Packet Mastering

Hack in the Box, 2004

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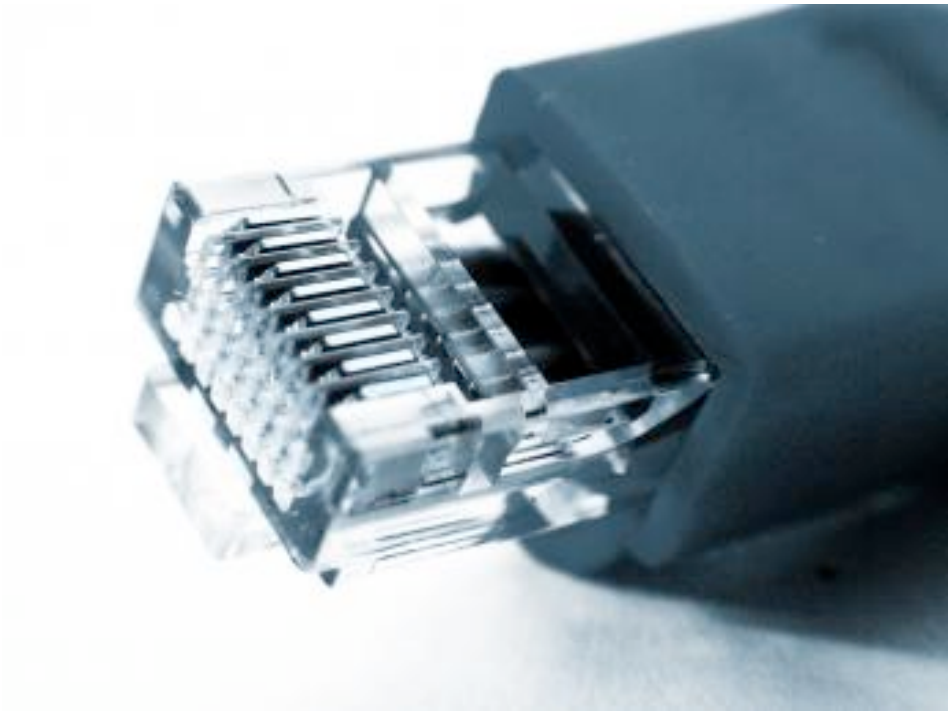
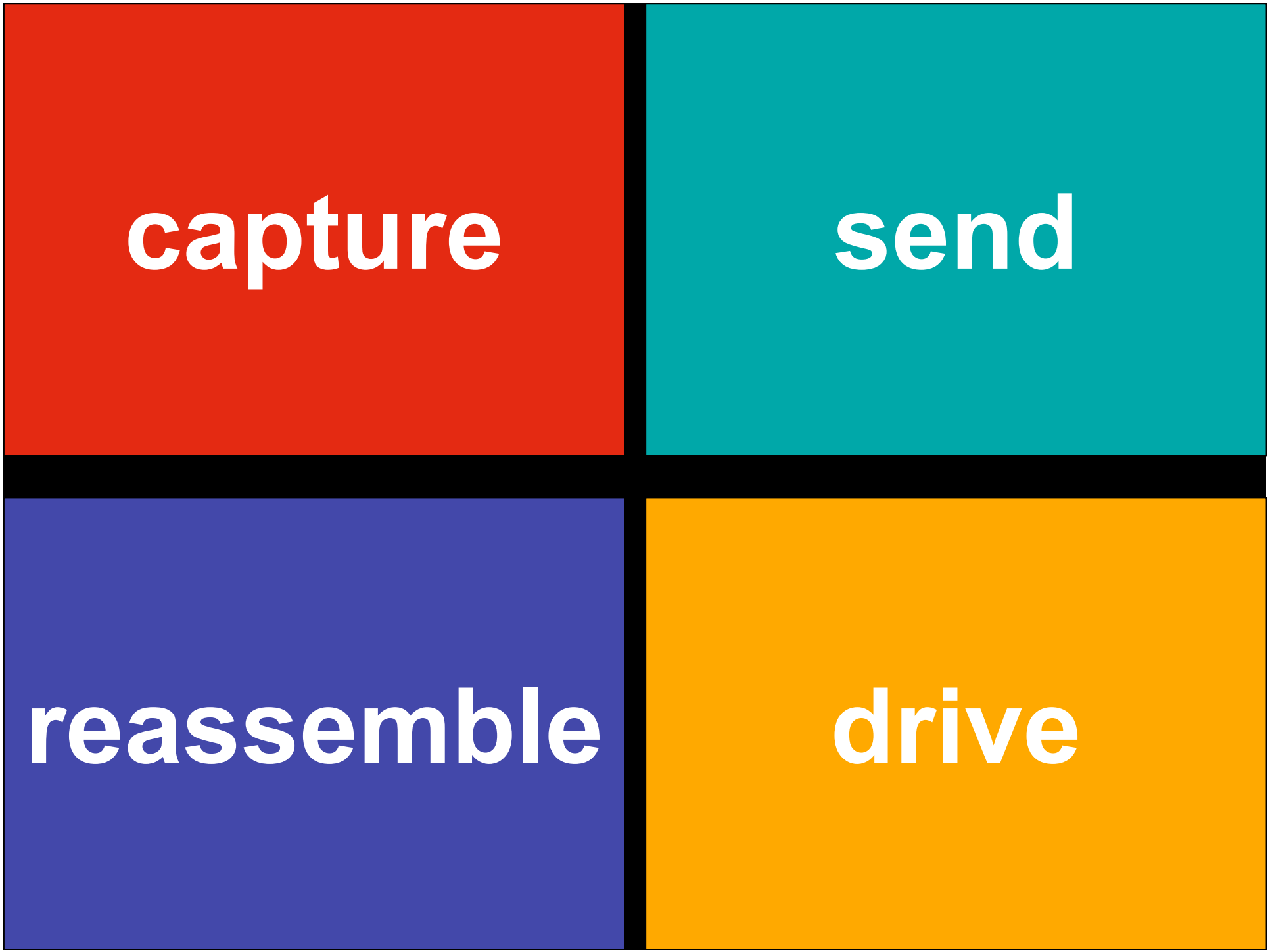
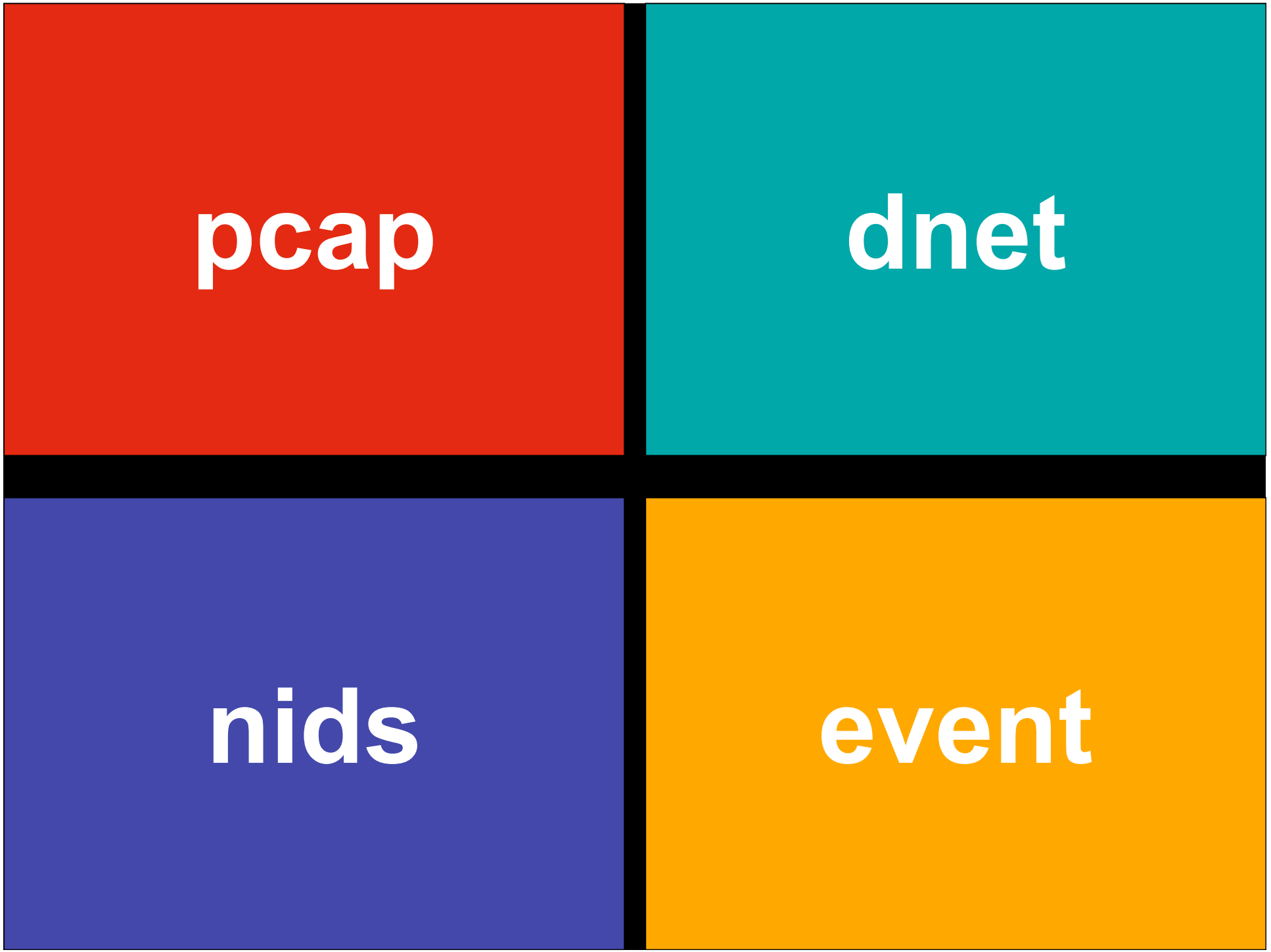
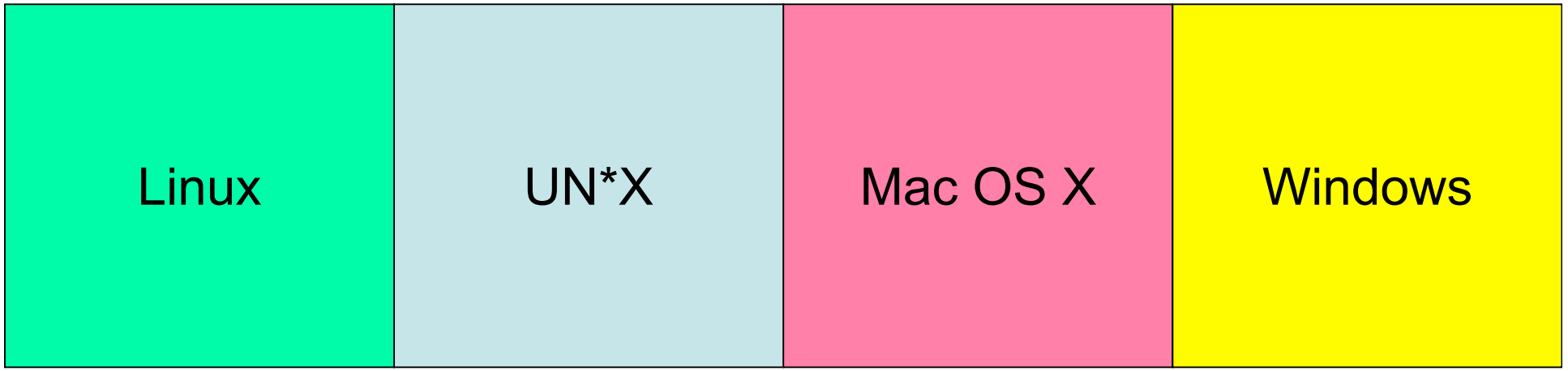
Raw IP vs socket based networking



