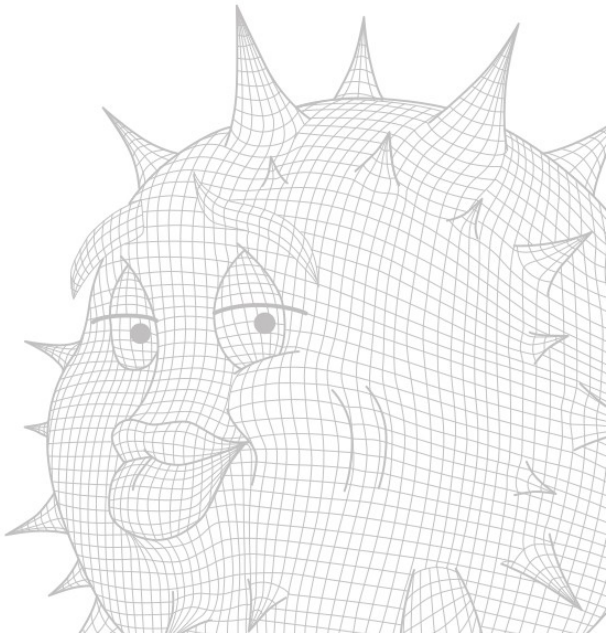
OpenBSD/x-ray

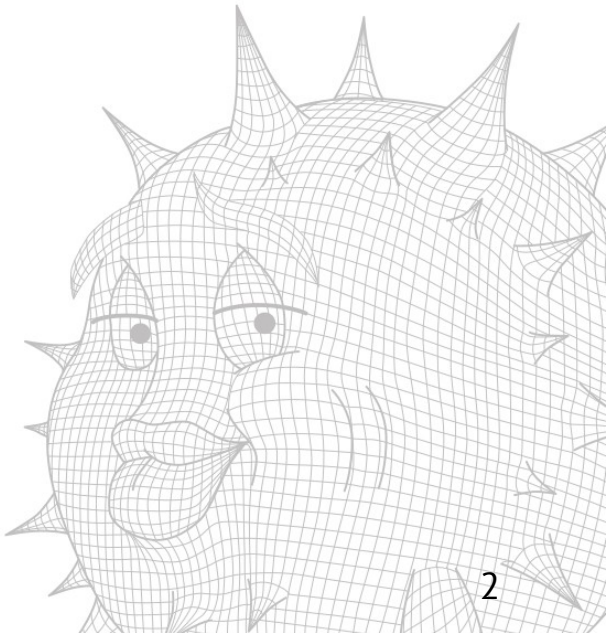
OpenBSD on medical x-ray machines

Henning Brauer
<info@henningbrauer.com>



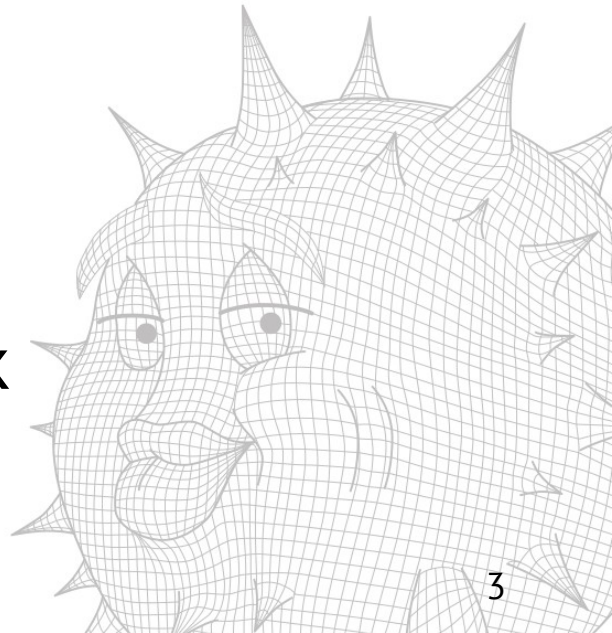
Medical Environment

- Certification, certification, certification
- Major changes require re-certification
  - Fixing problems is hard
- Long equipment lifetime



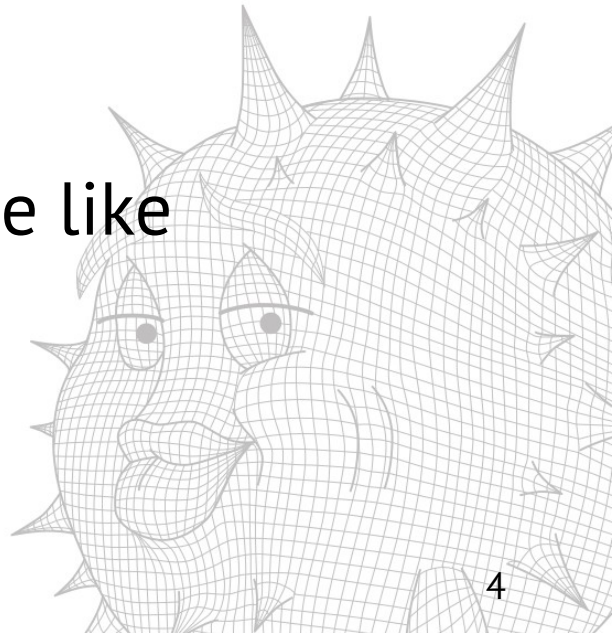
Medical Environment

- No remote access to live systems
  - Limited access in maintainance mode
  - Cannot legally acquire any data
    - Not even a typical request rate
- No remote updates
- Incremental development does not work



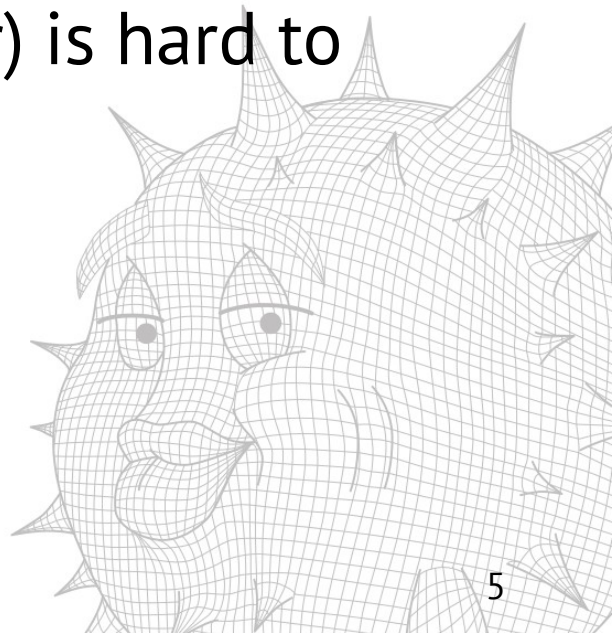
Medical environment

- Field engineers are x-ray engineers
- Not IT people, not sysadmins
- Can replace components
  - But not debug network problems or the like



