Spicy: A Unified Deep Packet Inspection Framework Dissecting All Your Data

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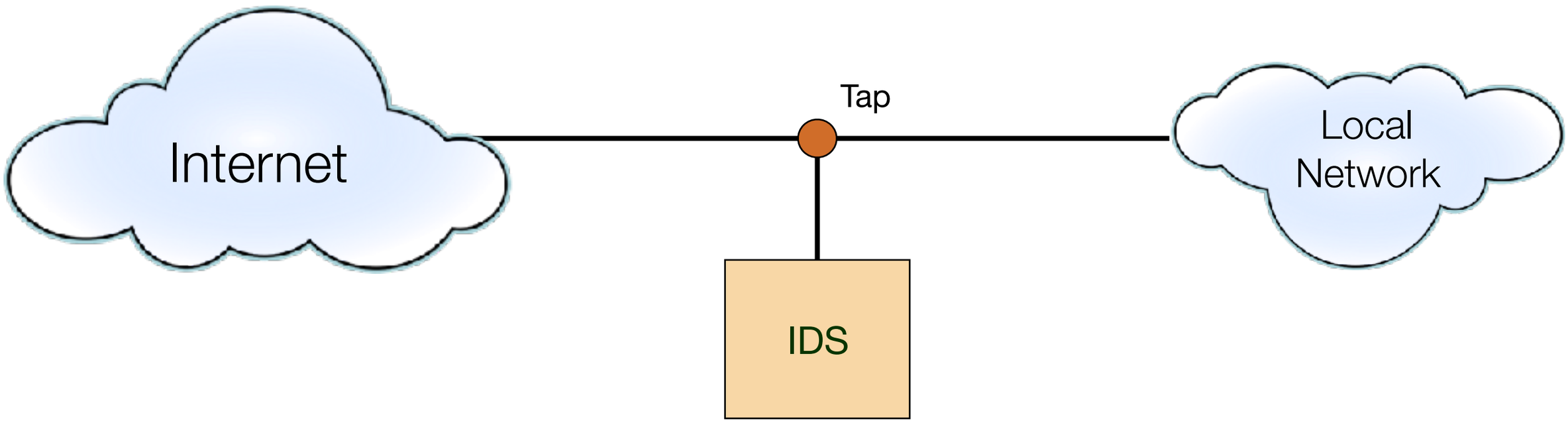
Deep Packet Inspection



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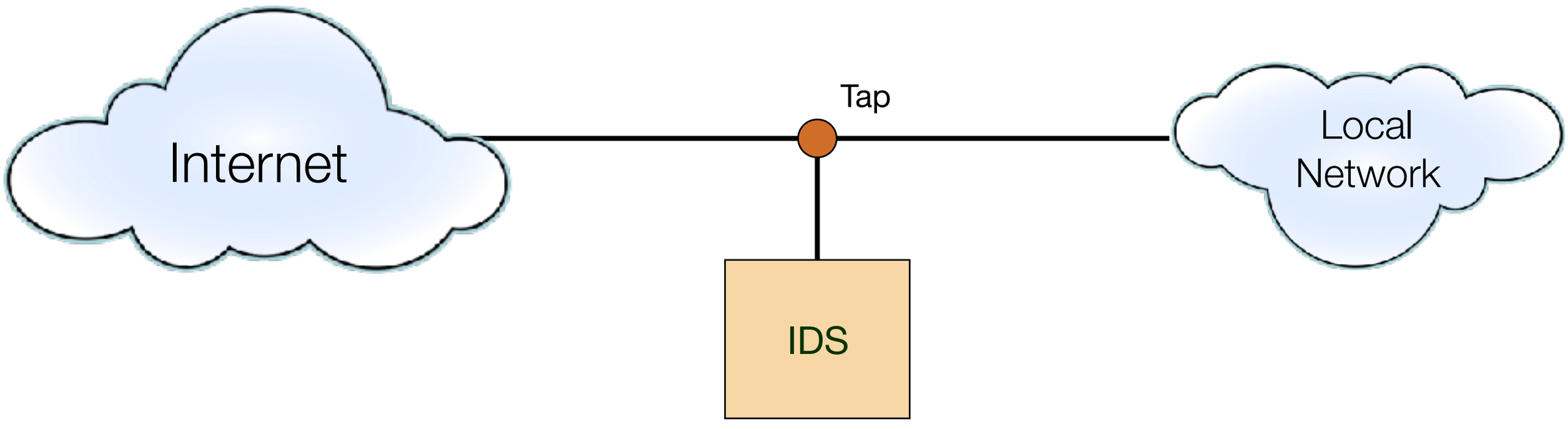

Example: Finding downloads of known malware.

1. Find and parse all Web traffic.
2. Find and extract binaries.
3. Compute hash and compare with database.
4. Report, and potentially kill, if found.

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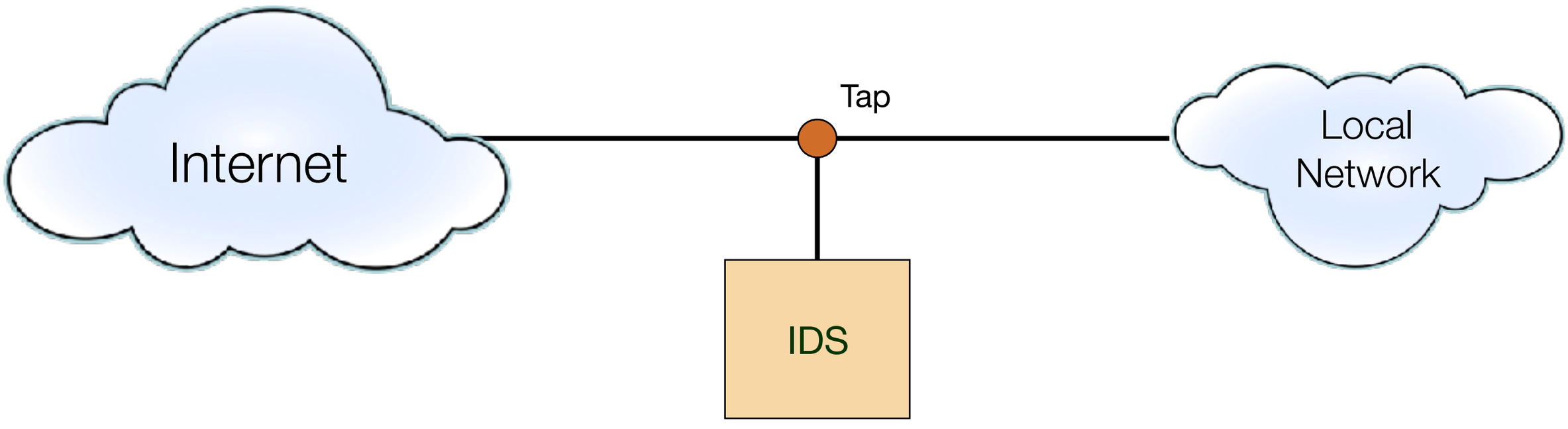

