HILTI: An Abstract Execution Environment for Deep, Stateful Network Traffic Analysis

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A Tale of Three Open-Source IDS

Shared
functionality?

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Essentially none.

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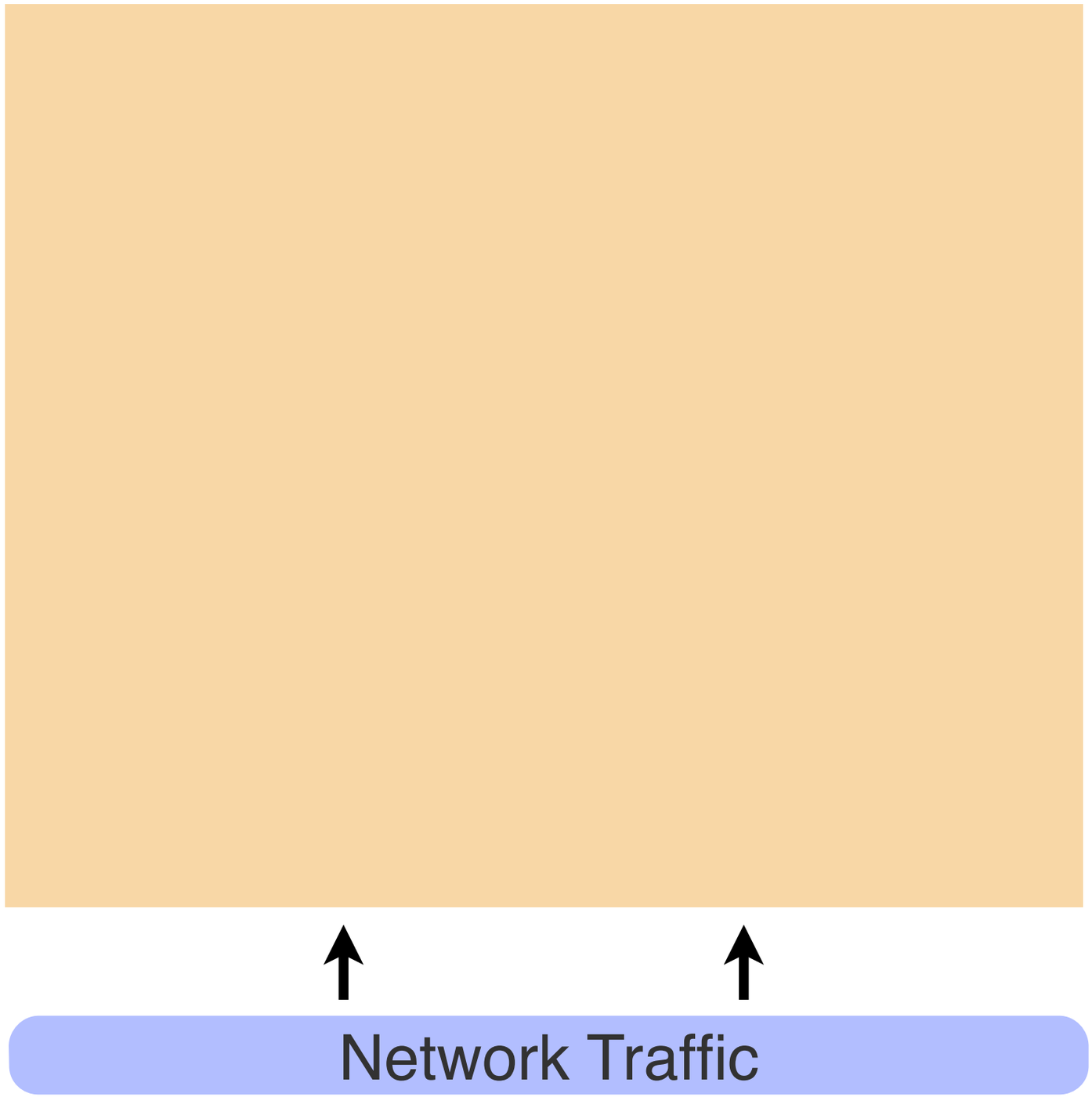
Same for packet filters, firewalls, proxies, routers, switches, OS stack …

DPI Architecture



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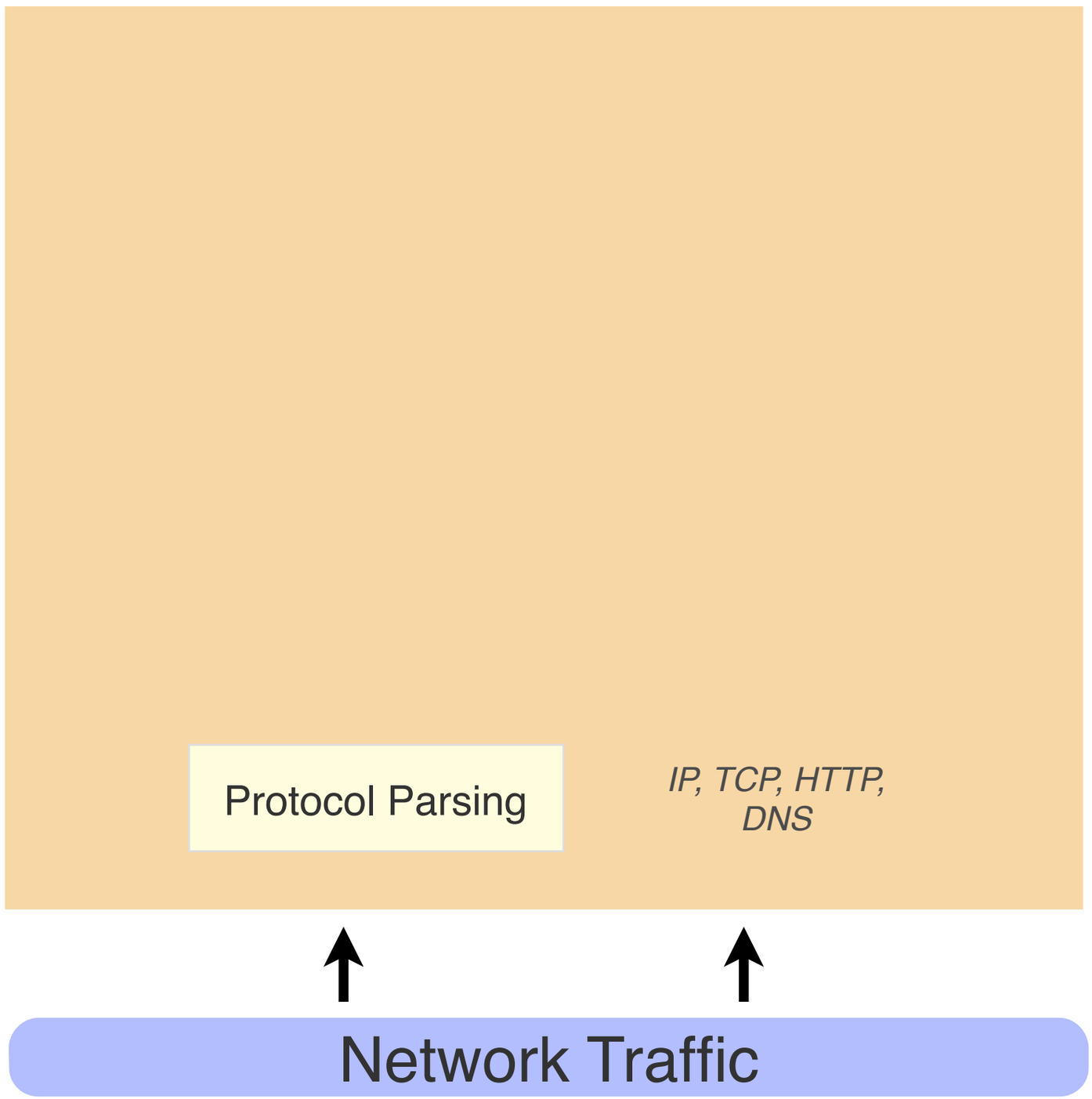

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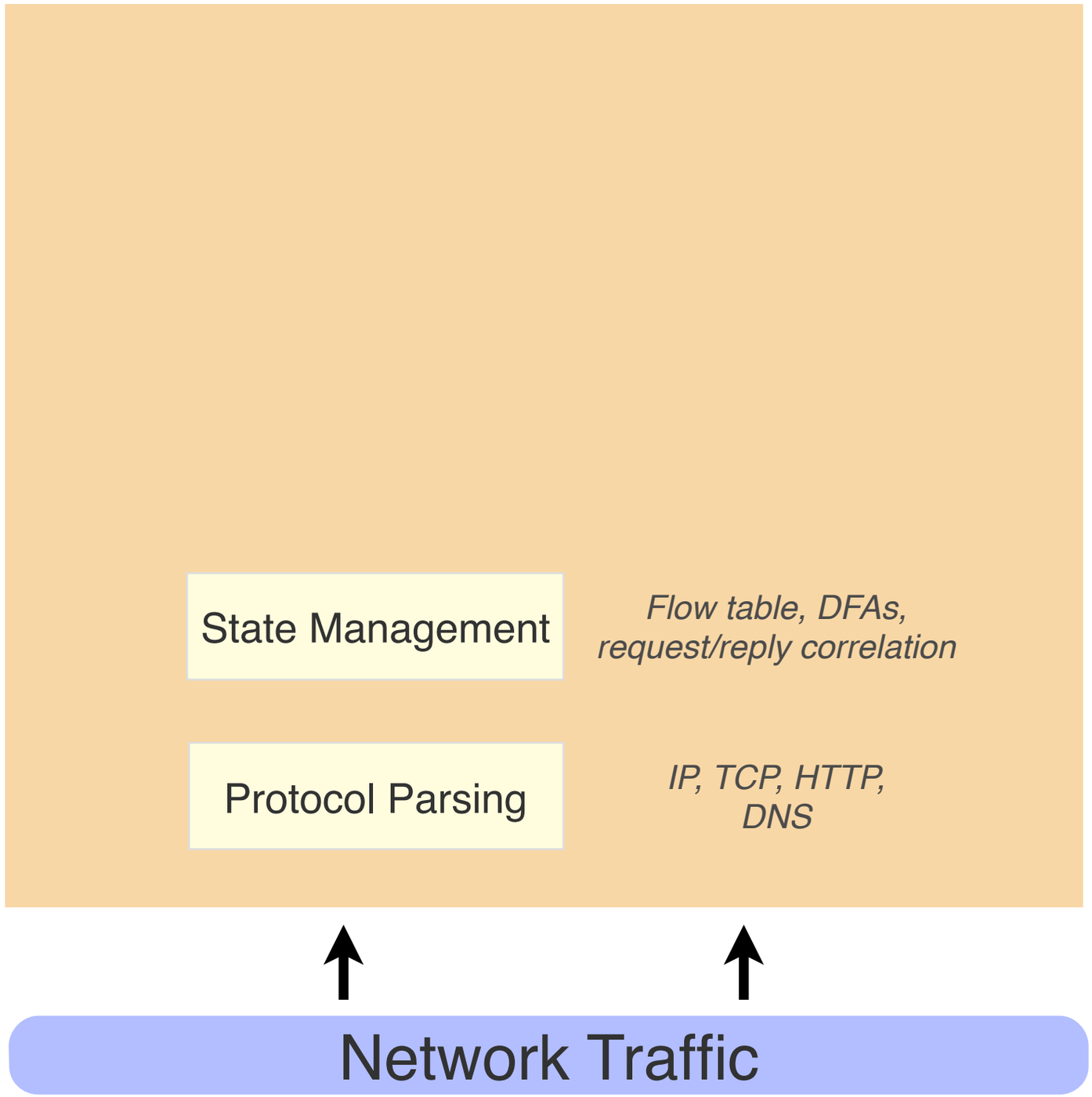