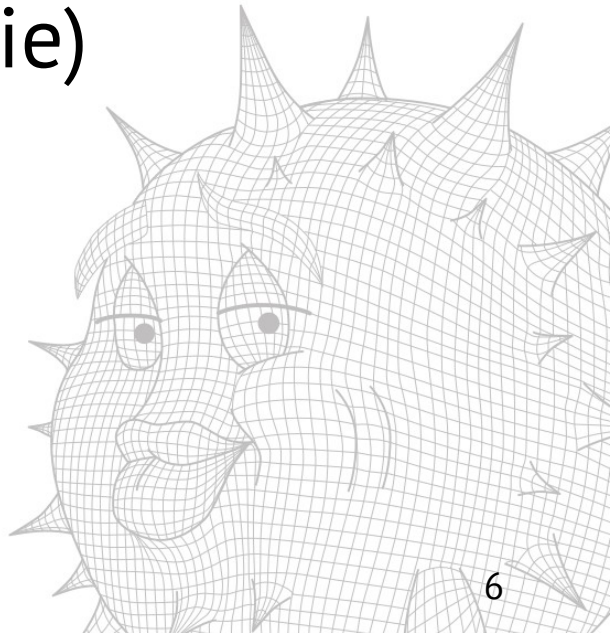
Medical Environment

- Patient data
  - A stolen credit card number can be voided
  - Medical fact (broken leg, breast cancer) is hard to change



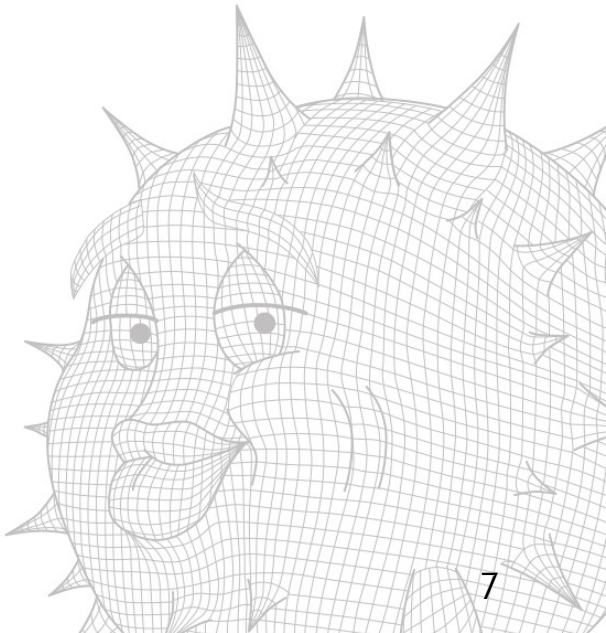
X-ray machine architecture

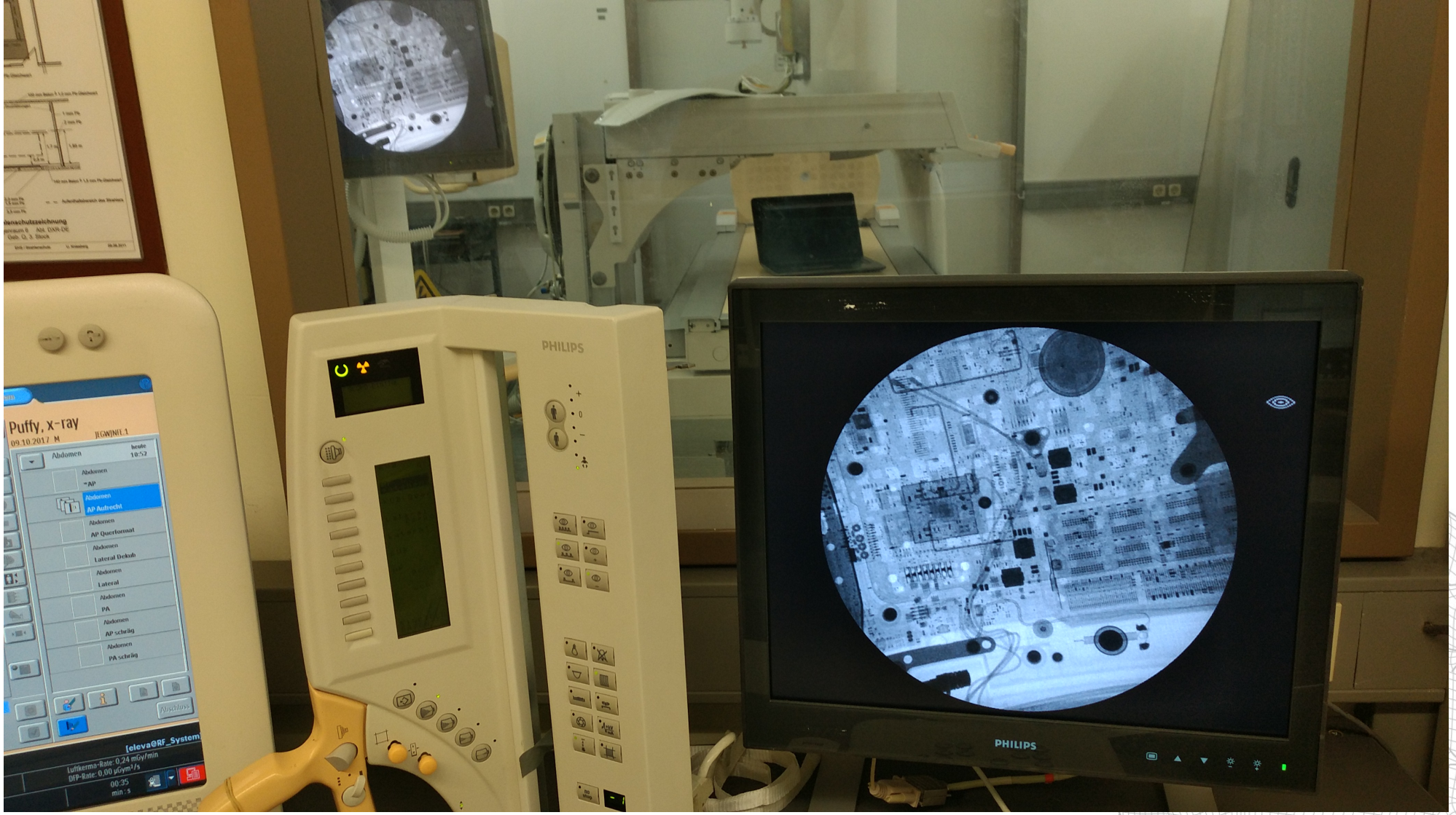
- Compact, mobile systems to fully equipped x-ray rooms
- X-ray (picture) and fluorescopy (movie)
- Several networked systems
- Connected to hospital network



