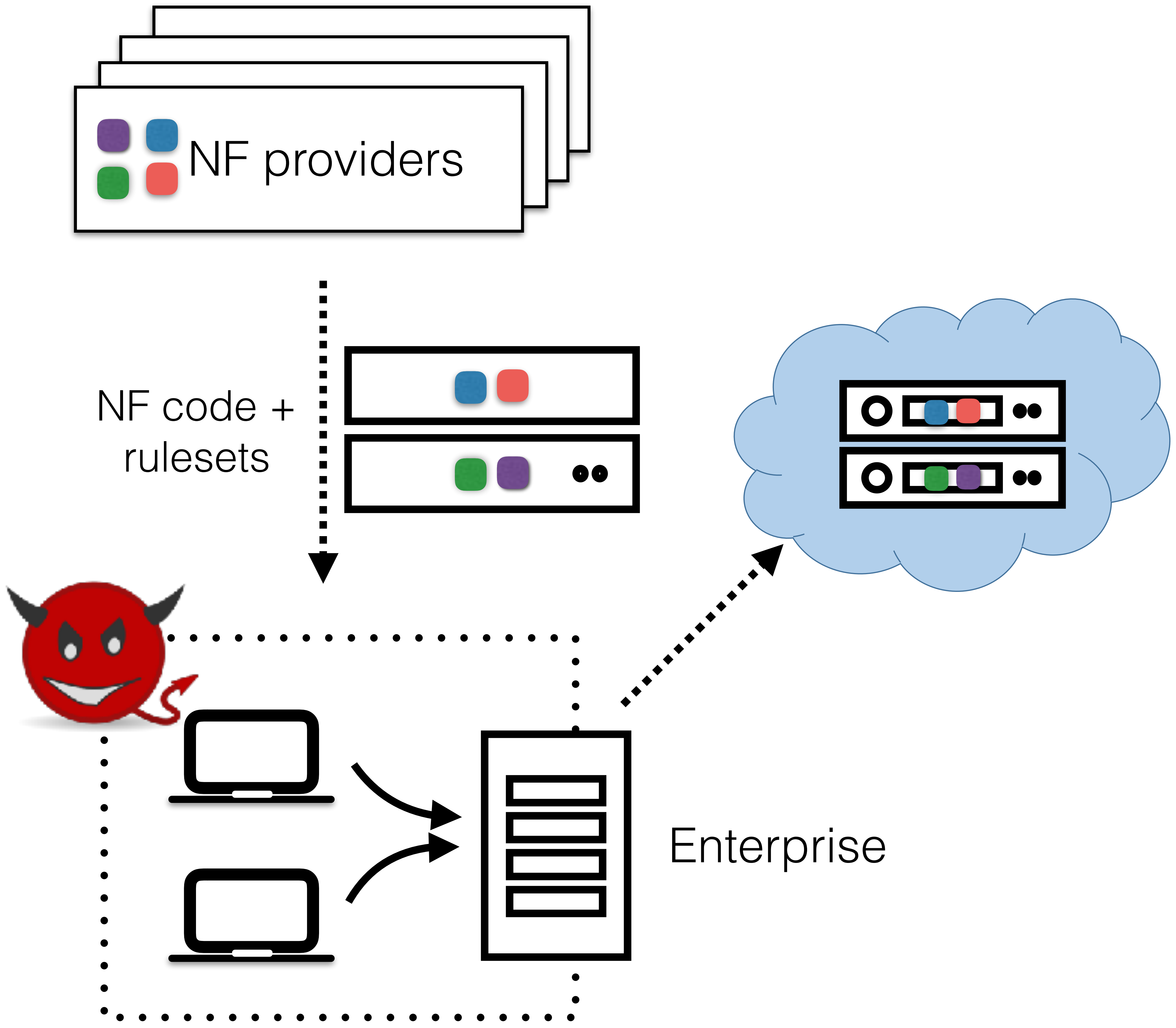
- **Problem:** This violates the confidentiality of NF source code!



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- **Key idea**: Build NFs within a special “meta”-enclave in the cloud using an **agreed upon compiler**