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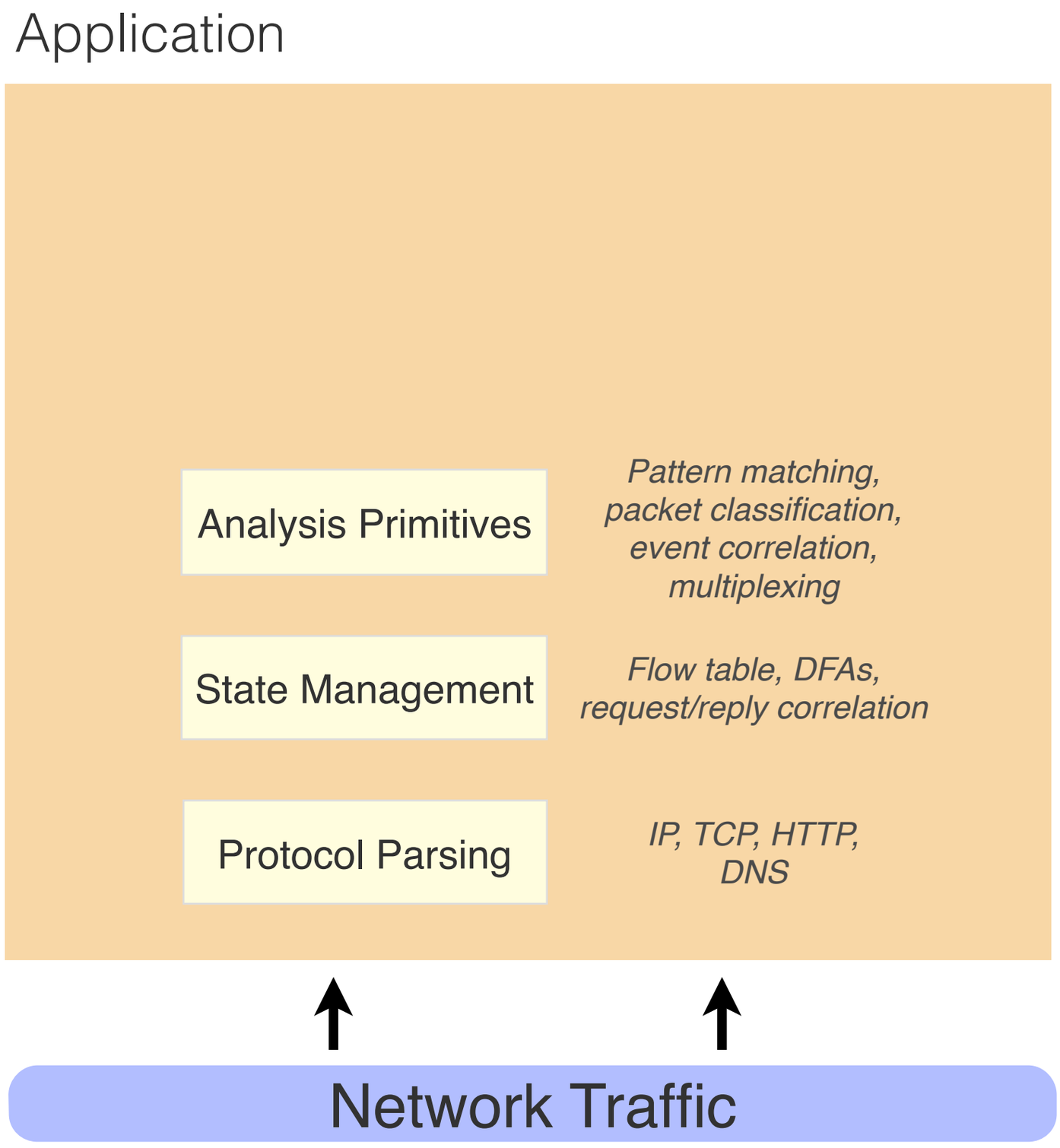

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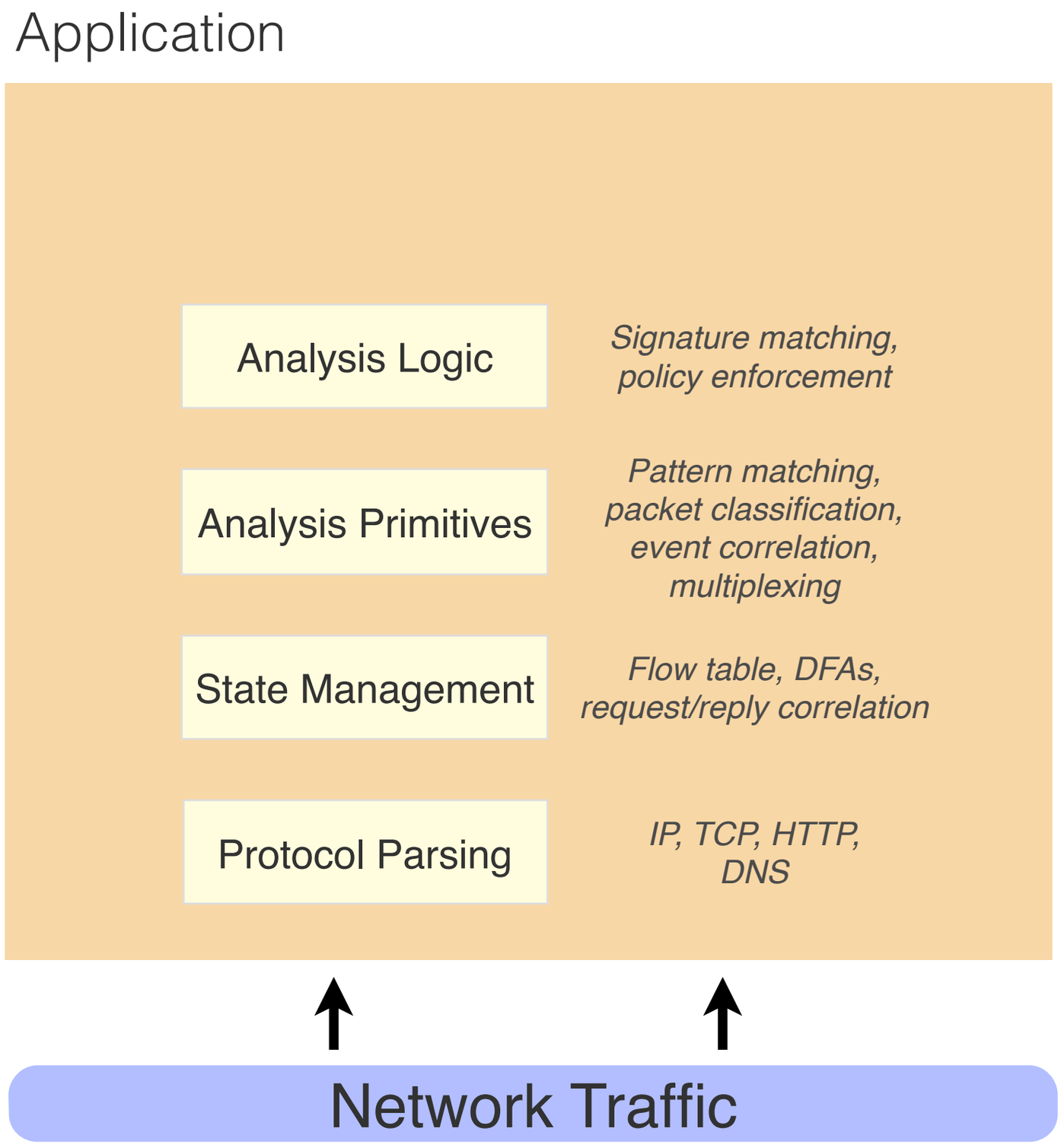