X-ray machine architecture

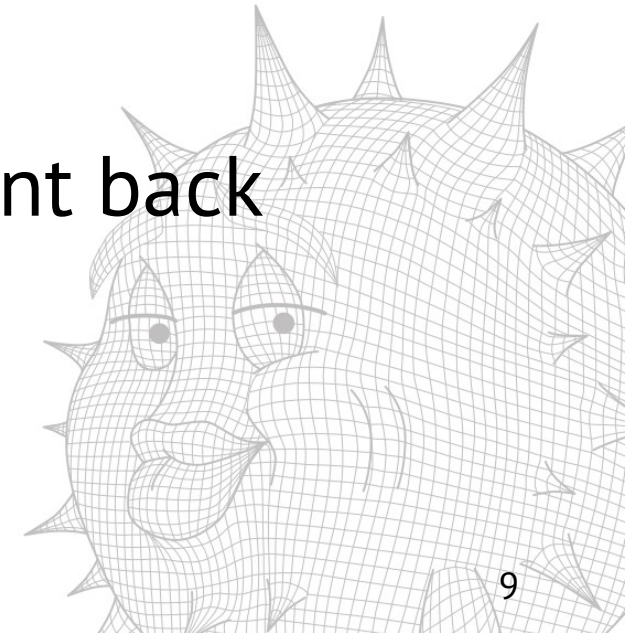
- Generator, x-ray tube and control circuits
- Image sensor
  - digital and wireless on new ones
- Table, wall mount
  - Usually motorized
- Foot switches
- Workstation for the operator




Puffy, x-ray
PHILIPS
PHILIPS

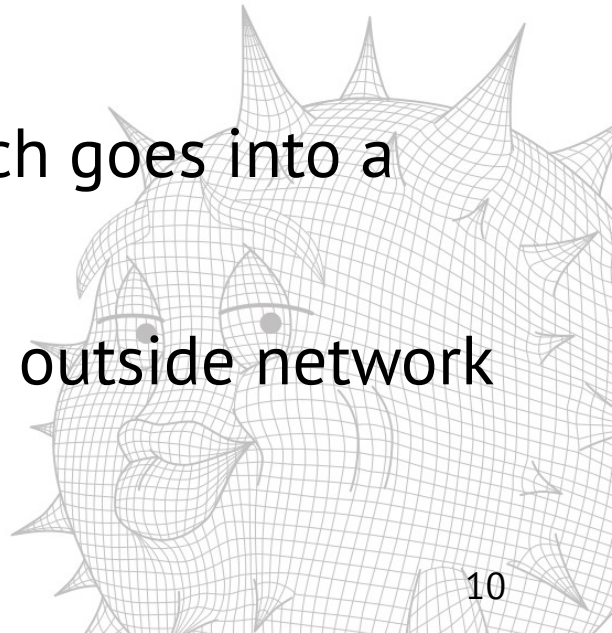
X-ray machine architecture

- Radiology Information System (RIS)
- Patient data with x-ray request is sent to the machine
- Patient data with x-ray images is sent back
  - Review, diagnosis, archiving



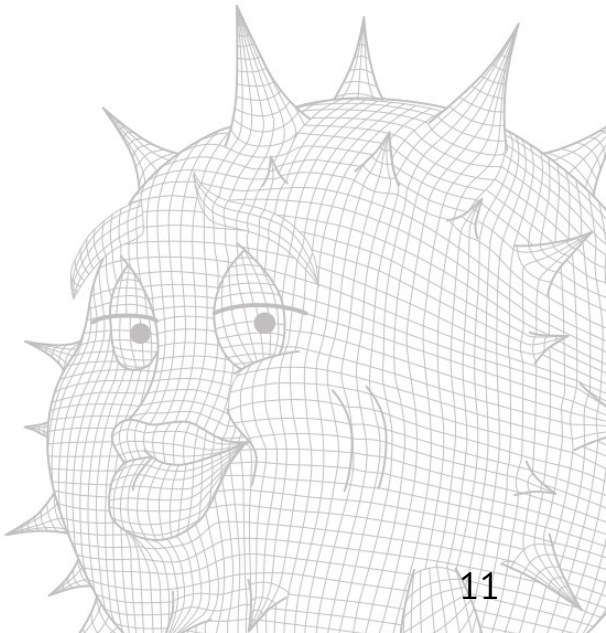
X-ray machine architecture

- New x-ray machines have digital sensors
  - Connected via Ethernet
- Several ways to retrofit older systems
  - Common: film replaced by a cassette, which goes into a reader, connected via Ethernet
  - Sometimes the reader is connected to the outside network



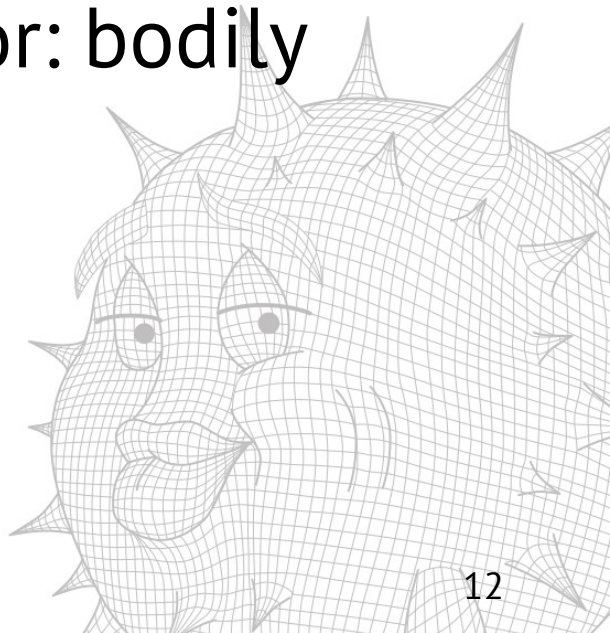
X-ray machine architecture

- 3rd party components
- Often little to no competition
  - Small market
  - high development and certification costs
- Old protocols don‘t die easily
  - FTP is alive



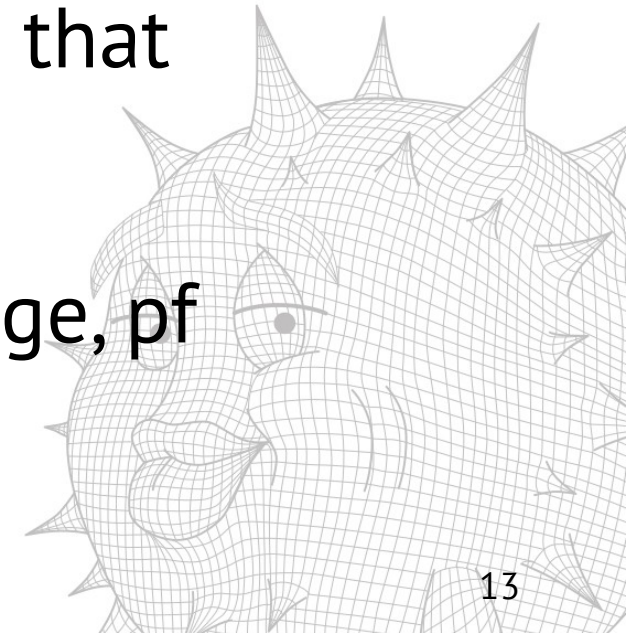
X-ray machine architecture

- Internal network and external network are the same Layer 2 network
- Interrupted data transfer from sensor: bodily injury!
  - x-ray process has to be repeated