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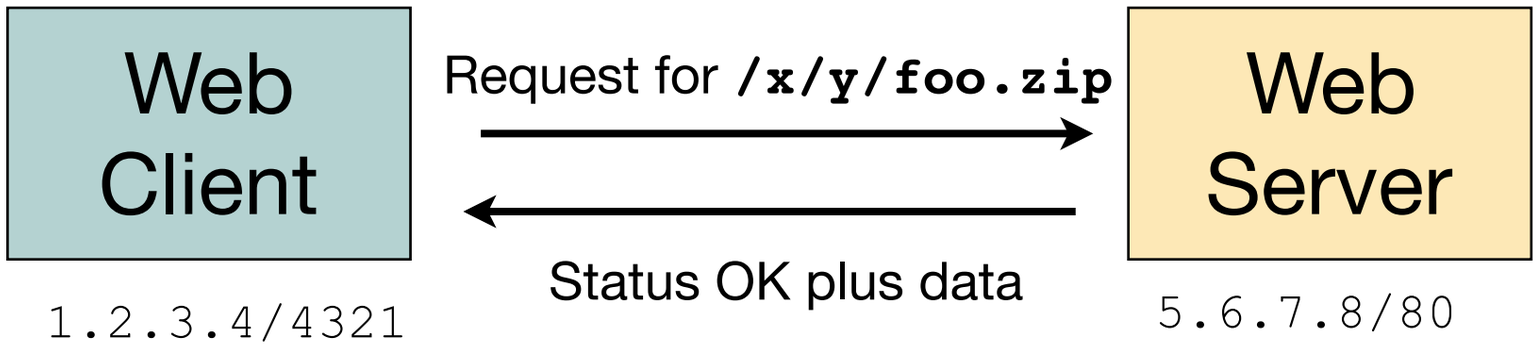
Protocol Parsing



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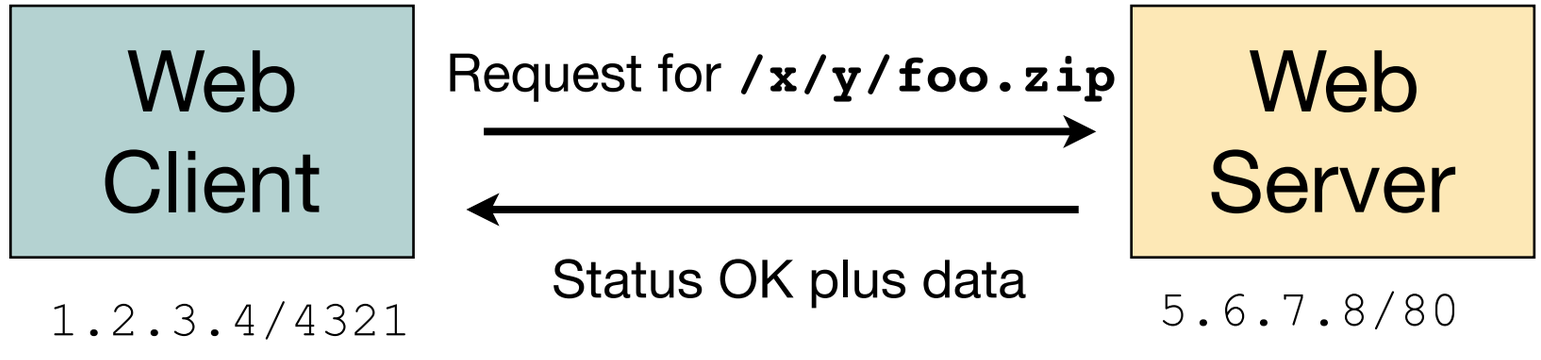

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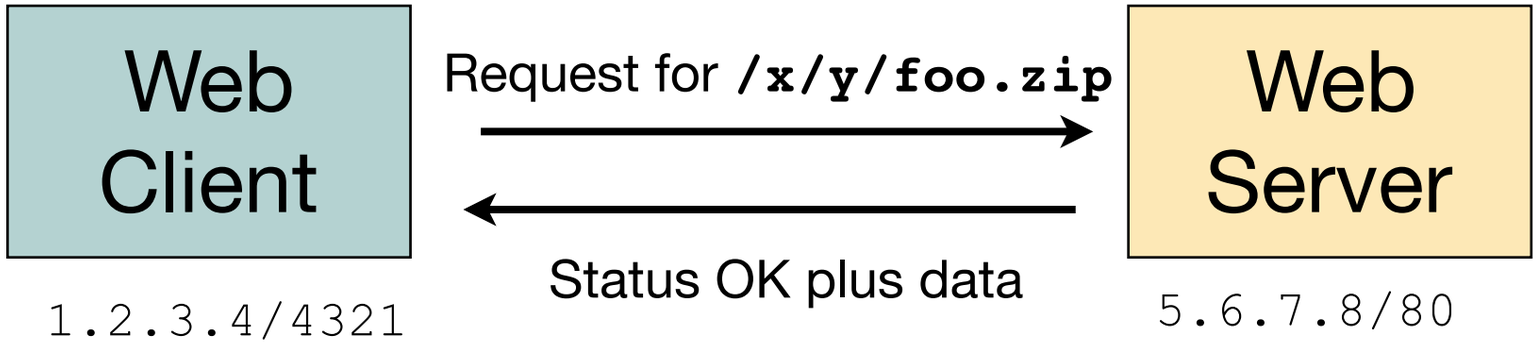