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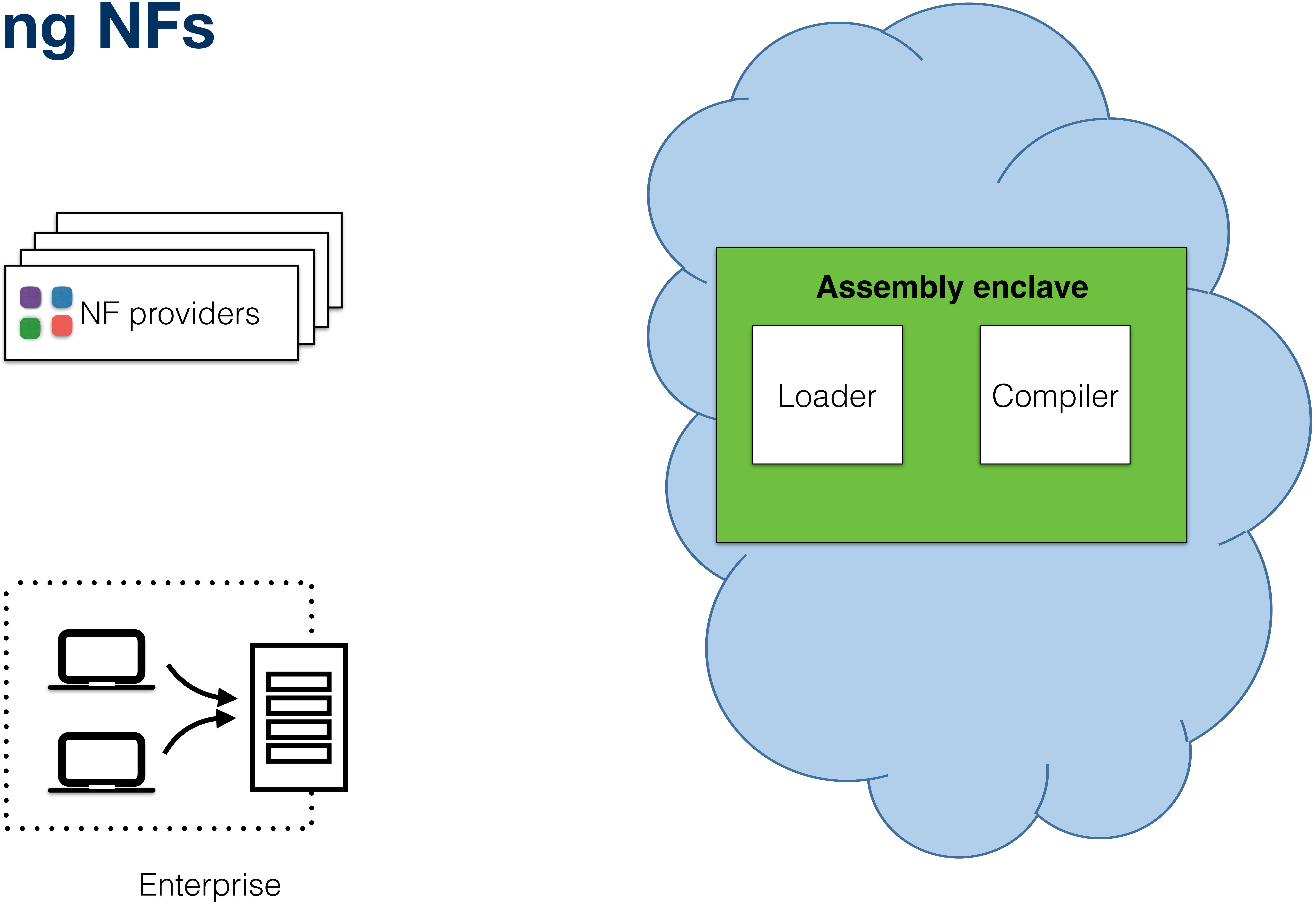
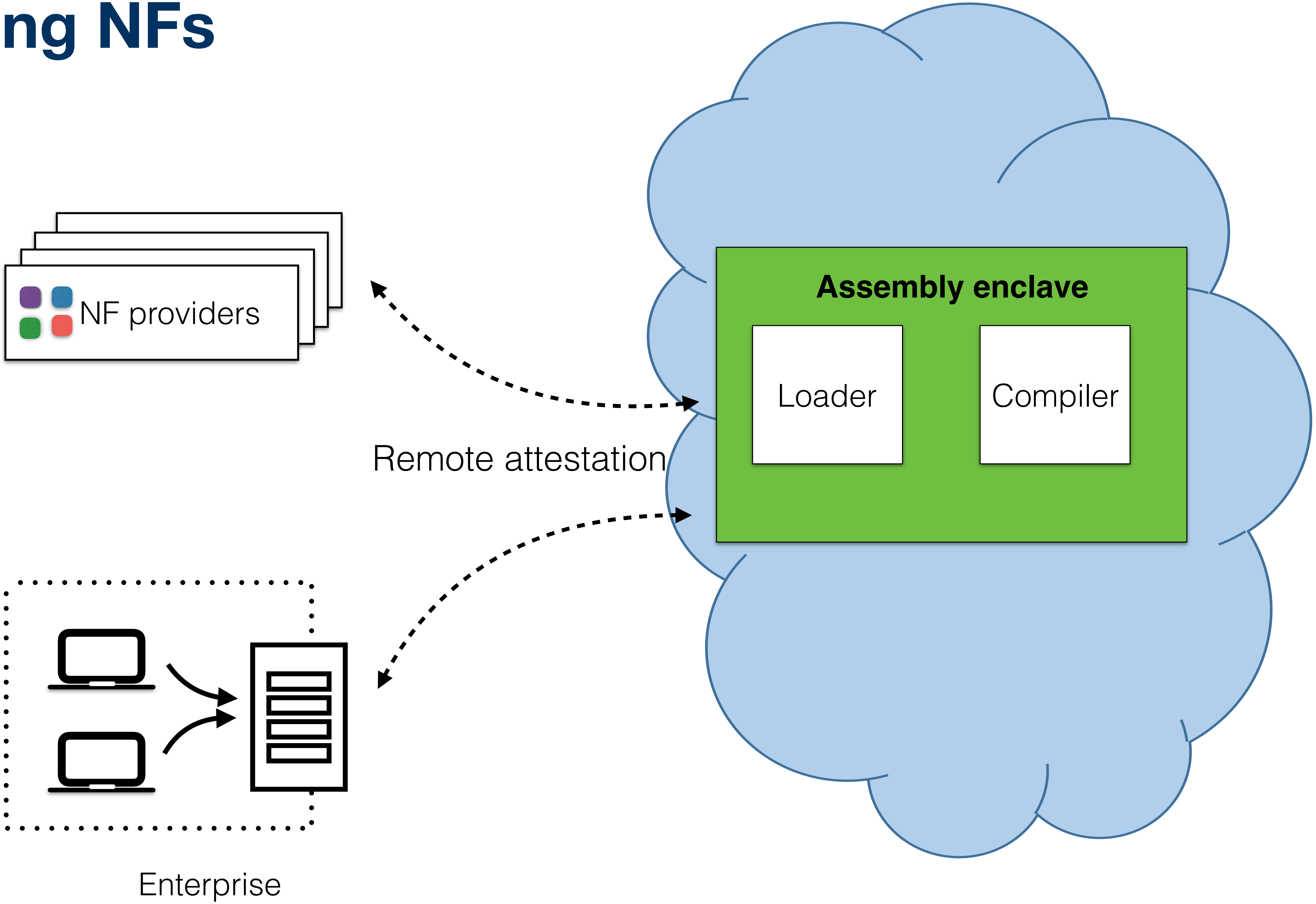
- **Key idea**: Build NFs within a special “meta”-enclave in the cloud using an **agreed upon compiler**

- Both client and NF providers can verify the agreed upon compiler using **remote attestation**

