Netfilter:
Making large iptables rulesets scale

Netfilter Developers
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by
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Who am I

- Name: Jesper Dangaard Brouer
  - Edu: Computer Science for Uni. Copenhagen
    - Focus on Network, Dist. sys and OS
  - Linux user since 1996, professional since 1998
    - Sysadm, Developer, Embedded
  - OpenSource projects
    - Author of
      - ADSL-optimizer
      - CPAN IPTables::libiptc
    - Patches accepted into
      - Kernel, iproute2 and iptables

Physical surroundings

ComX delivers fiber based solutions

- Our primary customers are apartment buildings
  - but with end-user relation
- Ring based network topology with POPs (Point Of Presence)
- POPs have fiber strings to apartment buildings
- CPE box in apartment performs
  - service separation into VLANs

The Linux box

The iptables box(es), this talk is all about

- placed at each POP (near the core routers)
- high-end server PC, with *only two netcards*

Internet traffic:

- from several apartment buildings,
- layer2 terminated via VLANs on one netcard,
- routed out the other.

Cost efficient

- but *needs to scale to a large number of customers*
- goal is to scale to 5000 customers per machine

Issues and limitations

First generation solution was in production.

- business grew and customers where added;
- several scalability issues arose

The two primary were:

- Routing performance reduced (20 kpps)
- Rule changes where slow

I was hired to rethink the system

Overview

Presentation split into two subjects

1) Routing performance

   Solved using effective traffic categorization

2) Slow rule changes

   Solved by modifying iptables to use binary search

Issue: Bad route performance

The first generation solution,

- naive approach: long list of rules in a single chain

Routing performance degradation problem:

- It all comes down to traffic categorizing
- binding packets to a customer
- where a customer can have several IP-addresses

Need to *find a scalable categorization mechanism*

Existing solutions

- Looking for existing solutions
  - for solving the categorization task
- Ended up using standard iptables chains
- **nf-hipac,** universal solution,
  - Optimize ruleset for memory lookups per packet
  - Did not work with current kernels
- **ipset**
  - Sets of IP, can be matched, given action

The categorization tasks

With the kind of categorization needed,

- why did I ended up using standard iptables chains?

Access Control

- simple open/close solution
- could use ipset

Bandwidth Control

- requires an individual shaper per customer
- cannot use ipset

Personal firewall

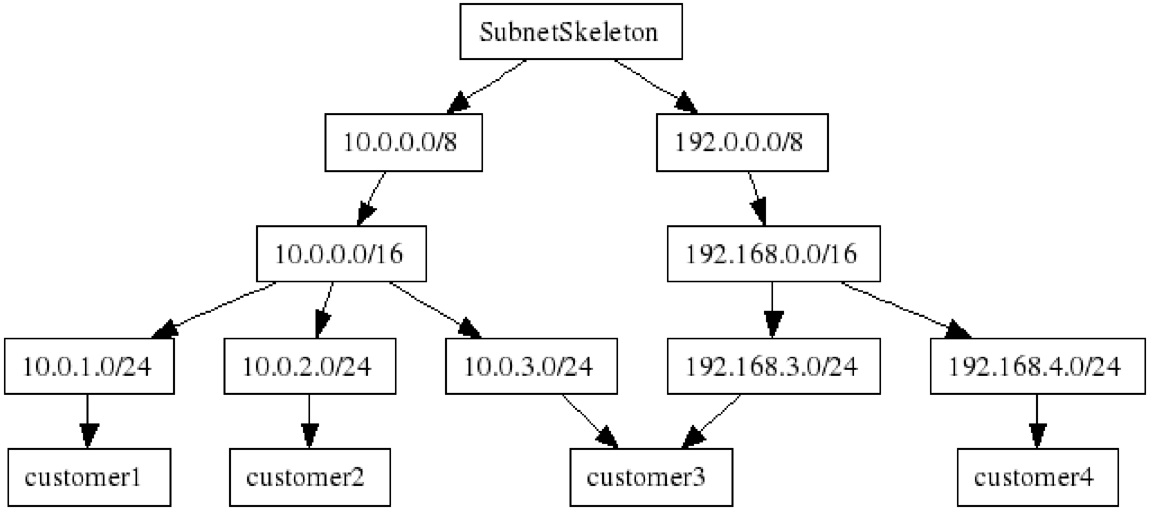
- most complicated: individual set of rules per customer
- cannot use ipset

Solution: SubnetSkeleton

The solution was to build a search tree;

for IP-addresses, based on subnet partitioning,

using standard iptables chains and jump rules.