→ TCP connection established

```
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TCP stream reassembly for originator

→ Request for /x/y/foo.zip, protocol version 1.1, HTTP headers

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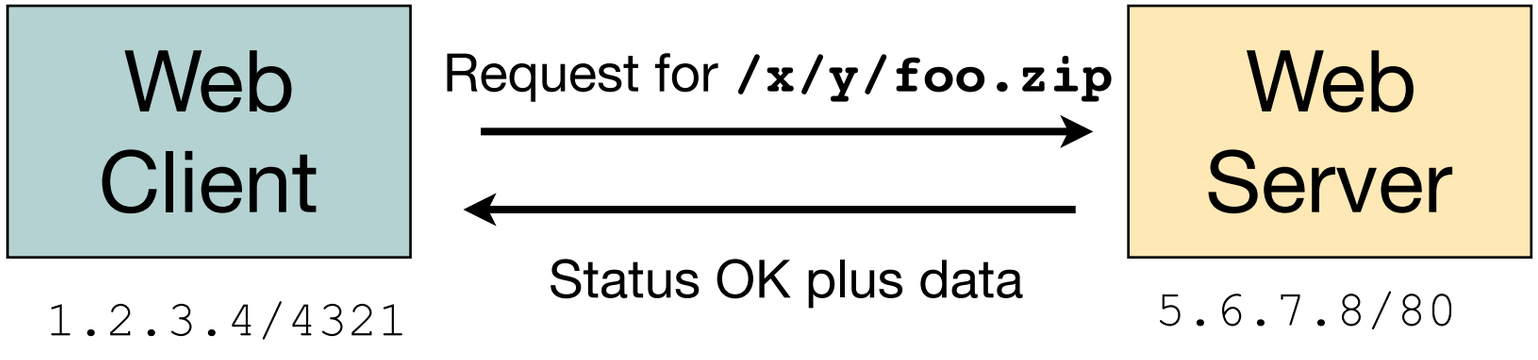

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→ Reply with page content for further analysis (e.g., hash; unpack & parse files)

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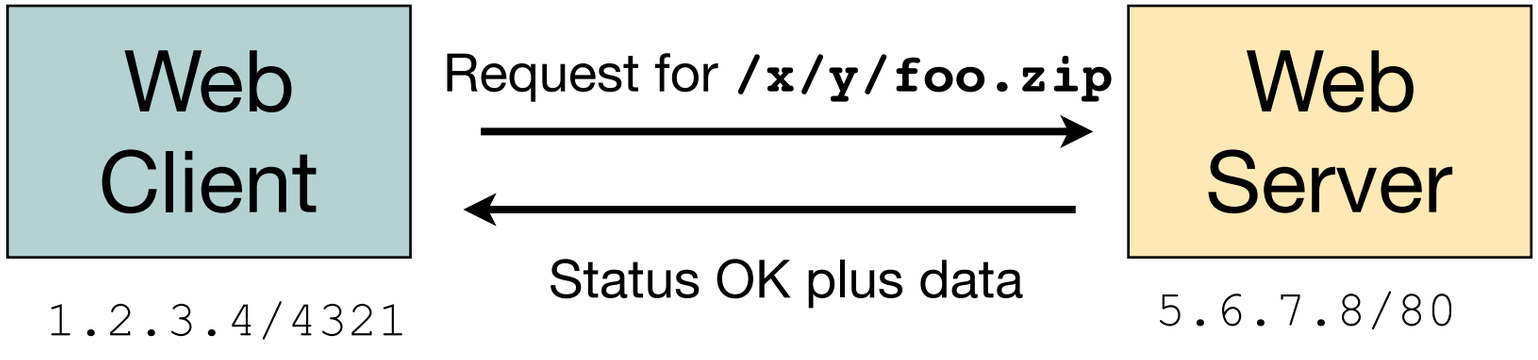

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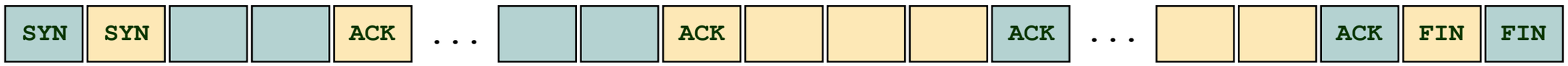
TCP stream reassembly for responder

↳ Reply with page content for further analysis (e.g., hash; unpack & parse files)

↳ TCP connection tear down

Parsing Is Hard



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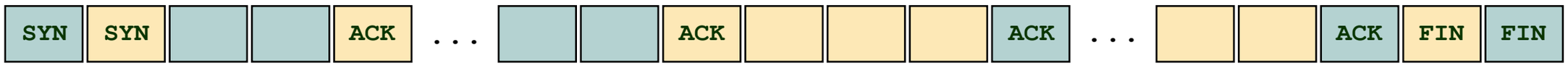

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- Cannot trust input

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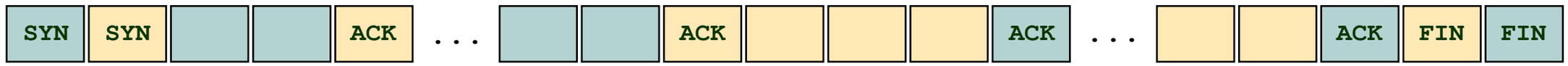

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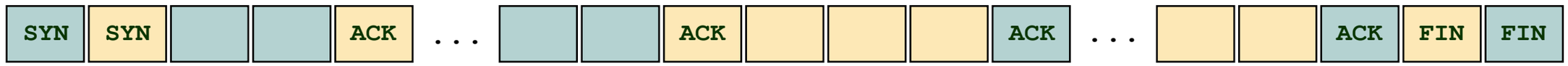

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Must be efficient

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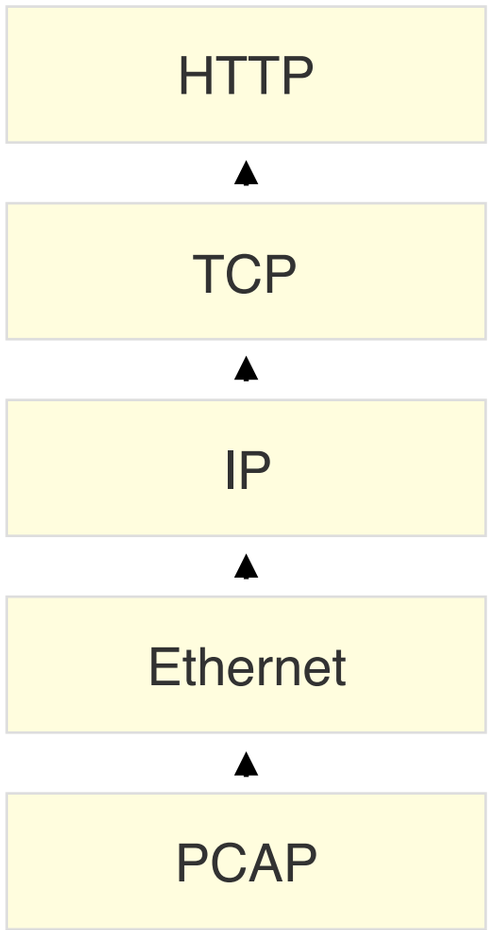
Must be complete

- Leaving out parts of the protocol opens evasion opportunities
- Protocols can be really complex (SMB …)

There are a lot of protocols out there …



Even a simple case involves 5 protocols

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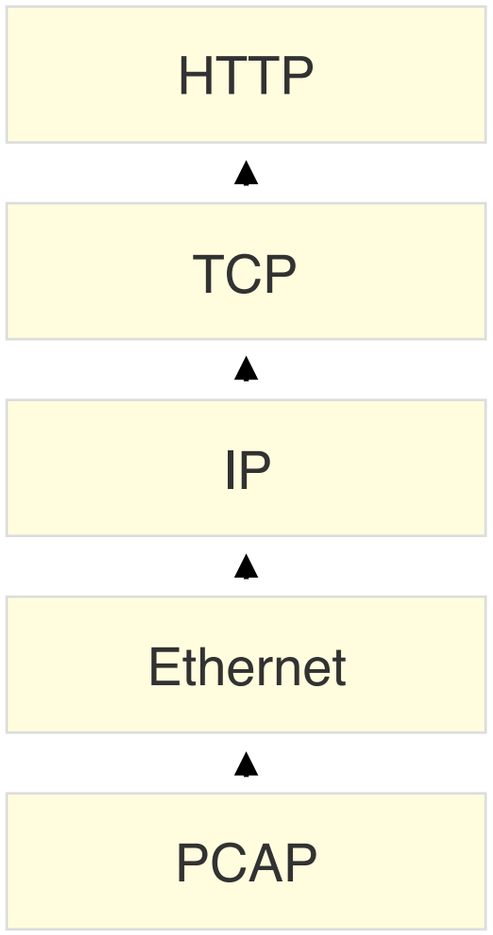

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(e.g., TCP/IP, HTTP, TLS, DNS, SMTP, IMAP)

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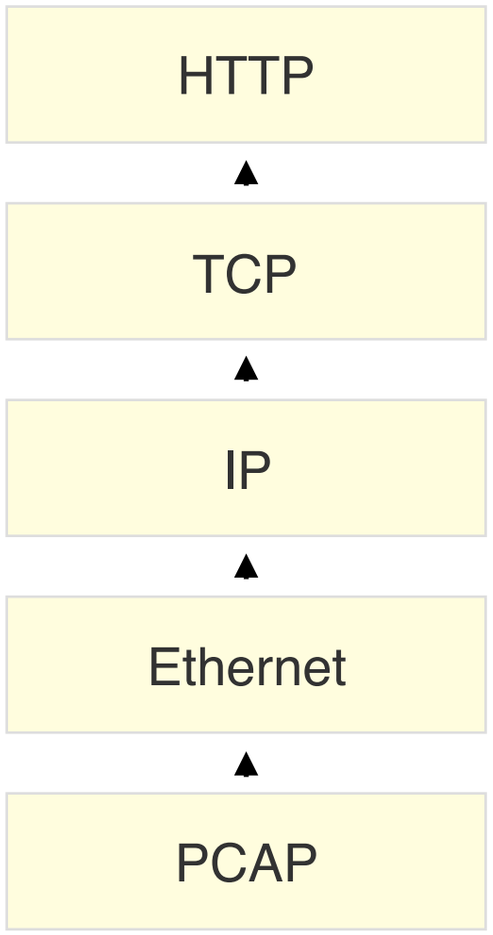

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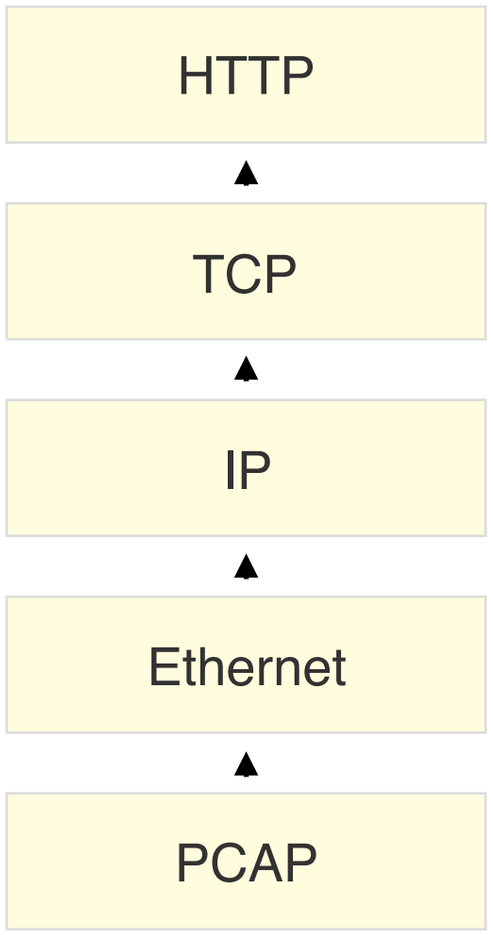

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File formats amplify the challenge

Example: Bro 2.5

AYIYA	Kerberos	
BitTorrent	Login	SIP
DCE_RPC	Modbus	SMTP
DHCP	MySQL	SNMP
DNP3	NCP	SOCKS
DNS	NFS	SSH
DTLS	NTP	SSL
FTP	NetBIOS	Syslog
Finger	PE	TCP
GTPv1	POP3	Telnet
Gnutella	Portmapper	Teredo
HTTP	Radius	UDP
ICMP	RDP	X509
IPv4/6	Rlogin	ZIP
IRC	Rsh	
Ident	SMB	

A Tale of Three Open-Source IDS

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Shared parsers?

None.

Every DPI application rewrites its parsers — usually in C/C++!

Opportunity: Provide Platform for Parsers

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Protocols leverage a rather small set of patterns

- Readable line-based formats for text protocols
- Static “prototocol data units” (PDU) for binary protocols
- Request/response structure
- Common sub-formats (HTTP/MIME/ASN.1)
- Fragmentation (even at app layer!)

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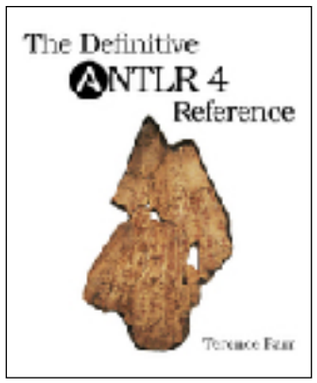
Can we leverage similarities, while remaining flexible?

Can we reuse code across applications?

Meanwhile, in another domain …

There are powerful tools for implementing parsers for programming languages.



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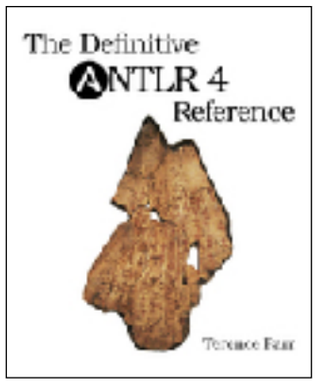