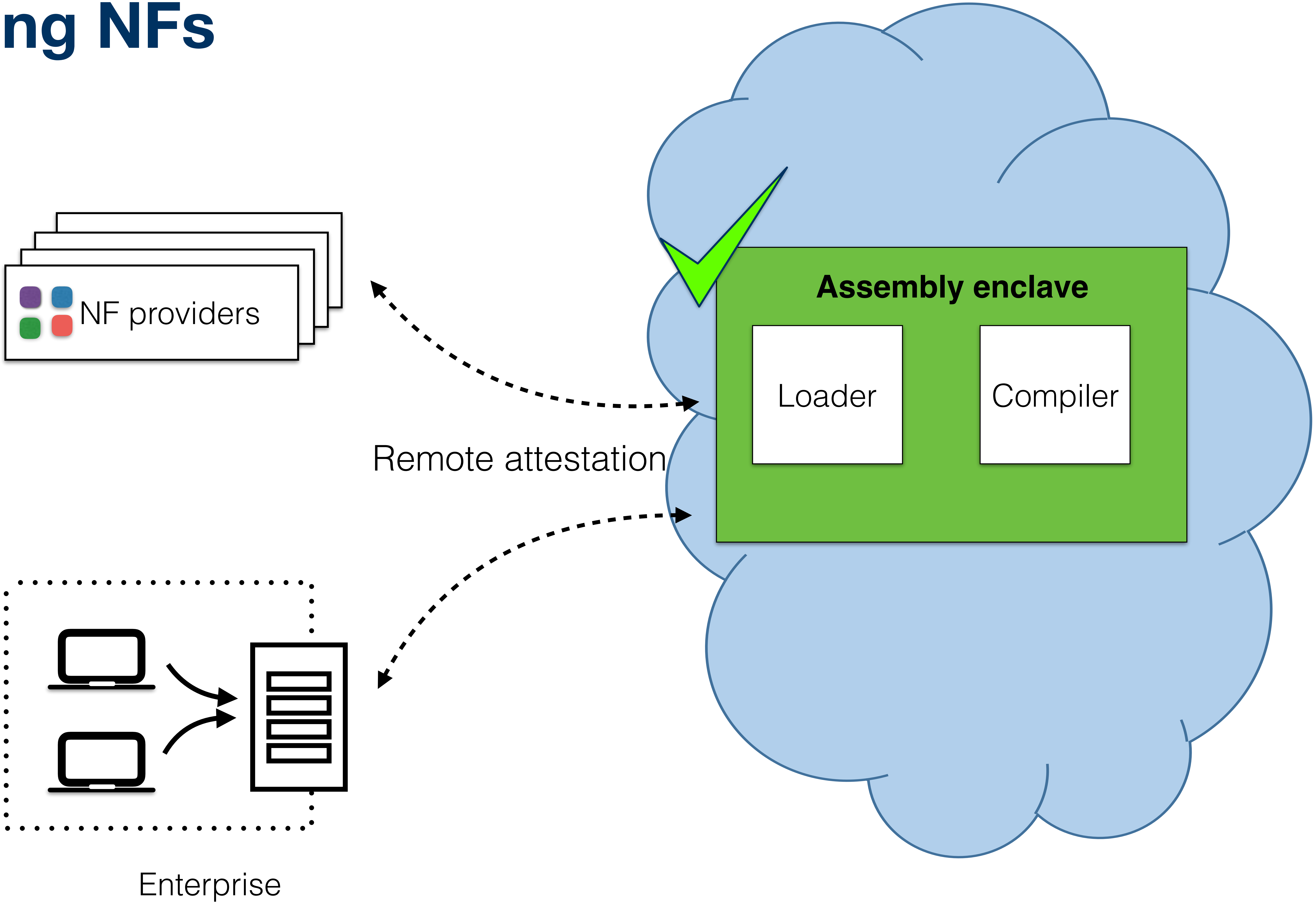
Assembling NFs



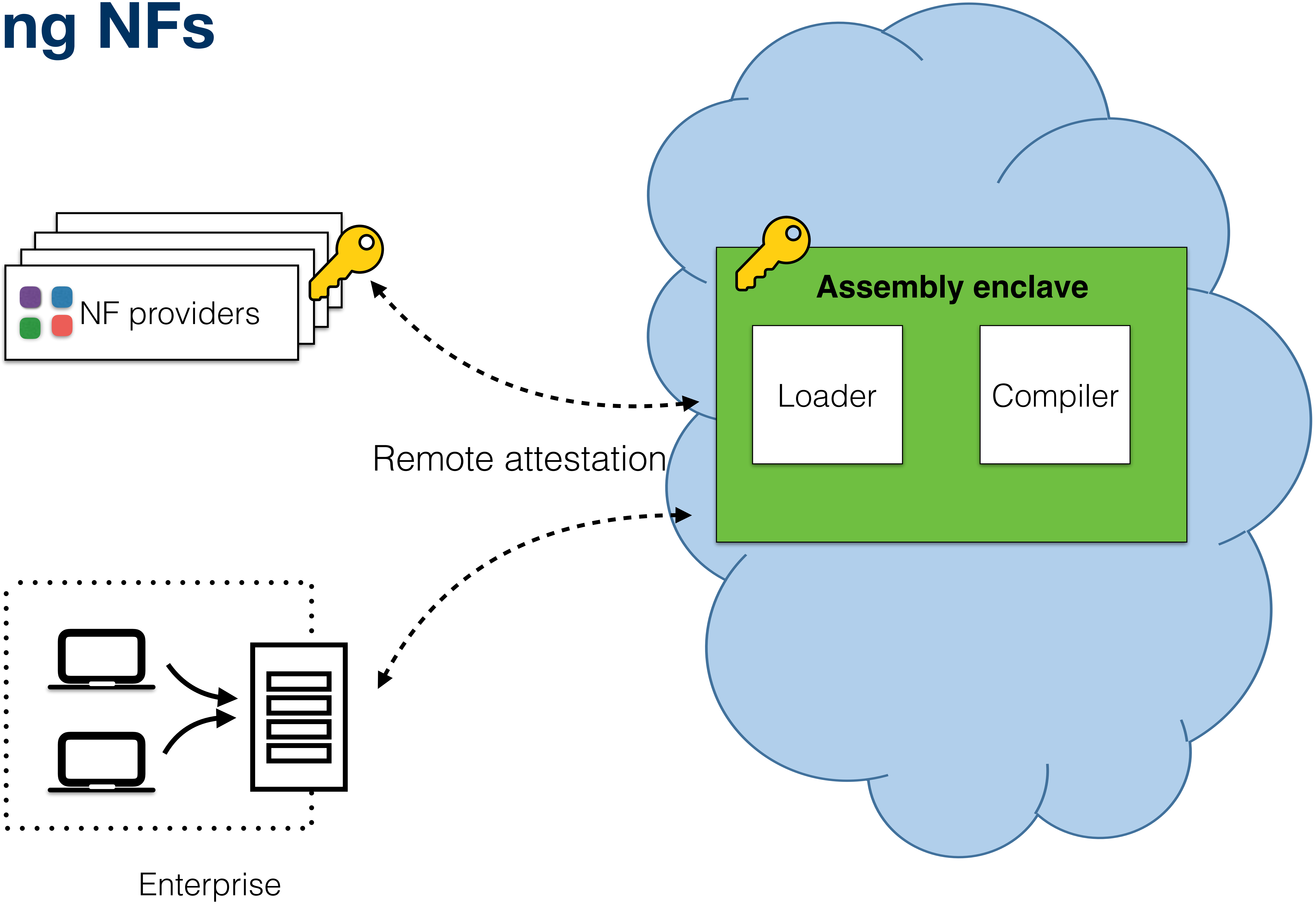
Assembling NFs