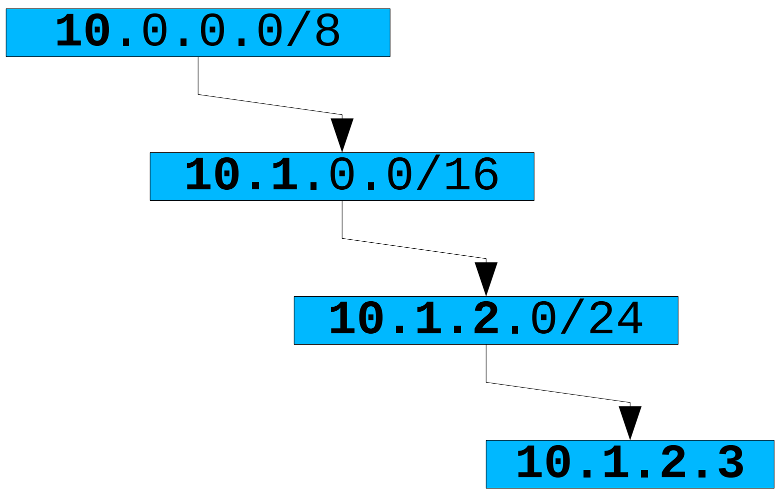
SubnetSkeleton: Algorithm

Algorithm, predefined partitioning of IP space;

- based on a user-defined *list of CIDR prefixes*
  - Depth of tree, determined by CIDR list length.
  - Max number of children, bits between CIDRs (2^n)

Creates tree by bit masking the IP with the CIDR list

- Example:
  - CIDR list = [/8, /16, /24]
  - IP: 10.1.2.3



SubnetSkeleton: CIDR partitioning

Choosing CIDR list is essential.

- Base it on IP-space that needs to be covered.
- E.g. our IP-address space, limited to AS number
  - AS31661 = 156.672 IPs.
    - Largest subnet we announce is a /16.
  - CIDR list: [8, 18, 20, 22, 24, 26, 28]
  - /8 needed as our subnets vary on first byte,
    - "0-8", 2^8=256 children, but only 4 different subnets
  - Between "8-18": 2^{10} = Max 1024 children.
    - But know /16 (2^2=4)
  - Between, rest 2 bits, thus max 4 children in nodes.
  - Last, "28-32": (2^4=16) max 16 direct IP matches.

SubnetSkeleton: iptables

Expressing the tree using iptables:

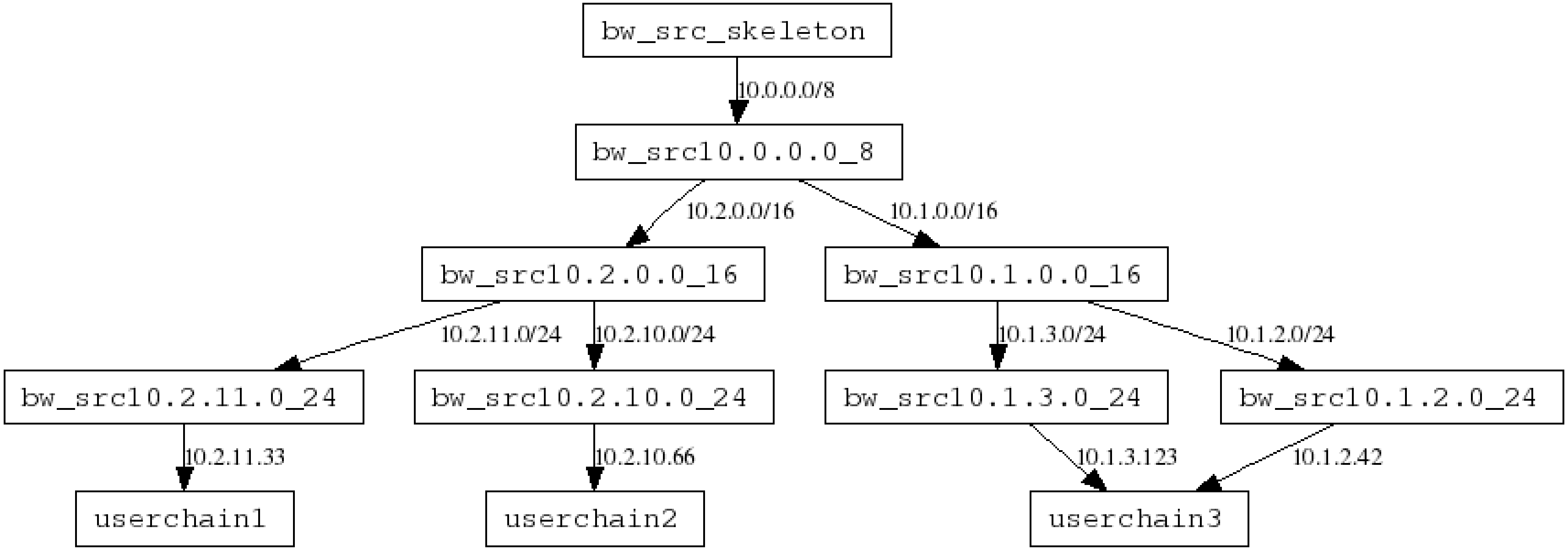
Each *node* in the tree is an iptables **chain**.