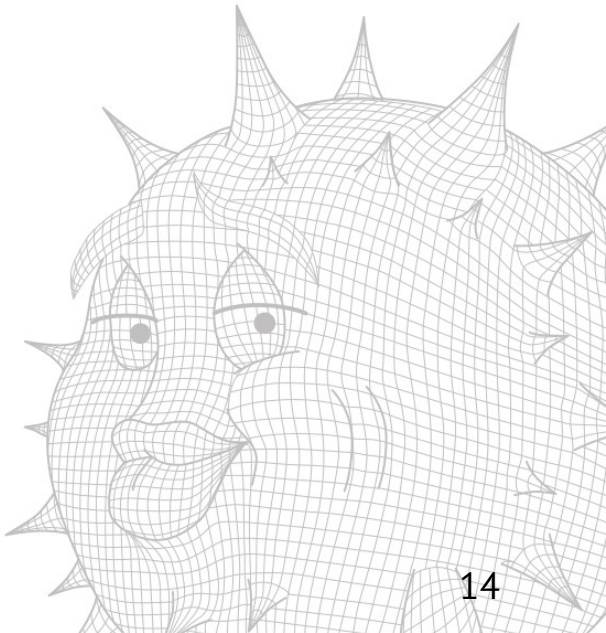
X-ray machine architecture

- Want to shield the internal network from the external
- Philips has an OpenBSD firewall for that
  - For 10 years already
- embedded i386, 4-5 LAN ports, bridge, pf



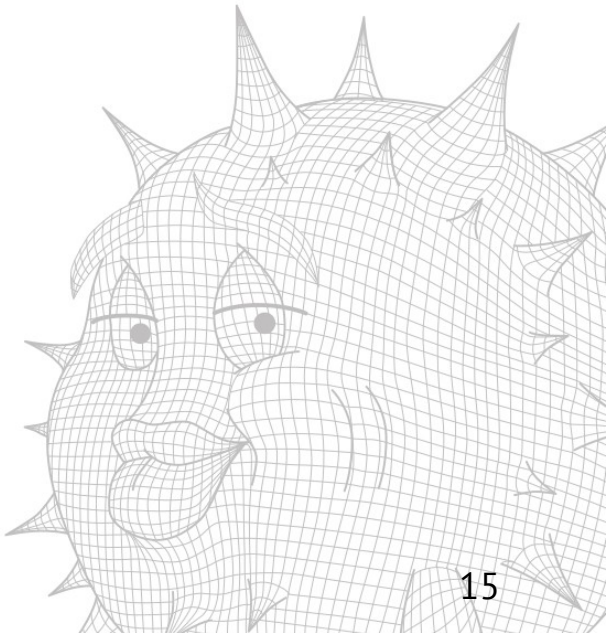
OpenBSD/x-ray

- Custom ramdisk
  - System can be powered off any time
  - Everything needed for bridge and pf
  - ssh and some basic tools



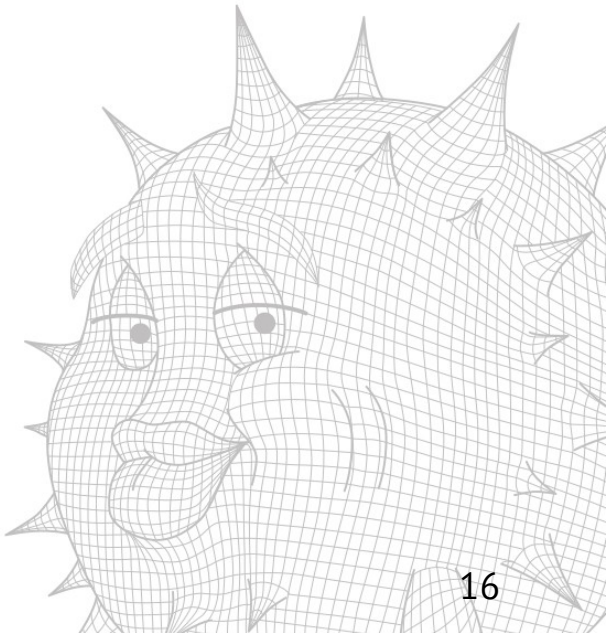
OpenBSD/x-ray

- no persistent config on the ramdisk
- „magic“ IP address
- Management system configures
  - Including pf and bridge rules



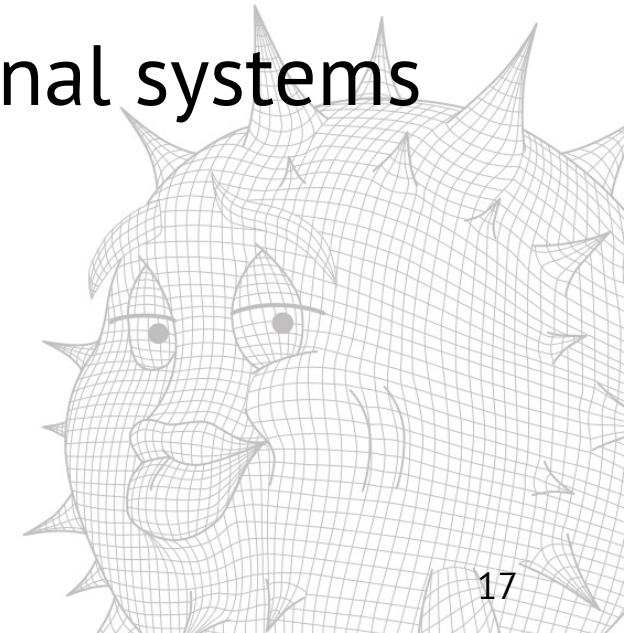
OpenBSD/x-ray

- pf provides everything one can wish for to filter IP traffic
- but ARP...