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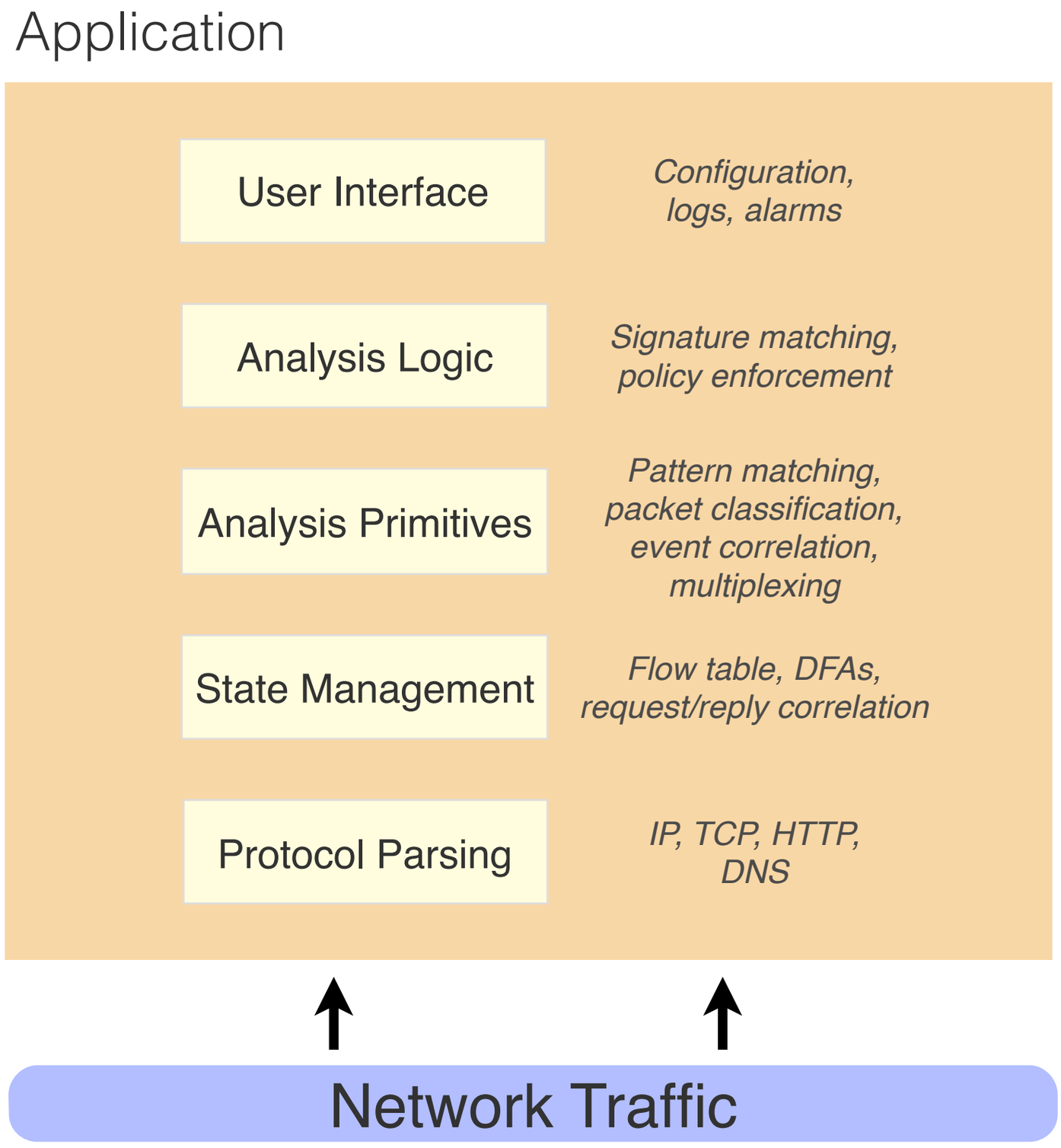

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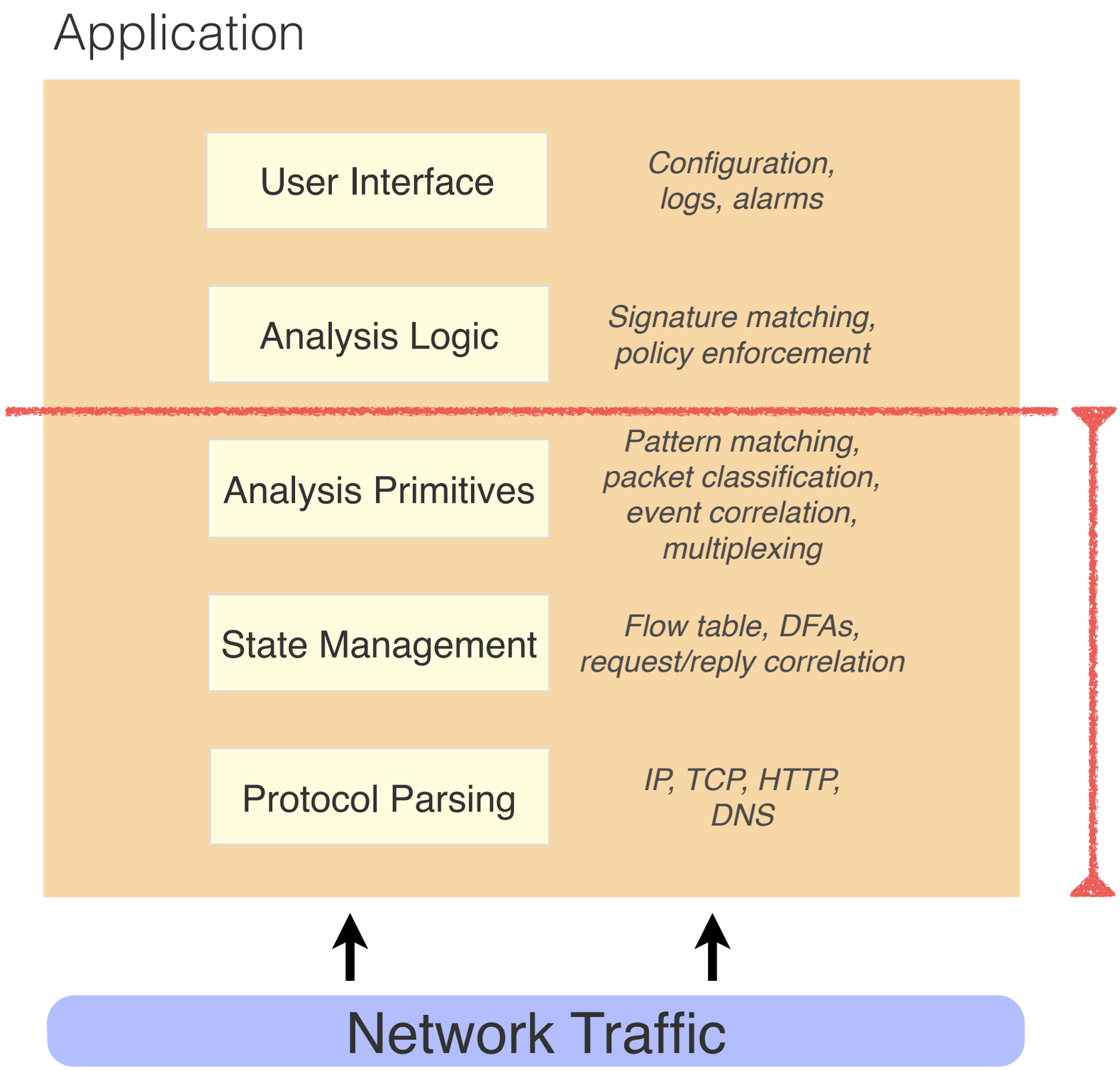

Common primitives & idioms — but hardly any reuse …

… and that even though this stuff is hard.

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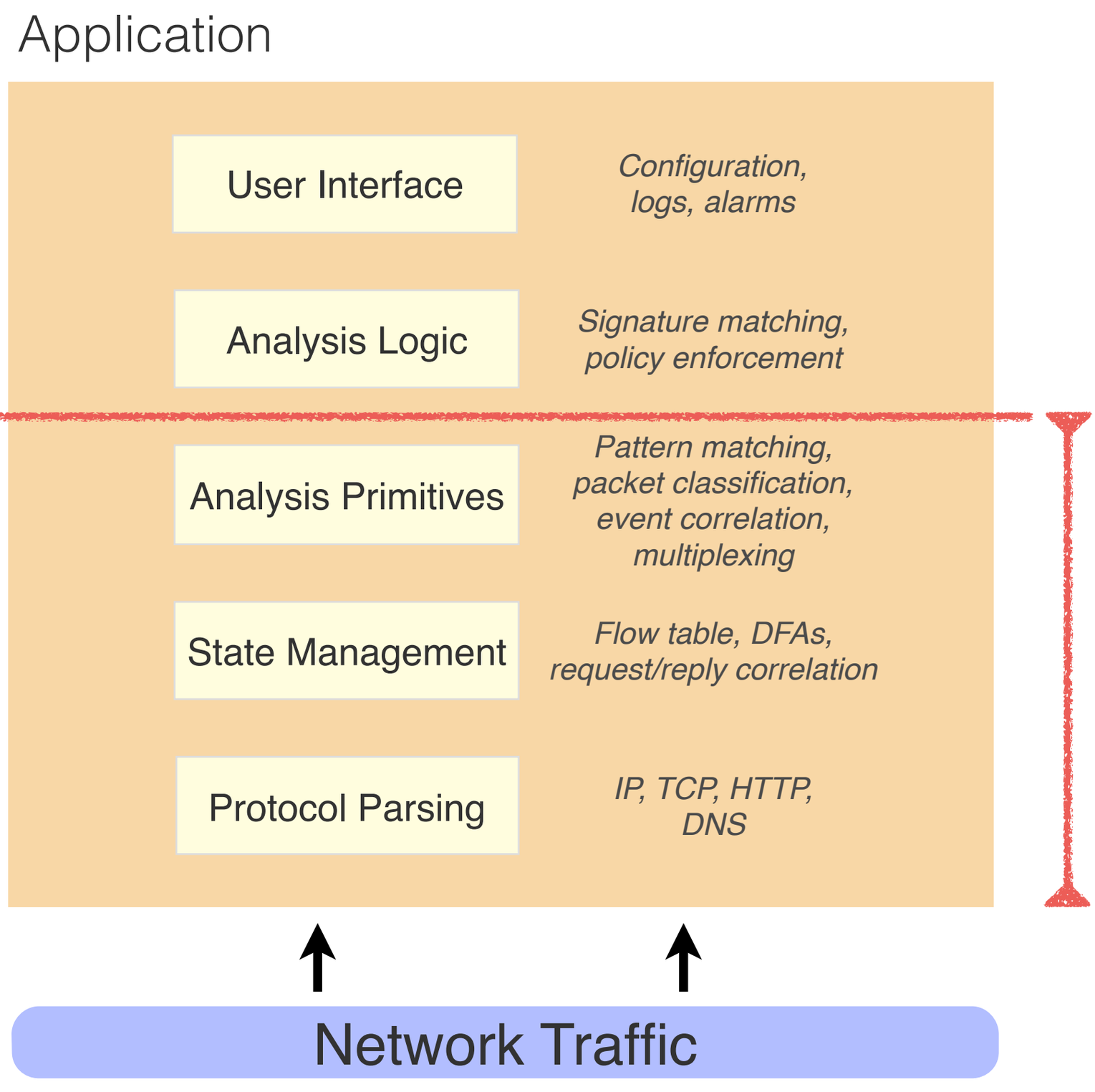

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Why?

