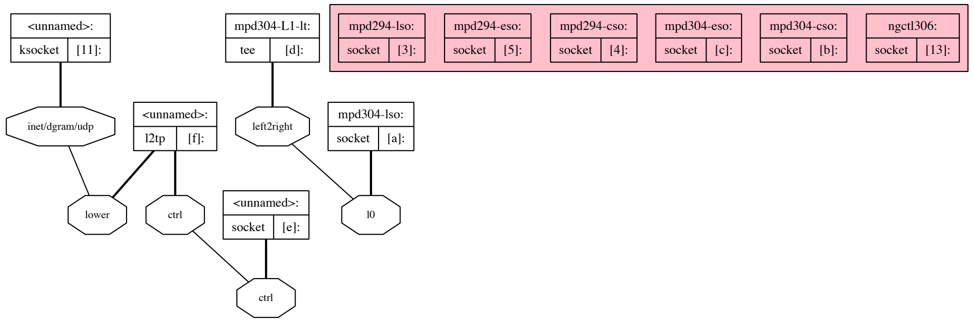

Introduction to NETGRAPH on FreeBSD Systems

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AsiaBSDCon 2012

Tokyo University of Science, Tokyo, Japan
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Tutorial Materials

Extended Abstract

Tutorial Slides

‘All About Netgraph’

man 8 ngctl

man 8 nghook

man 4 netgraph

About Myself

Ph.D. in Mathematical Physics (long time ago)

Webgroup Consulting AG (now)

IT Consulting: Open Source, Security, Perl

FreeBSD since version 1.0 (1993)

NetBSD since version 3.0 (2005)

Traveling, Sculpting, Go

Tutorial Outline

(1) Netgraph in a historical context

(2) Getting to know netgraph

(3) Working with netgraph

(4) Details of frequently used netgraph node types

(5) Examples using netgraph nodes as building blocks

(6) Investigate some more sophisticated examples

(7) Guidelines for implementing custom node types

What is Netgraph

Netgraph is in-kernel ‘network plumbing’

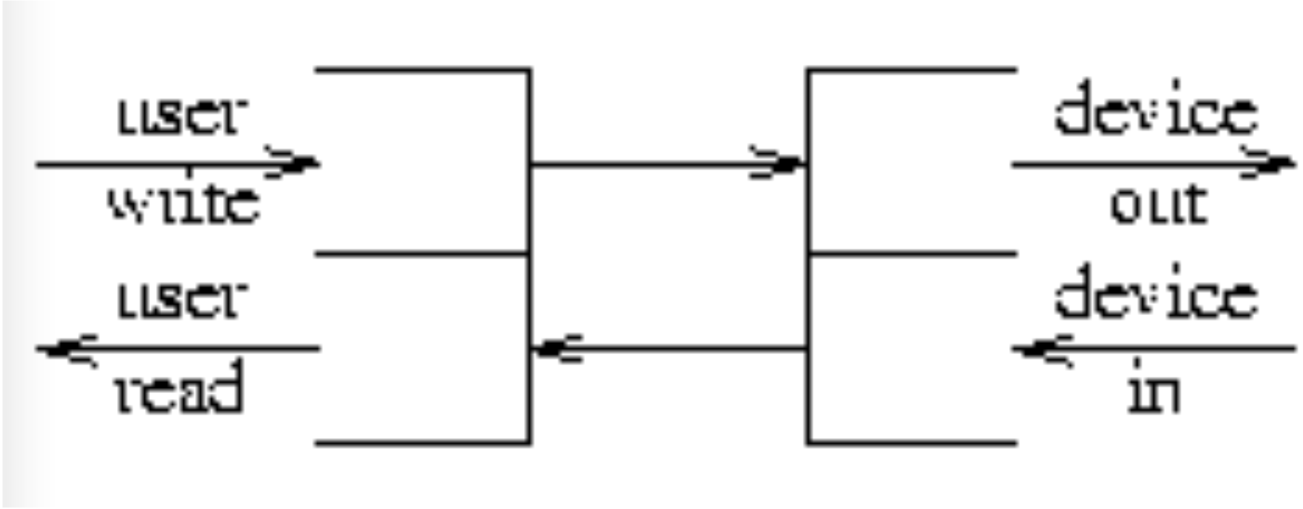
Drawn as a *graph*, a communication protocol can be seen as data packets flowing (bidirectionally) along the **edges** (lines) between **nodes** where the packets are processed.

In FreeBSD since version 3.0 (2000)

Created on FreeBSD 2.2 (1996) by Archie Cobbs <archie@freebsd.org> and Julian Elischer <julian@freebsd.org> for the Whistle InterJet at Whistle Communications, Inc.

Ancient History

Dennis Ritchie (Eighth Edition Research Unix, Bell Labs)
October 1984: ‘A Stream Input-Output System’



After open() of a plain device

Ancient History

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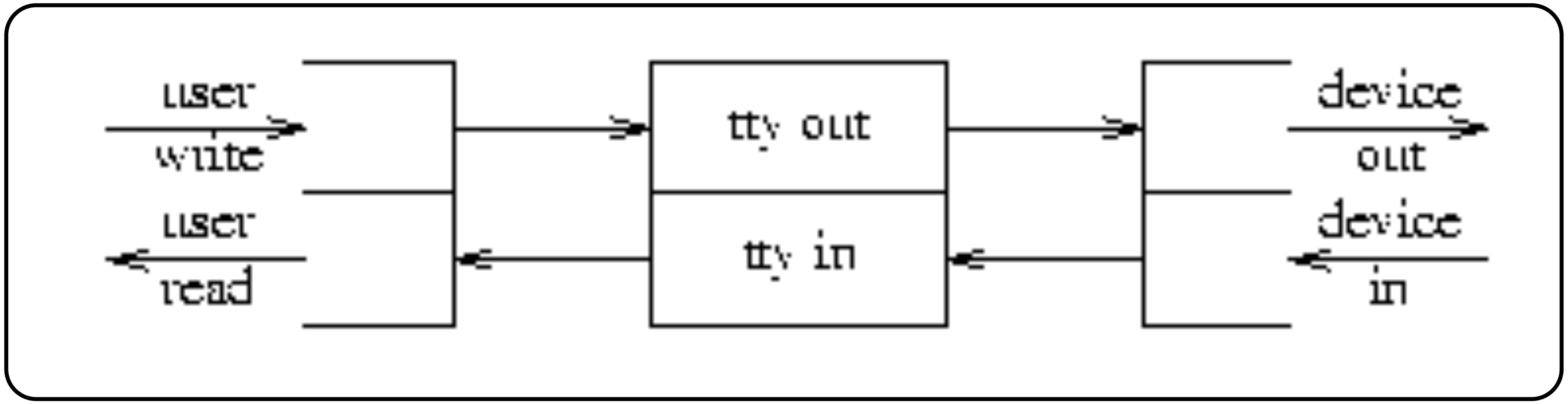
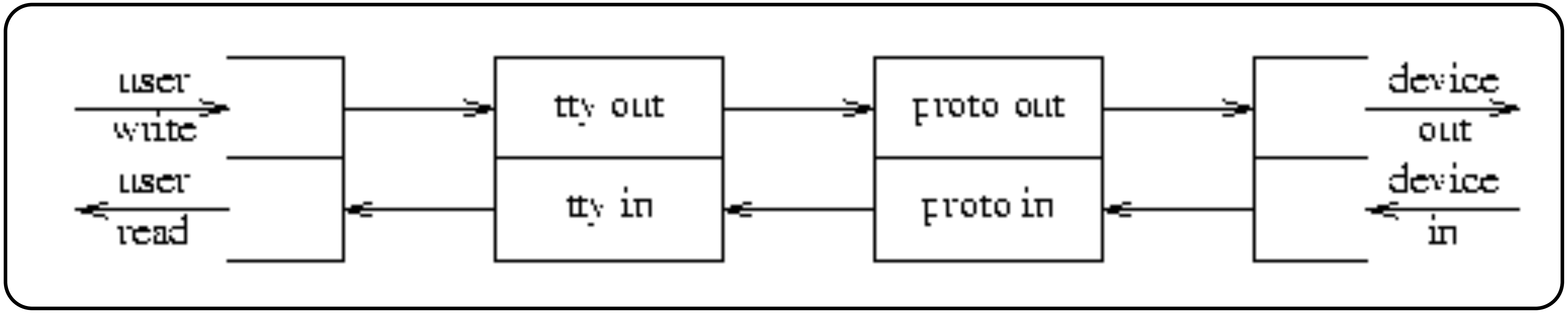


After open() of TTY device

Ancient History

Dennis Ritchie (Eighth Edition Research Unix, Bell Labs)
October 1984: ‘A Stream Input-Output System’



Networked TTY device

System V STREAMS

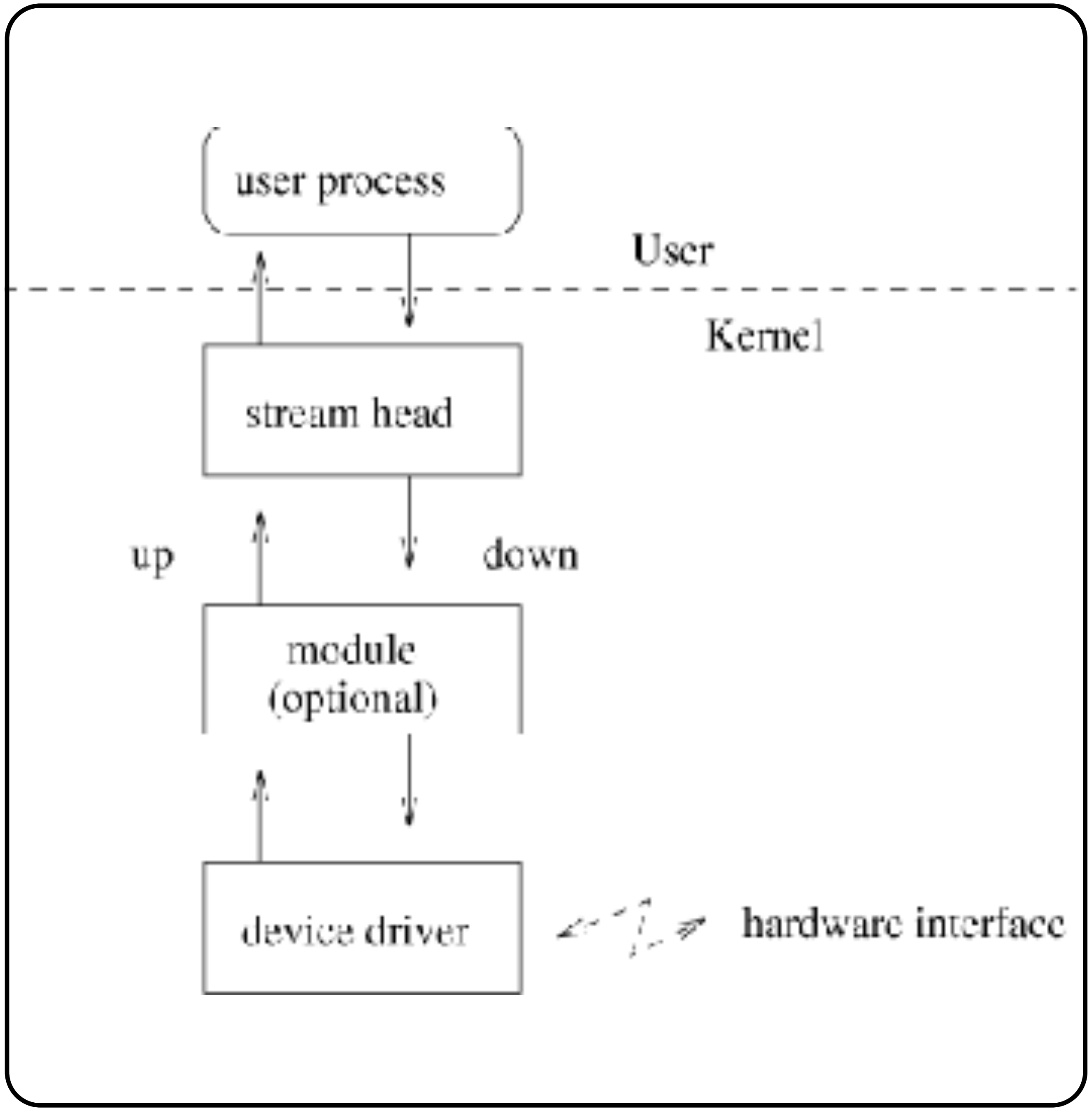
SVR3, SVR4, X/Open

Push modules onto a stack pointed to by the handle returned by the open() system call to the underlying device driver.

System V STREAMS

FreeBSD supports basic STREAMS system calls – see **`streams(4)`**

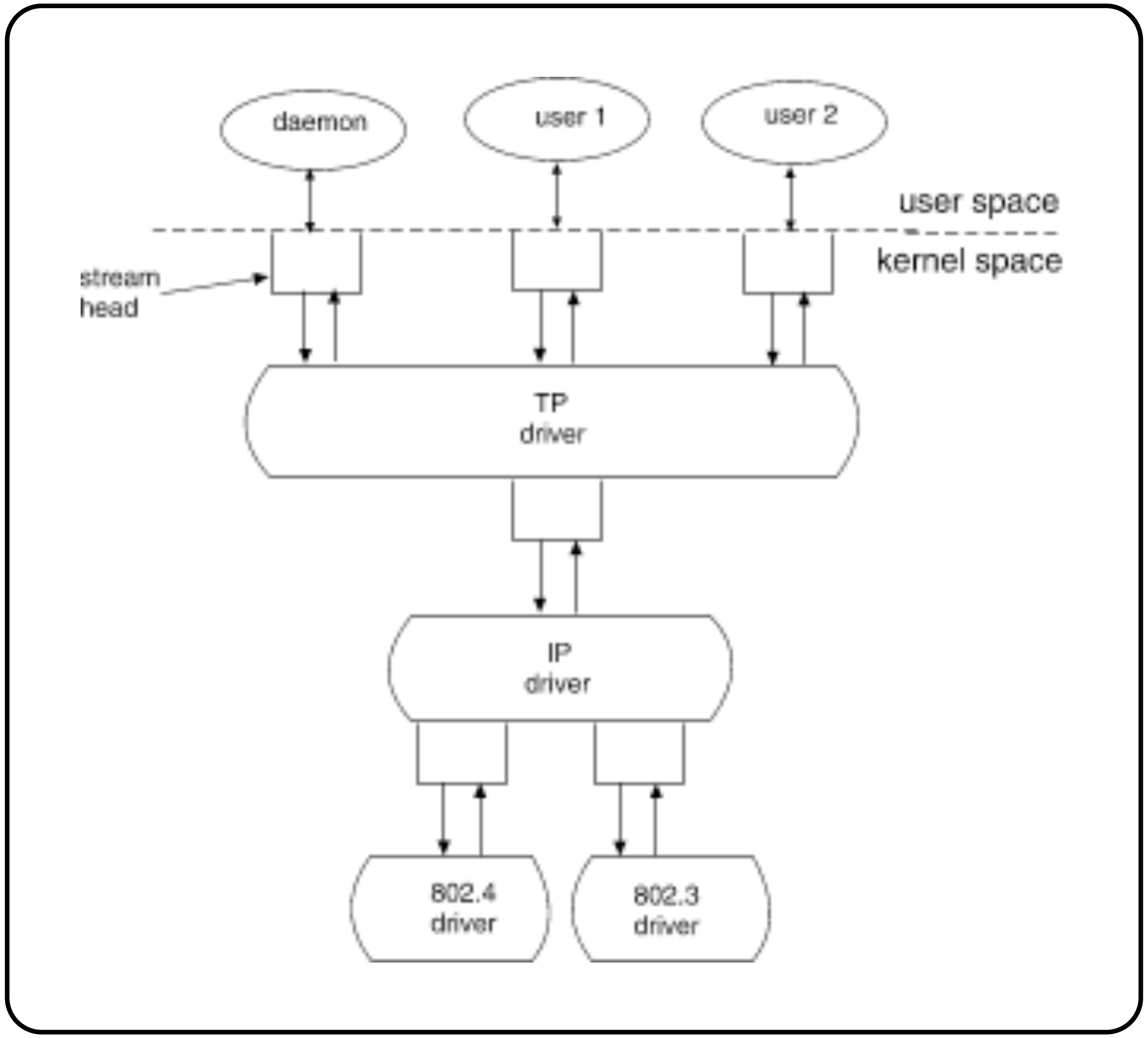
Linux STREAMS (LiS)



STREAMS Multiplexors

A transport protocol (TP) supporting multiple simultaneous STREAMS multiplexed over IP.