```
exp: NUM               { $$ = $1;         }
   | exp '+' exp       { $$ = $1 + $2; }
   | exp '-' exp       { $$ = $1 - $2; }
   | exp '*' exp       { $$ = $1 * $2; }
   | exp '/' exp       { $$ = $1 / $2; }
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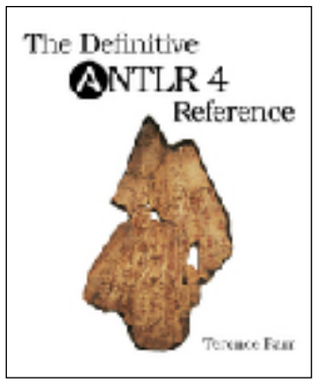


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Yacc → **yyparse()** → Host Application

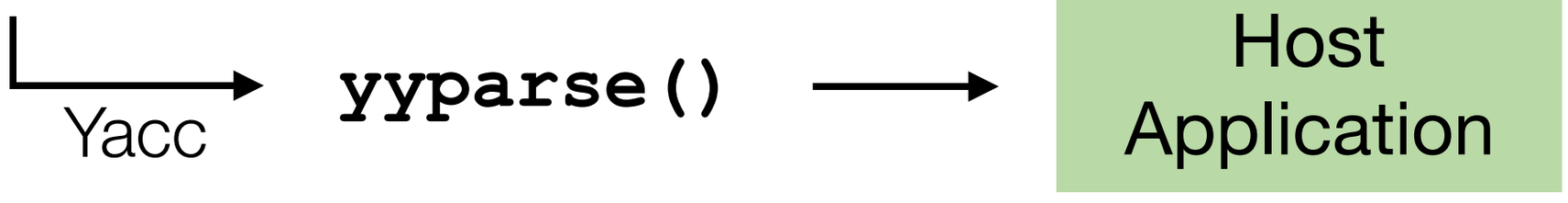
Meanwhile, in another domain …

There are powerful tools for implementing parsers for programming languages.

These parsers aren't suitable for DPI, unfortunately.

No support for concurrent, incremental processing

No support for domain-specific idioms



Domain-specific Parser Generation

binpac: A yacc for Writing Application Protocol Parsers

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IMC 2006

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```
type ClientHello(rec: HandshakeRecord) = record {
    client_version: uint16;
    gmt_unix_time : uint32;
    random_bytes  : bytestring &length = 28;
    session_len   : uint8;
    session_id    : uint8[session_len];
    dtls_cookie   : case client_version of {
        DTLSv10, DTLSv12 -> cookie : ClientHelloCookie(rec);
        default          -> nothing: bytestring &length=0;
    };
    […]
}
```

TLS v3 Client Hello (Source: Bro's TLS analyzer)

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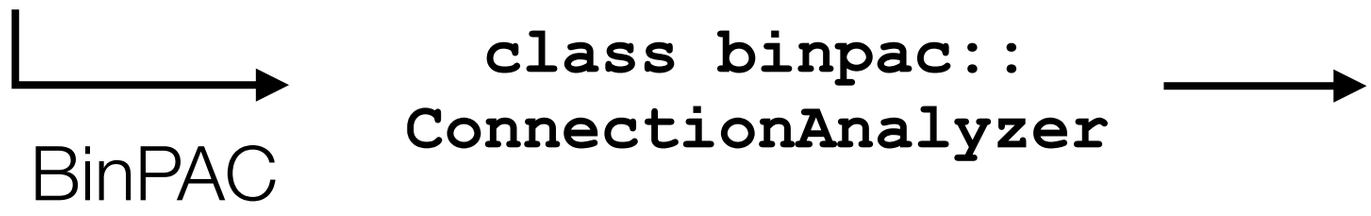

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BinPAC works, but solves the problem only partially.

Remains limited to syntax, cannot express logic.

Still needs custom C++ for logic & integration.

Remains limited to app protocols & connection structure.

Lacks support for higher-level idioms.

BinPAC → `class binpac::ConnectionAnalyzer` → Host Application

New Framework: Spicy

Integrates experience from many years of writing parsers manually and with BinPAC.

corelight

New Framework: Spicy

Integrates experience from many years of writing parsers manually and with BinPAC.

Expresses both syntax and logic

Supports protocols and file formats

Facilitates composition and reuse

Supports error handling and recovery

Just-in-time compilation via LLVM

Spicy Example: Parsing SMTP Banners