Different low-level structure & data flows.

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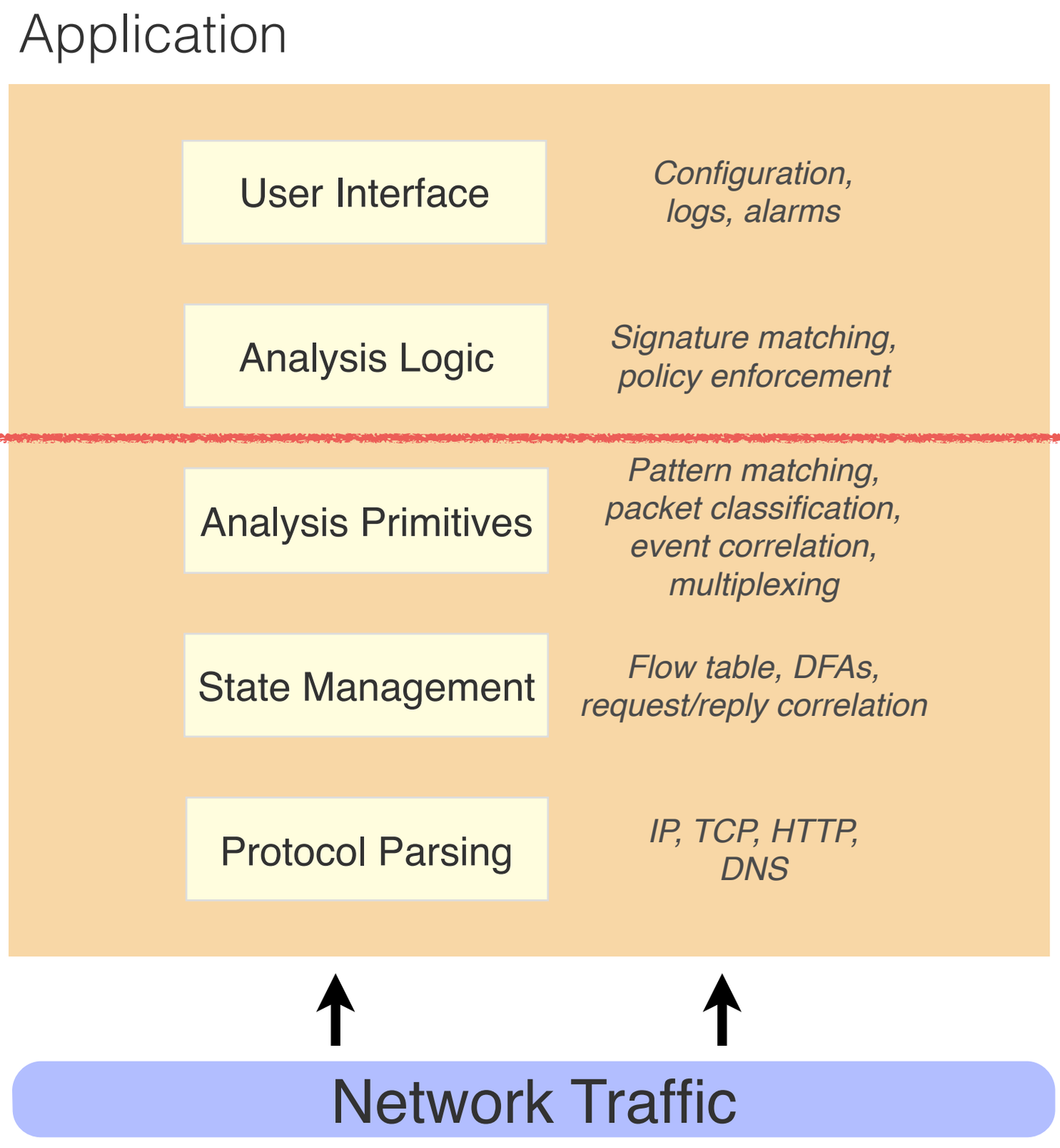

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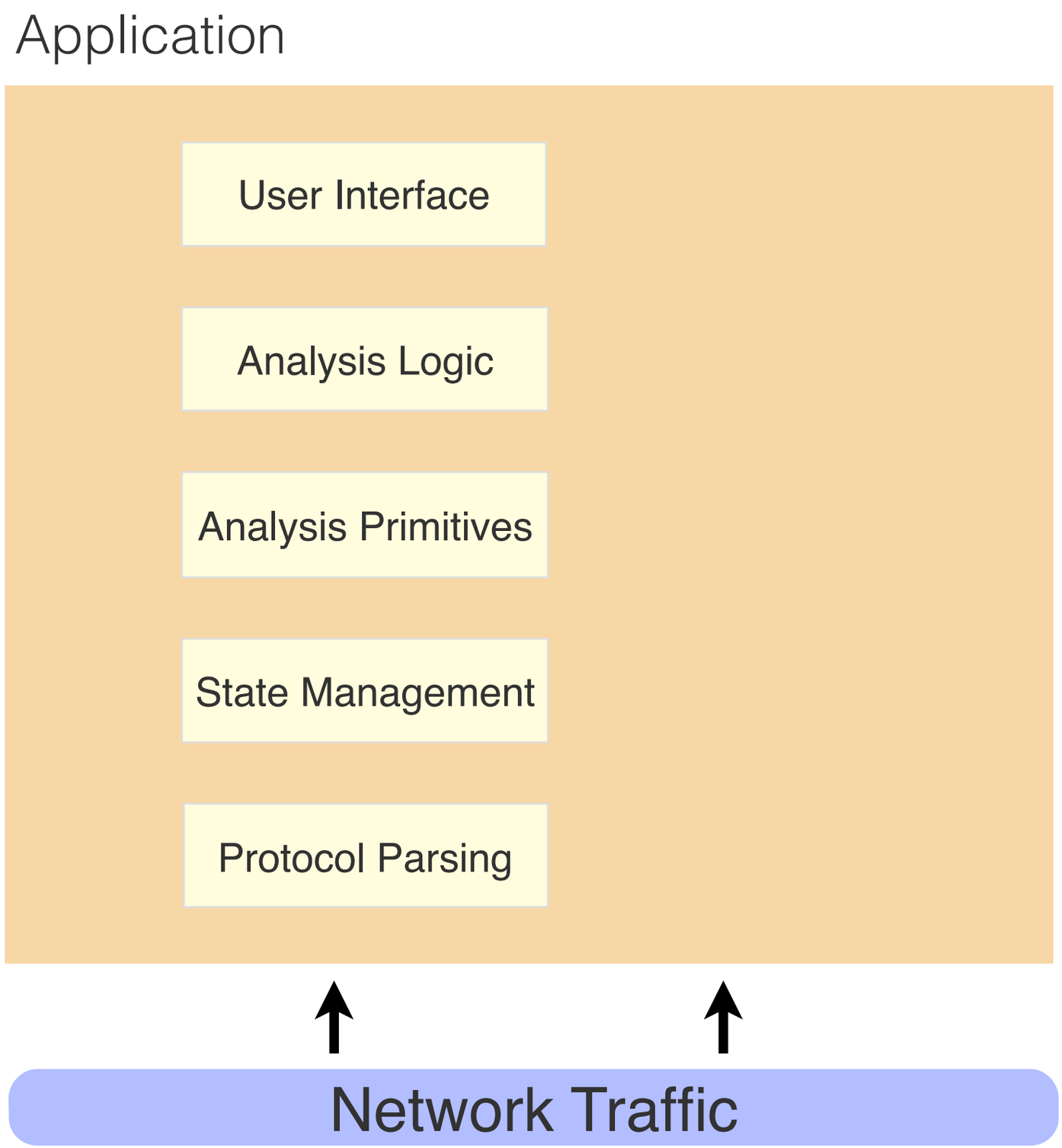
Why?

Different low-level structure & data flows.

No “common language”.