The TP routes data from the single lower STREAM to the appropriate upper STREAM.

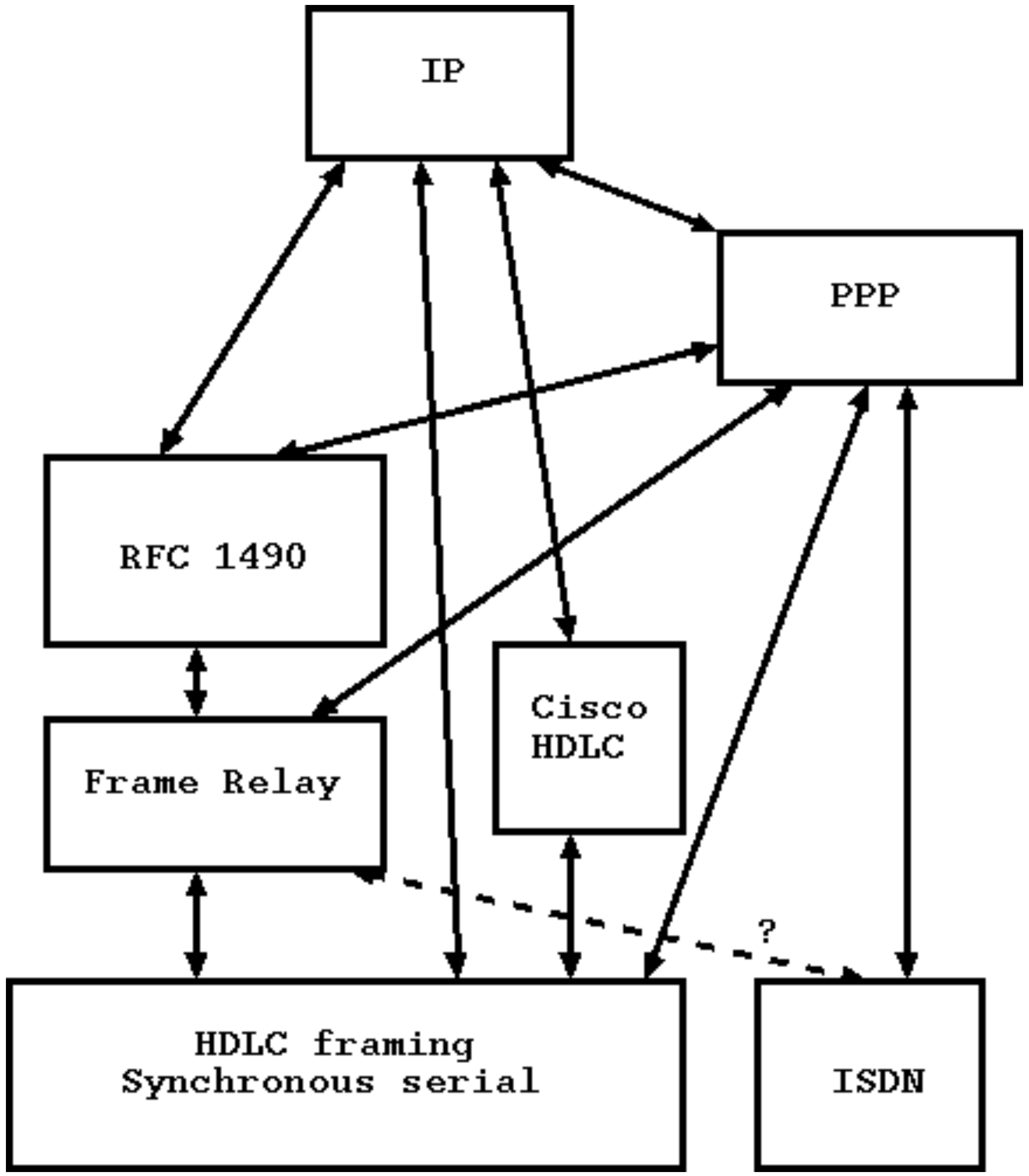


‘All About Netgraph’

Best intro to NETGRAPH:
‘All About Netgraph’
by Archie Cobbs
Daemon News, March 2000

http://people.freebsd.org/~julian/netgraph.html

(last retrieved February 2012)



Ways to talk IP over synchronous serial and ISDN WAN connections

Netgraph Platforms

- FreeBSD 2.2; mainline as of FreeBSD 3.0
- Port to NetBSD 1.5 (from FreeBSD 4.3) but not in mainline NetBSD
- DragonFly BSD "Netgraph7" (upgrade from netgraph from FreeBSD 4.x to FreeBSD 7.x)
- In one commercial Linux

  6WindGate's VNB (Virtual Networking Blocks) are derived from netgraph

New Approaches Today
Streamline (on Linux)

Herbert Bos
www.cs.vu.nl/~herbertb
VU University, Amsterdam

Scalable I/O Architecture (ACM TOCS 2011)

Address network latency problem on OS design level
Beltway Buffers, Ring Buffers: minimize copying in IPC
PipeFS for visualizing/manipulating nodes/graph

New Approaches Today
netmap (on FreeBSD)

Luigi Rizzo, Università di Pisa, Italy
http://info.iet.unipi.it/~luigi/netmap/

Multicore CPU systems hit buffer contention at high speeds
New buffer sharing needed when cores and memory are cheap

New Approaches Today
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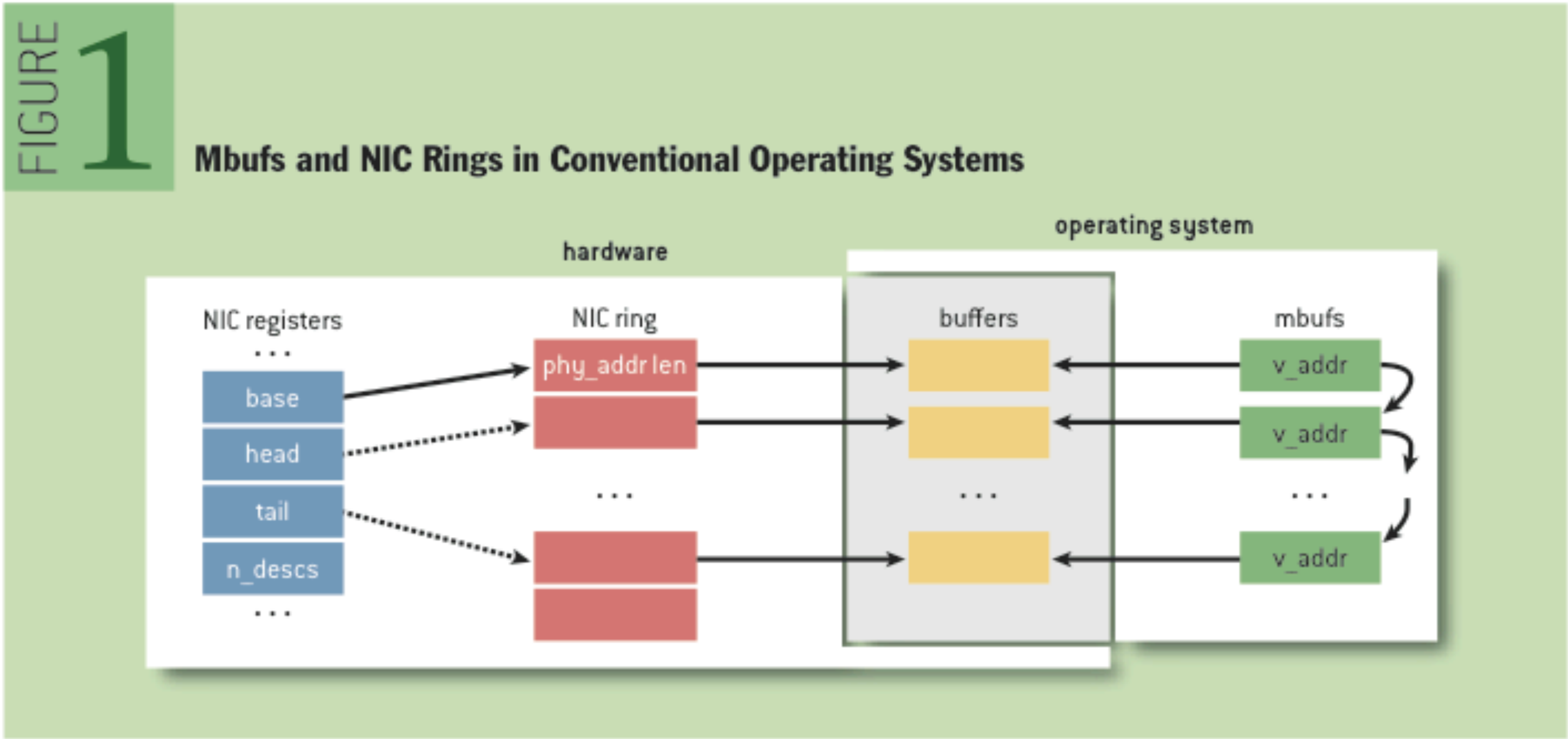


FIGURE 1

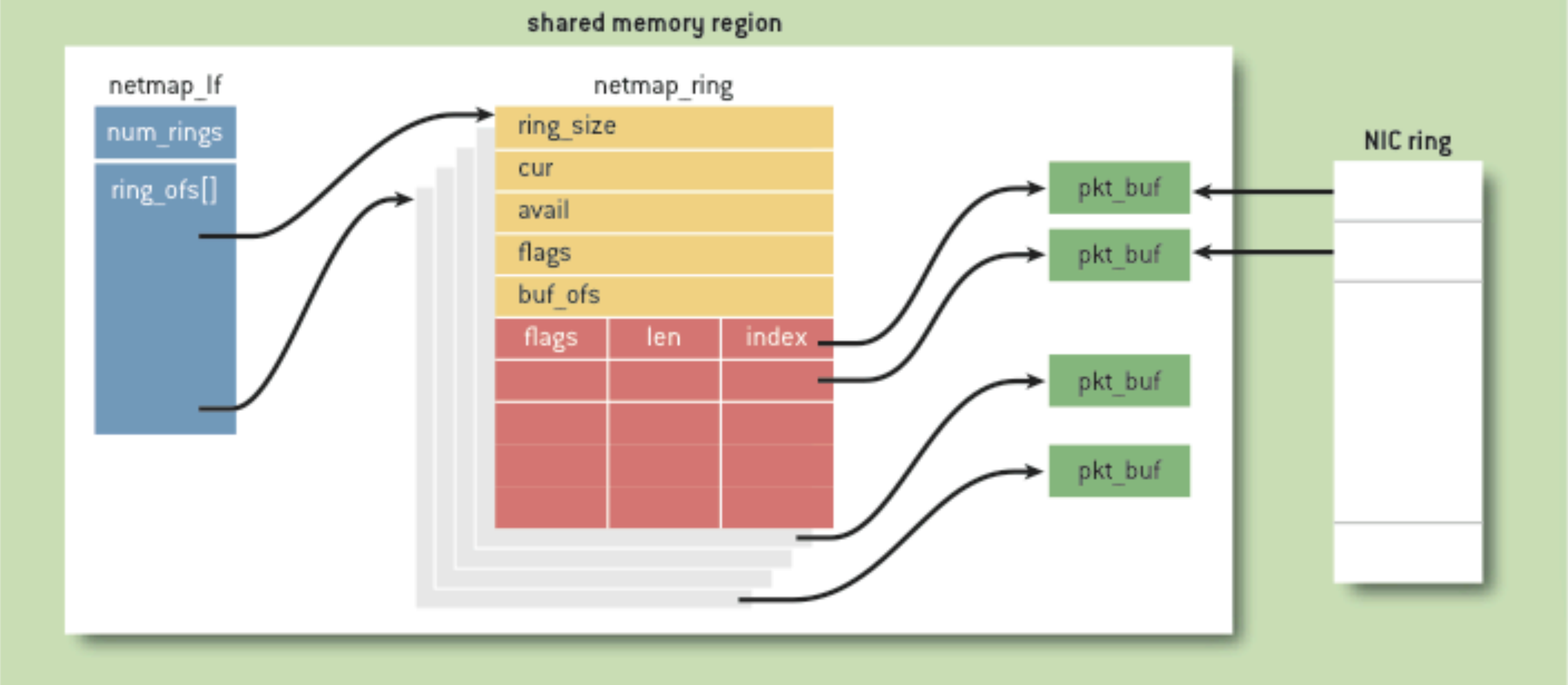
Mbufs and NIC Rings in Conventional Operating Systems

New Approaches Today
netmap (on FreeBSD)

Memory mapped access to network devices
Fast and safe network access for user space applications

FIGURE 2

Shared Memory Structures and NIC Rings



Evolution on FreeBSD

- Netgraph continues to be in mainline FreeBSD tree since 3.0 (started with10 netgraph modules)
- New networking abstractions appearing in FreeBSD remain netgraph-aware via additional netgraph modules