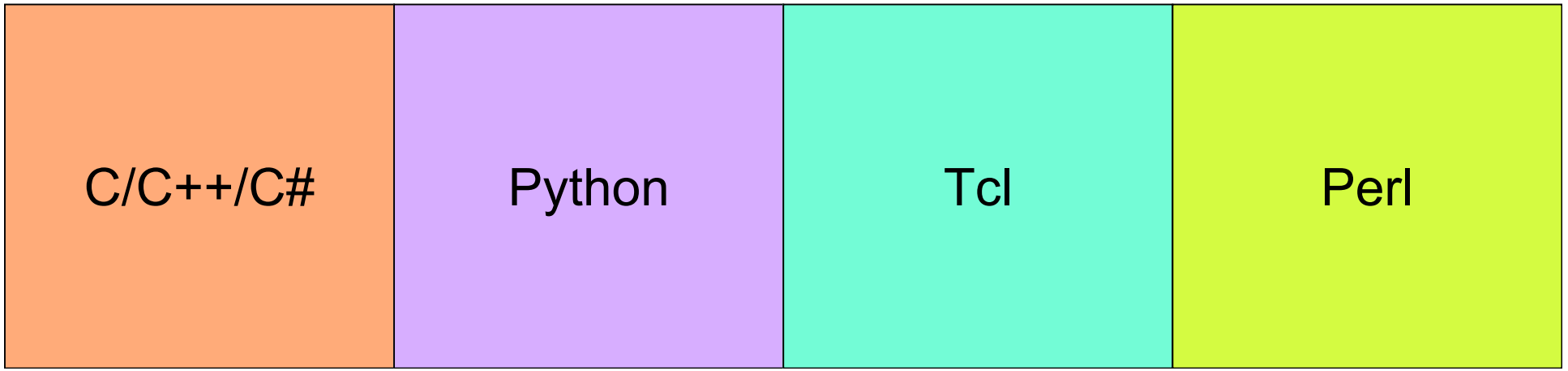

capture
send
reassemble
drive


pcap
dnet
nids
event



cross platform

cross language



libevent – event wrapper library

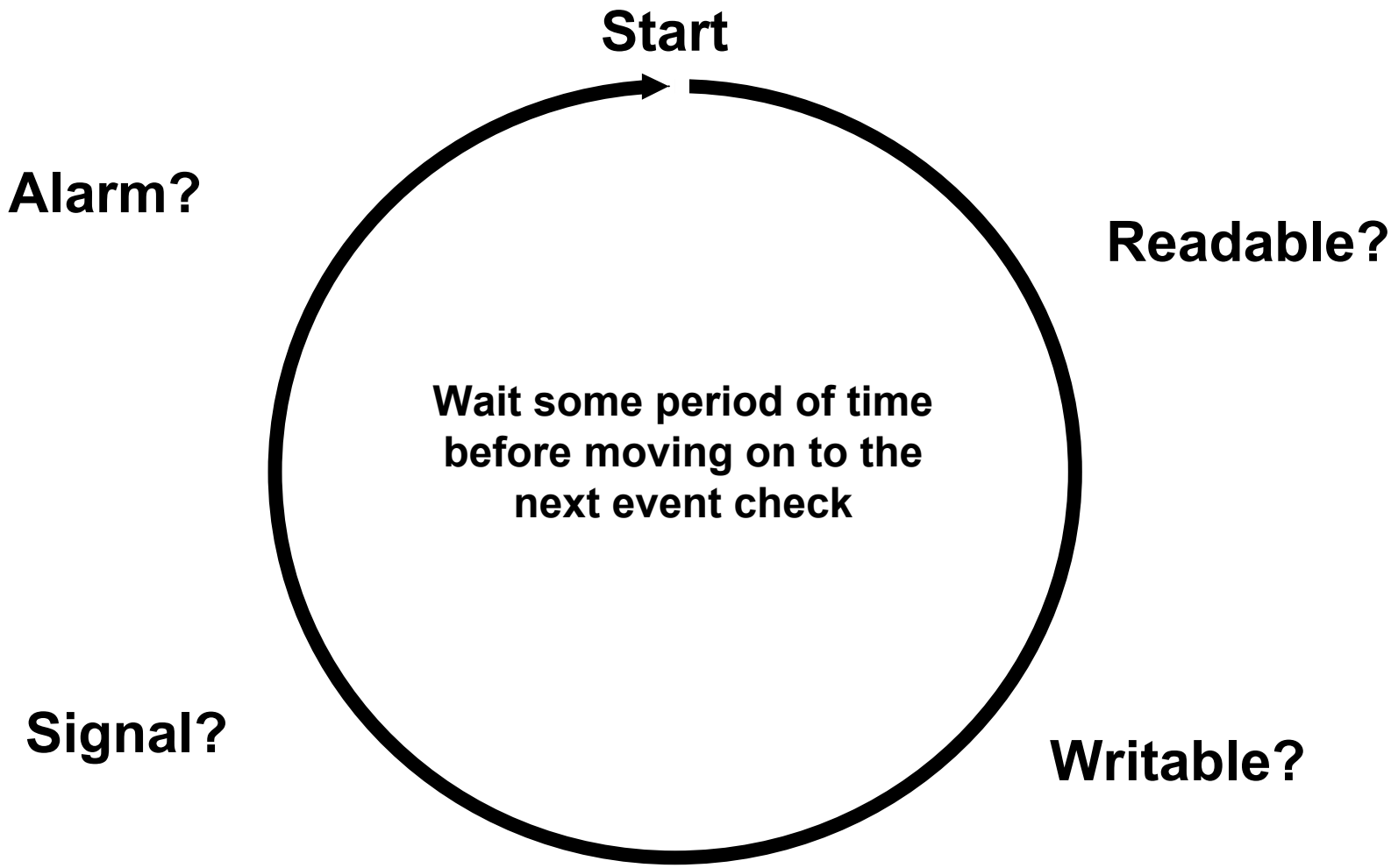
Abstract event framework

- **uses poll(), select(), epoll(), kqueue()**
- **optimized for target platform at libevent compile time**
- **write once, optimized everywhere**
- **handles signals and alarms, too**
- **works on file descriptors**