A High-Level Intermediary Language for Traffic Inspection



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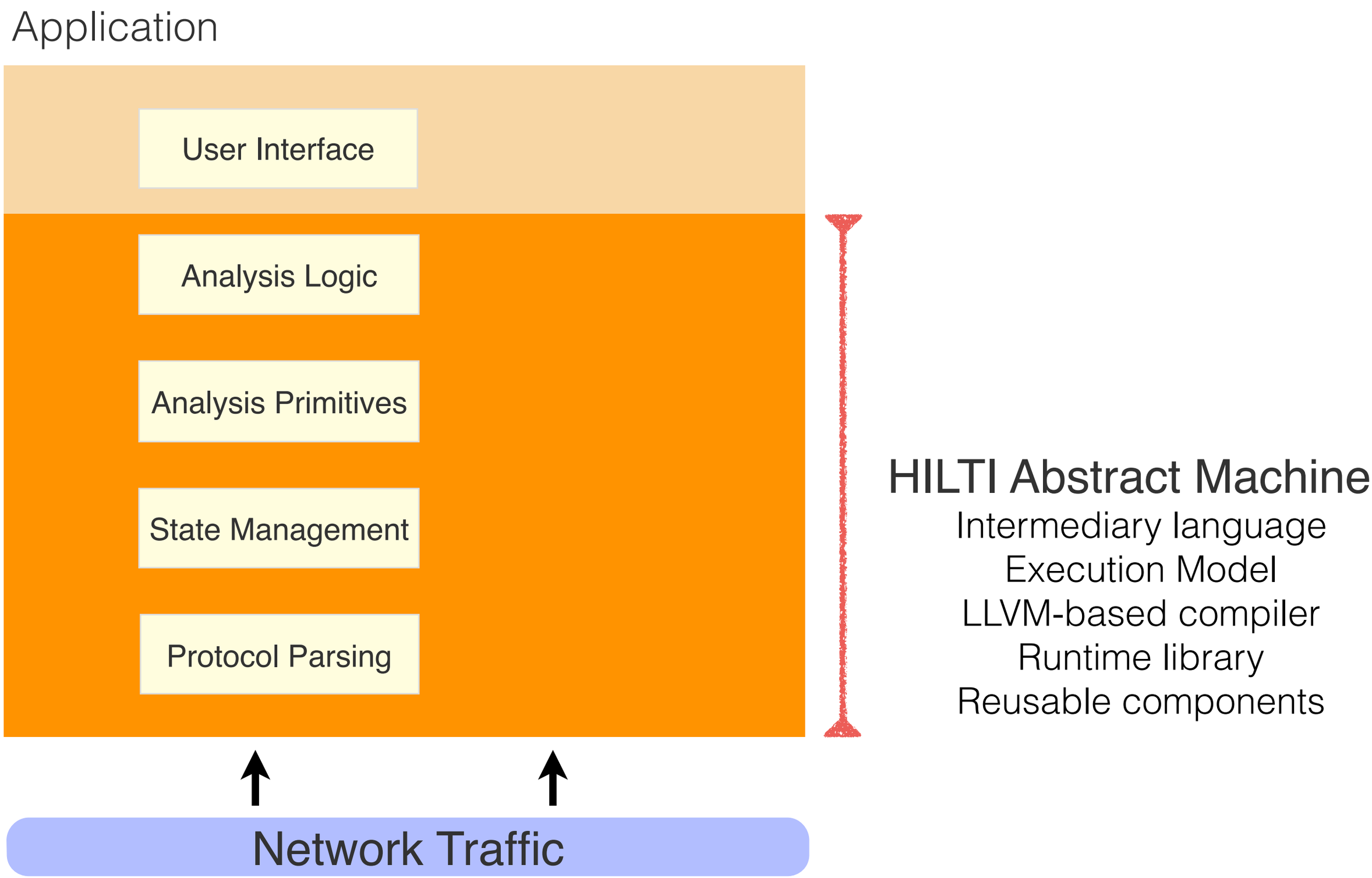

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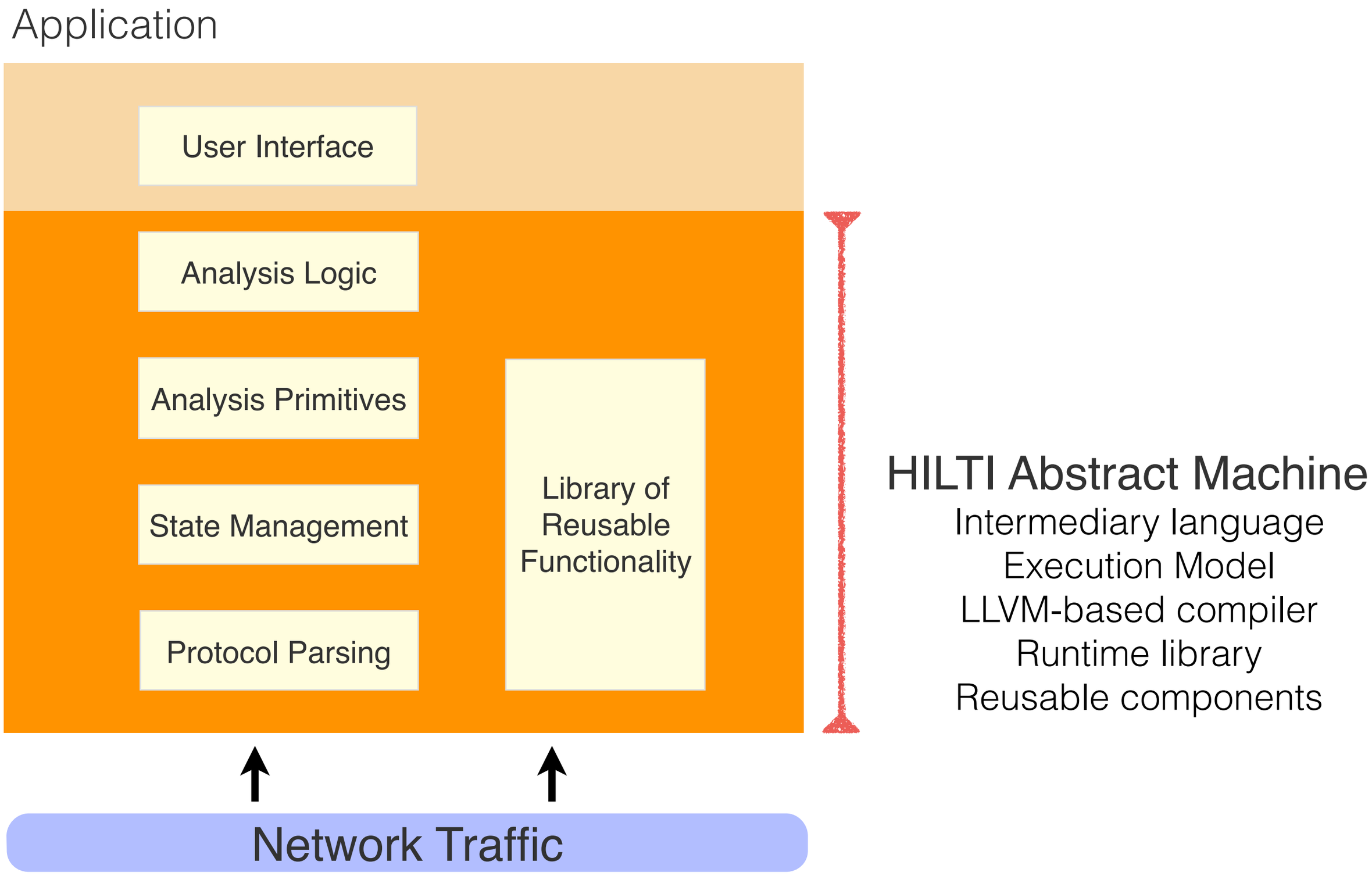

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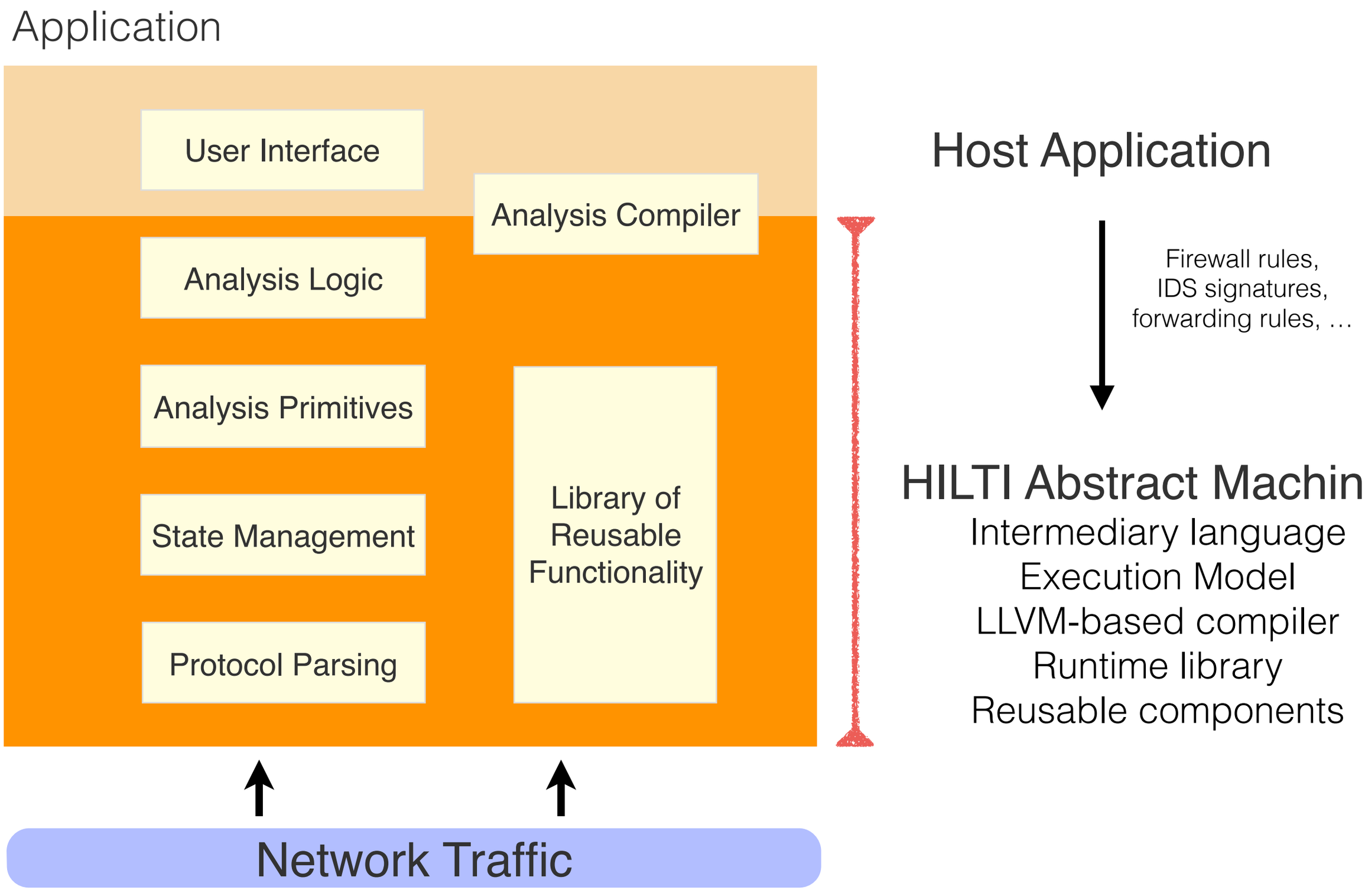