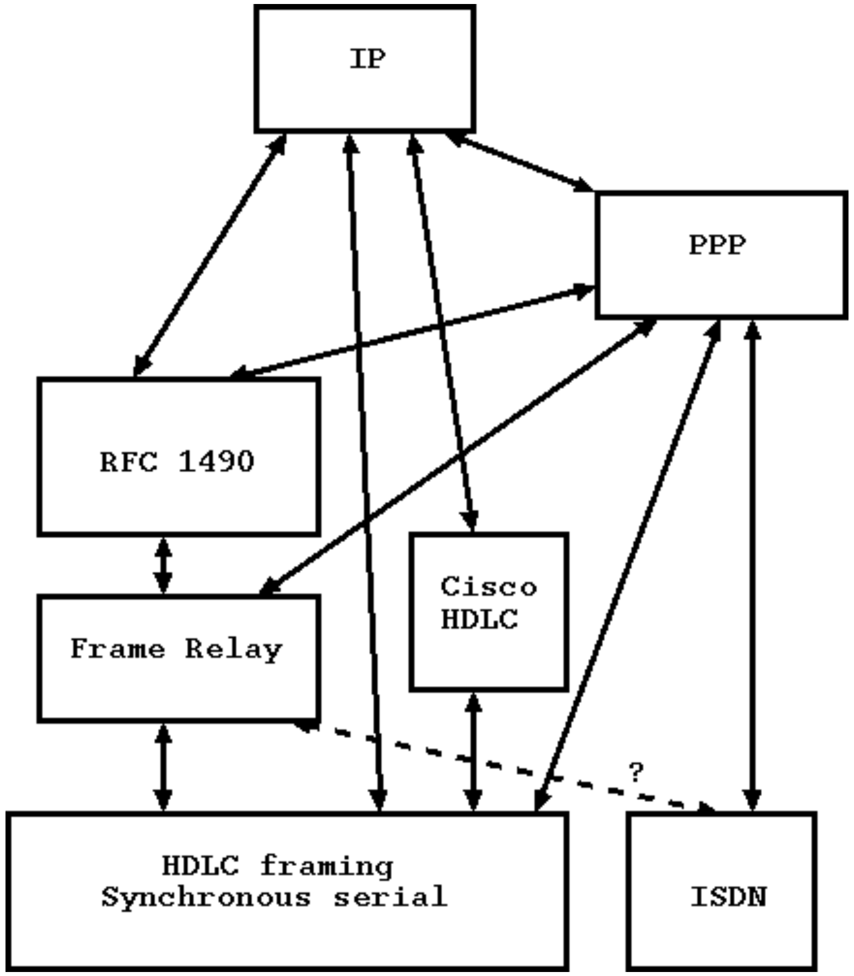
  (4.4: ~20, 4.9: ~25, 5.4: ~30, 6.3: ~45, 7.2:~50, 8.x: ~60)
- Netgraph in 5.x: added SMP (that is: locking, queuing, timers, bidirectional hooks)
- Netgraph in 8.x: support for VIMAGE
  most recent addition: ng_patch(4)

Timeline on FreeBSD

Initial "NETGRAPH 2"

FreeBSD 2.2 customized for Whistle InterJet

10 modules



Timeline on FreeBSD

First Public Release

FreeBSD 3.3

16 modules

```
async cisco echo frame_relay hole iface ksocket lmi ppp pppoe
rfc1490 socket tee tty UI vjc
```

Timeline on FreeBSD

NETGRAPH

FreeBSD 4.11

16 + 2 modules

`async cisco echo frame_relay hole iface ksocket lmi ppp pppoe rfc1490 socket tee tty UI vjc`

`bpf ether`

Timeline on FreeBSD

NETGRAPH

FreeBSD 5.5 / FreeBSD 6.x

18 + ~30 modules

`async cisco echo frame_relay hole iface ksocket lmi ppp pppoe rfc1490 socket tee tty UI vjc`

`bpf ether`

`atm` `atmllc atmpif` **`bluetooth bridge`** `bt3c btsocket device eiface etf fec` **`gif`** `gif_demux h4 hci hub ip_input l2cap` **`l2tp`** `mppc` **`netflow one2many`** `pptpgre split sppp sscfu sscop ubt uni` **`vlan`**

Timeline on FreeBSD

"NETGRAPH 7"

FreeBSD 7.4 / 8.x

~48 + ~12 modules

`async cisco echo frame_relay hole iface ksocket lmi ppp pppoe rfc1490 socket tee tty UI vjc`

`bpf ether`

`atm atmllc atmpif bluetooth bridge bt3c btsocket device eiface etf fec gif gif_demux h4 hci hub ip_input l2cap l2tp mppc netflow one2many pptpgre split sppp sscfu sscop ubt uni vlan`

`car ccatm deflate` **`ipfw`** `nat` **`patch`** `pred1 source sync_ar sync_sr` **`tag`** `tcpmms`

Software Licensing

The netgraph framework is in FreeBSD kernel, hence it is under BSD license

Netgraph nodes may have any license

‘A Gentlemen's Agreement – Assessing The GNU General Public License and its Adaptation to Linux’ by Douglas A. Hass, Chicago-Kent Journal of Intellectual Property, 2007 mentioned netgraph as an example to be followed:

For example, FreeBSD uses a networking architecture called netgraph. Along with the rest of FreeBSD, this modular architecture accepts modules under virtually any license. Unlike Linux, Netgraph’s API integrates tightly with the FreeBSD kernel, using a well-documented set of standard function calls, data structures, and memory management schemes. Regardless of the underlying licensing structure, modules written for netgraph compliance must interact with netgraph’s structure in a predictable, predefined manner.

- ★ man 4 netgraph

The aim of netgraph is to supplement rather than replace the existing kernel networking infrastructure

- A flexible way of combining protocol and link level drivers
- A modular way to implement new protocols
- A common framework for kernel entities to inter-communicate
- A reasonably fast, kernel-based implementation

More

- ★ ‘All About Netgraph’
- ★ man -k netgraph
- netgraph(3) is the programmer’s API
- News archives:

  Many (sometimes good) questions, less answers, some working examples, and very often “I did that once but don’t have the working example here right now” ... (for some counterexamples, see URLS at end of tutorial slides)

How to Build a Netgraph

(i) Create a node *node_A* (with unconnected hooks)

(ii) Create a peer node *node_B*, connecting one of the hooks of *node_A* (*hook_A*) to one of the hooks of *node_B* (*hook_B*) – this creates an edge from *node_A* to *node_B* along *hook_A* to *hook_B*

(iii) Repeat step (i) or step (ii), or:

Connect an unconnected hook to another one, creating a new edge between existing nodes

Control Messages

- Nodes can receive control messages, they reply to them by setting a reply flag
- Control messages are C structures with a (generic) netgraph type cookie and variable payload
- A node can also define its own message types by taking a unique netgraph type cookie

Addressing Nodes

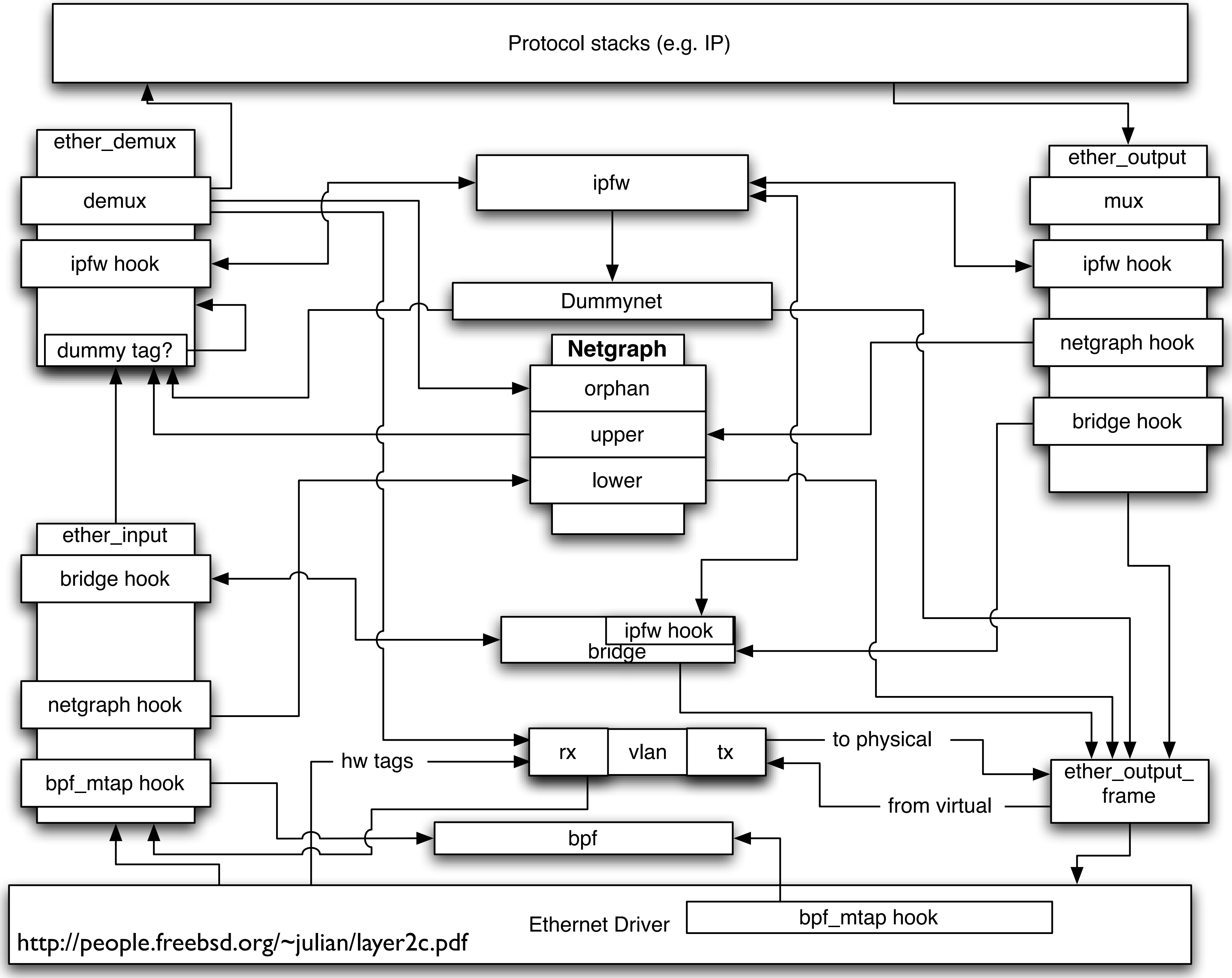
- Every node has an address (also called path) and an internal ID
- A named node can be addressed absolutely

  nodename: (for example, **`em0:`**)

- A nameless node can be addressed absolutely via its internal ID

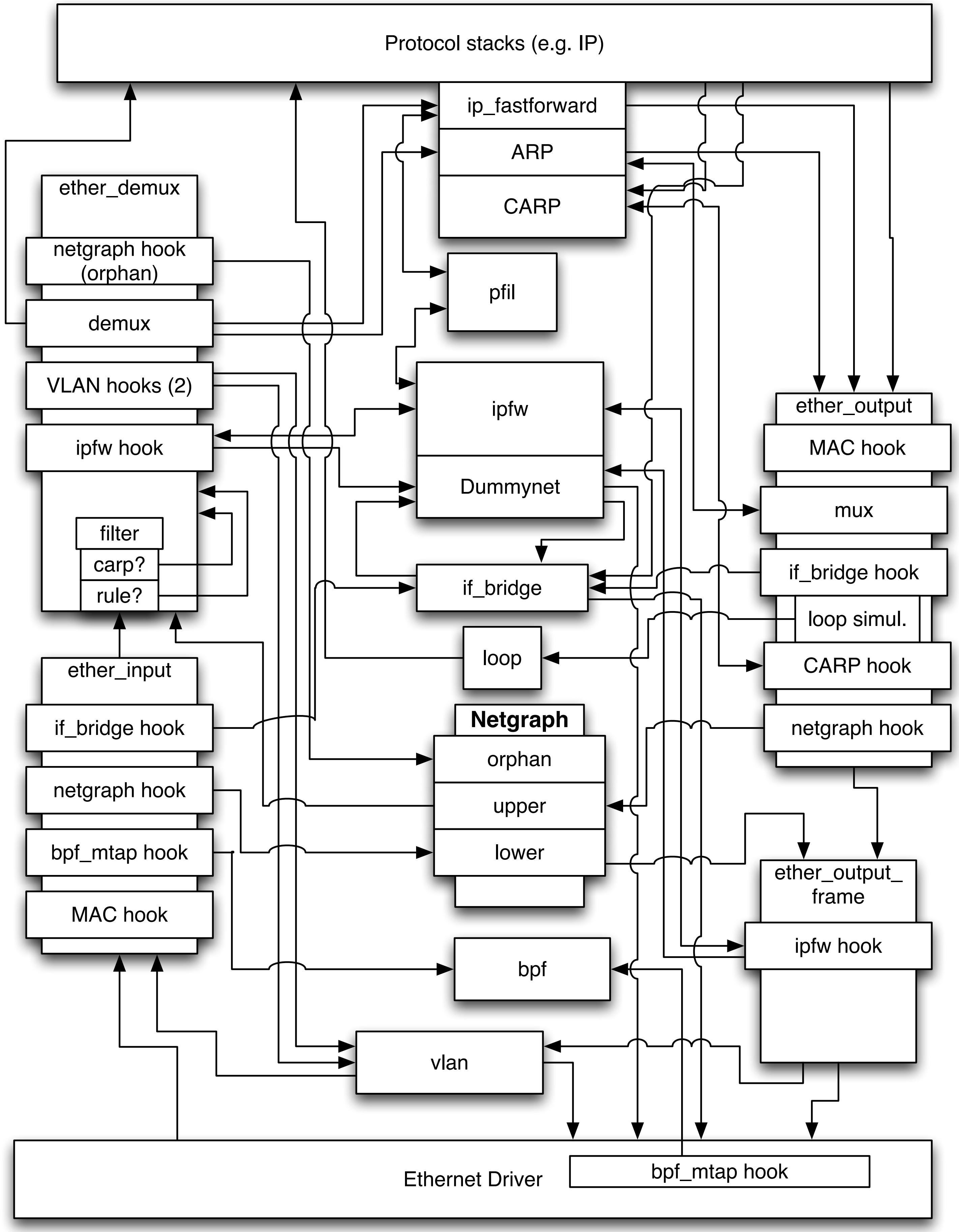
  If node has internal ID **`0000007e`**, it can be address as **`[7e]:`**

Where NETGRAPH hooks live in FreeBSD 4.x kernel



http://people.freebsd.org/~julian/layer2c.pdf

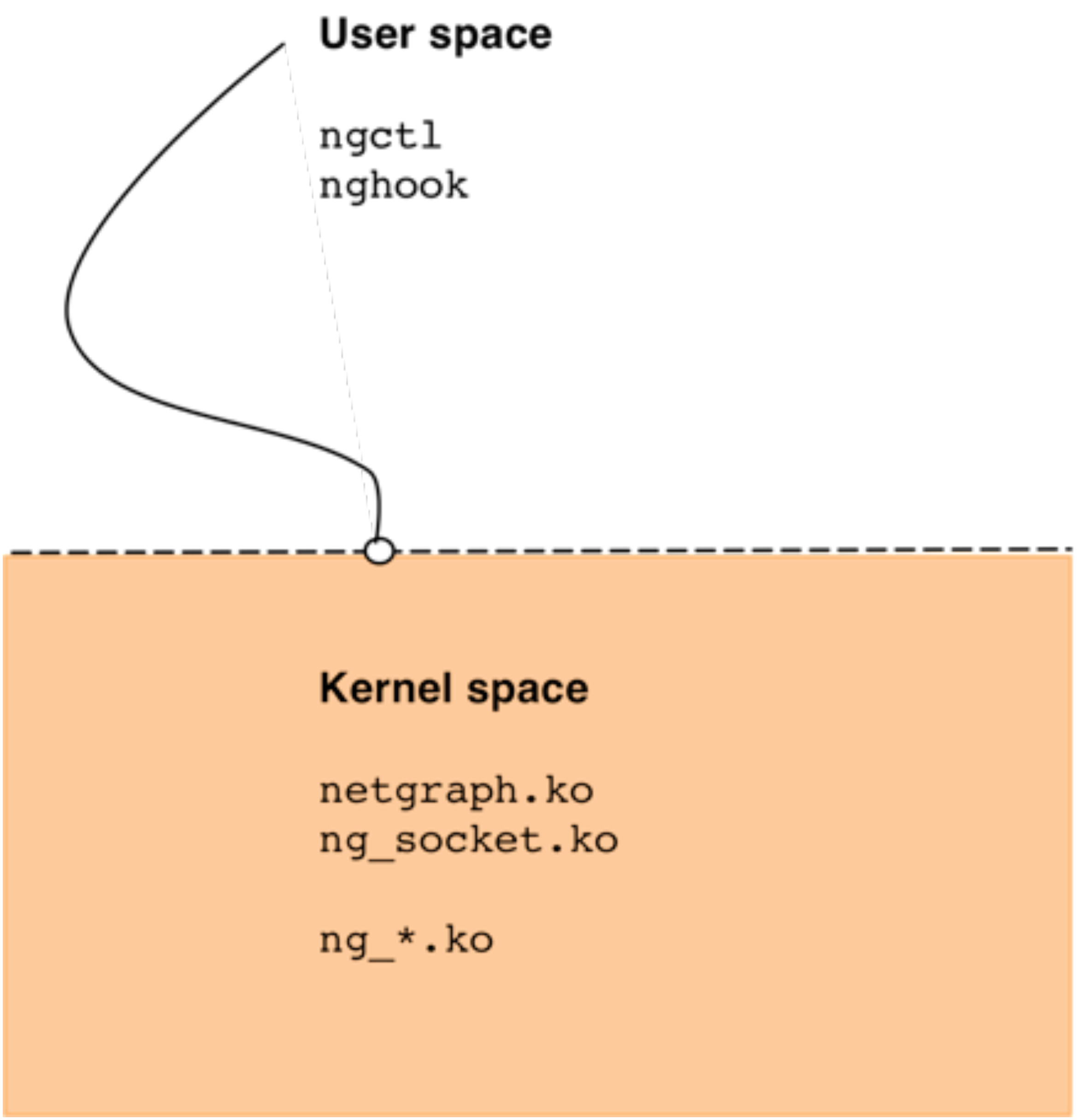
Where NETGRAPH hooks live in FreeBSD 6.x kernel



Netgraph User/Kernel Interface

BSD Sockets!