```
220 mx.foo.com ESMTP Postfix
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```
module SMTP;

export type Greeting = unit {
                : /220 +/;
    domain      : /[^ ]+/;
                : / */;
    protocol: /(E?SMTP)?/;
                : / */;
    software: /[^ ]*/;

    on %done { print self; }
}
```

smtp.spicy

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```

smtp.spicy

```
# echo "220 mx.foo.com ESMTP Postfix" | spicy-driver smtp.spicy
<domain=mx.foo.com, protocol=ESMTP, software=Postfix>
```

Host Application API

```
# Compile Spicy code just-in-time (C++)

auto ctx = new spicy::CompilerContext();

atuo llvm_module = ctx->compile(“smtp.spicy”);

auto linked_module = ctx->linkModules("SMTP", llvm_module);

auto jit = ctx->jit(linked_module);

auto parse_func = jit->nativeFunction(“smtp_greeting_parse”)
auto resume_func = jit->nativeFunction(“smtp_greeting_resume”)
```

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```

```
# Feed data into parser (C).

hlt_bytes* data = hlt_bytes_new_from_data(“220 mx.foo.”);
void* cookie = (*parse_func)(data);

hlt_bytes* next = hlt_bytes_new_from_data(“.com ESMTP Postfix”);
hlt_bytes_append(data, next);
cookie = (*resume_func)(cookie);
```

A File Format: Tar

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```
module tar;

export type Archive = unit {
   files: list<File>;
        : uint<8>(0x0);
        : bytes &length=511;
};

type File = unit {
   header: Header;
   data  : bytes &length=self.header.size;
         : bytes &length=512-(self.header.size mod 512)
};

type Type = enum {
   REG=0, LNK=1, SYM=2, CHR=3, BLK=4, DIR=5, FIFO=6
};
```

```
type Header = unit {
 name  : bytes &length=100;
 mode  : bytes &length=8;
 uid   : bytes &length=8;
 gid   : bytes &length=8;
 size  : bytes &length=12 &convert=$$.to_uint(8);
 mtime : bytes &length=12 &convert=$$.to_time(8);
 chksum: bytes &length=8  &convert=$$.to_uint(8);
 tflag : bytes &length=1  &convert=$$.to_uint(8);
 lname : bytes &length=100;
       : bytes &length=88; # Skip further fields
 prefix: bytes &length=155;
       : bytes &length=12;.

 var full_path: bytes;

 on %done {
  if ( ! self.tflag ) self.tflag = Type::REG;
  self.full_path = self.prefix + b"/"+ self.name;
 }
```

A File Format: Tar

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module tar;

export type Archive = unit {
   files: list<File>;
        : uint<8>(0x0);
        : bytes &length=511;
};

type File = unit {
   header: Header;
   data  : bytes &length=self.header.size;
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type Type = enum {
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```

```
# tar tvf mp.tar
foobar/staff       0 2016-05-15 18:58 mp/
foobar/staff   39548 2016-05-15 18:58 mp/part01.txt
foobar/staff   39503 2016-05-15 18:58 mp/part02.txt*/

# cat print-tar.spicy
module PrintTar;

import tar;

on tar::Archive::%done {
 print self.files;
}

# cat mp.tar | spicy-driver tar.spicy print-tar.spicy
[<header=<name=b"mp/", mode=b"000755", uid=b"000771",
  gid=b"000024", size=0, mtime=2016-05-16T02:58:19Z,
  chksum=5100, tflag=DIR>, data=b"",
   […], full_path=b"mp/">]

[<header=<name=b"mp/part01.txt", mode=b"000644",
 uid=b"000771", gid=b"000024", size=39548,
 mtime=2016-05-16T02:58:19Z, chksum=6351, tflag=REG>,
 data=b"A seashore. Some way out to sea […]",
 […], full_path=b"mp/part01.txt">]


[<header=<name=b"mp/part02.txt", mode=b"000644",
 uid=b"000771", gid=b"000024", size=39503,
 mtime=2016-05-16T02:58:11Z, chksum=6348, tflag=REG>,
 data=b"A man appears on the top of a sand […]",
 […] full_path=b"mp/part02.txt">]
```

Composition: Pipelining Layers

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```
type HTTP::Body = unit(msg: Message, delivery_mode: DeliveryMode) {

  var data: sink;

  on %init {
      # Add parser for body content (e.g., application/x-tar)
      self.data.connect_mime_type(msg.content_type);

      if ( msg.content_encoding == b"gzip" ) {
              self.data.add_filter(Spicy::Filter::GZIP);
 }

  switch ( delivery_mode ) {
    DeliveryMode::EndOfData -> : bytes &eod -> self.data;
    DeliveryMode::Length    -> : bytes &length=msg.content_length -> self.data;
    DeliveryMode::Multipart -> : list<[^\r\n]*\r?\n/> &until($$ == msg.boundary)
                                 foreach { self.data.write($$); }
};
```

Error Recovery

Error Recovery

```
type HTTP::Requests = unit {
    requests: list<Request> &synchronize;
};

type HTTP::Request = unit {
    request: RequestLine;
    message: Message;
};

type HTTP::RequestLine = unit {
    %synchronize-at = /^(GET|POST|HEAD) /;

     method: Token;
           : WhiteSpace;
        uri: Token;
           : WhiteSpace;
           : /HTTP\//;
    version: /[0-9]+\.[0-9]*/;
           : NewLine;
};