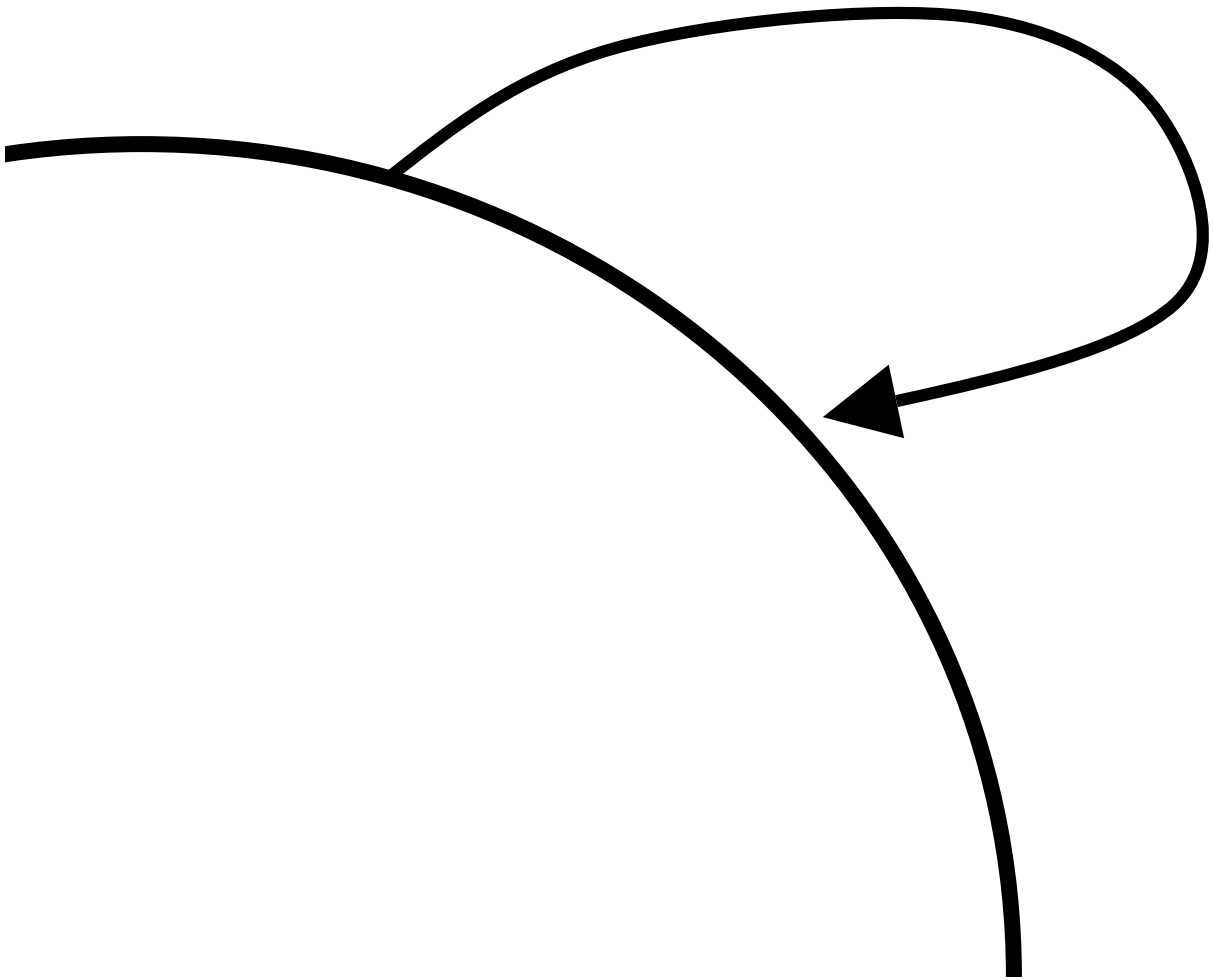
libevent programming basics:

1. Initialize event framework: `event_init()`
2. Create event: `event_set()`
3. Install event into list to check: `event_add()`
4. Run the events: `event_dispatch()`

The Main Event Loop



When an Event Is Caught



Execute callback, return to main event loop.

Pass data to the event. Example: data to write to a file descriptor.

Event is removed from queue upon completion, unless EV_PERSIST is set or the event is rescheduled.

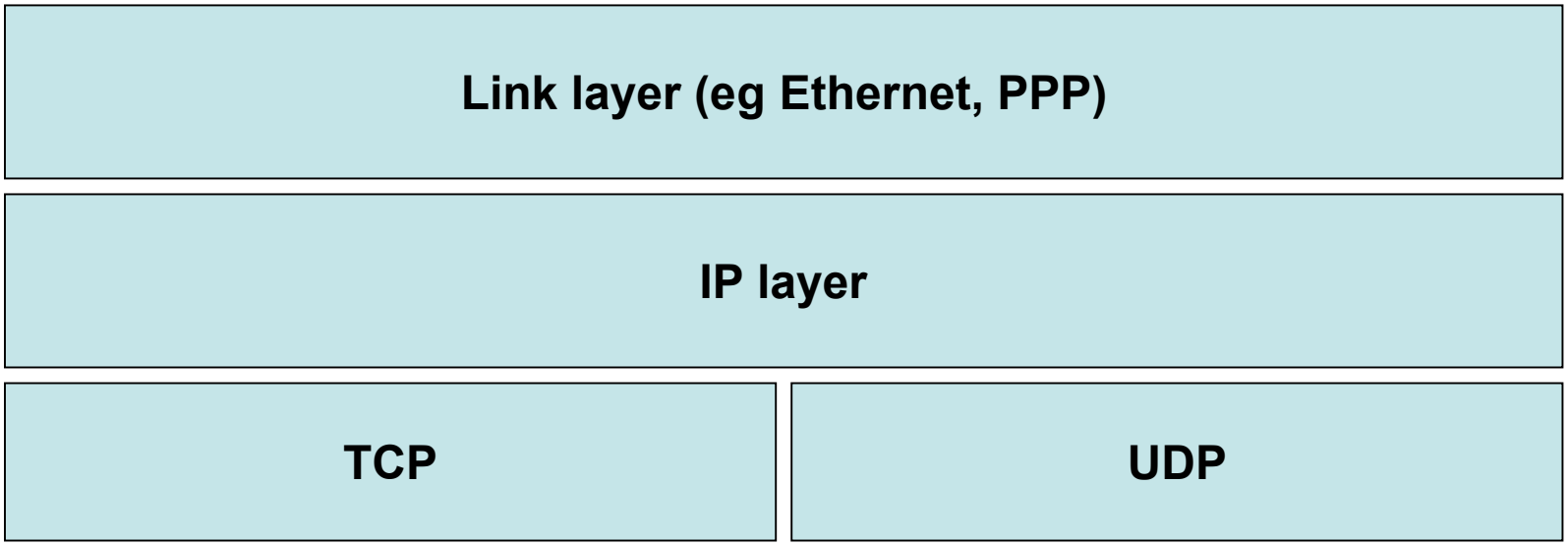
Events vs threads

Both used in high performance programming
Both excellent for high performance packet actions

- Spawn threads for tasks (read, write, process)
- Any thread can wait until it has input, overall program still moves
- Threads are difficult to debug
- Threads can deadlock against each other
- Not all functions are thread safe, clobbering data
- Onus is on you to choreograph a careful dance, easy to mess up