AF_NETGRAPH address family for ctrl, data protocols (netstat -f ... -p ...)



User space

ngctl
nghook

Kernel space

netgraph.ko
ng_socket.ko

ng_*.ko

ngctl

```
# ngctl
Available commands:
  config       get or set configuration of node at <path>
  connect      Connects hook <peerhook> of the node at <relpath> ...
  debug        Get/set debugging verbosity level
  dot          Produce a GraphViz (.dot) of the entire netgraph.
  help         Show command summary or get more help on a specific ..
  list         Show information about all nodes
  mkpeer       Create and connect a new node to the node at "path"
  msg          Send a netgraph control message to the node at "path"
  name         Assign name <name> to the node at <path>
  read         Read and execute commands from a file
  rmhook       Disconnect hook "hook" of the node at "path"
  show         Show information about the node at <path>
  shutdown     Shutdown the node at <path>
  status       Get human readable status information from the node ...
  types        Show information about all installed node types
  write        Send a data packet down the hook named by "hook".
  quit         Exit program
+ ^D
```

Starting Netgraph

Netgraph automatically loads necessary kernel modules

```
# kldstat
Id Refs Address    Size     Name
 1    8 0xc0400000 9fad10   kernel
 2    1 0xc0dfb000 6a45c    acpi.ko

# ngctl list
There are 1 total nodes:
  Name: ngctl39213   Type: socket   ID: 00000001   Num hooks: 0

# kldstat
Id Refs Address    Size     Name
 1    8 0xc0400000 9fad10   kernel
 2    1 0xc0dfb000 6a45c    acpi.ko
 6    1 0xc85ba000 4000     ng_socket.ko
 7    1 0xcc648000 b000     netgraph.ko
```

Querying Netgraph Status

```
# ngctl &
# netstat -f ng
Netgraph sockets
Type  Recv-Q Send-Q Node Address   #Hooks
ctrl       0      0 ngctl1314:        0
data       0      0 ngctl1314:        0

# ngctl list
There are 1 total nodes:
  Name: ngctl99971   Type: socket   ID: 00000008   Num hooks: 0
```

There used to be a bug in 7.x, 8.x introduced 2006 (when ng_socket.c became a loadable module) which caused netstat -f netgraph to fail (see kern/140446)

Creating Nodes

- ng_ether and ng_gif nodes are created automatically once the corresponding kernel module is loaded (and once loaded, they cannot be unloaded)
- ngctl mkpeer <node> <ngtype> <hook> <peerhook>

  node is usually `[id]:` or `name:`

  – the default is the current node

```
ngctl mkpeer em3: tee lower right
```

Naming Nodes

- ngctl name <target> <name>
  where <target> is node:hook

  ```
  ngctl name em3:lower T
  ```

- Example: hook *lower* is one of the three hooks for the ng_ether (*lower* connects to raw ether device, *upper* to the upper protocols, *orphans* is like *lower*, but only receives unrecognized packets – see man ng_ether)

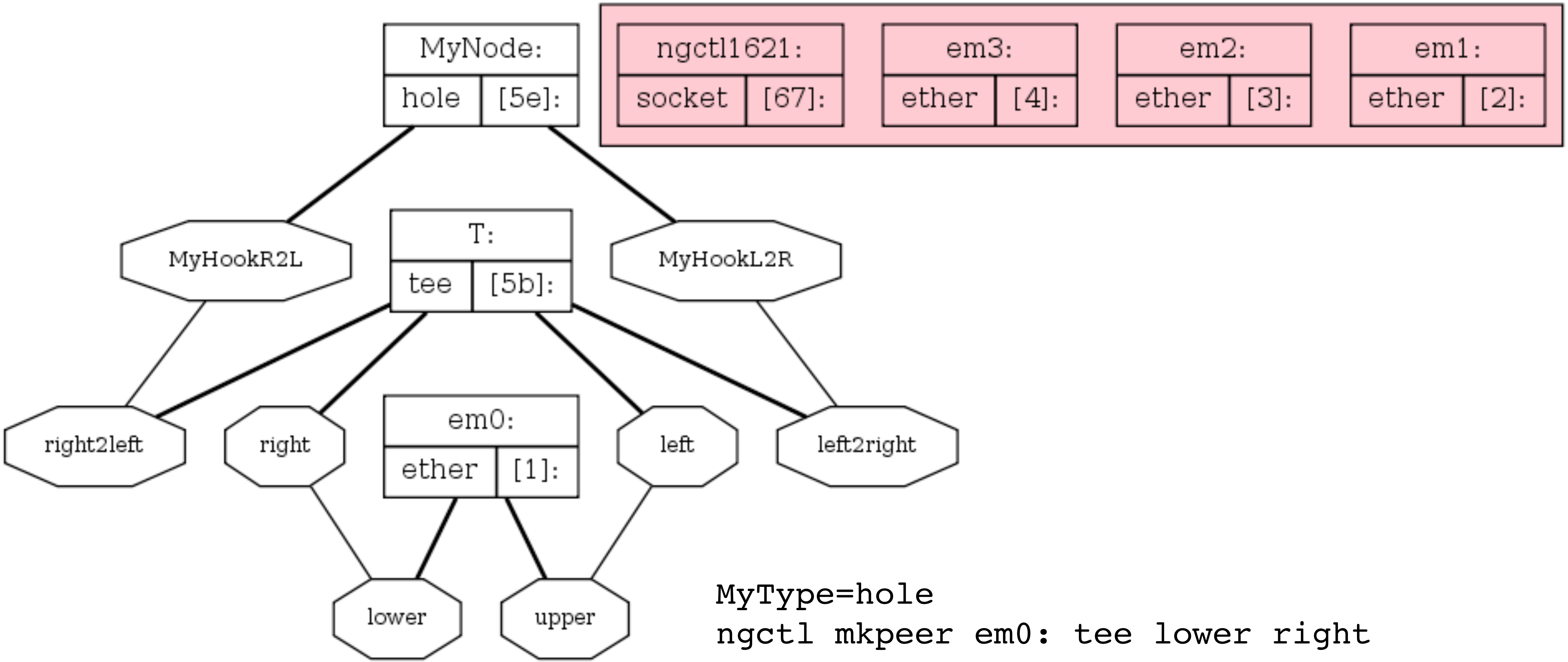
  ```
  ngctl mkpeer T: MyType right2left MyHookR2L
  ngctl name T:right2left MyNode
  ```

Connecting Nodes

- Connecting nodes creates edges
- Hooks that are not connected do nothing, i.e. packets that would go there according to node type are dropped
- ngctl connect is used when both nodes already exist (as opposed to mkpeer, where a new node is created and connected in one step)
- ngctl connect <node_a> <node_b> <hook_a> <hook_b>

```
ngctl connect MyNode: T: MyHookL2R left2right
ngctl connect T: em0: left upper
```

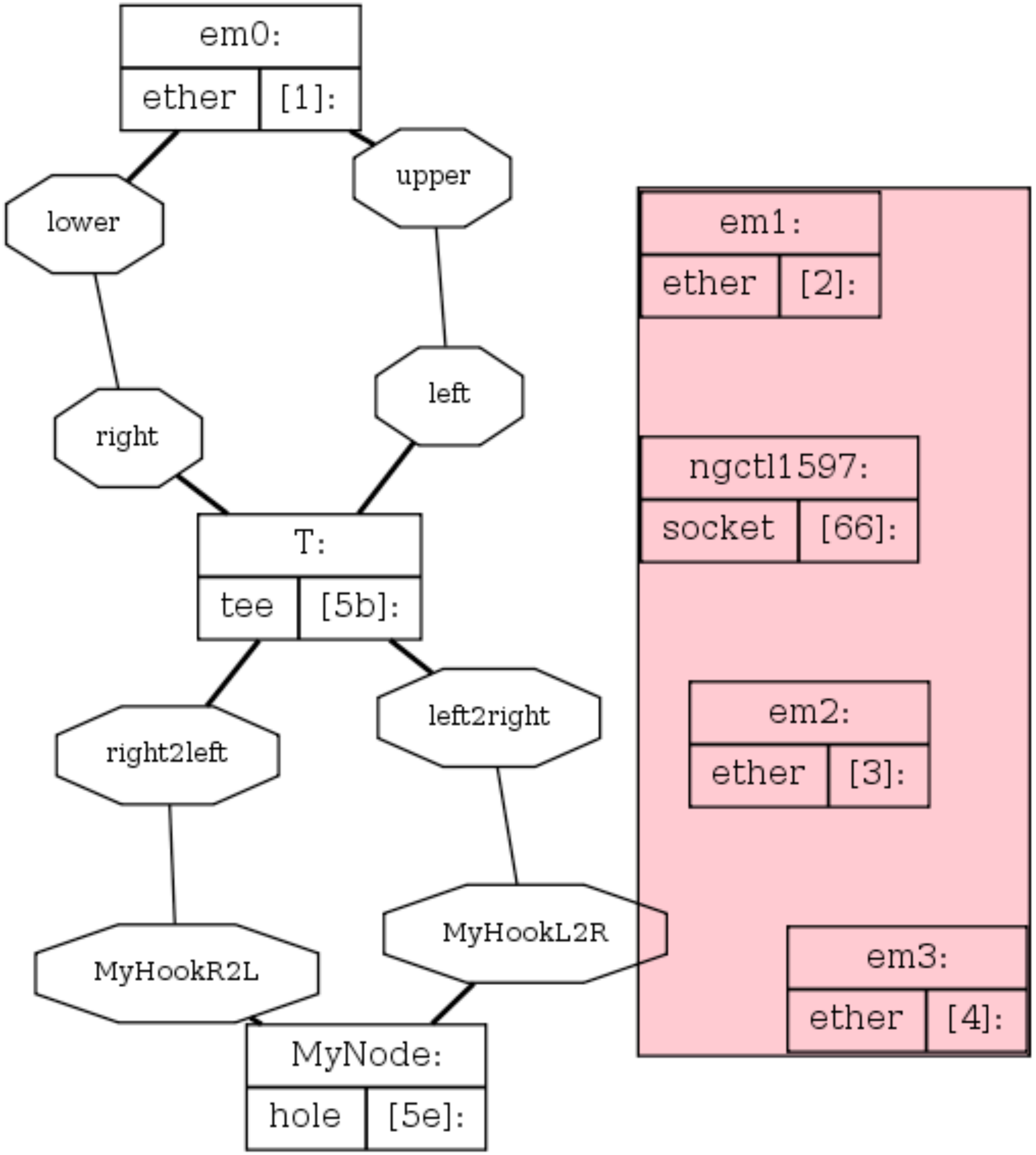
A first Net-graph



```
MyType=hole
ngctl mkpeer em0: tee lower right
ngctl name em0:lower T
ngctl mkpeer T: $MyType right2left MyHookR2L
ngctl name T:right2left MyNode
ngctl connect MyNode: T: MyHookL2R left2right
ngctl connect T: em0: left upper
```

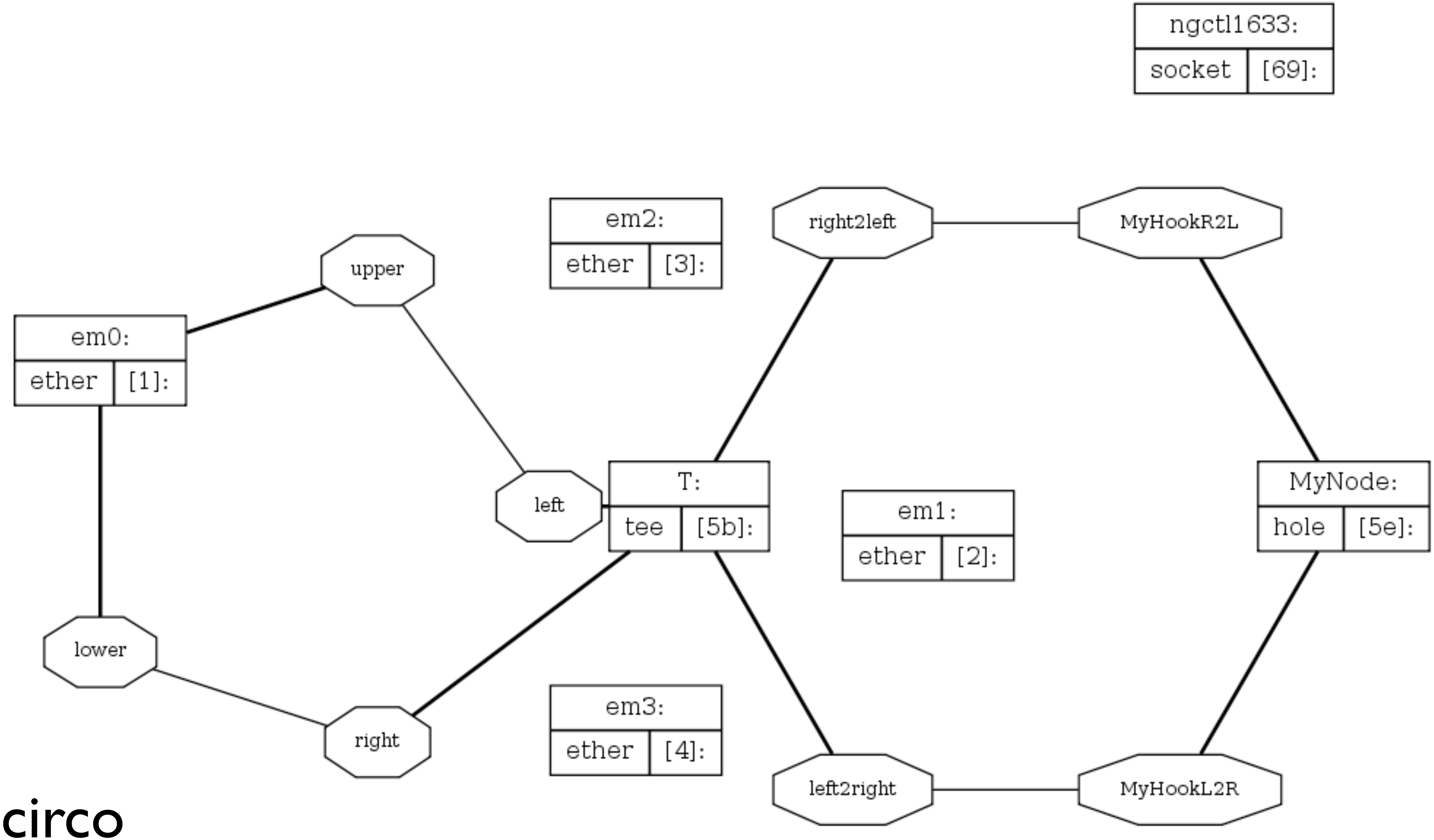
dot

Another Net-graph



neato

And another Net-graph



circo

Speaking with Nodes

- ngctl msg <node> <command> [args ...]

```
ngctl msg T: getstats
```

- What messages a particular node accepts (and what arguments it takes) depends on the node – read section 4 of the manual for ng_xyz
- Netgraph has ascii syntax for passing binary information to node – see, for example, ng_ksocket(4) or ng_bpf(4)