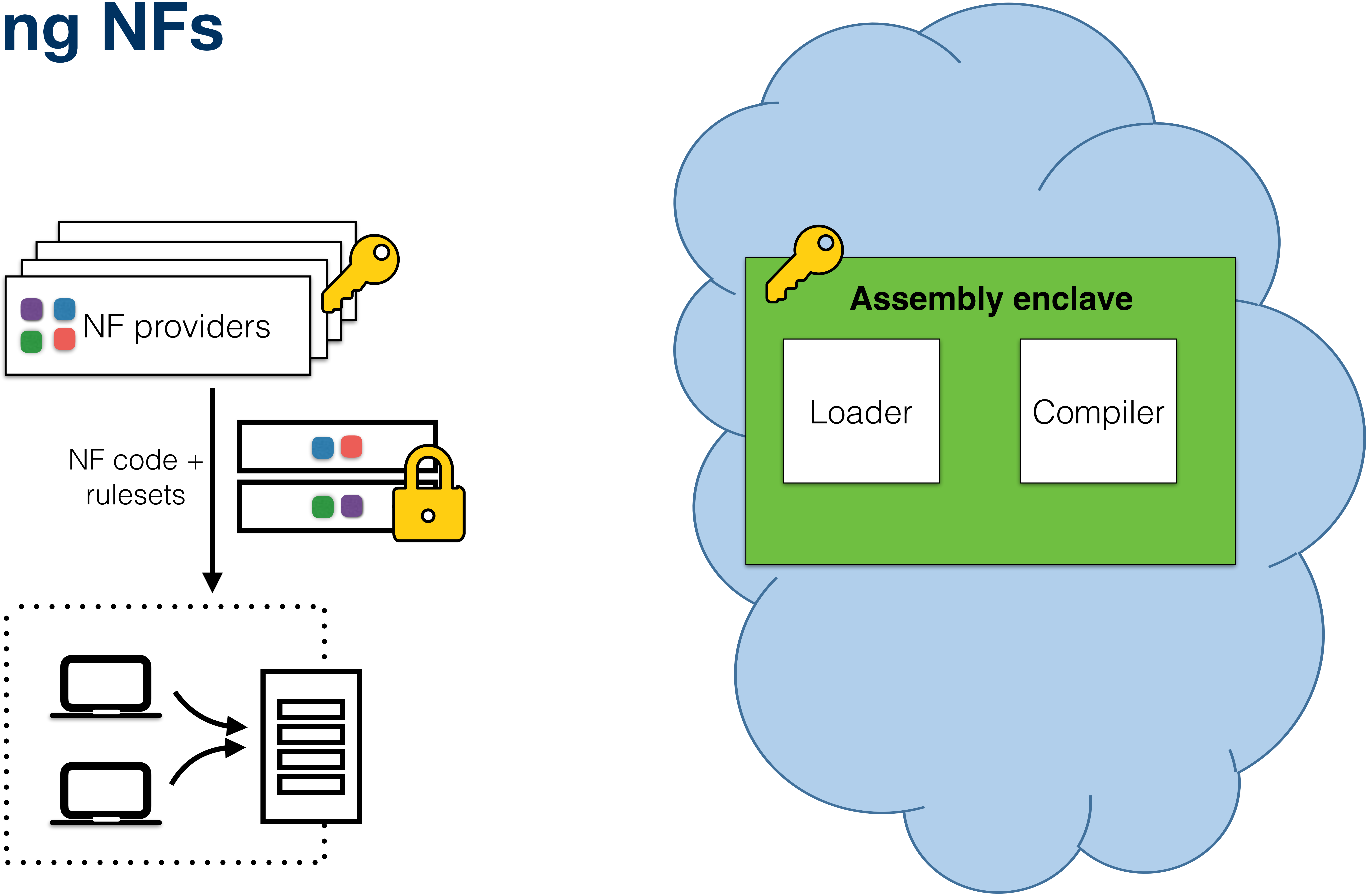
Assembling NFs



Assembling NFs

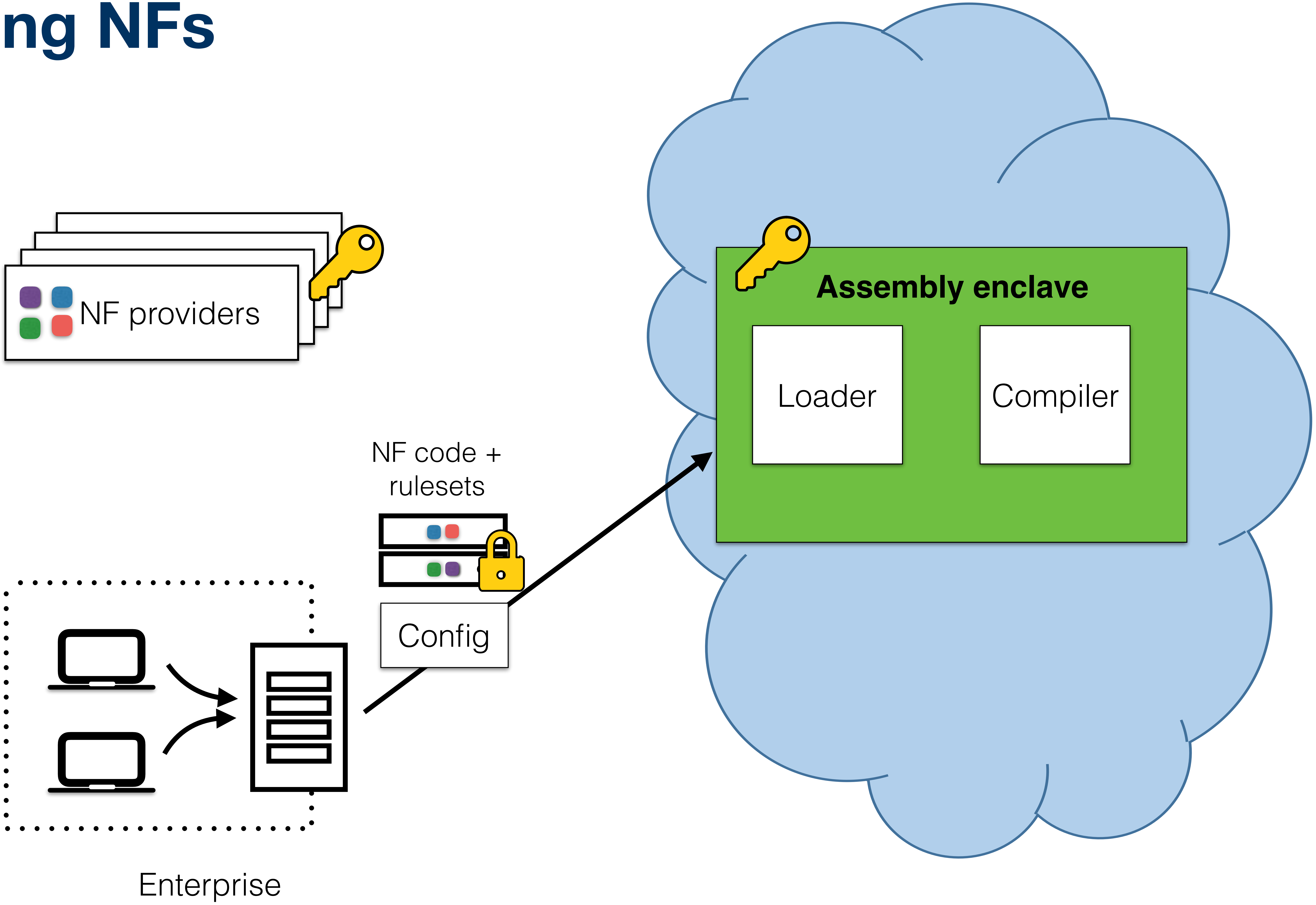


Assembling NFs