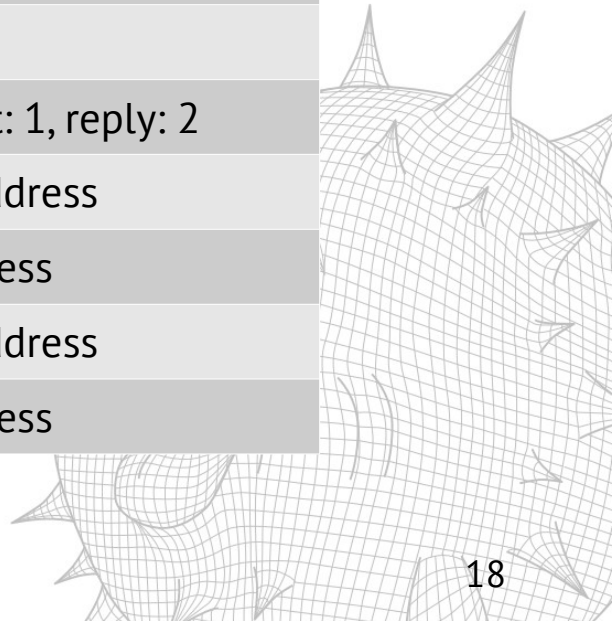
ARP

- IP to MAC address
- Outside systems must not claim internal IPs
- Static IP-MAC mappings on all internal systems not feasible



ARP

Off	*Len*			
0	2	HTYPE	Hardware Address Type	Ethernet: 1
2	2	PTYPE	Protocol Address Type	IPv4: 0x0800
4	1	HLEN	Hardware Address Length	Ethernet: 6
5	1	PLEN	Protocol Address Length	IPv4: 4
6	2	OPER	Operation	request: 1, reply: 2
8	6	SHA	Sender Hardware Address	MAC address
14	4	SPA	Sender Protocol Address	IP address
18	6	THA	Target Hardware Address	MAC address
24	4	TPA	Target Protocol Address	IP address

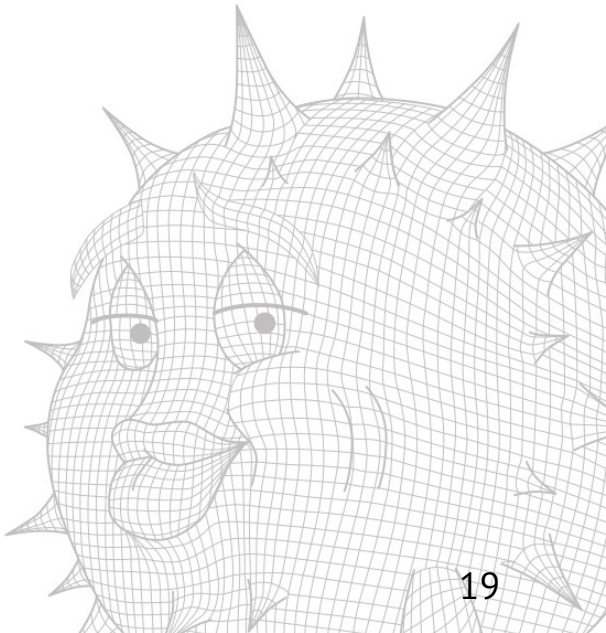


ARP request

- 10.0.0.1 (MAC: 11:22:33:44:55:66) wants to talk to 10.0.0.2
- Request sent to ff:ff:ff:ff:ff:ff (broadcast)

OPER	1 (request)
SHA	11:22:33:44:55:66
SPA	10.0.0.1
THA	*ignored*
TPA	10.0.0.2

- 10.0.0.2 learns: 10.0.0.1 is 11:22:33:44:55:66

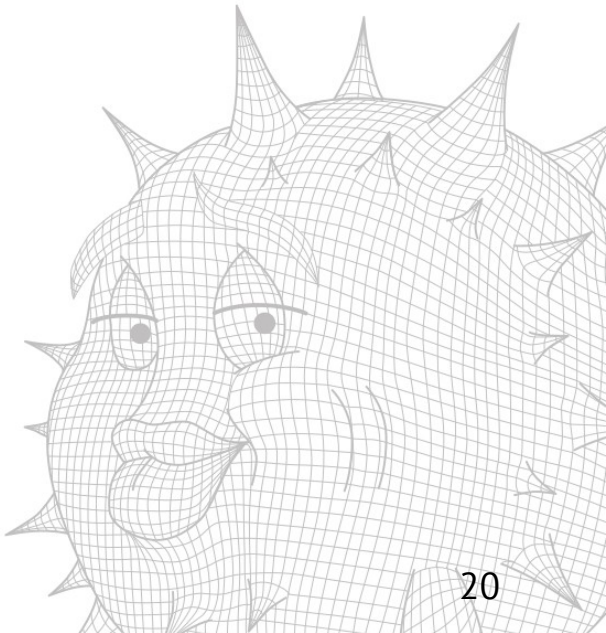


ARP reply

- 10.0.0.2 (MAC: 77:88:99:aa:bb:cc) replies to 11:22:33:44:55:66 (10.0.0.1)

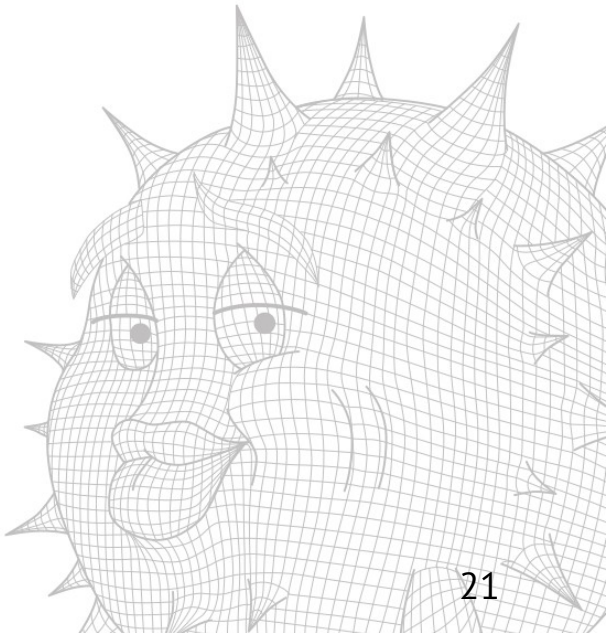
OPER	2 (reply)
SHA	77:88:99:aa:bb:cc
SPA	10.0.0.2
THA	11:22:33:44:55:66
TPA	10.0.0.1

- 10.0.0.1 learns: 10.0.0.2 is 77:88:99:aa:bb:cc



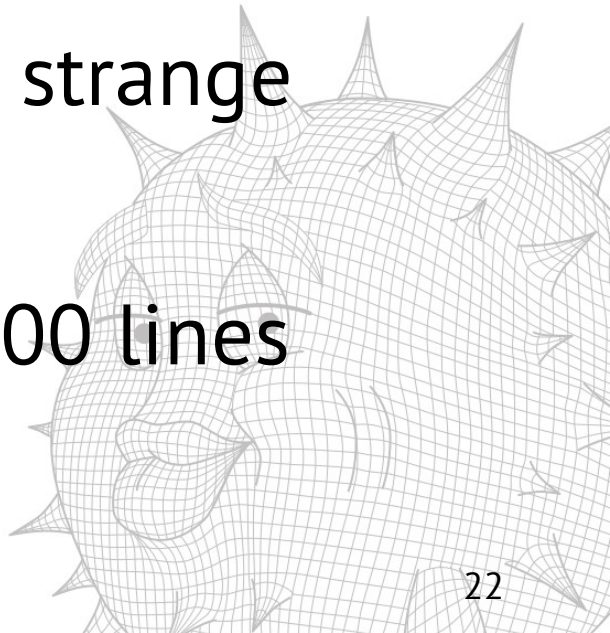
ARP filter

- Need to filter ARP to control MAC learning
  - block arp from outside with any inside MAC/IP in SHA/SPA
- pf doesn‘t even see ARP traffic
- the bridge filter is the obvious place