Removing an Edge

- ngctl rmhook <hook>

```
ngctl rmhook MyHookR2L
```

- Specifying the node is optional:

ngctl rmhook <node> <hook>

```
ngctl rmhook MyNode MyHookL2R
```

Removing a Node

- Shutting down a node (all edges to hooks on this node are removed)
- ngctl shutdown <node>

```
ngctl shutdown T:
```

These edges disappear:

```
T:left - em0:lower
T:right - em0:upper
T:left2right - MyNode:MyHookL2R
T:right2left - MyNode:MyHookL2R
```

Common Node Types

ng_ether(4) **`fxp0:`**

- Hooks: upper, lower, orphans
- Process raw ethernet traffic to/from other nodes
- Attach to actual 802.11 hardware and are named automatically
- Messages

getifname, getifindex, getenaddr, setenaddr,

getpromisc, setpromisc, getautosrc, setautosrc,

addmulti, delmulti, detach

Common Node Types

ng_eiface(4) **`ngeth0:`**

- Hooks: ether
- Virtual ethernet interface providing ethernet framing
- Messages:

  set, getifname

More Nodes Types

ng_iface(4) Virtual interface for protocol-specific frames

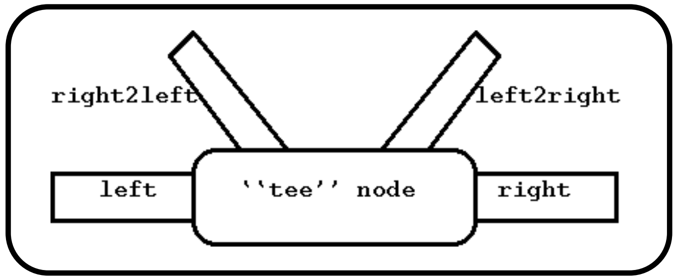
- Hooks: inet, inet6, ipx, atalk, ns, atm, natm
- Messages: getifname, point2point, broadcast, getipaddr, getifindex

`ng0:`

ng_tee(4) Useful for tapping (for example, to snoop traffic)

- Hooks: left, right, left2right, right2left
- Messages: getstats, clrstats, getclrstats

Example: Snooping



```
kldload ng_ether
ngctl mkpeer ${int}: tee lower left
ngctl name ${int}:lower T

ngctl connect ${int}: T: upper right
ngctl show T:
  Name: T                Type: tee                ID: 0000003e   Num hooks: 2
  Local hook        Peer name         Peer type     Peer ID          Peer hook
  ----------        ---------         ---------     --------         ---------
  right             ${int}               ether         00000019         upper
  left              ${int}               ether         00000019         lower

nghook -an T: left2right
...
0020:  d0 aa e4 d2 14 84 47 ae 24 fb 40 fd df 9b 80 10  ......G.$.@.....

ngctl msg T: getstats
Rec'd response "getstats" (1) from "[66]:":
Args:   { right={ inOctets=15332 inFrames=117 outOctets=13325 outFrames=126 }
left={ inOctets=13325 inFrames=126 outOctets=15332 outFrames=117 }
left2right={ outOctets=1027 outFrames=6 } }

ngctl shut T:
ngctl shut ${int}:
```

Nodes of Special Interest

ng_socket(4)

- Enables the user-space manipulation (via a socket) of what is normally a kernel-space entity (the associated netgraph node)
- Hooks: arbitrary number with arbitrary names

ng_ksocket(4)

- Enables the kernel-space manipulation (via a netgraph node) of what is normally a user-space entity (the associated socket)
- Hooks: exactly one, name defines <family>/<type>/<proto>

These two examples show how to use ng_ksocket(4):

- **`/usr/share/examples/netgraph/ngctl`**
- **`/usr/share/examples/netgraph/udp.tunnel`**

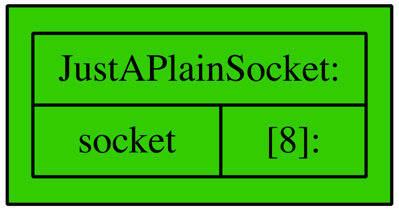
Visualizing Netgraph

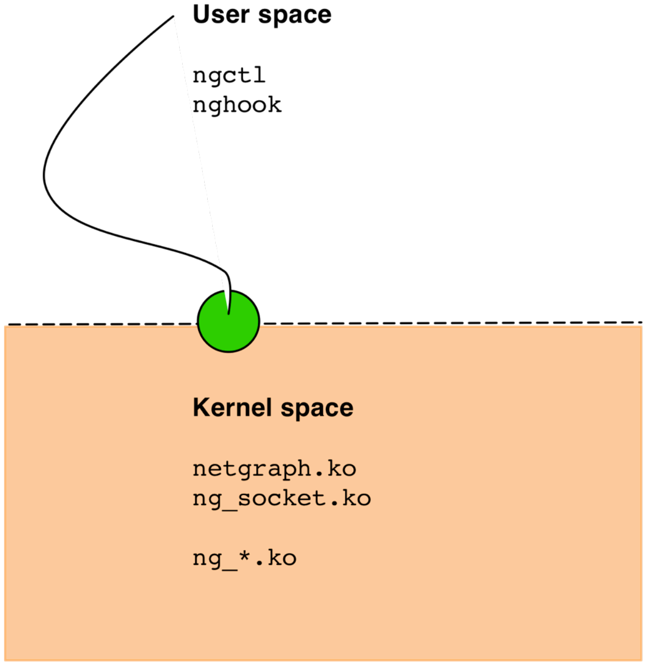
- Graph Visualization Software from AT&T and Bell Labs: http://www.graphviz.org/
- Port graphics/graphviz; various layouts:

dot	filter for hierarchical layouts of graphs
neato	filter for symmetric layouts of graphs
twopi	filter for radial layouts of graphs
circo	filter for circular layout of graphs
fdp	filter for symmetric layouts of graphs

Graphing Netgraph Graphs

```
# ngctl
+ name [8]: JustAPlainSocket
+ dot
graph netgraph {
        edge [ weight = 1.0 ];
        node [ shape = record, fontsize = 12 ] {
                "8" [ label = "{JustAPlainSocket:|{socket|[8]:}}" ];
        };
        subgraph cluster_disconnected {
                bgcolor = pink;
                "8";
        };
};
^D
$ dot -Tpng ngctl.dot > ngctl.png
```





User space

ngctl
nghook

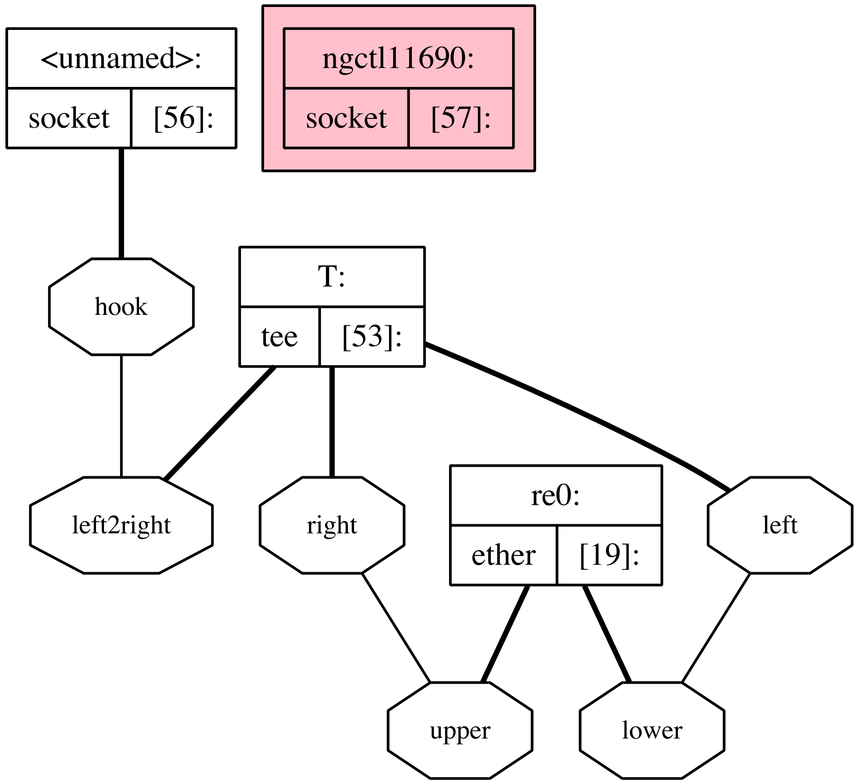
Kernel space

netgraph.ko
ng_socket.ko

ng_*.ko

Snoop Example Revisited

```
int=re0
ngctl mkpeer ${int}: tee lower left
ngctl name ${int}:lower T
ngctl connect ${int}: T: upper right
nghook -an T: left2right >/dev/null &
ngctl dot
ngctl shut T:
ngctl shut ${int}:
```



```
graph netgraph {
        edge [ weight = 1.0 ];
        node [ shape = record, fontsize = 12 ] {
                "5e" [ label = "{\<unnamed\>:|{socket|[5e]:}}" ];
                "56" [ label = "{\<unnamed\>:|{socket|[56]:}}" ];
                "19" [ label = "{${int}:|{ether|[19]:}}" ];
                "5f" [ label = "{ngctl11738:|{socket|[5f]:}}" ];
                "5b" [ label = "{T:|{tee|[5b]:}}" ];
        };
        subgraph cluster_disconnected {
                bgcolor = pink;
                "56";
                "5f";
        };
        node [ shape = octagon, fontsize = 10 ] {
                "5e.hook" [ label = "hook" ];
        };
        {
                edge [ weight = 2.0, style = bold ];
                "5e" -- "5e.hook";
        };
        "5e.hook" -- "5b.left2right";
        node [ shape = octagon, fontsize = 10 ] {
                "19.upper" [ label = "upper" ];
                "19.lower" [ label = "lower" ];
        };
        {
                edge [ weight = 2.0, style = bold ];
                "19" -- "19.upper";
                "19" -- "19.lower";
        };
        node [ shape = octagon, fontsize = 10 ] {
                "5b.left2right" [ label = "left2right" ];
                "5b.right" [ label = "right" ];
                "5b.left" [ label = "left" ];
        };
        {
                edge [ weight = 2.0, style = bold ];
                "5b" -- "5b.left2right";
                "5b" -- "5b.right
                "5b" -- "5b.left";
        };
        "5b.right" -- "19.upper";
        "5b.left" -- "19.lower";
};
```

Bridge

ng_bridge(4)

Hooks:

link0, ..., link31 (NG_BRIDGE_MAX_LINKS = 32)

Messages:

setconfig, getconfig, reset, getstats, clrstats, getclrstats, gettable

This module does bridging on ethernet node types, each link carries raw ethernet frames so ng_bridge(4) can learn which MACs are on which link (and does loop detection). Typically, the link0 hook is connected to the first ng_ether(4) lower hook with ngctl mkpeer, and the subsequent ethernet interfaces' lower hooks are then connected with ngctl connect, making sure that the ethernet interfaces are in promiscuous mode and do not set the source IP:

```
ngctl msg ${int}: setpromisc 1 && ngctl msg ${int}: setautosrc 0
```

– see /usr/share/examples/netgraph/ether.bridge

One2Many

ng_one2many(4)

- Hooks:
  - one, many1, many2, ...
- Messages:
  - setconfig, getconfig, getstats, clrstats, getclrstats, gettable

Similar to ng_bridge() the one hook is connected to the first ng_ether(4) upper hook with ngctl mkpeer, and the subsequent ethernet interfaces' upper hooks are connected with ngctl connect, making sure that the ethernet interfaces are in promiscuous mode and do not set the source IP.