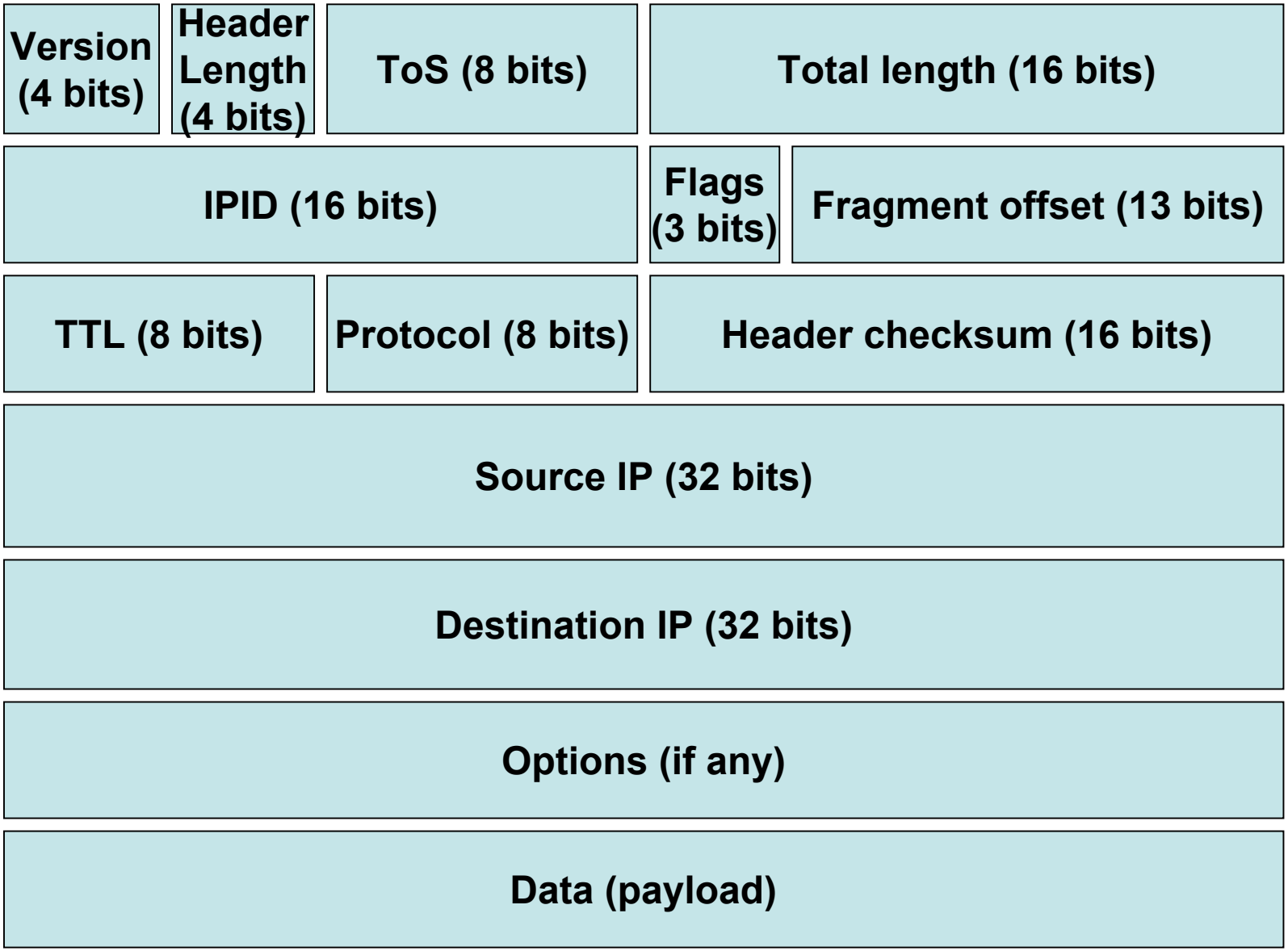
- Main thread of execution loops over possible actions
- Actions include: read, write, signal, alarm
- Every possible action has an associated “callback”
- Callbacks process data
- Easy to debug, look at active event handler
- Deadlocks don’t happen, data not clobbered by stray thread
- Program is always doing something, or looking for something to do

Networking Stack

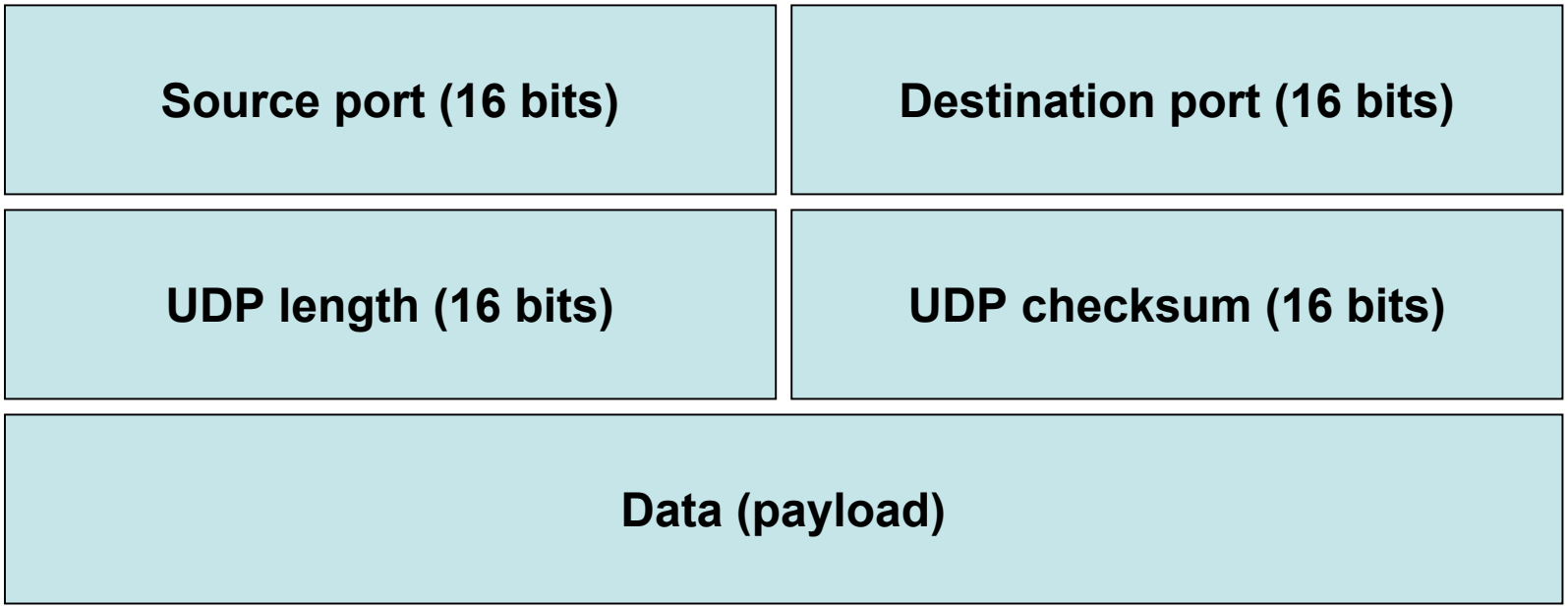


Ethernet Header Structure

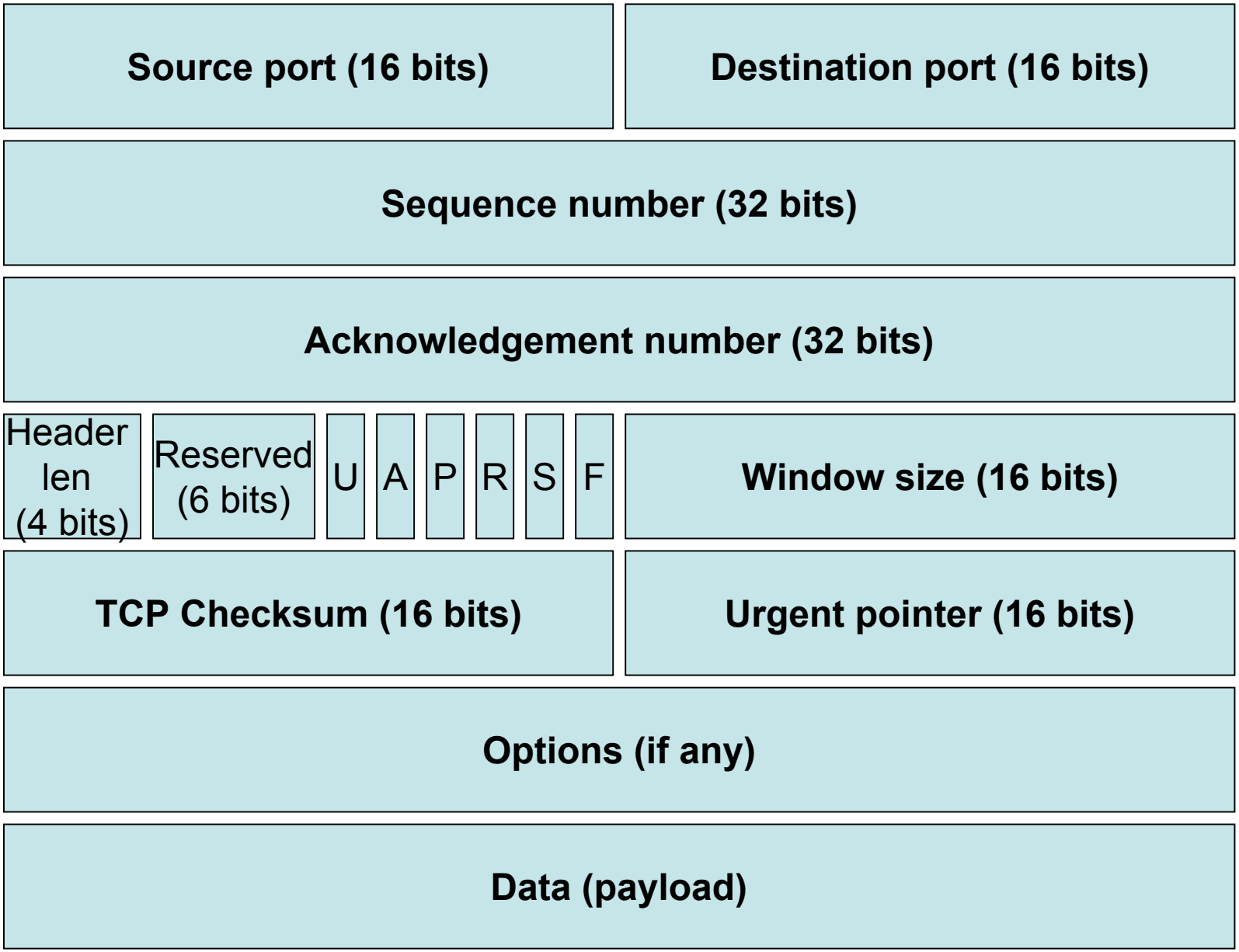
IP Header Structure



UDP Header Structure



TCP Header Structure

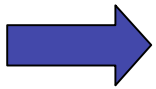


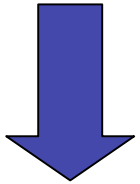
libpcap – packet capture

Platform independent
Flexible
Relatively decent performance
Very standard

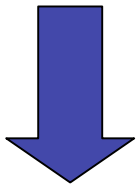
Order of operations
1. Create a pcap object: `pcap_open_live()`
2. Get data from the network, send to callback
3. Close pcap object: `pcap_close()`

```
pcap_loop()
pcap_dispatch()
pcap_next()
```