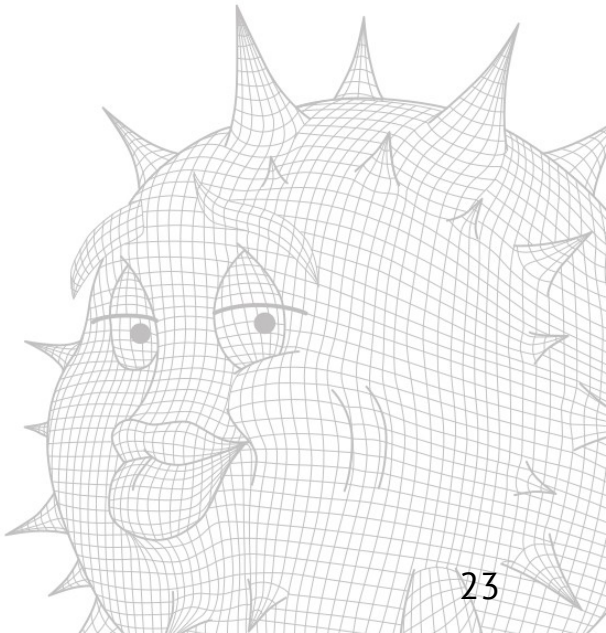
bridge arpfilter

- new bridge_arpfilter() is just ~40 LOC
- ioctl, headers etc add little
- the rule parser in ifconfig is a rather strange beast
- entire diff with manpage just over 400 lines



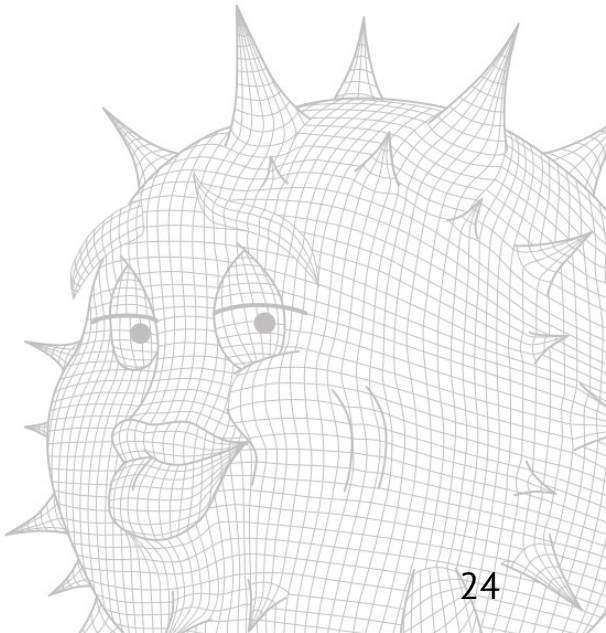
example

```
ifconfig bridge0 rule block in on em0 arp spa 10.0.0.1
ifconfig bridge0 rule block in on em0 src 11:22:33:44:55:66
ifconfig bridge0 rule block in on em0 \
    arp request sha 11:22:33:44:55:66
ifconfig bridge0 rule block in on em0 \
    arp reply sha 11:22:33:44:55:66
```



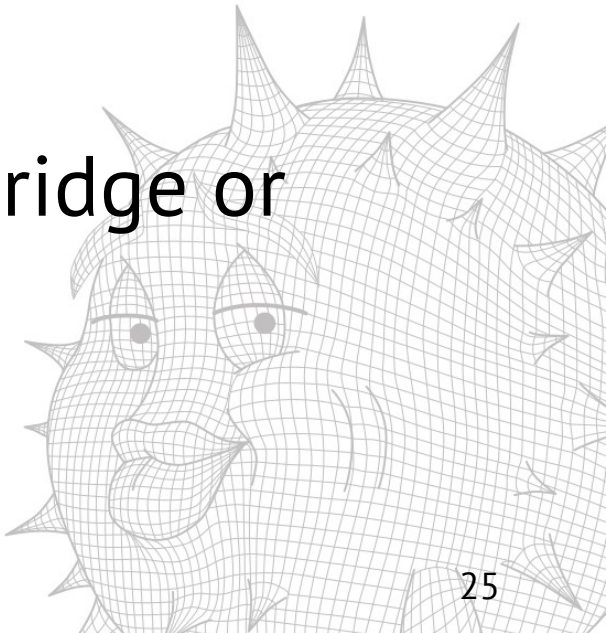
bridge arpfilter

- Reverse ARP can be matched likewise
- „rarp“ keyword instead of „arp“



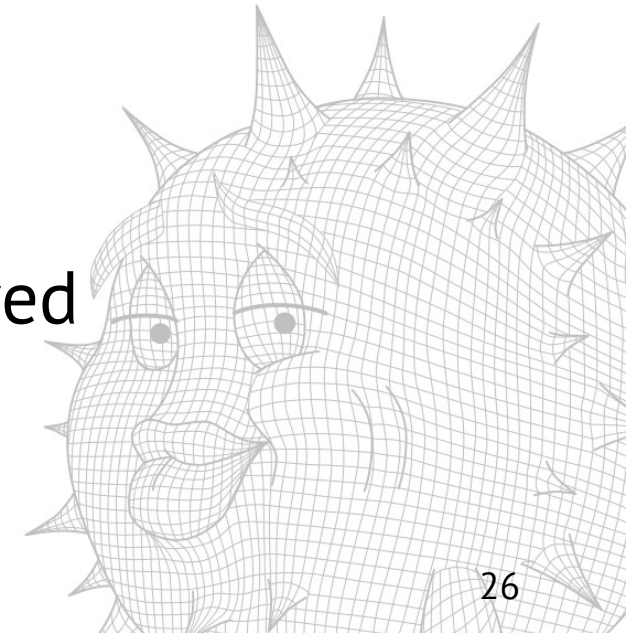
bridge(4) vs switch(4)

- bridge needs to die, switch is the future
- Implementing filters in switch was out of scope for this project
- Layer 2 filters make sense without bridge or switch