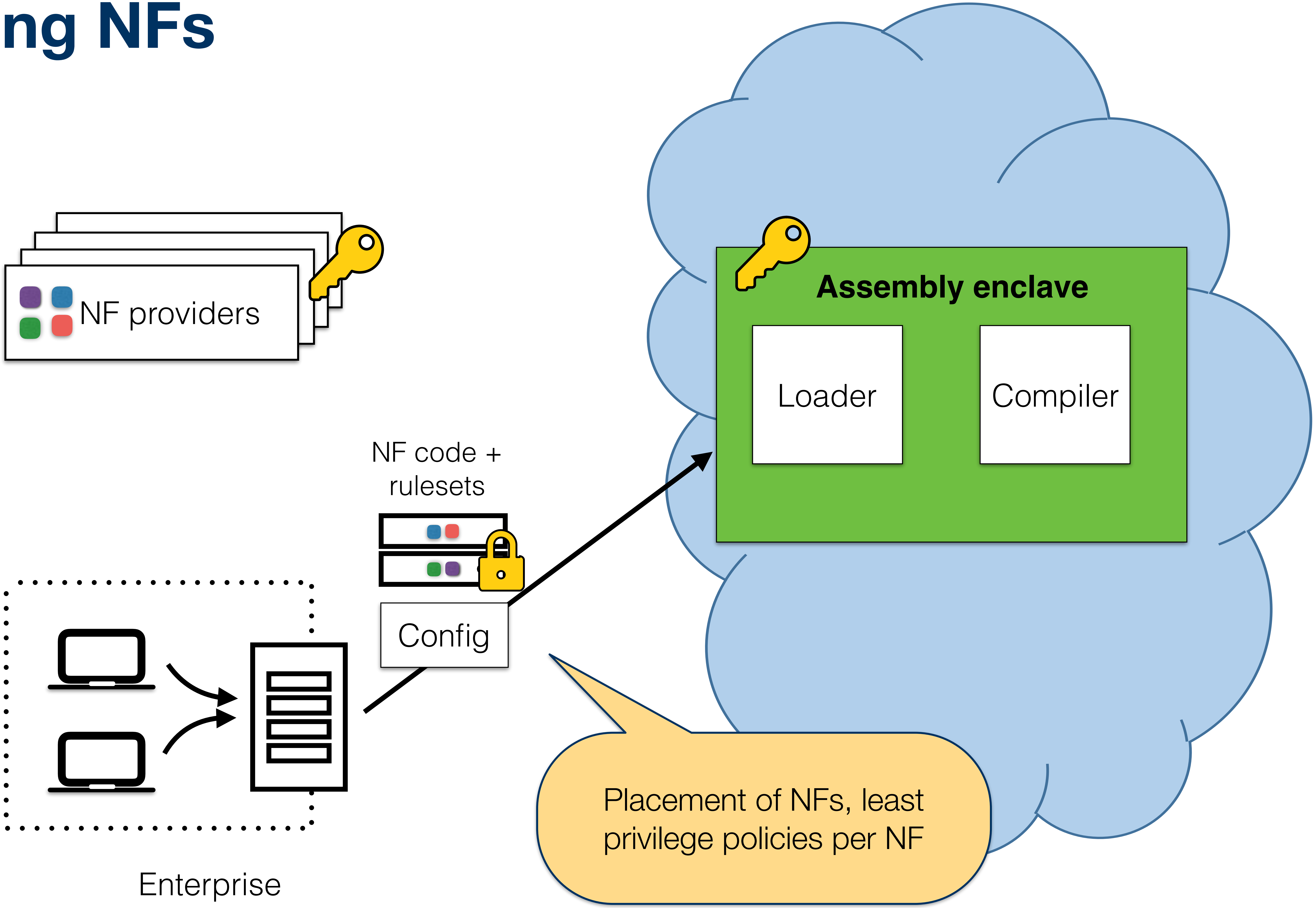


Enterprise

Assembling NFs

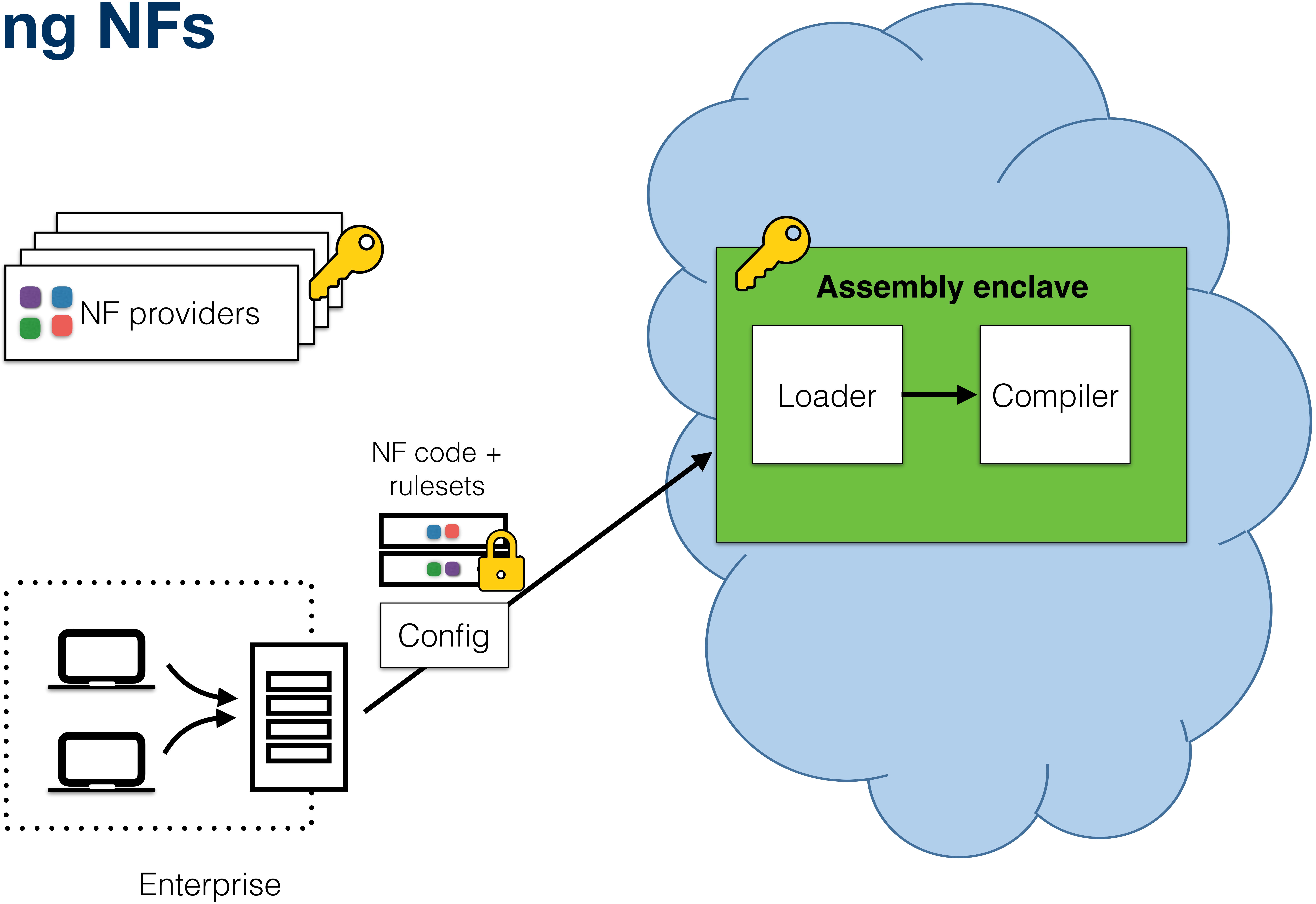