Packet processing callback

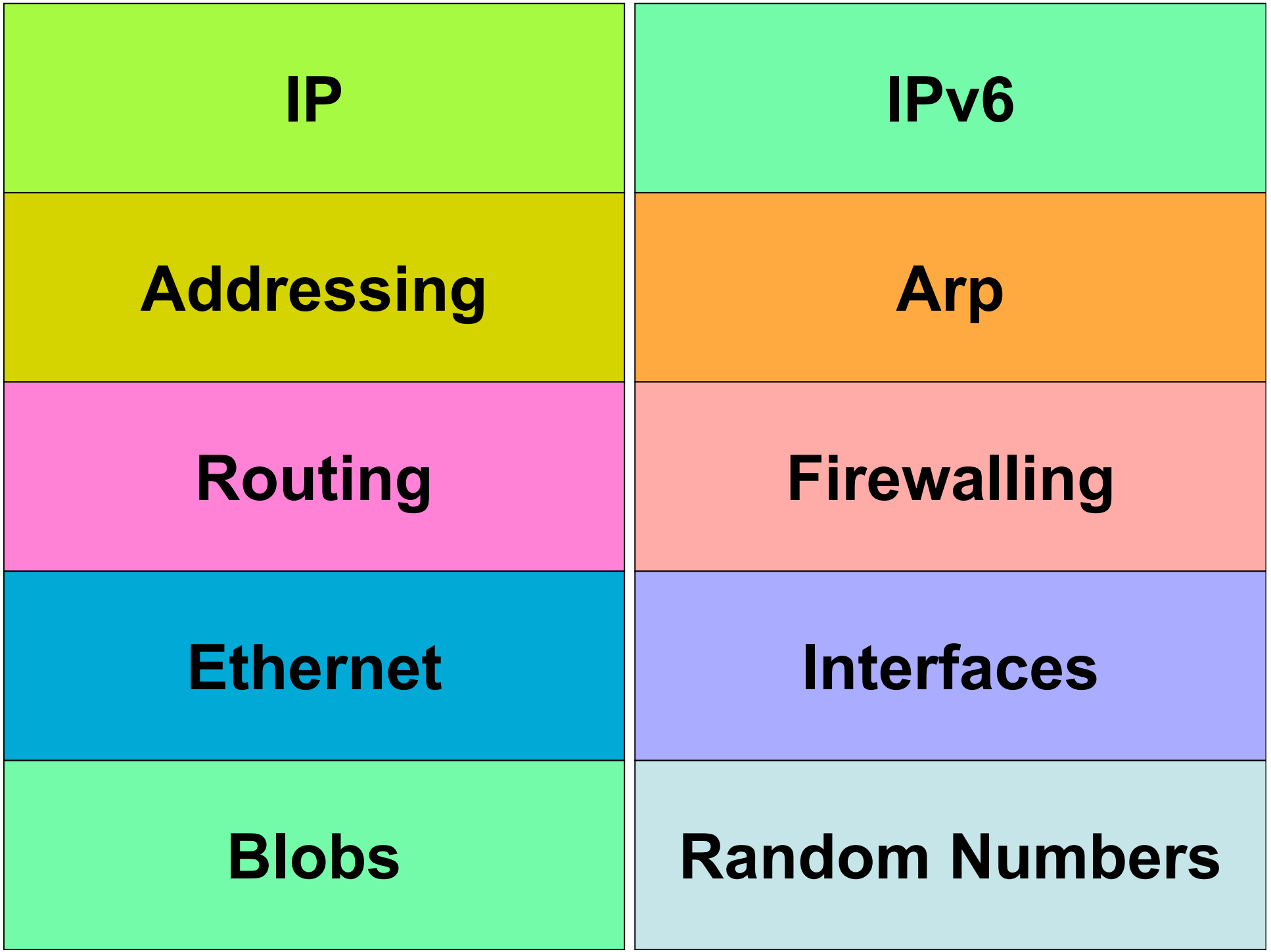


libdnet – low level networking

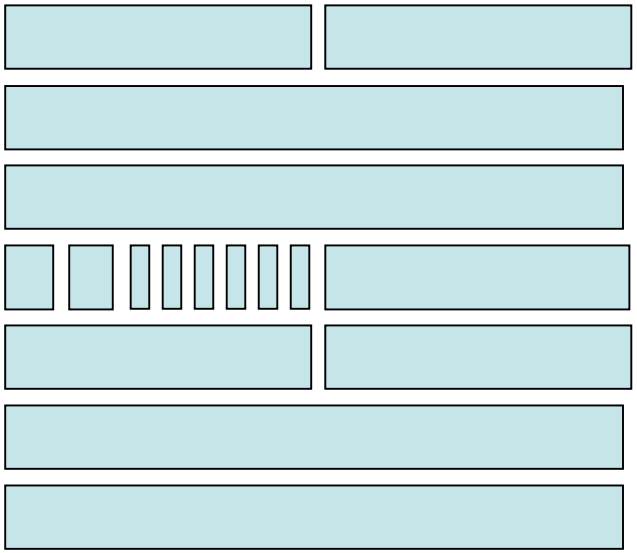
Simple interface to network, kernel material
Cross platform (Win, OS X, UN*X)
Easy to use interface

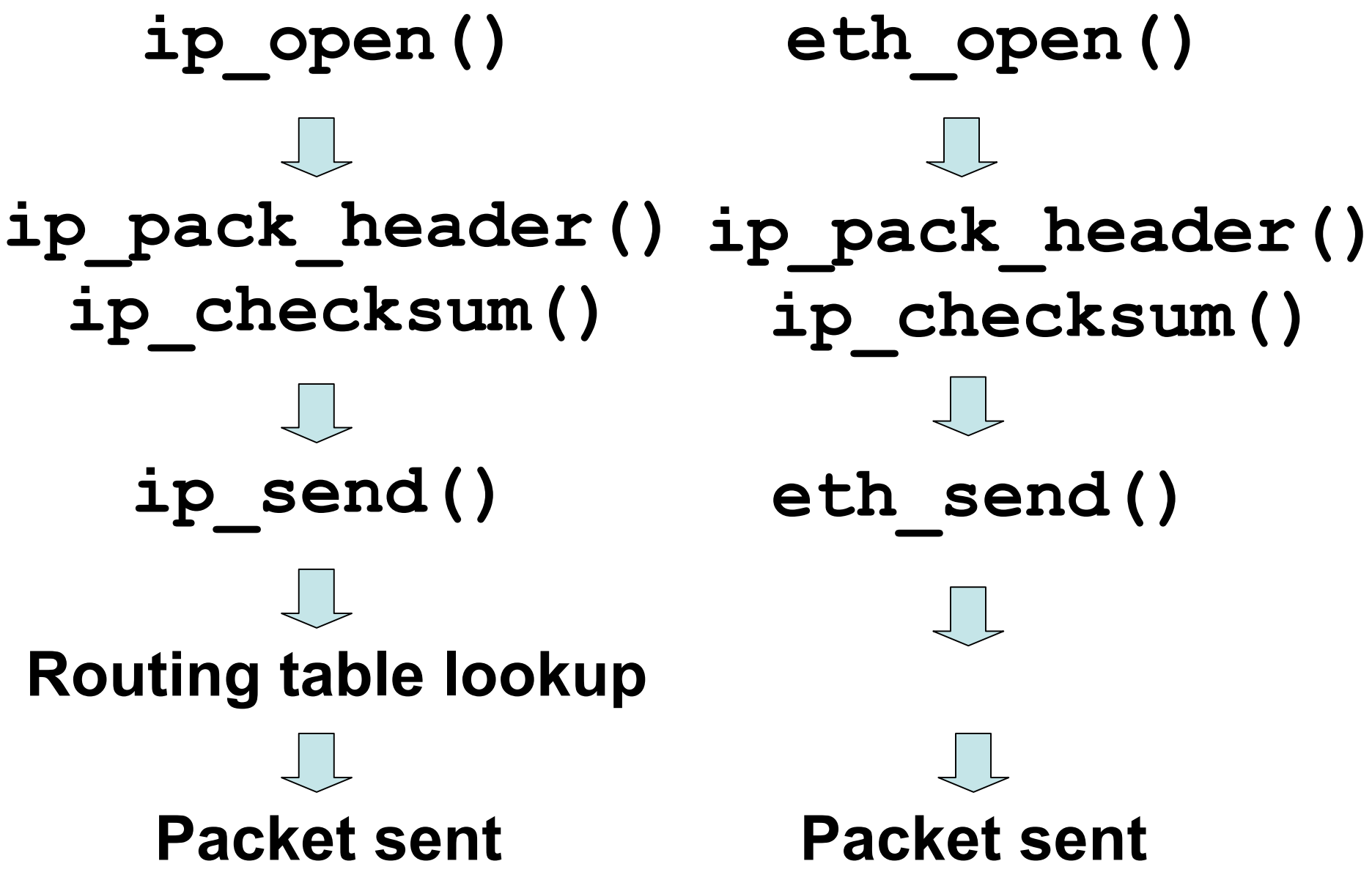
Libdnet basics:

1. Open network object: `ip_open()`
2. Allocate packet memory
3. Construct TCP packet: `tcp_pack_header()`
4. Construct IP packet: `ip_pack_header()`
5. Checksum: `ip_checksum()`
6. Write the packet: `ip_send()`
7. Close the object: `ip_close()`


IP
IPv6
Addressing
Arp
Routing
Firewalling
Ethernet
Interfaces
Blobs
Random Numbers

tcp_pack_hdr(hdr,
sport,
dport,
seq,
ack,
flags,
win,
urp)




ip_open()
ip_pack_header()
ip_checksum()
ip_send()
Routing table lookup
Packet sent
eth_open()
ip_pack_header()
ip_checksum()
eth_send()
Packet sent

pcap, event, dnet example: jscan

- TCP SYN port scanner
- OS fingerprinting
- Passive fingerprinting
- Passive port scanning
- Active port scanning
- Can be decoupled

http://monkey.org/~jose/software/jscan/

jscan Program flow

- Open pcap object (for receiving)
- Open IP object (for sending)
- Create and set send and receive events
- Send callback
- Receive callback
  - Fingerprint OS using the packet
  - Report results
- Loop until all ports scanned or stopped

```
<includes>
<report results>
<send callback>
<receive callback>

int main (int argc, char *argv[])
{
      <getopt setup>
      ctx.rand = rand_open();
      ctx.p = pcap_open_live(intf, 1500,
            (ctx.flags == SCAN_FLAGS_PASSIVE), 500,
             ebuff);
      if (ctx.p == NULL)
            err(1, "pcap_open_live");
      ctx.dl_len = pcap_dloff(ctx.p);
      <event setup>
      printf("scan completed in %d seconds.\n",
            time(NULL) - start);
      return (1);
}
```

event setup:

```
event_init();
ctx.tv.tv_sec = 0;
ctx.tv.tv_usec = 500;
p_fd = pcap_fileno(ctx.p);

event_set(&ctx.recv_ev, p_fd, EV_READ,
          _recv, (void *) &ctx);
event_add(&ctx.recv_ev, &ctx.tv);
if (ctx.flags == SCAN_FLAGS_ACTIVE) {
        ctx.ip = ip_open();
        if (ctx.ip == NULL)
                err(1, "ip_open() failed ..");
        event_set(&ctx.send_ev, p_fd, EV_WRITE,
                  _send, (void *) &ctx);
        event_add(&ctx.send_ev, &ctx.tv);
        ctx.dport = 1;
}
event_dispatch();
```

receive callback:

```
static void _recv(int fd, short event, void *arg)
{
        struct myctx *ctx = (struct myctx *) arg;
        struct pcap_pkthdr ph;
        u_char *pread;

        if ((ctx->flags == SCAN_FLAGS_ACTIVE)
                && (ctx->dport > 65535));
        else
                /* reschedule */
                event_add(&ctx->recv_ev, &ctx->tv);
        if ((pread = (u_char *) pcap_next(ctx->p, &ph)) != NULL)
                report(pread, ctx);
        return;
}
```

send callback:

```
static void _send(int fd, short event, void *arg)
{
        struct myctx *ctx = (struct myctx *) arg;
        struct jscan_pkt *pkt;
        u_char buf[BUFSIZ];
        int len = IP_HDR_LEN + TCP_HDR_LEN, dport;
        if (ctx->dport > 65535)
                return;
        event_add(&ctx->send_ev, &ctx->tv);
        pkt = (struct jscan_pkt *) buf;
        ip_pack_hdr(&pkt->pkt_hdr_i.ip, IP_TOS_LOWDELAY,
                len, rand_uint16(ctx->rand), 0, 128, IP_PROTO_TCP,
                ctx->src.addr_ip, ctx->dst.addr_ip);
        tcp_pack_hdr(&pkt->pkt_hdr_t.tcp, rand_uint16(ctx->rand),
                ctx->dport, rand_uint32(ctx->rand),
                rand_uint32(ctx->rand), TH_SYN,
                rand_uint16(ctx->rand), 0);
        ip_checksum(pkt, len);
        ip_send(ctx->ip, pkt, len);
        ctx->dport += 1;            /* we SYNed that port */
        return;
}
```

report callback (2 pages):

```
static void report(u_char * packet, void *arg)
{
        struct myctx *ctx = (struct myctx *) arg;
        static struct ip_hdr *ip_h;
        u_char *tmp;
        const char *p;
        struct addr ip_src;
        static struct entry *np, *n2;
        tmp = packet + ctx->dl_len;
        ip_h = (struct ip_hdr *) tmp;
        if (ip_h->ip_v != 4)
                return;
        p = inet_ntoa(ip_h->ip_src);
        if ((addr_aton(p, &ip_src)) == -1)
                return;
        /*
         * if it's a passive scan, don't care about the src
         * address. if it's an active scan, make sure it was the
         * dest we specified. make sure it's a TCP packet, too,
         * and has SA set.
         */
```

```
        if (((ctx->flags == SCAN_FLAGS_PASSIVE) ||
             ((addr_cmp(&ip_src, &(ctx->dst))) == 0)) &&
               (ip_h->ip_p == IP_PROTO_TCP)) {
                struct tcp_hdr *tcp_h =
                        (struct tcp_hdr *)(tmp + IP_HDR_LEN);
                if (tcp_h->th_flags == 0x12) {    /* SYN ACK */
                        struct servent *serv;
                        char *s_name = "unknown", *os = NULL;
                        if (ctx->osfile != NULL)
                                os = osprint(ctx, ntohs(tcp_h->th_win),
                                        ip_h->ip_ttl, ip_h->ip_off,
                                        ntohs(ip_h->ip_len));
                        serv = getservbyport(tcp_h->th_sport, "tcp");
                        if (serv != NULL)
                                s_name = strdup(serv->s_name);
                        printf("%-16s %35s %15s %6d/tcp\n",
                                addr_ntoa(&ip_src),        os ?
                                os : "unknown", s_name,
                                htons(tcp_h->th_sport));
                }
        }
        return;
}
```