Example: BPF Filters

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host 192.168.1.1 or src net 10.0.5.0/24
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type IP::Header = overlay {
  version: int<8> at 0 unpack UInt8InBigEndian (4, 7),
  hdr_len: int<8> at 0 unpack UInt8InBigEndian (0, 3),
  [...]
  src:     addr   at 12 unpack IPv4InNetworkOrder,
  dst:     addr   at 16 unpack IPv4InNetworkOrder
}
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}
```

```
bool filter(ref<bytes> packet) {
  local addr a1, a2
  local bool b1, b2, b3

  a1 = overlay.get IP::Header src packet
  b1 = equal a1 192.168.1.1
  a1 = overlay.get IP::Header dst packet
  b2 = equal a2 192.168.1.1
  b1 = or b1 b2
  b2 = equal 10.0.5.0/24 a1
  b3 = or b1 b2
  return b3
}
```

HILTI Machine Model

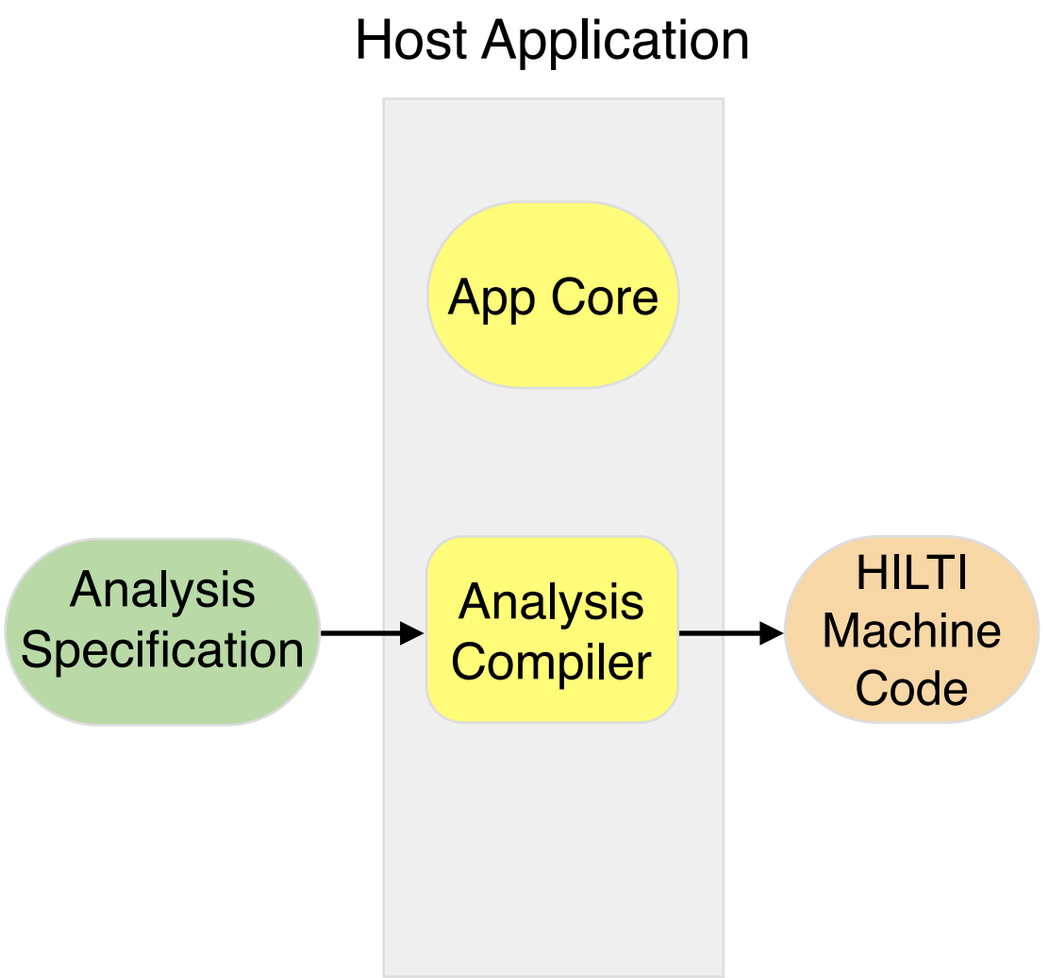
Focus Areas

- Rich Domain-specific Data Types
- Flexible Control Flow
- Concurrent Analysis
- Robust & Secure Execution
- Comprehensive Host Interface
- Real-time Performance
- Debugging & Profiling Support
- High-level Optimization

Instruction Set

Bitsets	Packet input
Booleans	Packet classification
CIDR masks	Packet dissection
Callbacks	Ports
Closures	Profiling
Channels	Raw data
Debug support	References
Doubles	Regular expressions
Enumerations	Strings
Exceptions	Structs
File i/o	Unions
Flow control	Time intervals
Hashmaps	Times
Hashsets	Timers
IP addresses	Threads
Integers	Tuples
Lists	Vectors/arrays

Implementation: The HILTI Toolchain



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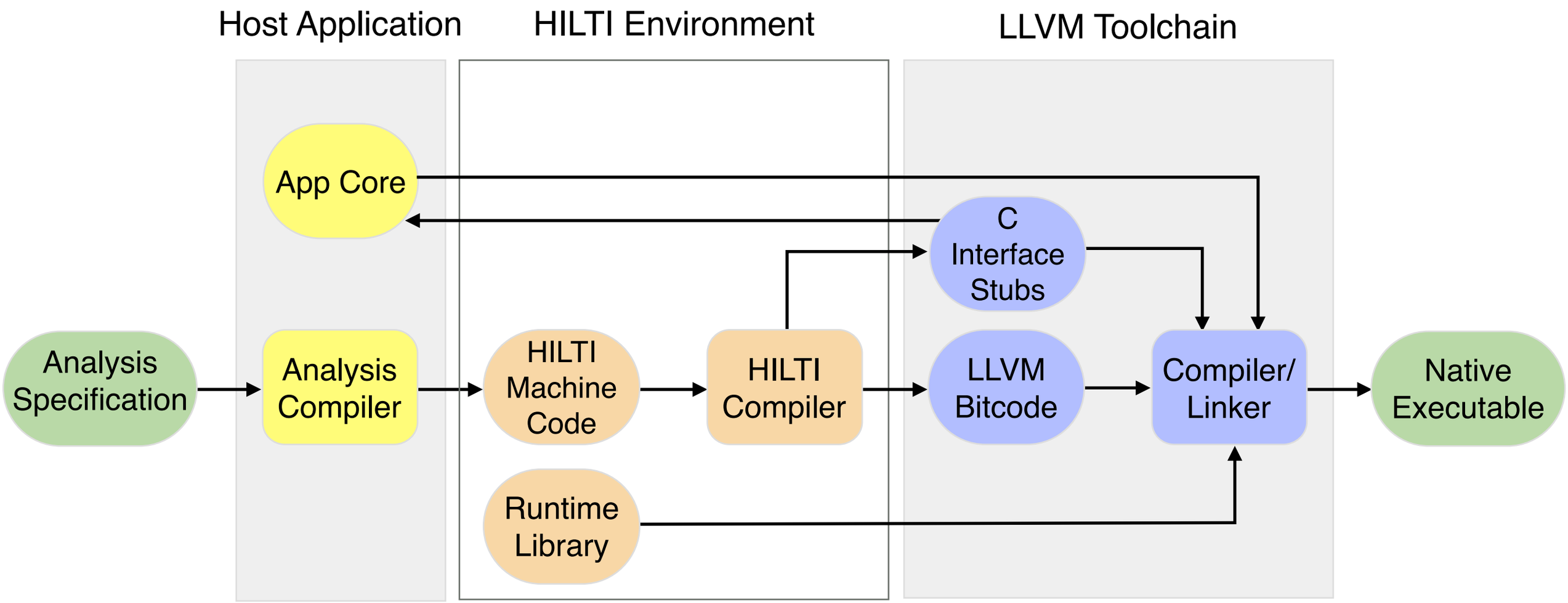

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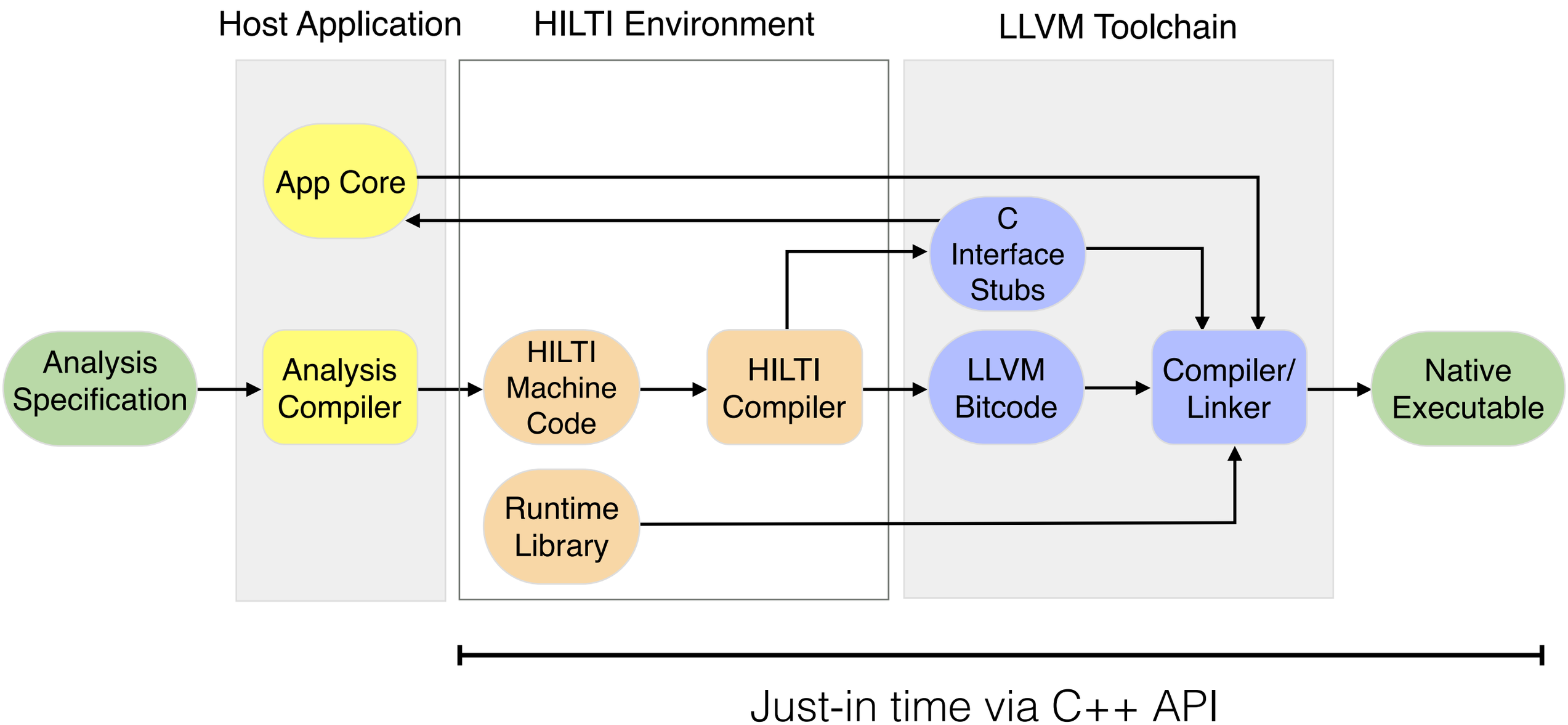

Can HILTI support complex applications?

Application Case Studies

BPF Filter

Stateful Firewall

Protocol Parsing

Bro Script Execution

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BinPAC - A Yacc for Network Protocols

Grammar example: Parsing SSH banners.

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type SSH::Banner = unit {
    magic   : /SSH-/;
    version : /[^-]*/;
    dash    : /-/;
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BinPAC compiles grammar into HILTI parser.

HILTI compiles parser into executable code just-in-time.

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HILTI compiles parser into executable code just-in-time.

Bro plugin integrates parsers at startup.

Bro Scripts

Script example: A simple scan detector.