child pointers in a *node* are **jump** rules.

A *leaf* has IP specific jump rules to a user-defined chain

leafs are allowed to jump to the same user-defined chain

children (**jump** rules) are processed linearly, in **chain**



Perl - IPTables::SubnetSkeleton

```
#!/usr/bin/perl
use IPTables::SubnetSkeleton;

my @CIDR = (8, 16, 24); # prefix list

my $name  = "bw";      # Shortname for bandwidth
my $table = "mangle"; # Use “mangle” table

my $subnet_src = IPTables::SubnetSkeleton::new("$name", "src", $table, @CIDR);

# Connect subnet skeleton to build-in chain "FORWARD"
$subnet_src->connect_to("FORWARD");

# Insert IP's to match into the tree
$subnet_src->insert_element("10.2.11.33", "userchain1");
$subnet_src->insert_element("10.2.10.66", "userchain2");
$subnet_src->insert_element("10.1.2.42",  "userchain3");
$subnet_src->insert_element("10.1.3.123", "userchain3");

# Remember to commit the ruleset to kernel
$subnet_src->iptables_commit();
```

Full routing performance achieved

Full route performance achieved

- *When using SubnetSkeleton*
- HTB shaper seems to scale well
- Better conntrack locking in 2.6.25,
  - reduced cpu load to half, Thanks Patrick McHardy!
- Parameter tuning
  - Increase route cache
  - Increase conntrack entries
    - remember conntrack hash bucket size (/sys/module/nf_conntrack/parameters/hashsize)
  - Adjust arp/neighbor size and thresholds

Back to subject:
Slow ruleset changes

libiptc: scalability issues

Minor:

- Inline functions iptcc_is_builtin() and set_changed()
- Don't sort all chains on pull-out, only on insert

Major:

- Initial ruleset parsing slow
- Chain name lookup slow

Issue: iptables command slow

The next scalability issue: Rule changes slow!

Rebuilding the entire ruleset could take hours

Discover *how iptables works*:

Entire ruleset copied to userspace

After possibly multiple changes, copied back to kernel

Performed by a IPTables Cache library "libiptc"

iptables.c is a command line parser using this library

Profiling: identified *first* scalability issue

Initial ruleset parsing, during “pull-out”

Could postpone fix...

Take advantage of libiptc

- Take advantage of pull-out and commit system
  - Pull-out ruleset (*one initial ruleset parsing penalty*)
  - Make all modification needed
  - Commit ruleset (to kernel)
  - This is how ***iptables-restore*** works
- Extra bonus:
  - Several rule changes appear atomic
    - Update all rules related to a customer at once
    - No need for temp chains and renaming

Perl - IPTables::libiptc

- Cannot use iptables-restore/save
  - SubnetSkeleton must have is_chain() test function
- Created CPAN IPTables::libiptc
  - Chains: Direct libiptc calls
  - Rules: Command like interface via iptables.c linking
  - iptables extensions available on system, dynamic loaded
  - No need to maintain or port iptables extensions
  - Remember to commit()
- Using this module
  - I could postponed fixing "initial ruleset parsing"

Next scalability issue: Chain lookup

- Slow chain name lookup
  - is_chain() testing (internal iptcc_find_label())
  - Cause by: linearly list search with strcmp()
- Affects: almost everything
    - Rule create, delete, even listing.
    - Multiple rule changes, eg. iptables-restore, SubnetSkeleton
- Rule listing (iptables -nL) with 50k chains:
  - Takes approx 5 minutes!
  - After my fix: reduced to 0.5 sec.