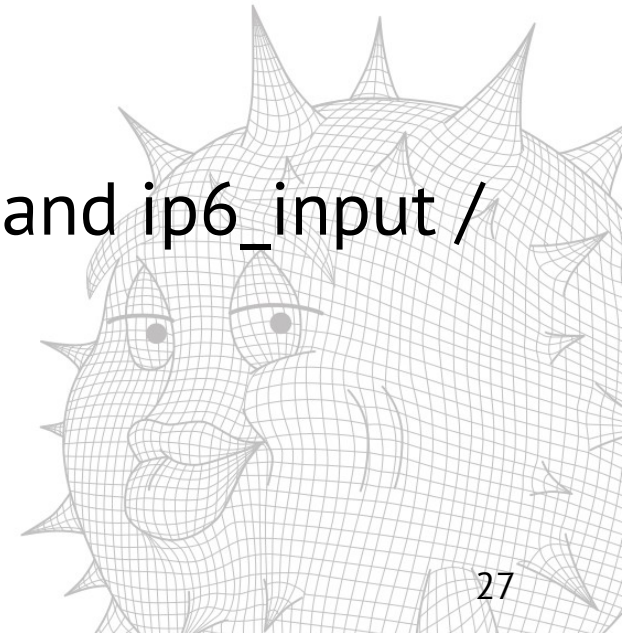
Generic Layer 2 Filters

- Should have layer 2 filtering capabilities on any Ethernet interface
- Want logging
  - bridge filters don‘t have that really
  - Adding proper logging is pretty involved



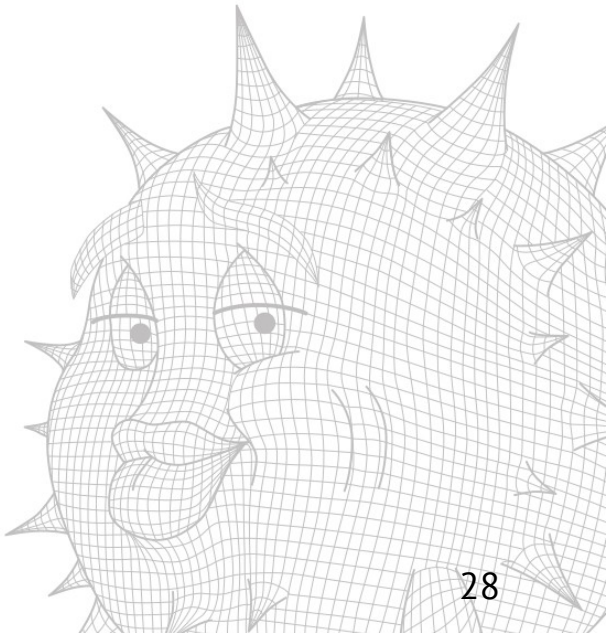
Generic Layer 2 Filters

- pflog already fits the bill
- a lot more infrastructure is already there in pf
- pf doesn‘t even see non-IP packets
  - Entry points in ip_input() / ip_output() and ip6_input / ip6_output()



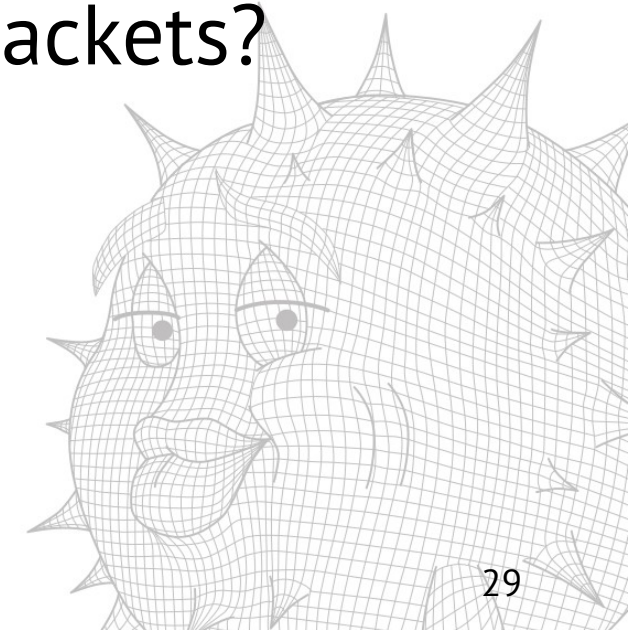
pf and Layer 2

- Could add new entry points lower in the stack
- Rules could even combine layer 2 and higher layers
- But it gets nasty quickly



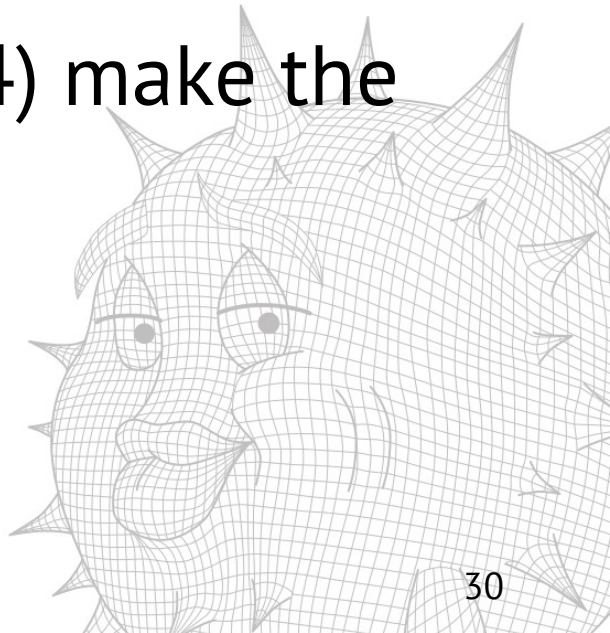
pf and Layer 2

- rule with MAC address matching and non-Ethernet packets?
- Rule with IP matching and non-IP packets?
- moving entry points is tricky