Assembling NFs

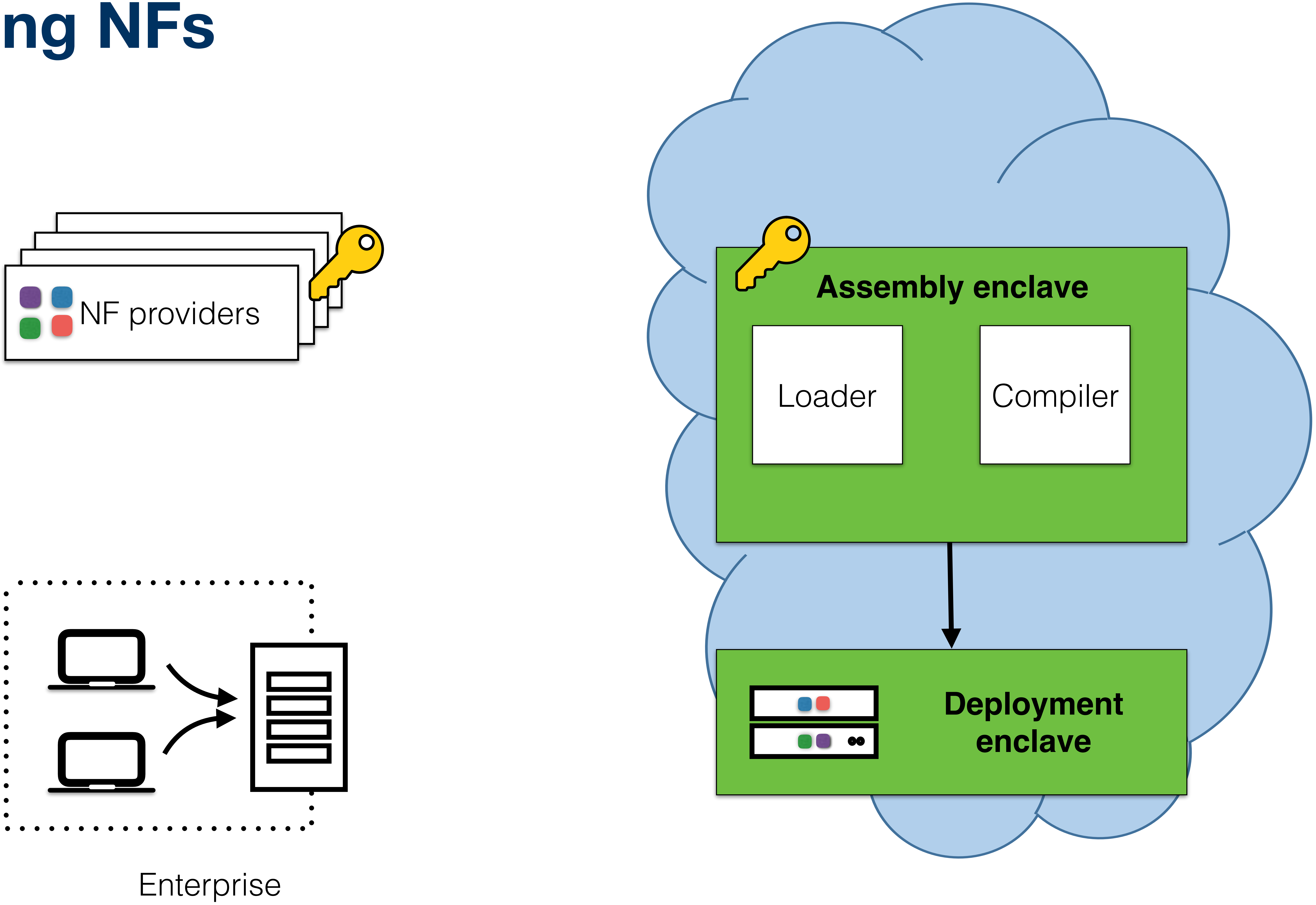


Placement of NFs, least privilege policies per NF

Assembling NFs