Example: Interface Bonding

```
kldload ng_ether
kldload ng_one2many

intA=vr0
intB=vr1
IP=192.168.1.1/24

# start with clean slate
ngctl shut ${intA}:
ngctl shut ${intB}:

# Plumb nodes together
ngctl mkpeer ${intA}: one2many upper one
ngctl connect ${intA}: ${intA}:upper lower many0
ngctl connect ${intB}: ${intA}:upper lower many1

# Allow ${intB} to xmit/recv ${intA} frames
ngctl msg ${intB}: setpromisc 1
ngctl msg ${intB}: setautosrc 0

# Configure all links as up
ngctl msg ${intA}:upper setconfig "{ xmitAlg=1 failAlg=1 enabledLinks=[ 1 1 ] }"

# Bring up interface
ifconfig ${intA} ${IP}

ngctl msg ${intA}:lower getconfig
Rec'd response "getconfig" (1) from "[11]:":
Args:   { xmitAlg=1 failAlg=1 enabledLinks=[ 1 1 ] }
```

VLAN

```
ETHER_IF=vr0

kldload ng_ether
kldload ng_vlan

ngctl shutdown ${ETHER_IF}:
ngctl mkpeer ${ETHER_IF}: vlan lower downstream
ngctl name ${ETHER_IF}:lower vlan
ngctl connect ${ETHER_IF}: vlan: upper nomatch

ngctl mkpeer vlan: eiface vlan123 ether
ngctl msg vlan: addfilter '{ vlan=123 hook="vlan123" }'

ngctl show vlan:
  Name: vlan              Type: vlan             ID: 00000038   Num hooks: 3
  Local hook       Peer name        Peer type    Peer ID          Peer hook
  ----------       ---------        ---------    --------         ---------
  vlan123          <unnamed>        eiface       0000003c         ether
  nomatch          vr0              ether        0000000b         upper
  downstream       vr0              ether        0000000b         lower
```

ng_vlan(4)

Hooks: downstream,
nomatch,
<arbitrary_name>

Messages: addfilter,
delfilter,
gettable

Ethernet Filter

ng_etf(4)

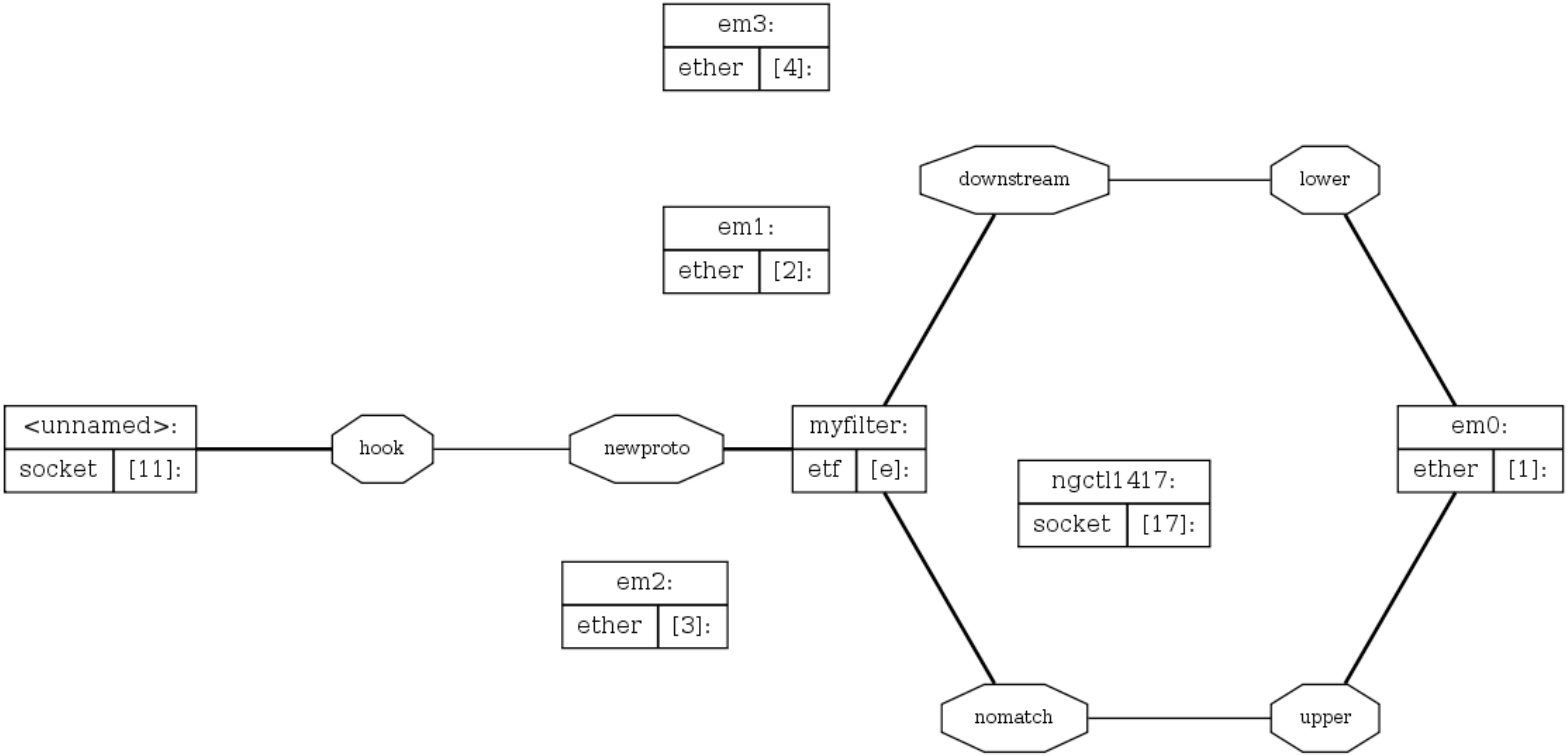
- Hooks:
  - downstream, nomatch, <any_name>
- Messages:
  - getstatus, setfilter

The downstream hook is usually connected to an ng_ether lower hook and the nomatch hook to the corresponding ng_ether upper; the <any_name> hook can then be captured by, say, an nghook process

Example: ng_etf(4)

```
kldload ng_ether
kldload ng_etf

int=fxp0

MATCH1=0x834
MATCH2=0x835

# Clean up any old connection, add etf node and name it
ngctl shutdown ${int}:lower
ngctl mkpeer ${int}: etf lower downstream
ngctl name ${int}:lower myfilter

# Connect the nomatch hook to the upper part of the same interface.
# All unmatched packets will act as if the filter is not present.
ngctl connect ${int}: myfilter: upper nomatch

# Show packets on a new hook "newproto" in background, ignore stdin
nghook -an myfilter: newproto &

# Filter the two random ethertypes to this newhook
ngctl msg myfilter: setfilter "{ matchhook=\"newproto\" ethertype=${MATCH1} }"
ngctl msg myfilter: setfilter "{ matchhook=\"newproto\" ethertype=${MATCH2} }"
```

Example: ng_etf(4)



Berkeley Packet Filter

ng_bpf(4)

Hooks: an arbitrary number of <arbitrary_name> hooks

Messages: setprogram, getprogram,

getstats, clrstats, getclrstats

The setprogram message expects a BPF(4) filter program **`bpf_prog_len=16 bpf_prog=[...]`** which is generated from tcpdump -ddd output. Together with this filter one sets the **`thisHook="inhook"`**, **`ifMatch="matchhook"`**, and **`ifNotMatch="notmatchhook"`** hooks for use elsewhere.

Generating BPF Program

```
#!/bin/sh
i=0
{
    tcpdump -s 8192 -ddd "$@" \
        | while read line; do
            set -$- $line
            i=$(( $i + 1 ))
            if [ $i -eq 1 ]
            then
                echo "bpf_prog_len=$1"
                continue
            elif [ $i -eq 2 ]; then
                echo "bpf_prog=["
            fi
            echo " { code=$1 jt=$2 jf=$3 k=$4 }"
        done
    echo " ]"
} | xargs
exit 0
```

```
tcpdump -s 8192 -ddd \
      tcp dst port 80

16
40 0 0 12
21 0 4 34525
48 0 0 20
21 0 11 6
40 0 0 56
21 8 9 80
21 0 8 2048
48 0 0 23
21 0 6 6
40 0 0 20
69 4 0 8191
177 0 0 14
72 0 0 16
21 0 1 80
6 0 0 8192
6 0 0 0
```

```
tcpdump2bpf.sh tcp dst port 80
bpf_prog_len=16 bpf_prog=[ { code=40 jt=0 jf=0 k=12 } { code=21 jt=0 jf=4 k=34525 }
{ code=48 jt=0 jf=0 k=20 } ...  { code=6 jt=0 jf=0 k=8192 } { code=6 jt=0 jf=0 k=0 } ]
```

ng_ipfw(4), ng_tag(4)

- ng_ipfw(4) interface between IPFW and Netgraph
  - Hooks: arbitrary number, name must be numeric
  - Messages: none (only generic)
- ng_tag(4)
  - Hooks: arbitrary number and name
  - Messages: sethookin, gethookin, sethookout, gethookout, getstats, clrstats, getclrstats

BPF + IPFW + TAG = L7 Filter

RTFM ng_tag(4)

DirectConnect P2P TCP payloads contain the string “$Send|”, filter these out with ng_bpf(4), tag the packets with ng_tag(4), and then block them with an ipfw rule hooking them to a ng_ipfw(4) node.

man ng_tag(4)

```
kldload ng_ipfw; kldload ng_bpf; kldload ng_tag

ngctl mkpeer ipfw: bpf 41 ipfw
ngctl name ipfw:41 dcbpf
ngctl mkpeer dcbpf: tag matched th1
ngctl name dcbpf:matched ngdc

grep MTAG_IPFW /usr/include/netinet/ip_fw.h
#define MTAG_IPFW 1148380143  /* IPFW-tagged cookie */

ngctl msg ngdc: sethookin  { thisHook=\"th1\" ifNotMatch=\"th1\" }
ngctl msg ngdc: sethookout { thisHook=\"th1\" \
                             tag_cookie=1148380143 tag_id=412 }
ngctl msg dcbpf: setprogram { thisHook=\"matched\" \
                              ifMatch=\"ipfw\" bpf_prog_len=1 \
                              bpf_prog=[ { code=6 k=8192 } ] }

tcpdump2bpf.sh "ether[40:2]=0x244c && ether[42:4]=0x6f636b20"
bpf_prog_len=6 bpf_prog=[ {... { code=6 jt=0 jf=0 k=8192 } ... ]

ipfw add 100 netgraph 41 tcp from any to any iplen 46
ipfw add 110 reset tcp from any to any tagged 412

sysctl net.inet.ip.fw.one_pass=0
```

“$Lock ”

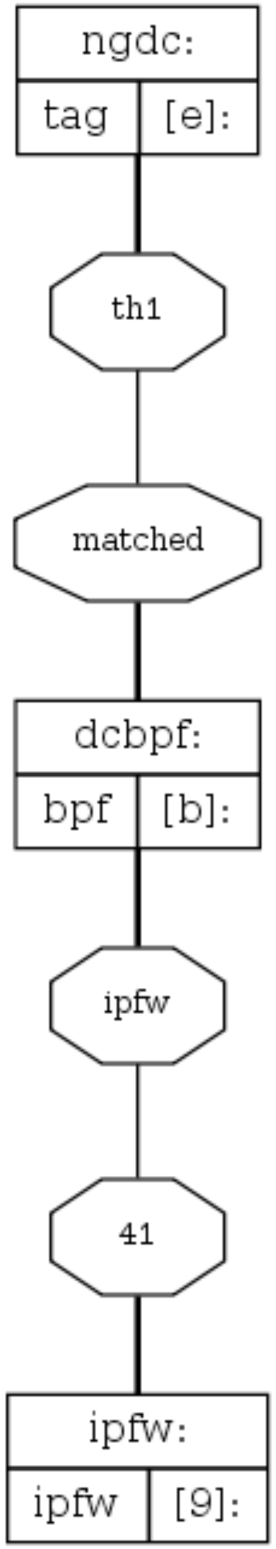
BPF + IPFW + TAG = L7 Filter

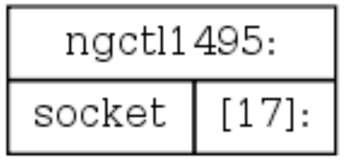
DirectConnect P2P TCP payloads contain the string "$Send|", filter these out with ng_bpf(4), tag the packets with ng_tag(4), and then block them with an ipfw rule hooking them to a ng_ipfw(4) node.

```
ipfw add 200 allow ip from any to any
kldload ng_ipfw; kldload ng_bpf; kldload ng_tag

ngctl mkpeer ipfw: bpf 41 ipfw
ngctl name ipfw:41 dcbpf
ngctl mkpeer dcbpf: tag matched th1
ngctl name dcbpf:matched ngdc

grep MTAG_IPFW /usr/include/netinet/ip_var.h
#define MTAG_IPFW 1148380143  /* IPFW-tagged cookie */

ngctl msg ngdc: sethookin  { thisHook=\"th1\" ifNotMatch=\"th1\" }
ngctl msg ngdc: sethookout { thisHook=\"th1\" \
                             tag_cookie=1148380143 tag_id=412 }
ngctl msg dcbpf: setprogram { thisHook=\"matched\" \
                              ifMatch=\"ipfw\" bpf_prog_len=6 \
                              bpf_prog=[ { ... (see below) ... } ] }

tcpdump2bpf.sh "ether[40:2]=0x2453 && ether[42:4]=0x656e647c"
bpf_prog_len=6 bpf_prog=[ bpf_prog_len=6 bpf_prog=[ { code=40 jt=0 jf=0 k=40 }
{ code=21 jt=0 jf=3 k=9299 } { code=32 jt=0 jf=0 k=42 } { code=21 jt=0 jf=1
k=1701733500 } { code=6 jt=0 jf=0 k=8192 } { code=6 jt=0 jf=0 k=0 } ]

ipfw add 100 netgraph 41 tcp from any to any iplen 46
ipfw add 110 reset tcp from any to any tagged 412

sysctl net.inet.ip.fw.one_pass=0
```

man ng_tag(4)
http://www.ipp2p.org/
ipt_ipp2p.c

BPF + IPFW + TAG = L7 Filter





```
ngctl mkpeer ipfw: bpf 41 ipfw
ngctl name ipfw:41 dcbpf
ngctl mkpeer dcbpf: tag matched th1
ngctl name dcbpf:matched ngdc
ngctl msg ngdc: sethookin  { thisHook=\"th1\" ifNotMatch=\"th1\" }
ngctl msg ngdc: sethookout { thisHook=\"th1\" \
                           tag_cookie=1148380143 tag_id=412 }
ngctl msg dcbpf: setprogram { thisHook=\"matched\" \
                            ifMatch=\"ipfw\" bpf_prog_len=6 \
                            bpf_prog=[ { ... } ] }
```

```
ipfw add 100 netgraph 41 tcp from any to any iplen 46
ipfw add 110 reset tcp from any to any tagged 412

sysctl net.inet.ip.fw.one_pass=0
```

Service Control Engine

`http://shveitser.blogspot.com/`

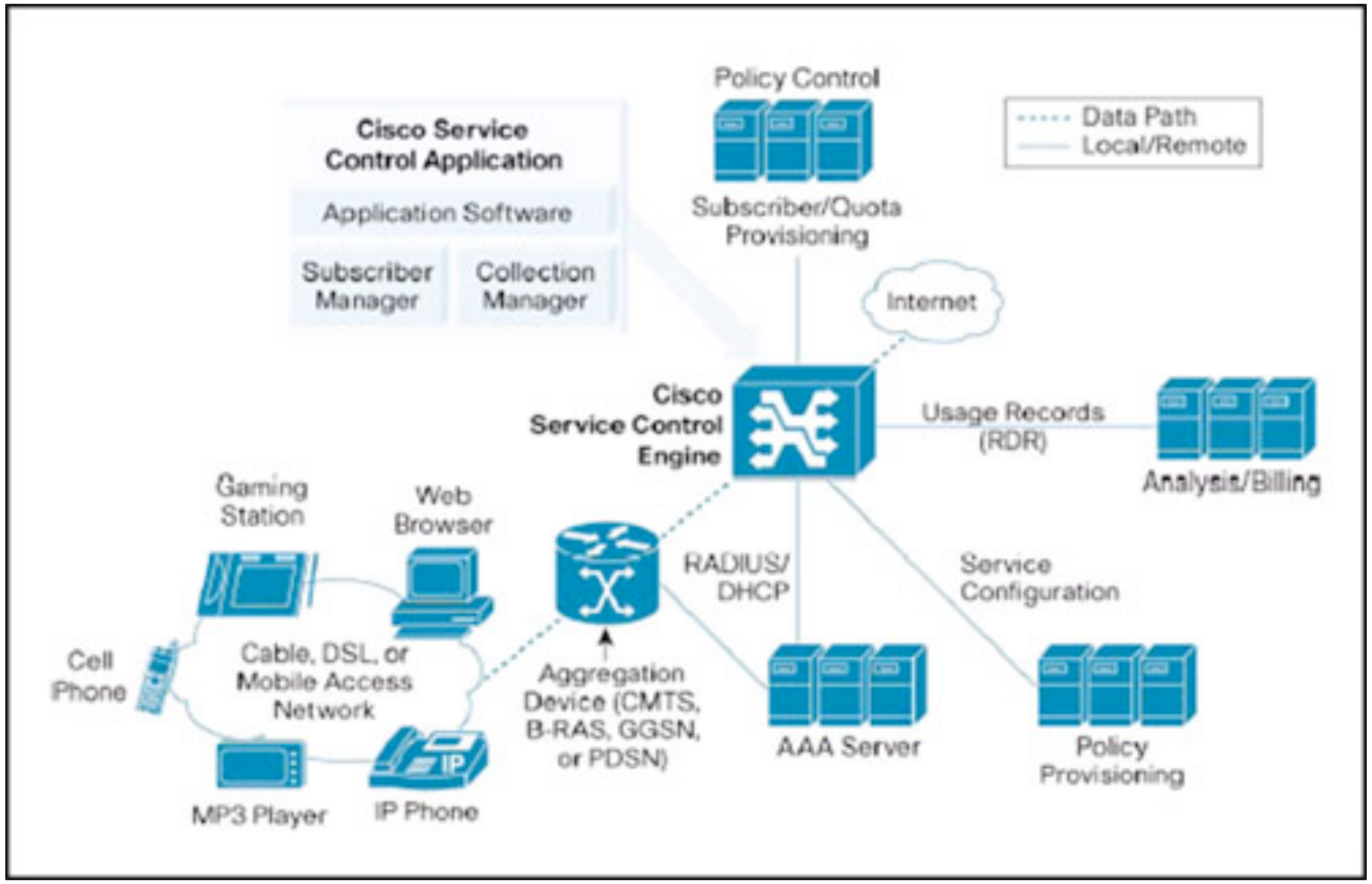
`ng_state`

(December 2011)

- User bandwidth policing
- Possibility of having common CIR for group of IP addresses
- Traffic classification and traffic policing according to class
- Netflow v5 export
- WEB traffic redirect to display informational messages
- Flood and attack protection (internal and external)
- P2P traffic detection by behavior

Number of supported users - 65k.
Tested on 5-7Gbits with 4 million flows.