type HTTP::Message = unit { ... }
```

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Evaluation: Writing Spicy Parsers

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Protocols	BACnet (ASHRAE/ANSI 135), DNS, Ethernet (IEEE 802.3), PCAP, HTTP, IPv4, RTMP (handshake), SSH (banner), SMTP (greeting), SMB2, TCP, TLS, TFTP, UDP
File Formats	ASF (headers & metadata), ASN.1, Gzip (header), ZIP (header), MS Certificate Store, Tar, X.509 certificates

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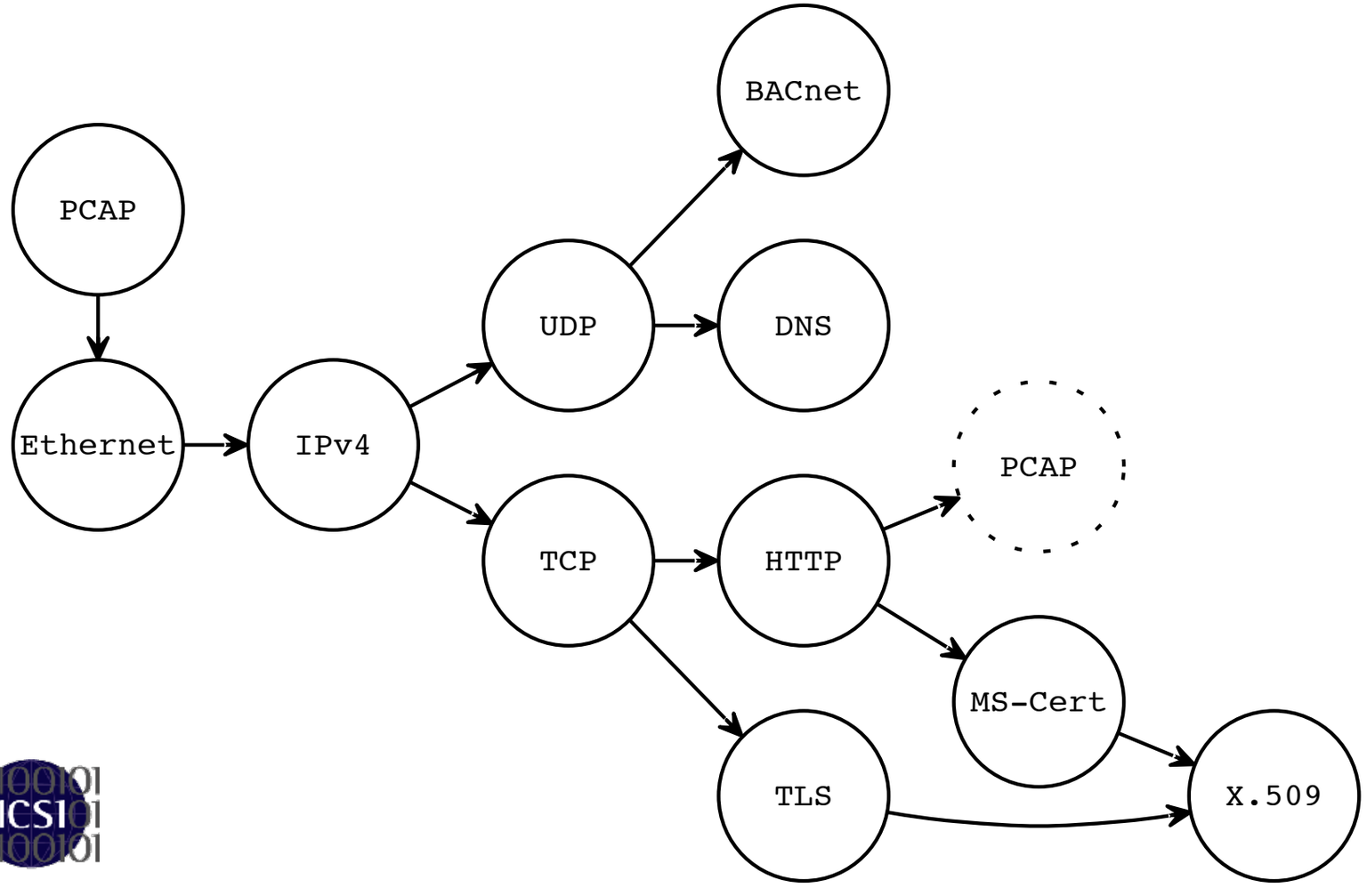

Evaluation: Writing Spicy Parsers

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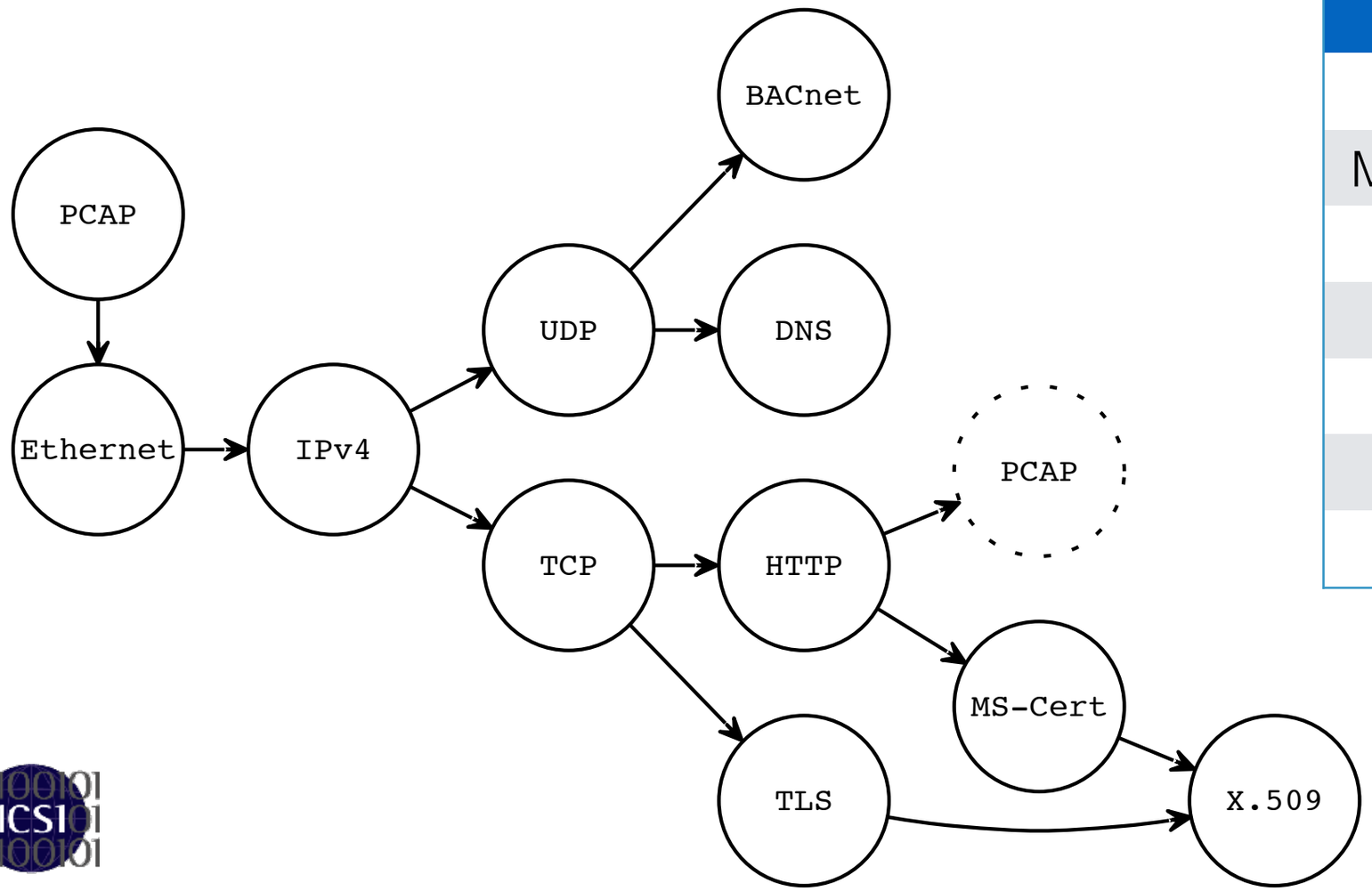

Trace 1
X.509
MS Cert Store
HTTP
TCP
IP
Ethernet
PCAP

Trace 2
X.509
TLS
TCP
IP
Ethernet
PCAP
HTTP
TCP
IP
Ethernet
PCAP

Evaluation: Real-world Performance