```
global attempts: table[addr] of count &default=0;

event connection_rejected(c: connection)
{
    local orig = c$id$orig_h;   # Get originator address.

    local n = ++attempts[orig]; # Increase counter.

    if ( n == SOME_THRESHOLD )  # Check for threshold.
        NOTICE(...);            # Alarm.
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Bro plugin compiles scripts into HILTI code.

HILTI compiles that into executable code just-in-time.

Evaluation

Use HILTI plugin for Bro to compare parsing & script execution with a native Bro.

Traces: HTTP: 1/25 of Berkeley port 80 traffic.
30GB trace, 52min, 340k messages.

DNS: Full Berkeley port 53 traffic.
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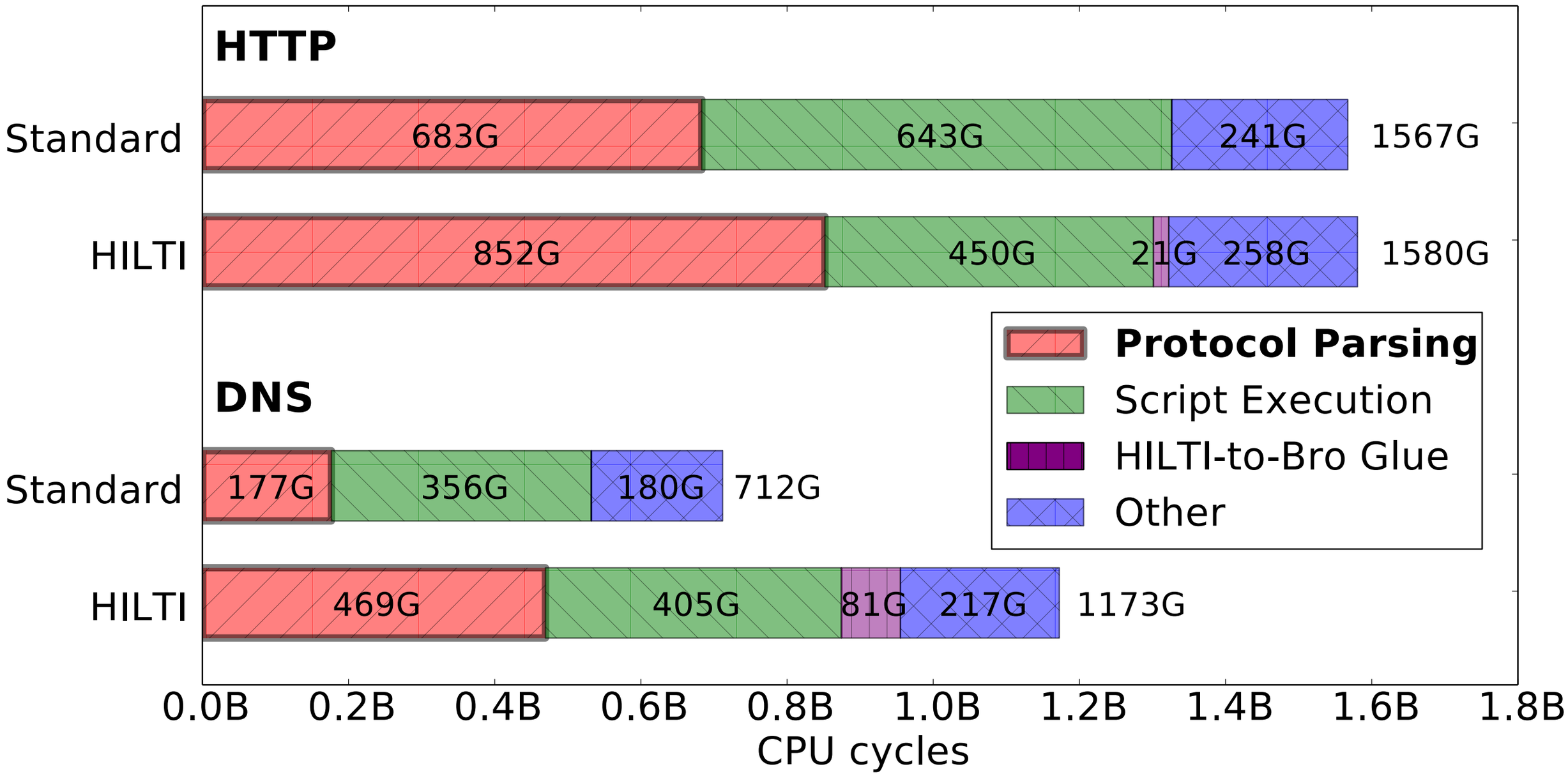
Performance

Let's see.

Protocol Parsing



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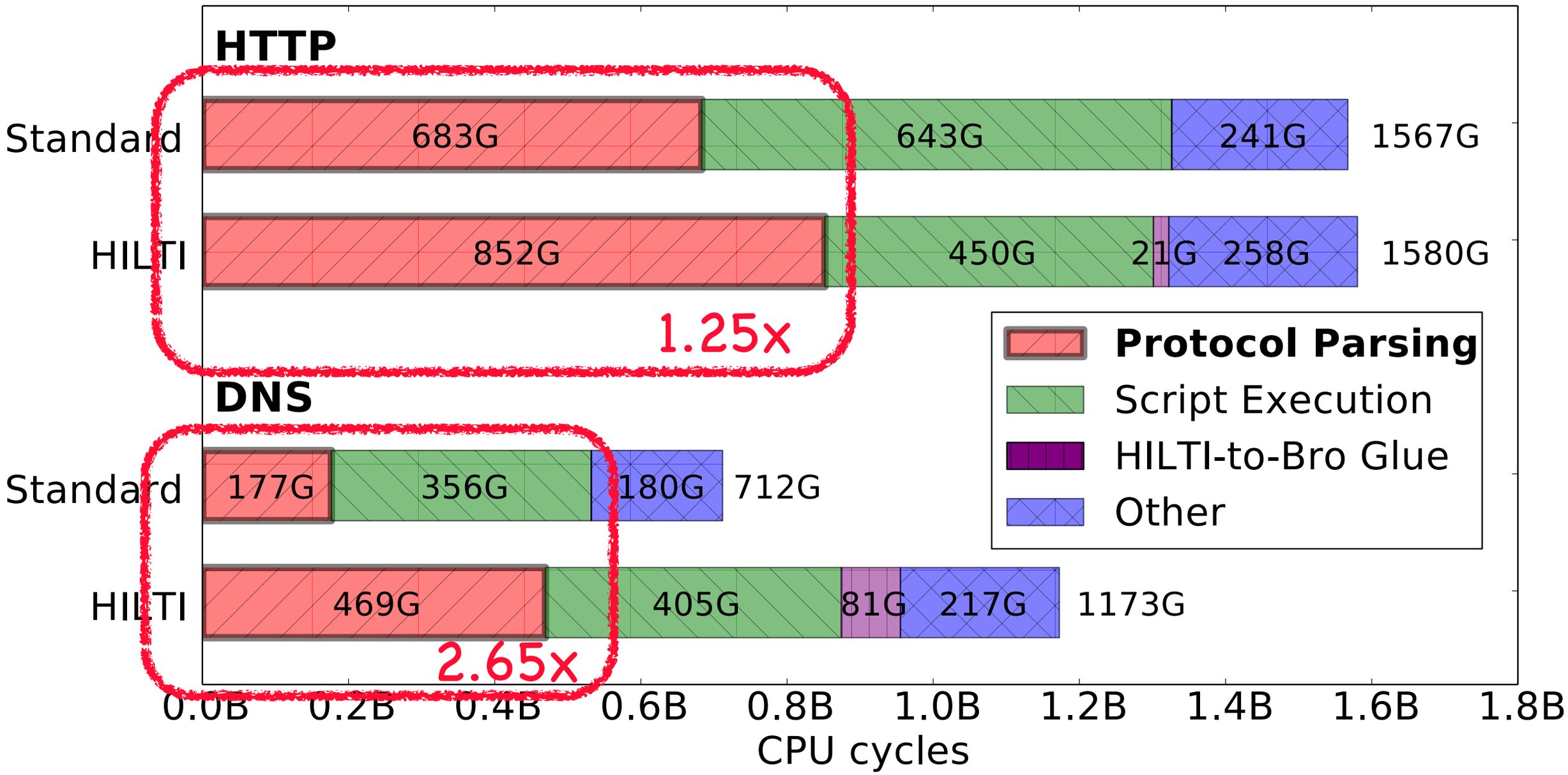