Cisco Service Control Engine Clone



ng_state

(December 2011)

- User bandwidth policing
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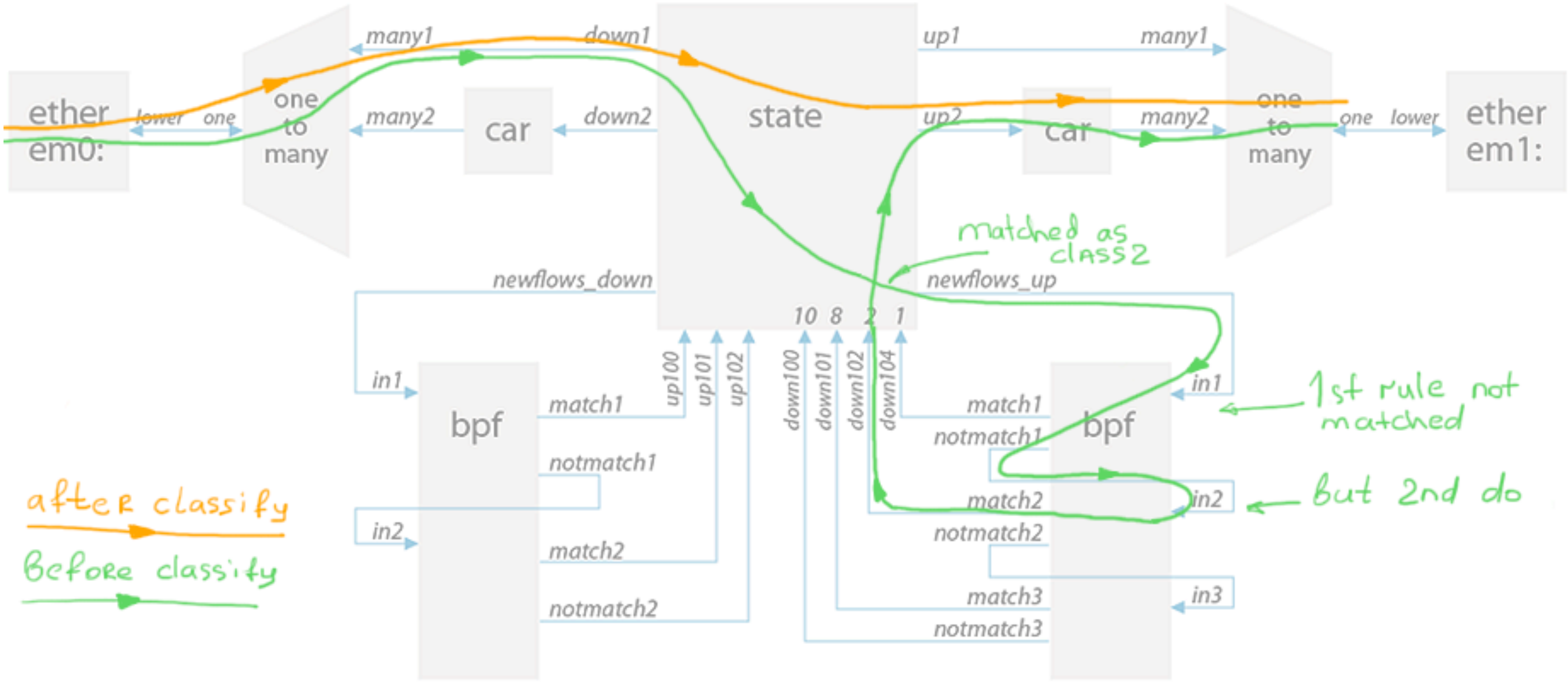
`ng_state`


ether em0:
lower
one
one to many
many1
many2
car
down1
down2
state
up1
up2
many1
many2
one to many
one
lower
ether em1:
newflows_down
newflows_up
10
8
2
1
in1
in2
bpf
match1
notmatch1
match2
notmatch2
up100
up101
up102
down100
down101
down102
down104
match1
notmatch1
match2
notmatch2
match3
notmatch3
in1
in2
in3
bpf
matched as class2
1st rule not matched
but 2nd do
after classify
before classify

MPD Champion of netgraph(3) User Library

ng_async
ng_bpf
ng_car
ng_deflate
ng_ether
ng_iface
ng_ksocket
ng_l2tp
ng_mppc
ng_nat
ng_netflow
ng_ppp
ng_pppoe
ng_pptpgre
ng_pred1
ng_socket
ng_tcpmss
ng_tee
ng_tty
ng_vjc

http://sourceforge.net/projects/mpd/files/

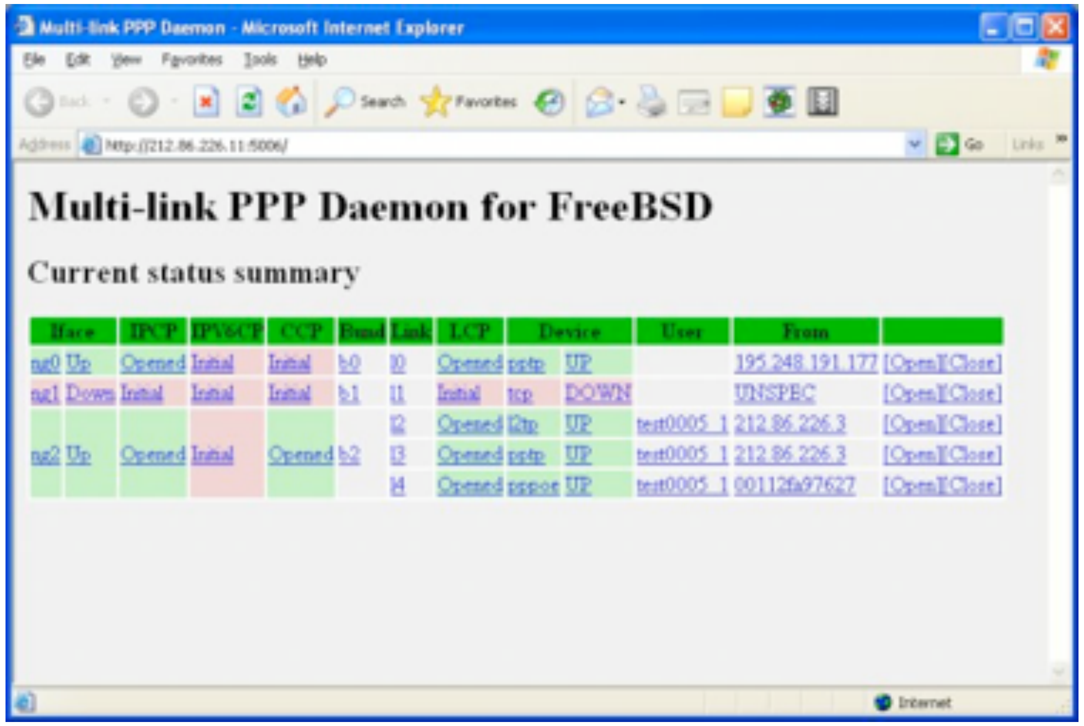
“MPD is a netgraph based PPP implementation for FreeBSD. MPD5 supports thousands of Sync, Async, PPTP, L2TP, PPPoE, TCP and UDP links in client, server and access concentrator (LAC/PAC/TSA) modes. It is very fast and functional”

Uses netgraph User Library (libnetgraph, -lnetgraph)

man 3 netgraph

Scales well

Built-in web monitor



Multi-link PPP Daemon for FreeBSD

Current status summary

Iface		IPCP	IPV6CP	CCP	Bund	Link	LCP	Device		User	From	
ng0	Up	Opened	Initial	Initial	b0	l0	Opened	pptp	UP		195.248.191.177	[Open][Close]
ng1	Down	Initial	Initial	Initial	b1	l1	Initial	tcp	DOWN		UNSPEC	[Open][Close]
ng2	Up	Opened	Initial	Opened	b2	l2	Opened	l2tp	UP	test0005_1	212.86.226.3	[Open][Close]
						l3	Opened	pptp	UP	test0005_1	212.86.226.3	[Open][Close]
						l4	Opened	pppoe	UP	test0005_1	00112fa97627	[Open][Close]

MPD Multi-link PPP Daemon Link Types

- **modem** to connect using different asychronous serial connections, including modems, ISDN terminal adapters, and null-modem. Mpd includes event-driven scripting language for modem identification, setup, manual server login, etc.
- **pptp** to connect over the Internet using the Point-to-Point Tunnelling Protocol (PPTP). This protocol is supported by the most OSes and hardware vendors
- **l2tp** to connect over the Internet using the Layer Two Tunnelling Protocol (L2TP). L2TP is a PPTP successor supported with modern clients and servers
- **pppoe** to connect over an Ethernet port using the PPP-over-Ethernet (PPPoE) protocol. This protocol is often used by DSL providers
- **tcp** to tunnel PPP session over a TCP connection. Frames are encoded in the same was as asychronous serial connections
- **udp** to tunnel PPP session over a UDP connection. Each frame is encapsulated in a UDP datagram packet
- **ng** to connect to netgraph nodes

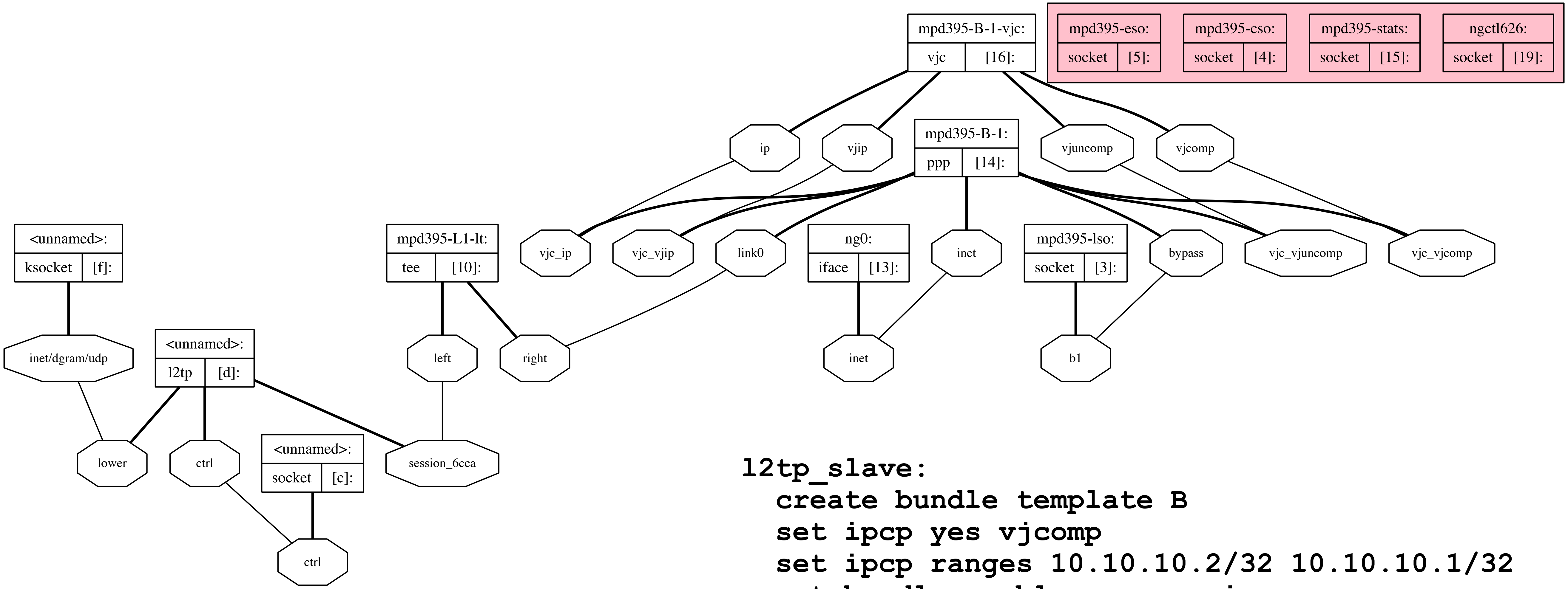
MPD Multi-link PPP Daemon Configuration

- MPD operates on several protocol layers (OSI layering) and acts as a PPP terminator with Radius or other AAA and IP accounting; usually used for IP but could be used for other protocols
- Can act in PPP repeater mode too (L2TP or PPTP access concentrator)
- PPP Terminator Layers:

  Interface – NCPs – Compression/Encryption – Bundle – Links

  A set of Links is a Bundle connecting to the peer, after optional compression/encryption the NCP (IPCP or IPv6CP) layer presents the interface which is visible via the ifconfig command