Chains lookup: Solution

Solution: binary search on chain names

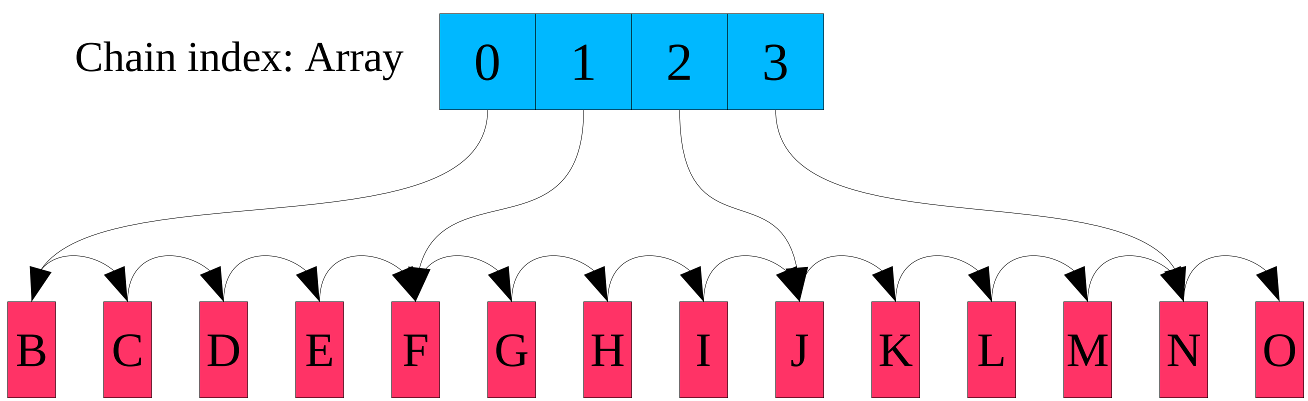
- Important property chain list is sorted by name
- Keep original linked list data structure

New data structure: "Chain index"

- Array with pointers into linked list with a given spacing (40)

Result: better starting points when searching the linked list

Chain index: Array



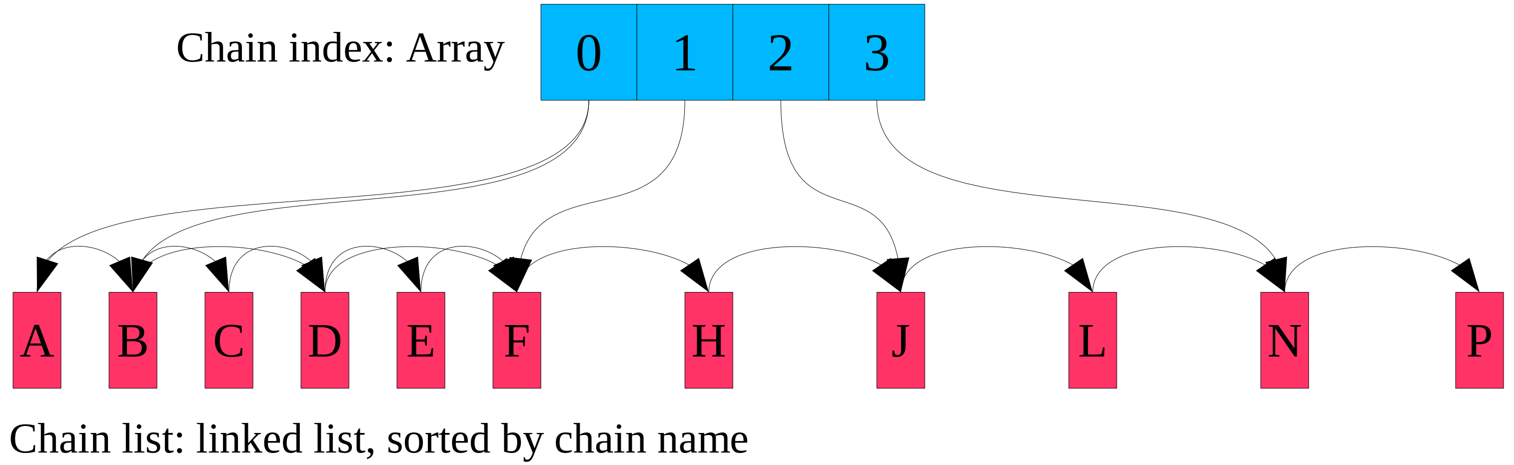
Chain list: linked list, sorted by chain name