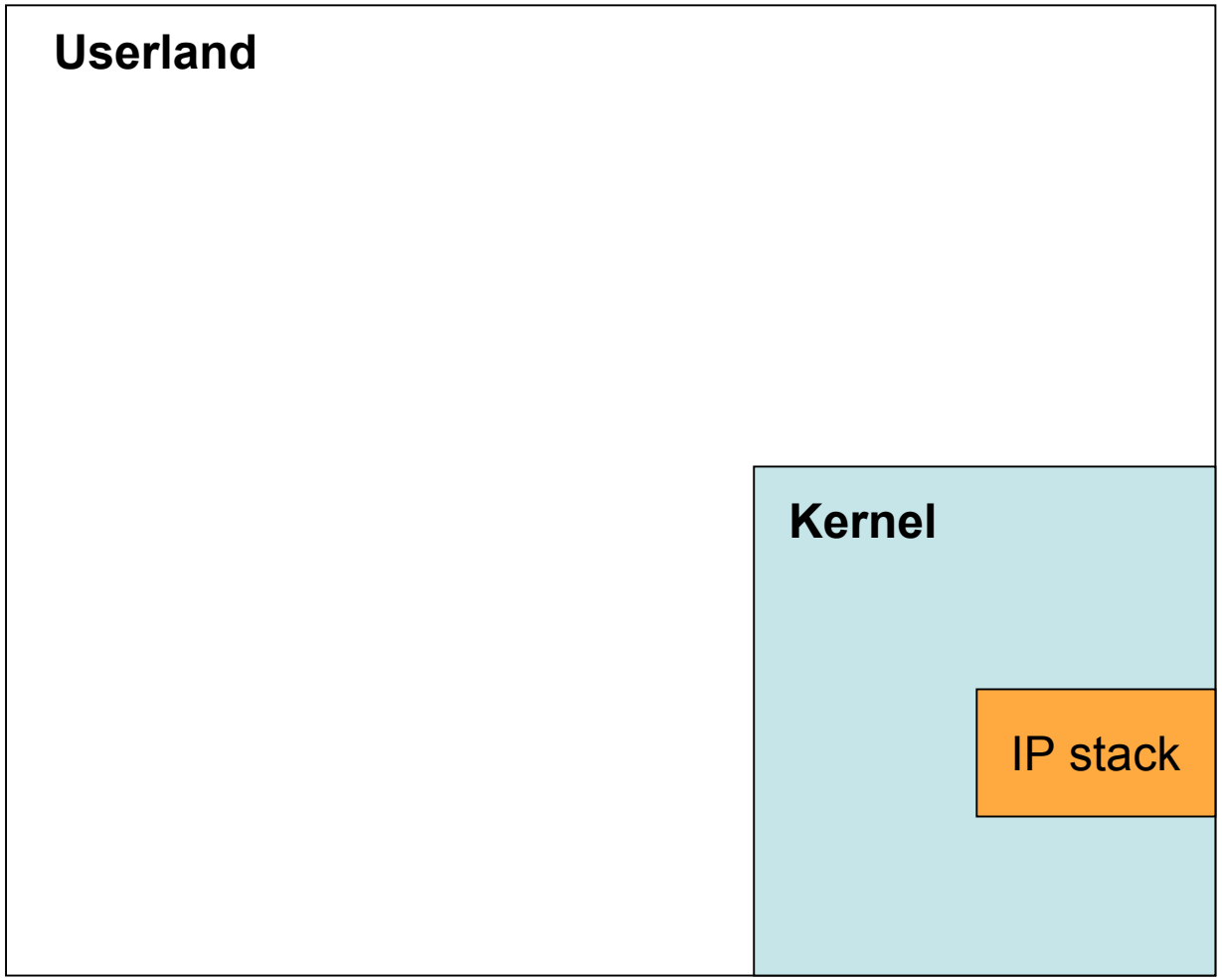
jscan output

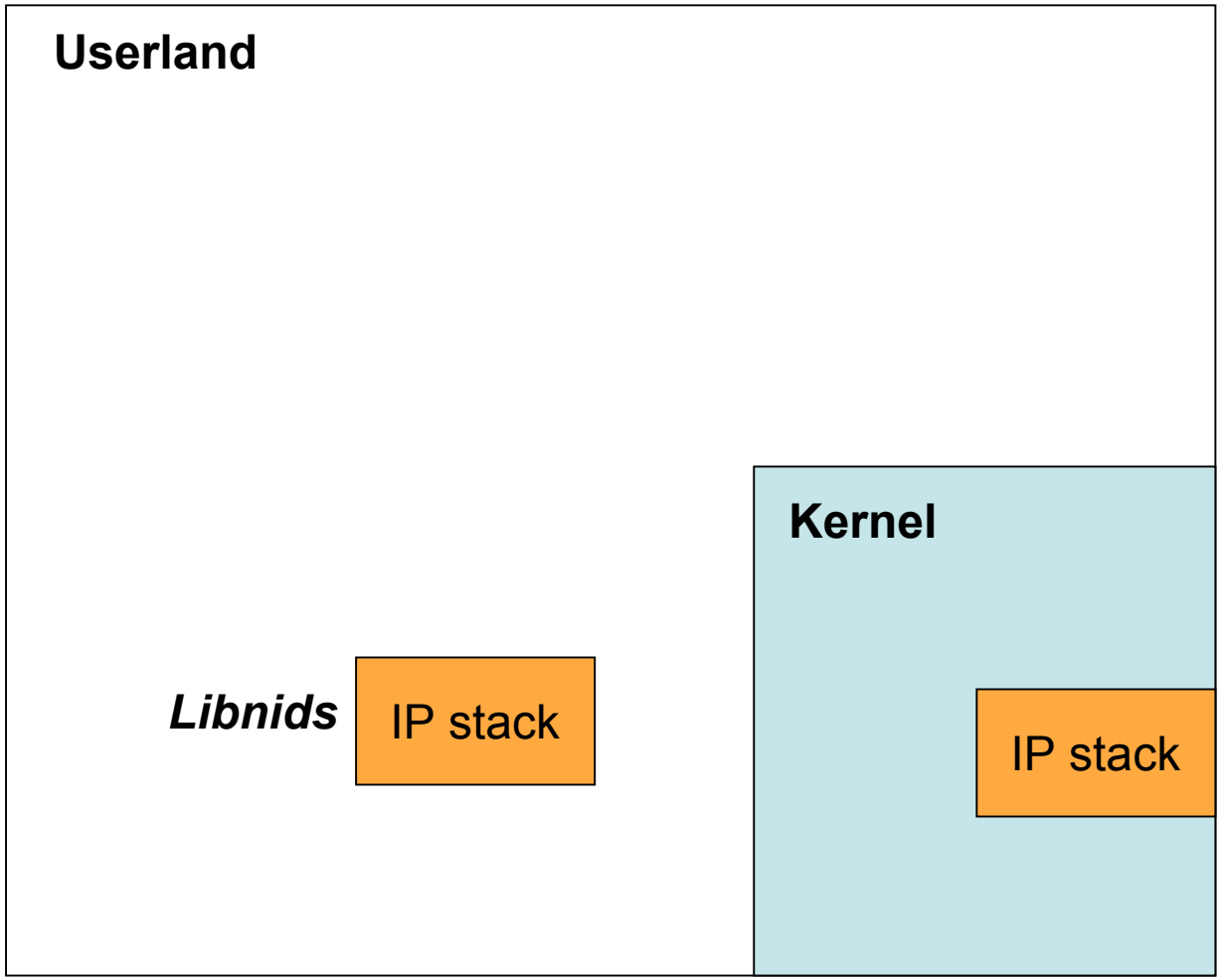
```
$ sudo jscan -t passive -i fxp0 -f compat/pf.os
scan started, type is passive, listening on fxp0
192.48.159.40              unknown                www      80/tcp
216.136.204.117  FreeBSD 4.6-4.8                  www      80/tcp


$ sudo jscan -t active -s 192.168.3.4 -d 192.168.1.4
   -i fxp0 -f compat/pf.os
scan started, type is active, listening on fxp0
192.168.1.4          Linux 2.0.3x                 ssh      22/tcp
192.168.1.4          Linux 2.0.3x               whois      43/tcp
192.168.1.4          Linux 2.0.3x                auth     113/tcp
192.168.1.4          Linux 2.0.3x                 bgp     179/tcp
scan completed. total execution time was 70 seconds.
```

libnids – reassemble IP streams

NIDS “E” box (event generation box)
Userland TCP/IP stack
Based on Linux 2.0.36 IP stack
Uses libpcap, libnet internally
IP fragment reassembly

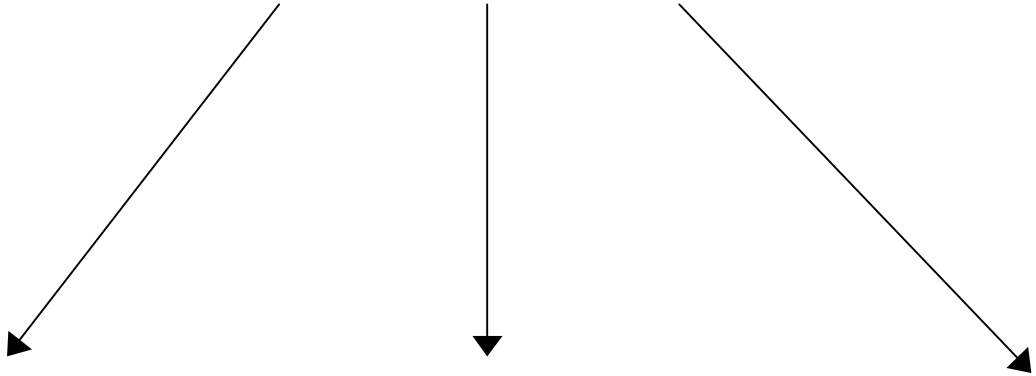

Userland
Kernel
IP stack


Userland
Kernel
Libnids
IP stack
IP stack

libnids Basics

- Initialize
  - **`nids_init()`**
- Register callbacks
  - **`nids_register_tcp()`**
  - **`nids_regster_ip()`**
  - **`nids_regiser_udp()`**
- Run!
  - **`nids_run()`**
- React
  - **`nids_kill_tcp()`**

`nids_run()`



TCP callback

TCP stream object:
- TCP state
- client data
- server data
- source IP, port
- dest IP, port
- seq, ack, etc …

UDP callback

UDP packet:
- source IP, port
- dest IP, port
- UDP payload

IP callback

IP packet
- struct IP packet
- contains upper layers

libnids TCP states

- **`NIDS_JUST_ESTABLISHED`**
  - New TCP connected state (3WHS)
  - Must set **`stream->{client,server}.collect=1`** to get stream payload collected
- **`NIDS_DATA`**
  - Data within a known, established TCP connection
- **`NIDS_RESET, NIDS_CLOSE, NIDS_TIMED_OUT`**
  - TCP connection is reset, closed gracefully, or was lost

libnids doesn't expose SYN_SENT, FIN_WAIT, etc …

Example libnids code: jflow

- jflow
  - Pcap to NetFlow summaries
  - Daemonizes
  - Sends to a receiving host over UDP
- Limitations of jflow
  - Not very lightweight
  - Inaccurate for some things

http://monkey.org/~jose/software/jflow/

```
<includes>
<export record>
<ip callback>

int main (int argc, char *argv[])
{
     <getopt handler>
     <UDP socket connect>
     nids_init();
     nids_register_ip(monitor_ip);
     nids_run();
     return(0);
}
```

ip callback (*truncated*):

```
void monitor_ip(struct ip *pkt)
{
        struct ip_record rec;
        int i;

        rec.rec.srcaddr = (u_int)(pkt->ip_src.s_addr);
        rec.rec.dstaddr = (u_int)(pkt->ip_dst.s_addr);
        rec.rec.nexthop = inet_addr("0.0.0.0");
        rec.rec.dOctets = htonl(pkt->ip_len);
        rec.rec.pad = 0x0;
        rec.rec.prot = pkt->ip_p;
        rec.rec.tos = 0x0;
        rec.rec.tcp_flags = 0x0;
        rec.rec.pad_2 = 0x0;
        rec.rec.pad_3 = 0x0;
        for (i = 0; i < 4; i++)
                rec.rec.reserved[i] = 0x0;
        export_ip_record(&rec);
        return;
}
```