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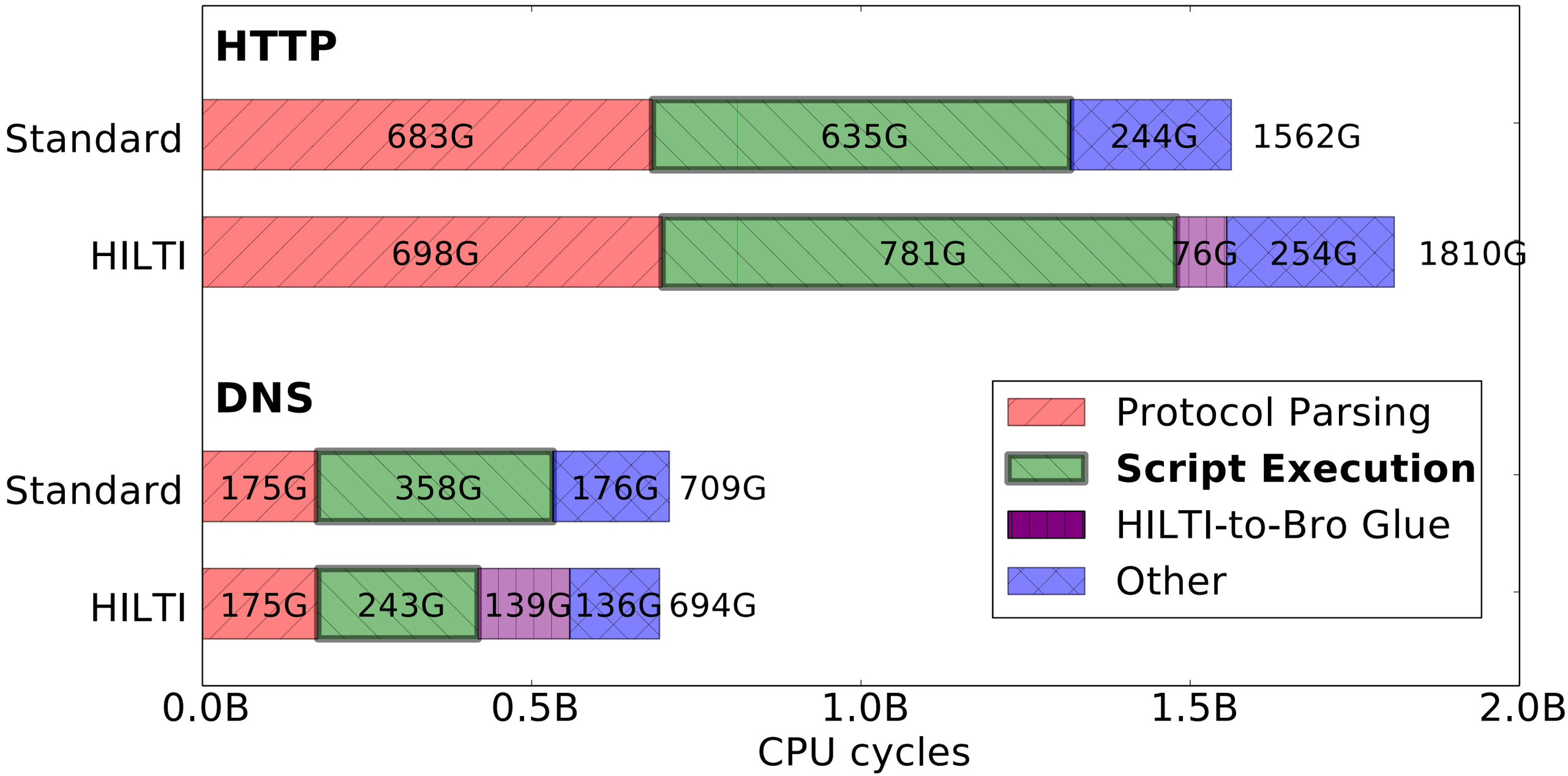
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Protocol Parsing
Script Execution
HILTI-to-Bro Glue
Other
0.0B
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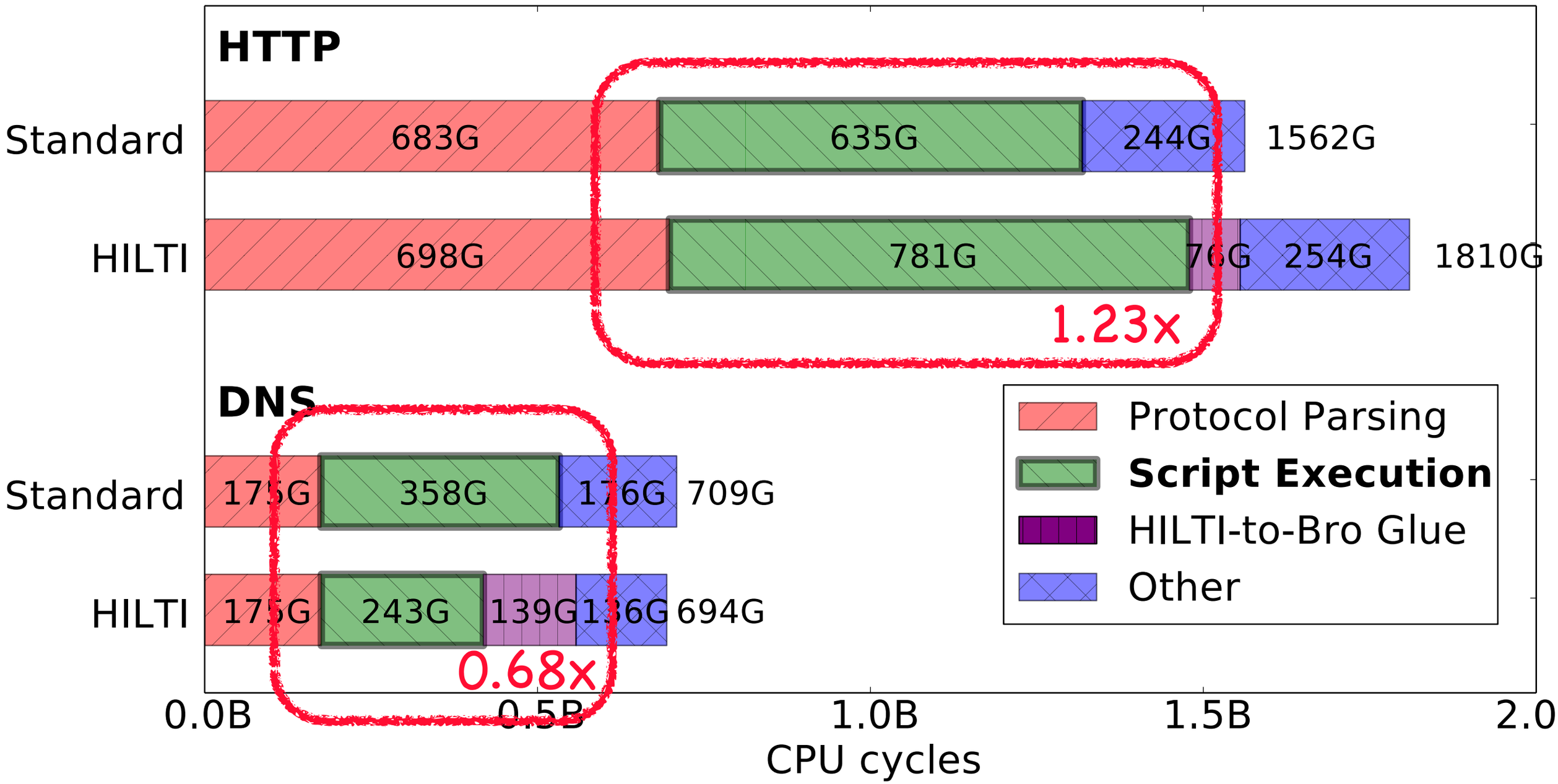
CPU cycles

Bro Scripts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Summary

HILTI: A new platform for network traffic analysis.

- A compiler-target for host applications to leverage.
- Provides common data structures and control flow primitives.

Case studies demonstrate aptness of design.

- Packet filter, stateful firewall, protocol parsing, Bro scripts.

Initial performance experiments encouraging.

- Not too different from native applications.
- It's still a prototype, with lots of potential.

The HILTI Vision

Performance via Abstraction

Transparent improvement under the hood.
Integration of non-standard hardware.
High-level compiler optimizations.
Automatic parallelization.*

Facilitate Reuse

Means and glue to share functionality.
HILTI library of common high-level components.

* De Carli/Sommer/Jha: “Beyond Pattern Matching: A Concurrency Model for Stateful Deep Packet Inspection”. ACM CCS 2014.

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HILTI is available under BSD license at

`http://www.icir.org/hilti`

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