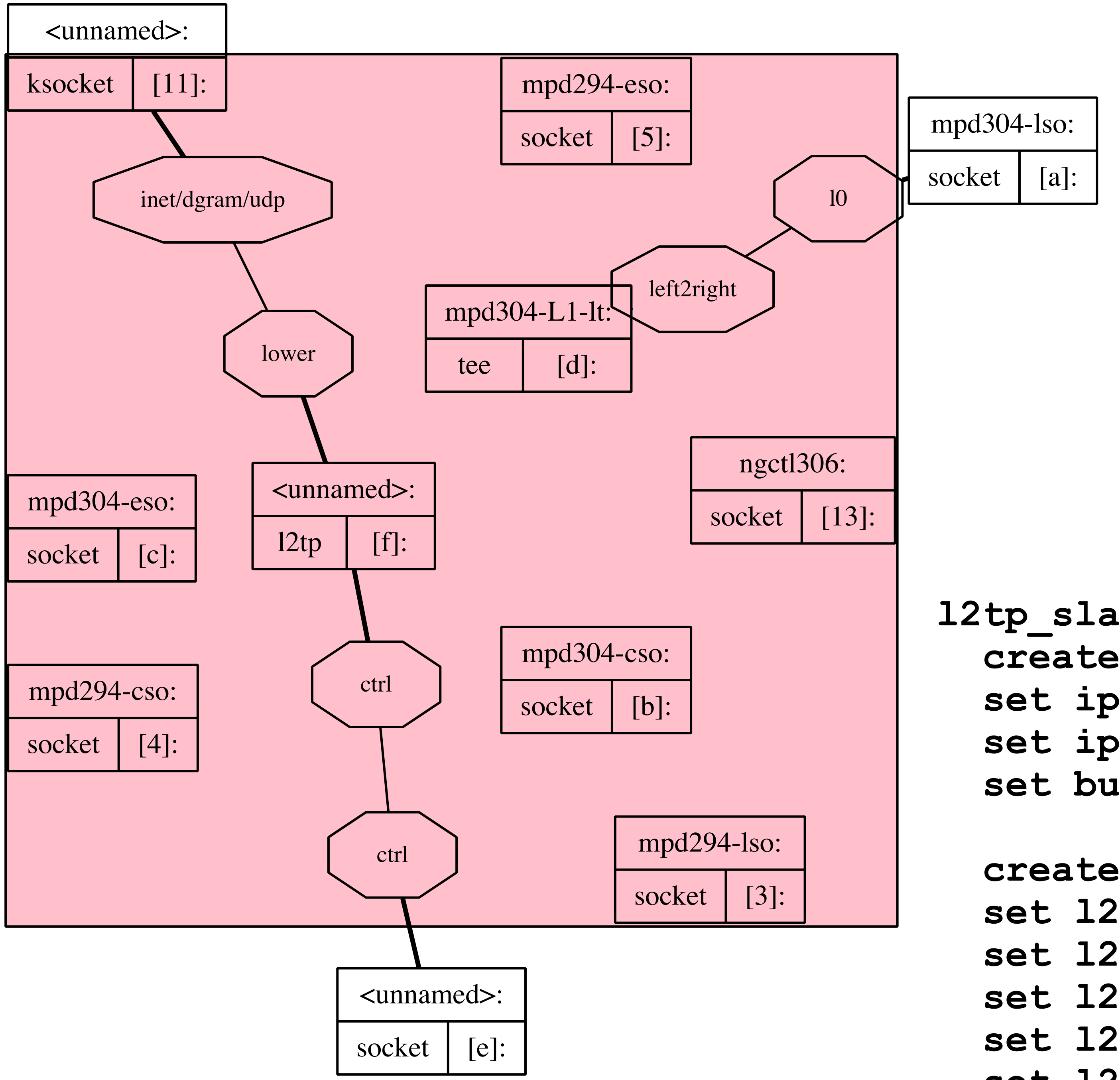
MPD NETGRAPH Net Graph Running



```
l2tp_slave:
  create bundle template B
  set ipcp yes vjcomp
  set ipcp ranges 10.10.10.2/32 10.10.10.1/32
  set bundle enable compression

  create link static L1 l2tp
  set l2tp self 10.10.10.11 1701
  set l2tp peer 10.10.10.10 1701
  set l2tp enable outcall
  set l2tp hostname slave
  set l2tp secret MySecret
  set link max-redial 0
  set link action bundle B
```

MPD NETGRAPH Net Graph Stopped



```
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  set l2tp self 10.10.10.11 1701
  set l2tp peer 10.10.10.10 1701
  set l2tp enable outcall
  set l2tp hostname slave
  set l2tp secret MySecret
  set link max-redial 0
  set link action bundle B
```

Creating Custom Node Type

- “Only” two steps:

  (1) Define your new custom **`struct ng_type`**

  (2) **`NETGRAPH_INIT(tee, &ng_tee_typestruct)`**

- **`sys/netgraph/ng_tee.c`** is a good example
- **`netgraph.h`**

  Defines basic netgraph structures

- **`ng_message.h`**

  Defines structures and macros for control messages, here you see how the generic control messages are implemented

Custom Node ng_sample.c

Skeleton module in sys/netgraph/ng_sample.{c,h}

```
static struct ng_type typestruct = {
        .version =      NG_ABI_VERSION,
        .name =         NG_XXX_NODE_TYPE,
        .constructor =  ng_xxx_constructor,
        .rcvmsg =       ng_xxx_rcvmsg,
        .shutdown =     ng_xxx_shutdown,
        .newhook =      ng_xxx_newhook,
/*      .findhook =     ng_xxx_findhook,       */
        .connect =      ng_xxx_connect,
        .rcvdata =      ng_xxx_rcvdata,
        .disconnect =   ng_xxx_disconnect,
        .cmdlist =      ng_xxx_cmdlist,
};
```

About mbuf(9)

An mbuf is a basic unit of memory management in kernel. Network packets and socket buffers use mbufs. A network packet may span multiple mbufs arranged into a linked list, which allows adding or trimming headers with minimal overhead.

Netgraph must have `M_PKTHDR` flag set, i.e., `struct pkthdr m_pkthdr` is added to the mbuf header. This means you also have access and are responsible for the data packet header information.

`m_pullup(mbuf, len)` is expensive, so always check if is needed:

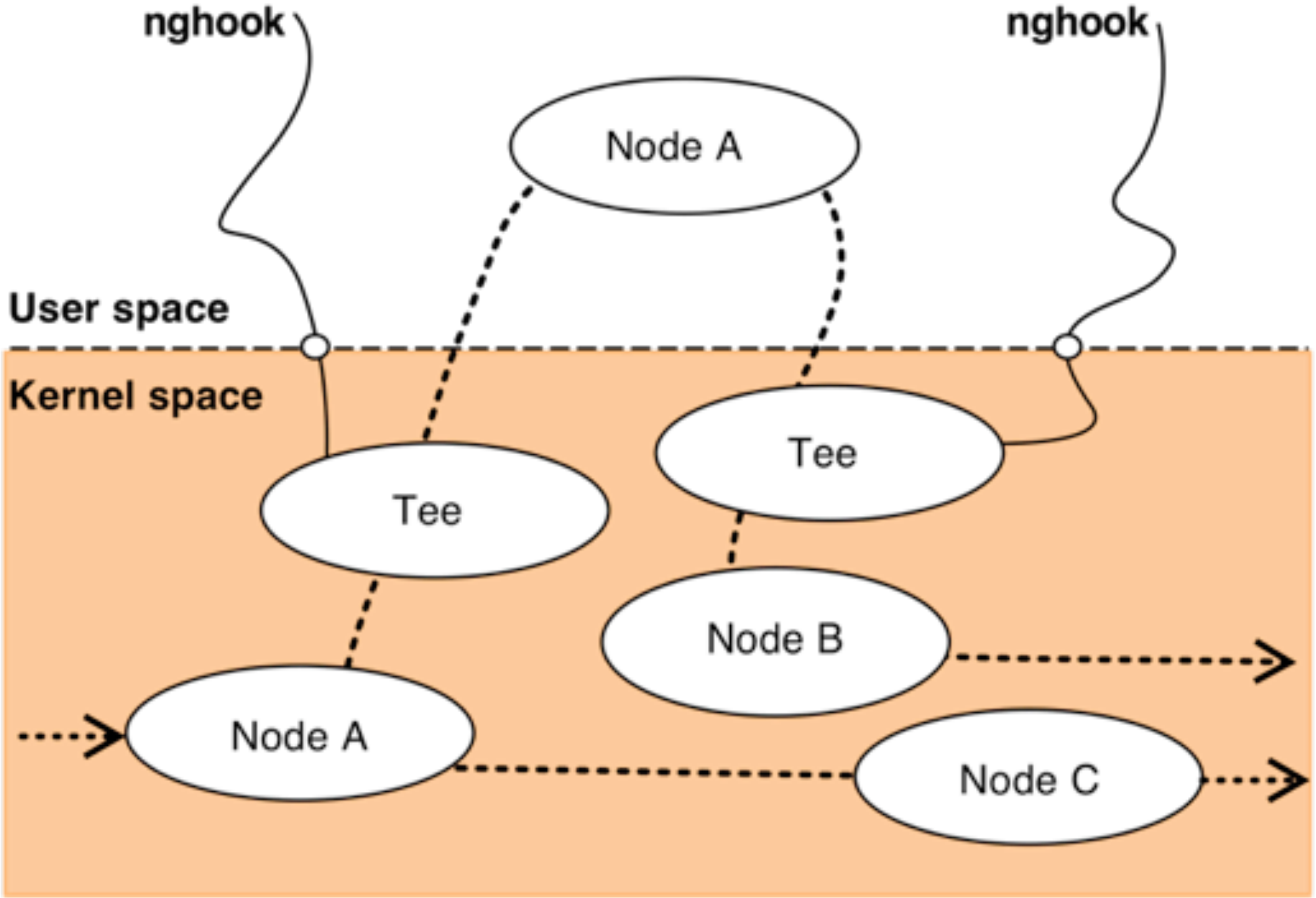
```
struct foobar *f;

if (m->m_len < sizeof(*f) && (m = m_pullup(m, sizeof(*f))) == NULL) {
    NG_FREE_META(meta);
    return (ENOBUFS);
}
f=mtod(m, struct foobar *);
...
```

User-space Prototyping

- User library libnetgraph – netgraph(3) – has a sufficiently similar API to the netgraph(4) kernel API, so that node types can be prototyped in user space

- Use an intermediate ng_tee(4) node and attach nghook(8) for debugging



Q & A

(1) Netgraph in a historical context

(2) Getting to know netgraph

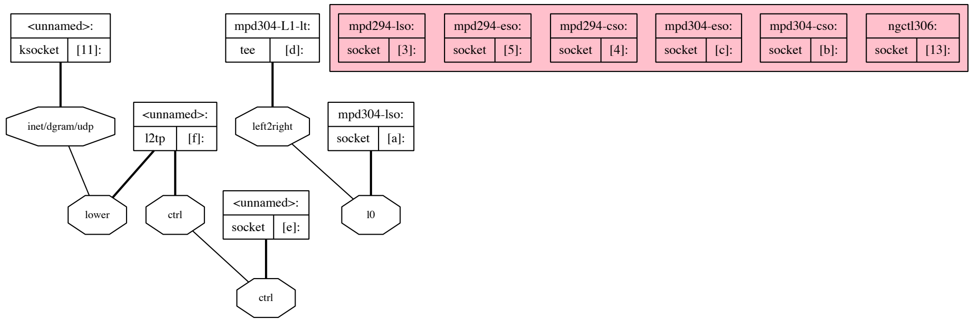
(3) Working with netgraph

(4) Details of frequently used netgraph node types

(5) Examples using netgraph nodes as building blocks

(6) Investigate some more sophisticated examples

(7) Guidelines for implementing custom node types



THANK YOU
for attending the Introduction to NETGRAPH on FreeBSD Systems Tutorial

URLS

(all URLS last retrieved in February 2012)

‘All About Netgraph’ (complete introduction to FreeBSD netgraph)

http://people.freebsd.org/~julian/netgraph.html

‘Netgraph in 5 and beyond’

A BAFUG talk where Julian Elischer points out things he fixed as FreeBSD transition from 4.x to 5.x (slides and movie)

http://people.freebsd.org/~julian/BAFUG/talks/Netgraph/

Re: diagram of 4.10 layer 2 spaghetti

http://www.mail-archive.com/freebsd-net@freebsd.org/msg16970.html

http://people.freebsd.org/~julian/layer2c.pdf

‘Netgraph7’ on DragonFly BSD

http://leaf.dragonflybsd.org/mailarchive/submit/2011-02/msg00008.html

http://gitweb.dragonflybsd.org/~nant/dragonfly.git/shortlog/refs/heads/netgraph7

Debugging a netgraph node

http://lists.freebsd.org/pipermail/freebsd-net/2009-June/022292.html

URLS, URLS

(all URLS last retrieved in February 2012)

STREAMS
http://cm.bell-labs.com/cm/cs/who/dmr/st.html (Initial article by Dennis Ritchie)
http://www.linuxjournal.com/article/3086 (LiS: Linux STREAMS)
http://en.wikipedia.org/wiki/STREAMS

“Hacking” The Whistle InterJet © (i486 internet access appliance 1996)
http://www.anastrophe.com/~paul/wco/interjet/ (Information on the Whistle Interjet)

6WINDGate™ Linux
Closed source virtual network blocks (VNB) stack derived from netgraph technology (press release 2007)
http://www.windriver.com/partner-validation/1B-2%20%20-%206WINDGate%20Architecture%20Overview%20v1.0.pdf

(ACM TOCS'11) Application-tailored I/O with Streamline
http://www.cs.vu.nl/~herbertb/papers/howard_ndss11.pdf

Marko Zec – network emulation using the virtualized network stack in FreeBSD
http://www.imunes.net/virtnet/eurobsdcon07_tutorial.pdf (Network stack virtualization for FreeBSD 7.0, EuroBSDCon Sept 2007)
http://meetbsd.org/files/2_05_zec.pdf (Network emulation using the virtualized network stack in FreeBSD, MeetBSD July 2010)
http://www.youtube.com/watch?v=wh09MirPd5Y (MeetBSD talk, July 2010)

URLS, URLS, URLS

(all URLS last retrieved in February 2012)

FreeBSD CVS Repository (to see all the currently available netgraph modules)
http://www.freebsd.org/cgi/cvsweb.cgi/src/sys/netgraph/
Latest addition ng_patch(4) 2010 by Maxim Ignatenko:
http://www.mail-archive.com/freebsd-net@freebsd.org/msg32164.html

A Gentlemen's Agreement
Assessing The GNU General Public License and its Adaptation to Linux
by Douglas A. Hass, Chicago-Kent Journal of Intellectual Property, 2007 mentions that netgraph has a good license model
http://papers.ssrn.com/sol3/papers.cfm?abstract_id=951842

Subject: NetBSD port of the freebsd netgraph environment
NetBSD 1.5, that is (port from the FreeBSD 4.3 netgraph)
http://mail-index.netbsd.org/tech-net/2001/08/17/0000.html

Netgraph on Debian GNU / kFreeBSD (in russian)
http://morbow.blogspot.com/2011/02/netgraph-debian.html

URLS, URLS, URLS, URLS

(all URLS last retrieved in February 2012)

Subject: [PATCH] ng_tag - new netgraph node, please test (L7 filtering possibility)
“Yes, netgraph always was a semi-programmer system”
Includes an example of in-kernel L7 (bittorrent) pattern matching filter using ng_bpf, ng_mtag and ipfw
http://lists.freebsd.org/pipermail/freebsd-net/2006-June/010898.html

(SIGCOMM Poster 2011 Winner) netmap: fast and safe access to network for user programs
http://info.iet.unipi.it/~luigi/netmap/20110815-sigcomm-poster.pdf
http://info.iet.unipi.it/~luigi/netmap/rizzo-ancs.pdf
http://queue.acm.org/detail.cfm?id=2103536 **Communications of the ACM 55 (3), 45-51**

Re: option directive and turning on AOE
In a discussion on ATA over Ethernet (frame type 0x88a2) other questions came up:
Does netgraph have locking issues? Is netgraph performant? – it depends:
http://unix.derkeiler.com/Mailing-Lists/FreeBSD/arch/2004-09/0006.html

ng_state
http://shveitser.blogspot.com/

Mikrotik's EoIP tunneling
http://wiki.mikrotik.com/wiki/Manual:Interface/EoIP
http://imax.in.ua/ng_mikrotik_eoip/