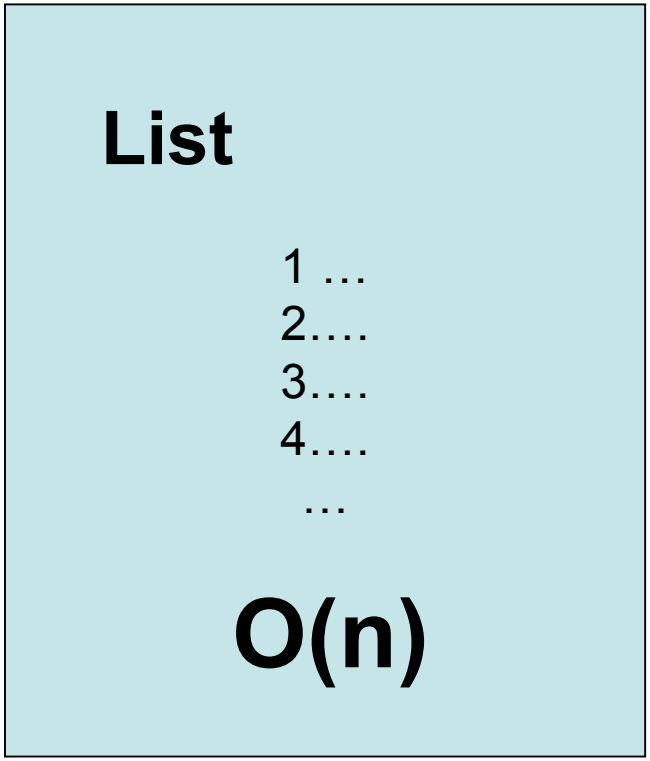
export record:

```
void export_ip_record(struct ip_record *rec)
{
        time_t now;
        /* fill out the header */
        now = time(NULL);
        rec->hdr.version = htons(1);
        rec->hdr.count = htons(1);
        rec->hdr.SysUptime = htonl(get_uptime());
        rec->hdr.unix_secs = htonl(now);
        rec->hdr.unix_nsecs = 0;   /* XXX */
        if (write(ctx.u, rec, sizeof(struct ip_record))
            < sizeof(struct ip_record))
               warn("ip_export_record(): short write()");
        else ctx.count += 1;
        return;
}
```

jflow output

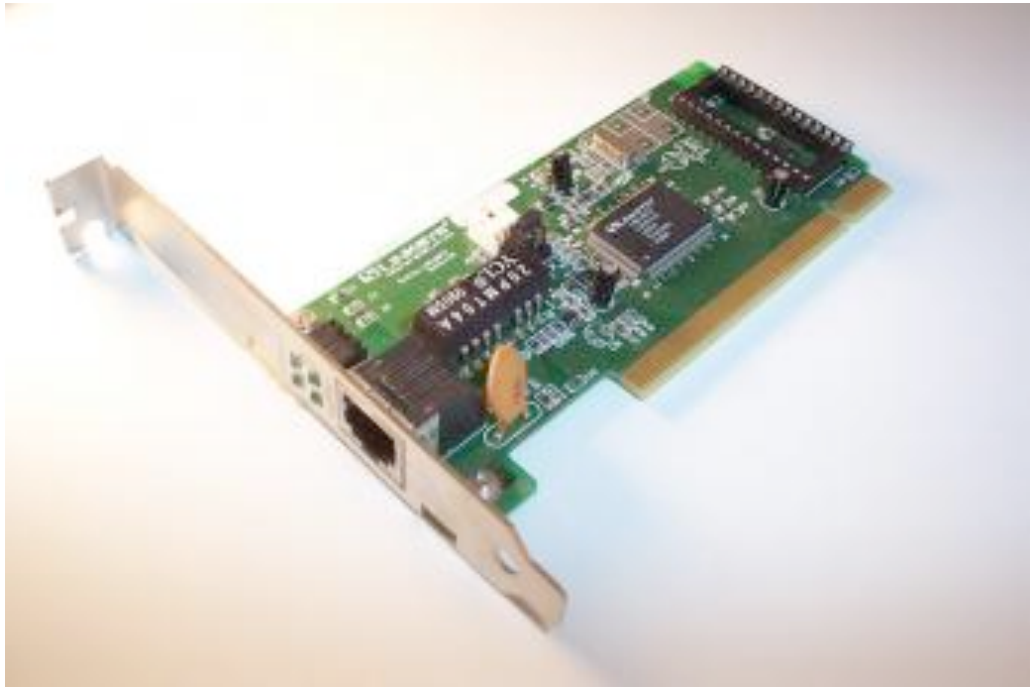
```
$ sudo tcpdump -lni fxp0 -s1500 -Tcnfp udp port 5000
11:21:50.256833 NetFlow v1, 611.550 uptime, 1095175310.0,  2 recs
  started 7209.020, last 536870.912
    65.205.8.103:80 > 192.168.1.190:37116 >> 0.0.0.0
    6 tos 0, 623 (623 octets)
  started 1103956.071, last 167772.606
    192.168.1.190:37116 > 65.205.8.103:80 >> 0.0.0.0
    6 tos 0, 4851 (4851 octets)
...
11:21:58.578965 NetFlow v1, 626.438 uptime, 1095175810.0,  1 recs
  started 1893728.316, last 2220884.028
    192.168.1.160:137 > 192.168.1.255:137 >> 0.0.0.0
    17 tos 0, 1 (50 octets) (ttl 64, id 8693)
```

Performance considerations



Loop:

1. **open file**
2. **malloc()**
3. **parse file**



Interrupts

Hardware checksumming

Memory management

Resources

- http://libdnet.sourceforge.net
- http://www.tcpdump.org
- http://www.packetfactory.net/projects/libnids
- http://monkey.org/~provos/libevent
- http://monkey.org/~jose/software/{jscan,jflow, jtrace}

Additional Resources

- Stevens, TCP/IP Illustrated vols 1 and 2
- Schiffman, Building Open Source Network Security Tools
- RFCs from the IETF

pynids example: VersionDetect

Small tool to grab client and server banner strings
Useful to inventory a network passively

```
   216.168.3.20:  80: Apache/1.3.31(Unix) AxKit/1.61 DAV/1.0.3
                   mod_perl/1.29 mod_ssl/2.8.19 OpenSSL/0.9.7d
 213.86.246.154:  80: DCLK-AdSvr
   216.39.69.70:  80: Microsoft-IIS/5.0
   206.16.0.178:  80: Apache
212.187.242.215:  80: Apache/1.3.27 (Unix) PHP/4.3.1
   65.216.78.68:  80: Microsoft-IIS/5.0
216.239.115.143:  80: Apache/2.0
212.187.242.207:  80: Apache/1.3.26 (Unix)
    192.168.3.4: ssh: SSH-2.0-OpenSSH_3.6p1
johndoe@foo.com:smtp: Microsoft Outlook 6.1.00010
```

```
#! /usr/bin/env python
# VersionDetect.py, copyright © 2004 jose nazario

import os, pwd, string, sys
seen = []

def main():
    nids.param("scan_num_hosts", 0)
    if not nids.init():
        print "error -", nids.errbuf()
        sys.exit(1)
    (uid, gid) = pwd.getpwnam(“nobody”)[2:4]
    os.setgroups([gid,])
    os.setgid(gid)
    os.setuid(uid)
    if 0 in [os.getuid(), os.getgid()] + list(os.getgroups()):
        print "error - drop root, please!“
        sys.exit(1)
    nids.register_tcp(handleTcpStream)
    try:
        nids.run()  # loop forever
    except KeyboardInterrupt:
        sys.exit(1)
```

```
def handleTcpStream(tcp):
    end_states=(nids.NIDS_CLOSE,nids.NIDS_TIMEOUT,nids.NIDS_RESET)

    if tcp.nids_state == nids.NIDS_JUST_EST:
        ((src, sport), (dst, dport)) = tcp.addr
        if dport in (80, 8000, 8080, 22, 2222, 2022, 25, 587):
            tcp.client.collect = 1
            tcp.server.collect = 1
    elif tcp.nids_state == nids.NIDS_DATA:
        # keep all of the stream's new data
        tcp.discard(0)
    elif tcp.nids_state in end_states:
        headers = string.split(tcp.client.data, "\n")
        for header in headers:
           if tcp.addr[1][1] in (22, 2222, 2022):
                if "SSH-" in header:
                    # SSH client string
                    if tcp.addr[0][0] not in seen:
                        print "%16s:%4s: \t%s" \
                          %(tcp.addr[0][0], "ssh", header)
                        seen.append(tcp.addr[0][0])
                        break
```