Add Spicy plugin for Bro to compare parsing 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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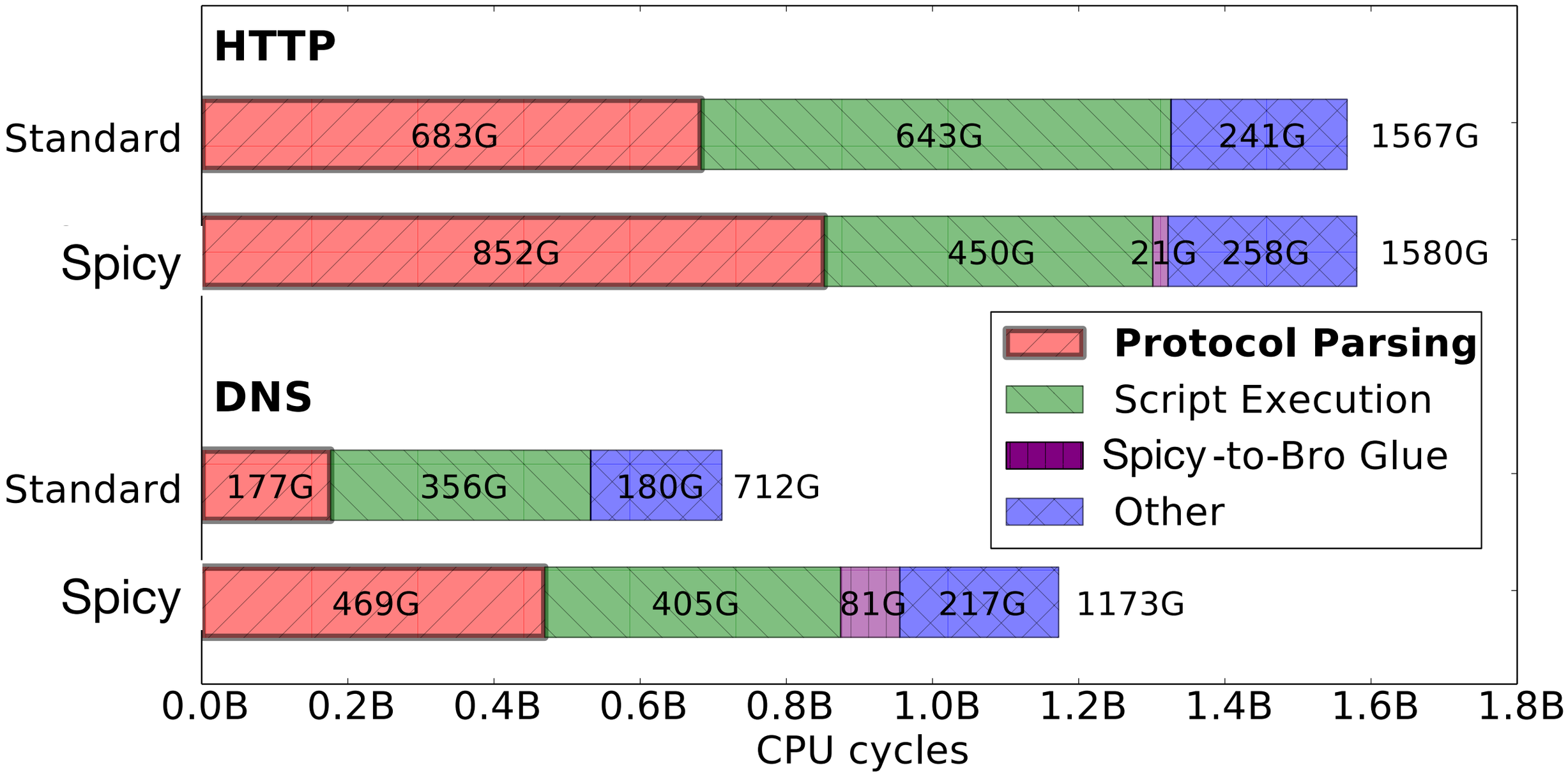
Let's see.

Performance: Spicy vs. C++ in Bro



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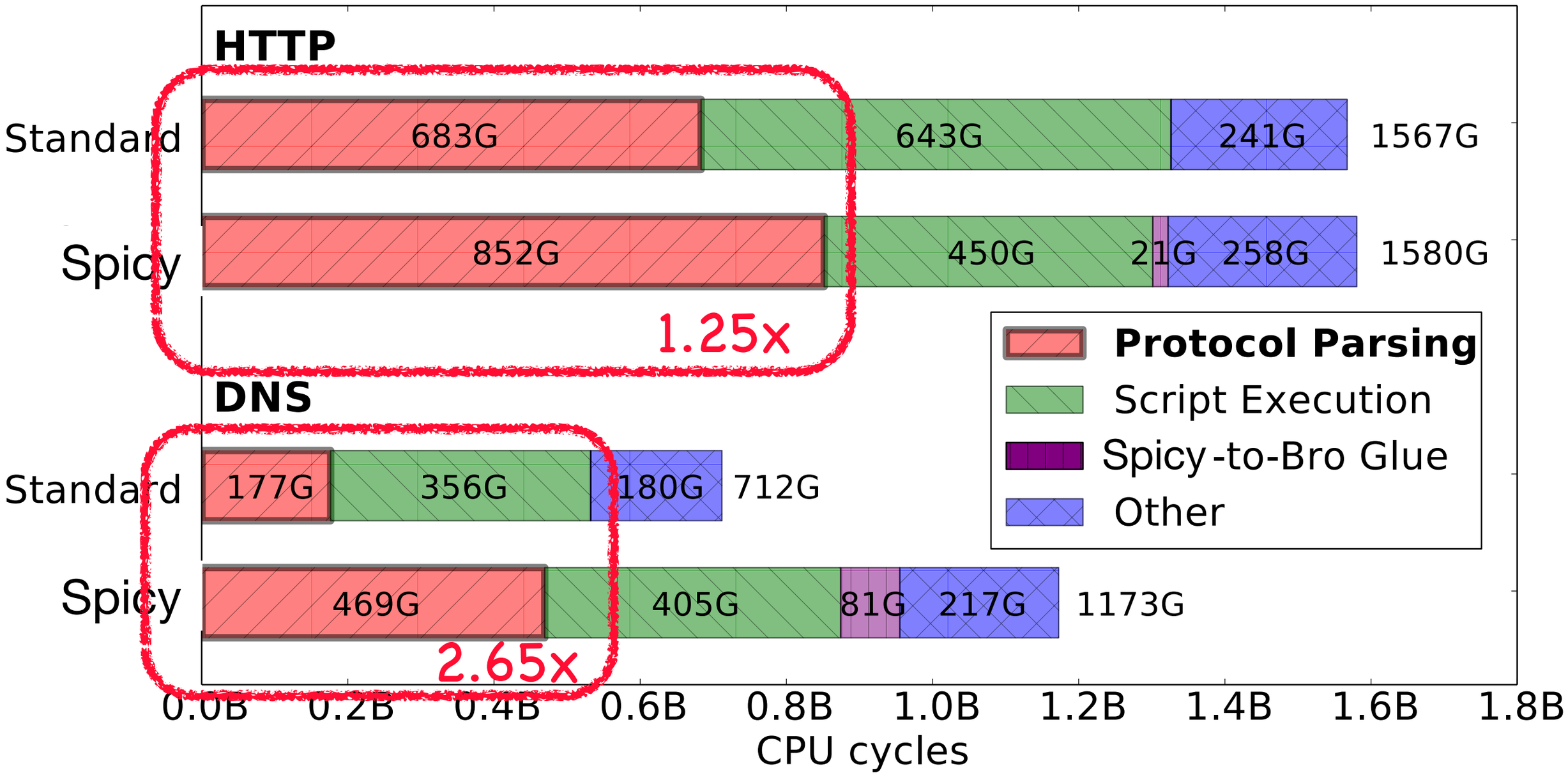

Bro Integration: “3rd Generation Parsers”

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corelight

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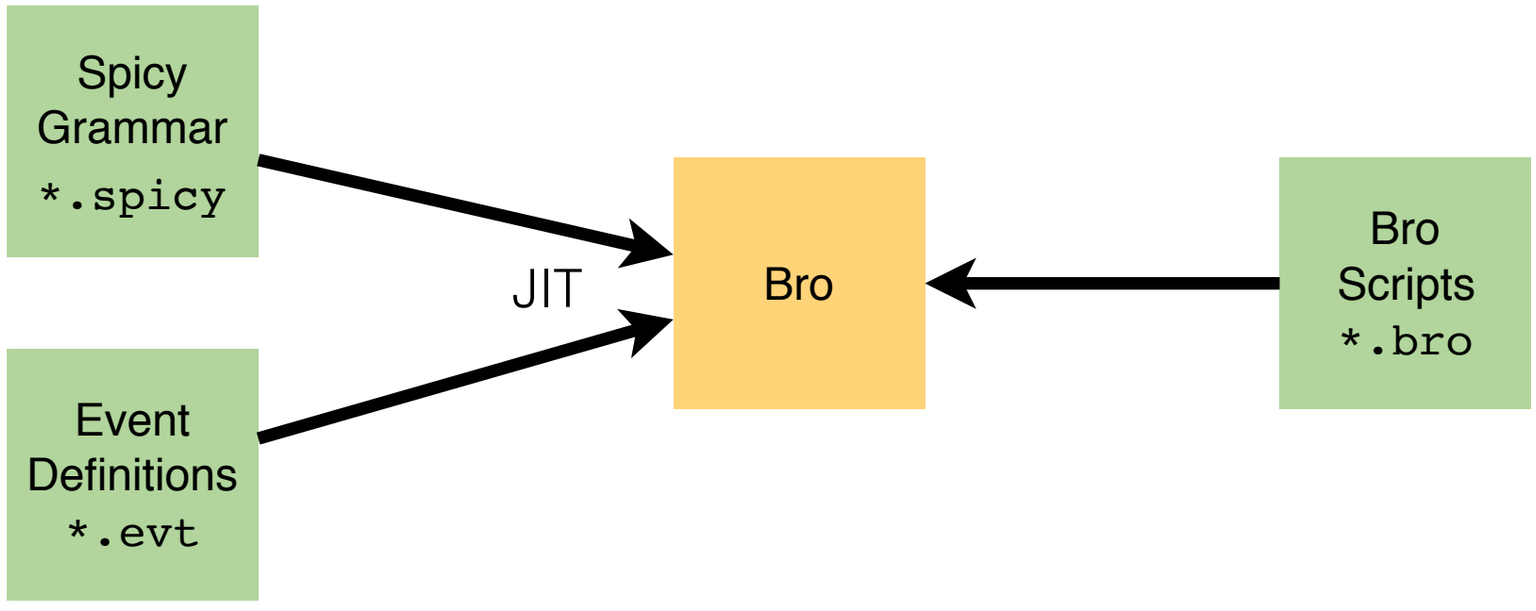
Generation 3: Spicy - A “closed” system.



Advanced Spicy Features

Composibility

Error detection & recovery

Protocol detection

Reassembly/defragmentation

Generating wire format

Implementation: HILTI Toolchain

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

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IMC 2014