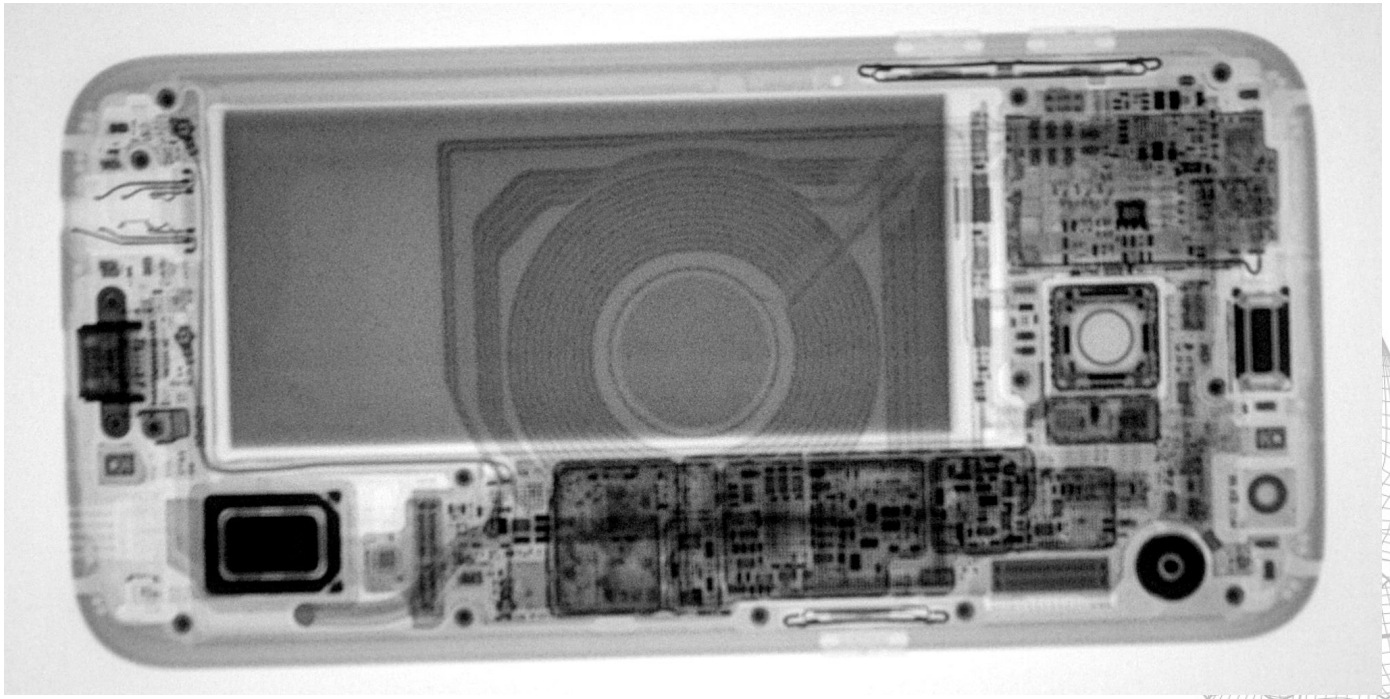


pf and Layer 2

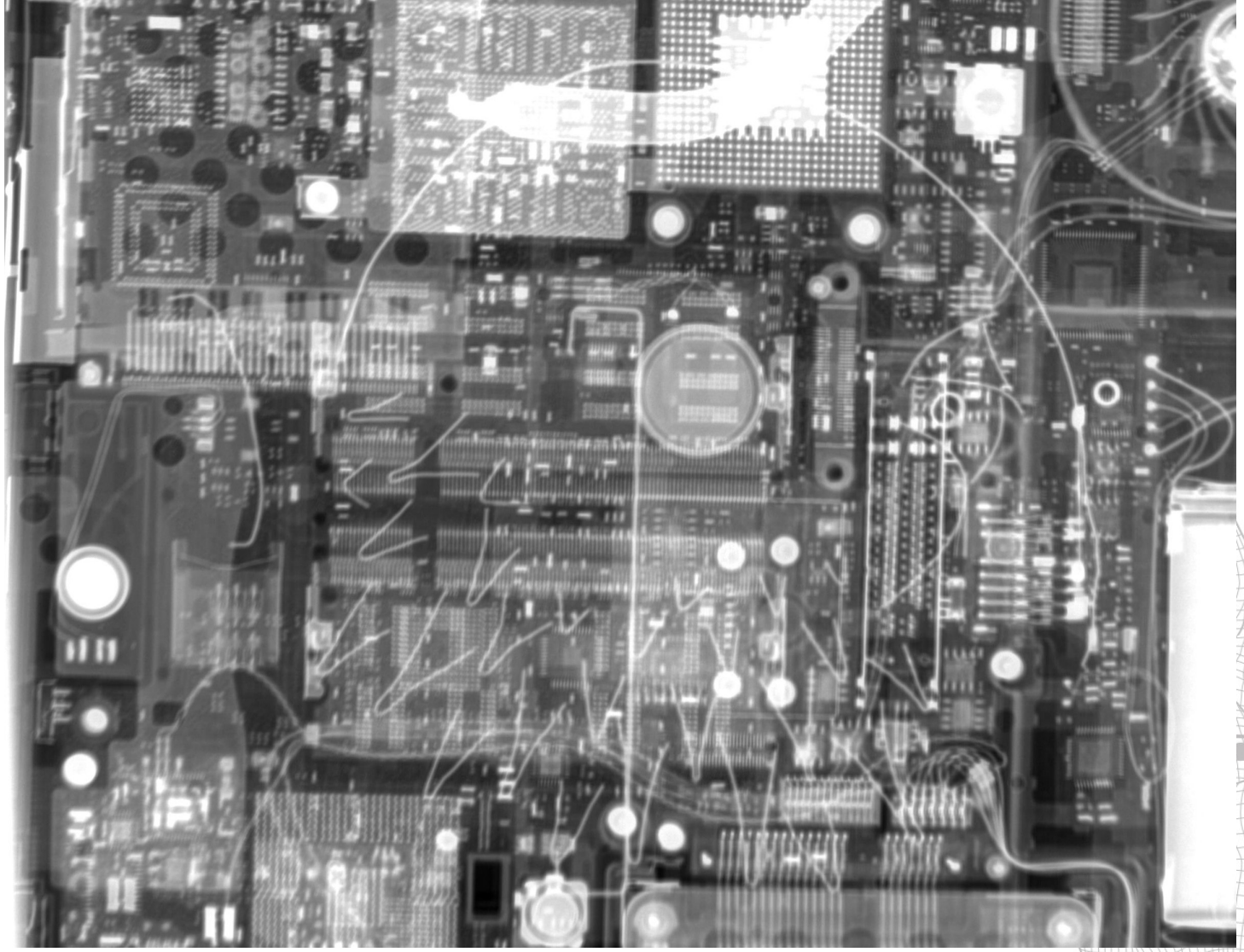
- Re-use pf code, but seperate L2 ruleset?
- New section in pf.conf or entirely seperate?
- L2 filters independent from bridge(4) make the transition to switch(4) easier



Lessons learned

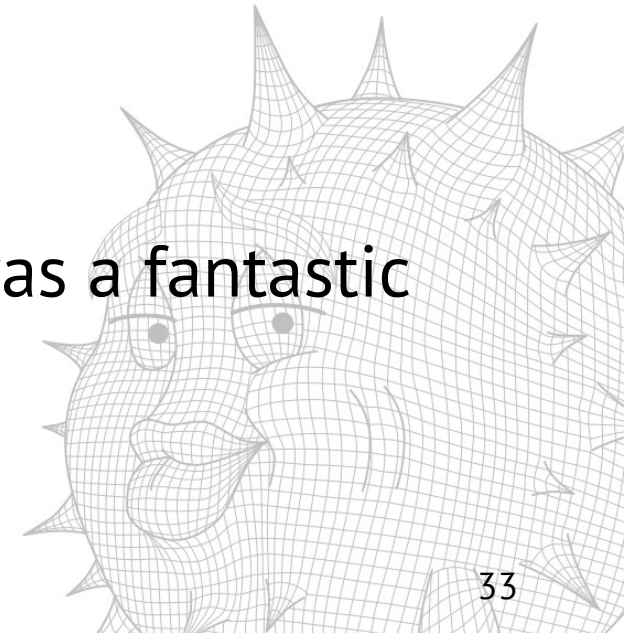


no obvious signs of NSA / BND / ... tampering in my phone



Thanks!

- Philips
  - for being very open and allowing me to present this extraordinary OpenBSD use case
- Holger Mikolon
  - who helped a lot with the paper and was a fantastic host at Philips



Questions?