Assembling NFs



SafeBricks

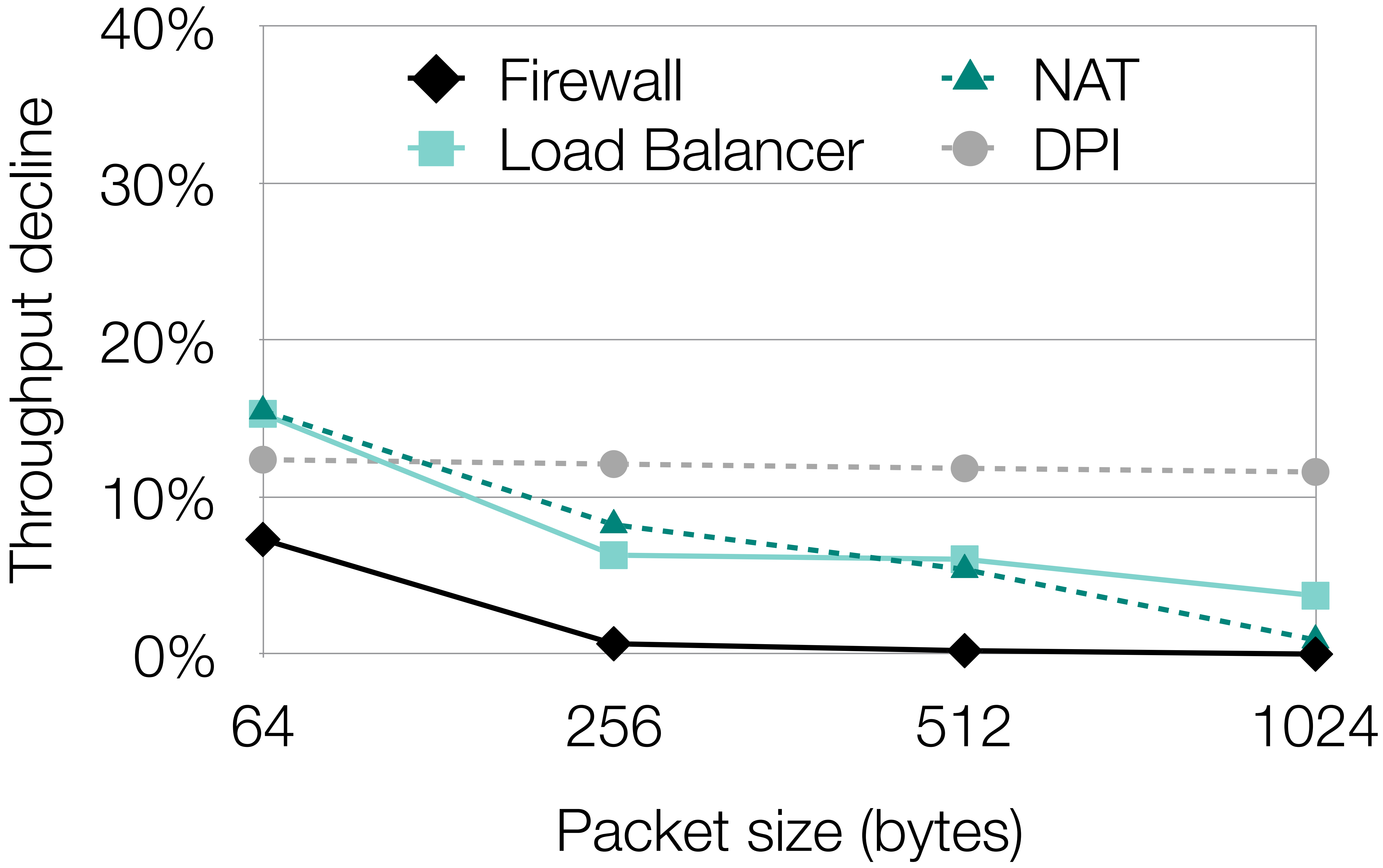
1. Protects **traffic** from the **cloud provider**