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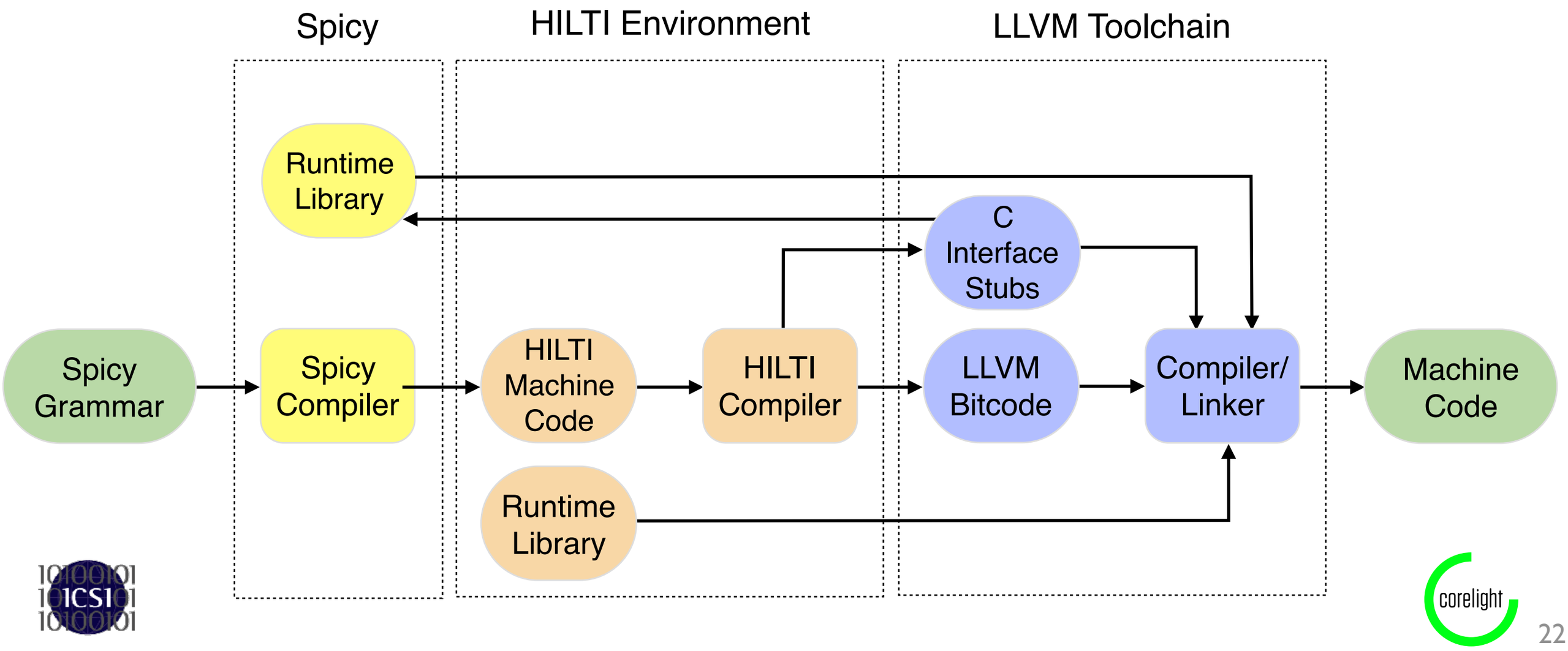

The HILTI Model

Secure Execution Environment

Sandboxed execution

Automatic memory management

Performance via Abstraction

Transparent improvement under the hood

Integration of non-standard hardware

High-level, global compiler optimizations

Automatic parallelization

Facilitating Reuse

Means and glue to share functionality

HILTI library of common high-level components

Summary

Spicy is a next-generation parser generator
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Open-source, BSD-licensed prototype.

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

Questions?

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Corelight is hiring!

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