2. Protects **traffic** from the **NF providers**

3. Protects **NF source code and rulesets** from client enterprise and cloud

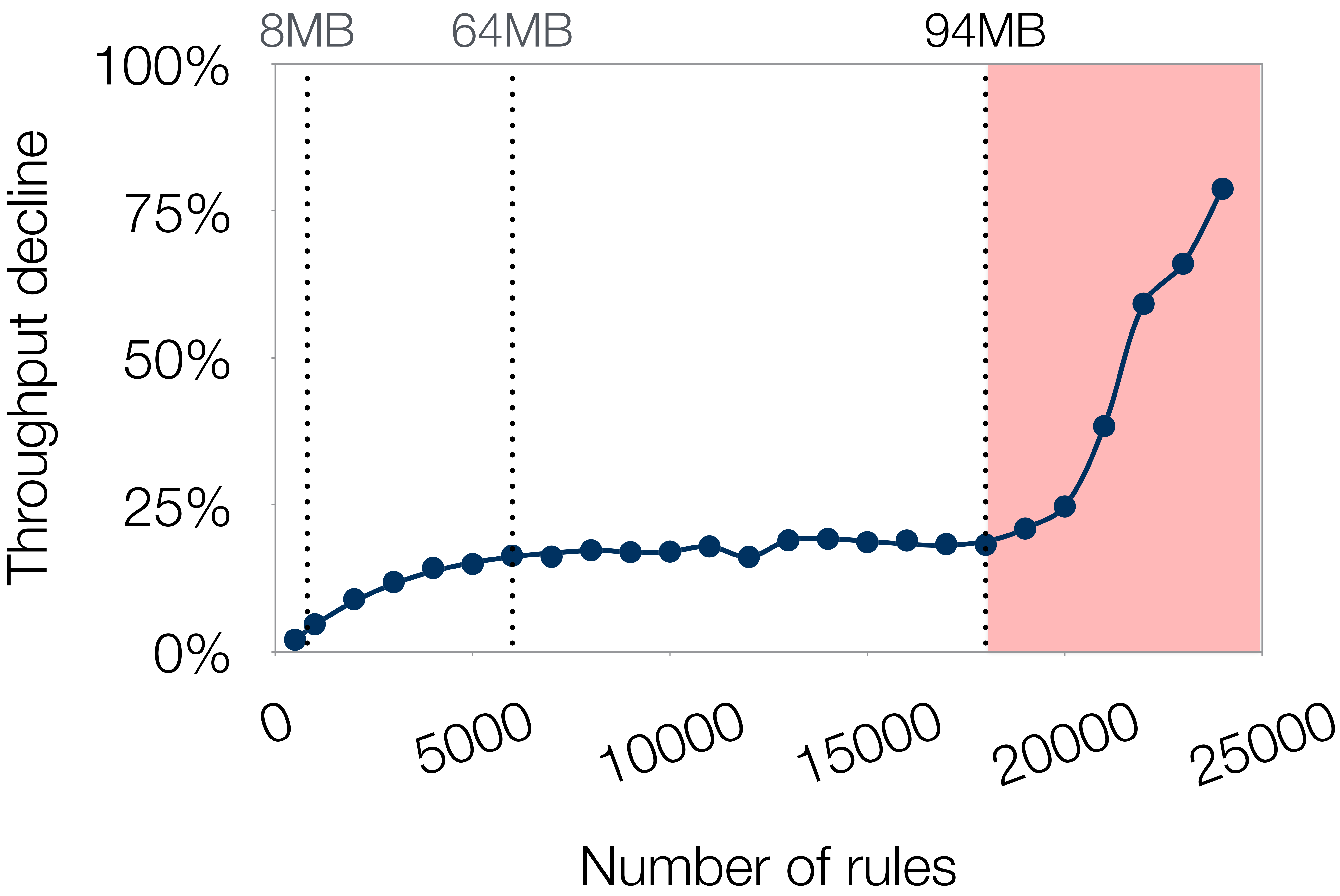
Performance

Throughput decline across NFs



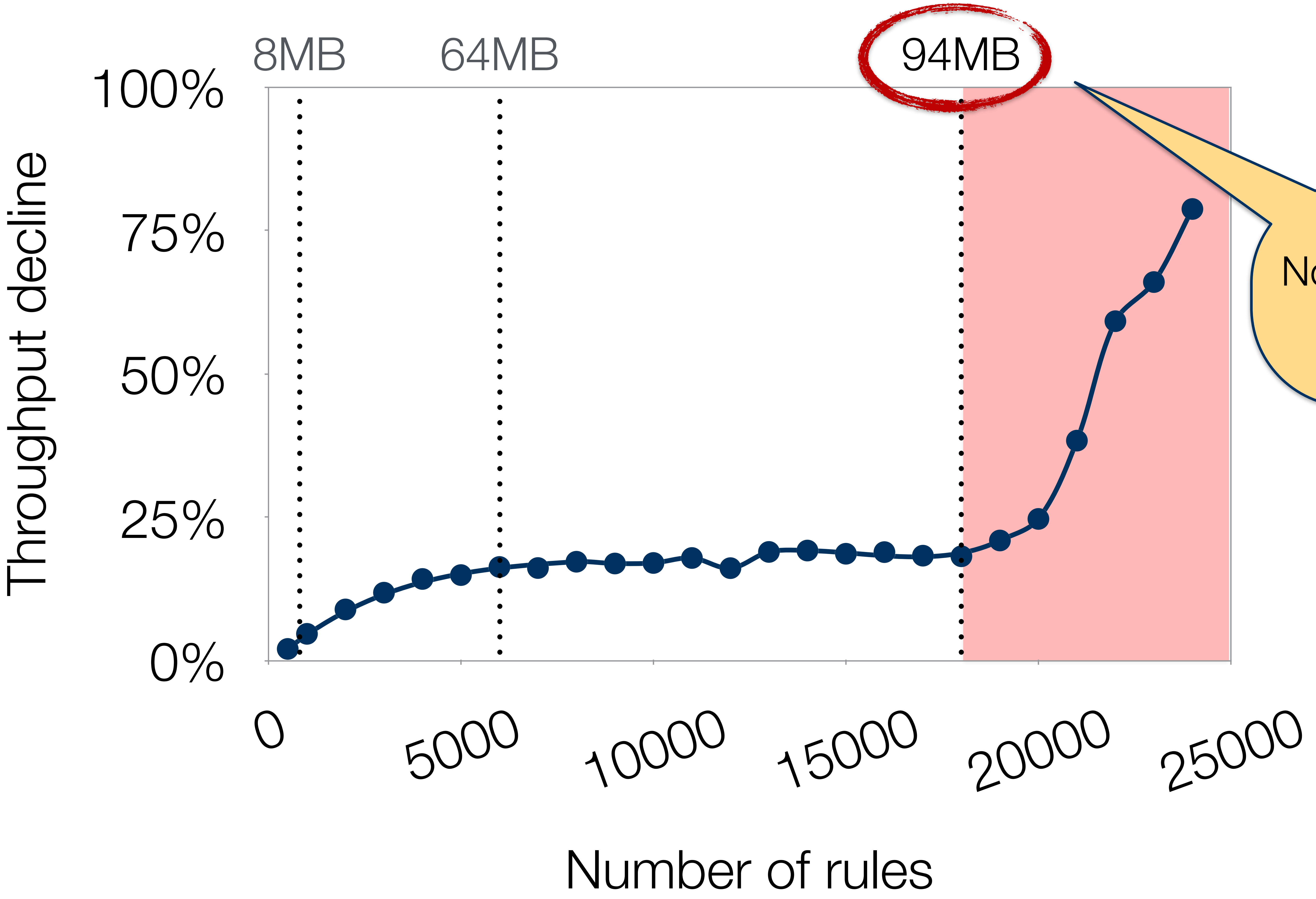
~**0–15% overhead** across applications for different packet sizes

DPI performance with increasing no. of rules



Overhead spikes when NF working set **exceeds enclave memory**

DPI performance with increasing no. of rules



Not a fundamental limitation

Overhead spikes when NF working set **exceeds enclave memory**

Summary

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SafeBricks uses a combination of **hardware enclaves** and **language-based isolation** to:

- Protect client traffic from the cloud provider
- Enforce least privilege across NFs
- Protect the confidentiality of NF code and rulesets

Modest overhead across a range of applications