Chain index: Insert chain

Handle: Inserting/creating new chains

- Inserting don't change correctness of chain index
  - only cause longer lists
  - rebuild after threshold inserts (355)

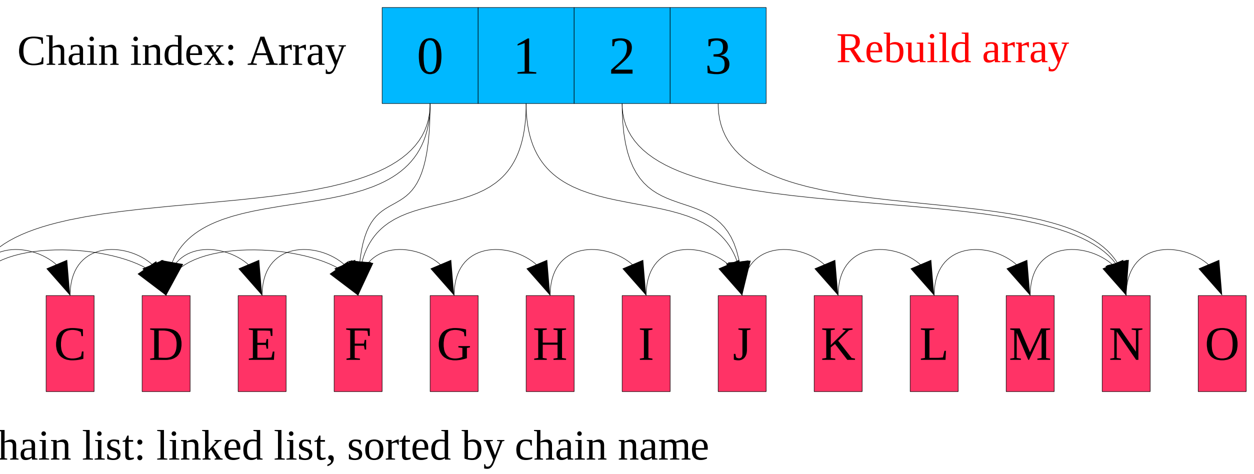
- Inserting before first element is special



Chain index: Delete chain

Handle: deletion of chains

- Delete chain ***not*** pointed to by chain index, no effect
- Delete chain pointed to by chain index, possible rebuild
  - Replace index pointer with next pointer
  - Only if next pointer not part of chain index



Solving: Initial ruleset parsing

Back to fixing "initial ruleset parsing".

- Did have a fix, but was not 64-bit compliant (2007-11-26)

Problem: Resolving jump rules is slow

- For each: Jump Rule
  - Do a linearly, offset based, search of chain list

Solution:

- Reuse binary search algorithm and data structure
- Realize chain list are both sorted by name and offsets
  - Ruleset from kernel already sorted

Summary: Load time

Personal firewall

Reload all rules on a production machine

Chains: 5789

Rules: 22827

Number of calls	74659	
Total time used	1.92	sec
Average per call	0.00002567	sec

action	calls	time	per call
set_policy	1	0.00007701	0.00007701
append_rule	8399	0.49619532	0.00005908
insert_rule	4463	0.24729586	0.00005541
flush_entries	4726	0.03449988	0.00000730
init	1	0.04638195	**0.04638195**
commit	1	0.08120894	0.08120894
list_rules_IPs	1181	0.02705002	0.00002290
is_chain	46965	0.37487888	**0.00000798**
delete_rule	8922	0.60892868	0.00006825
Sum	**74659**	**1.91651654**	sec

Total time entire script 23.72 sec

Machine with the most customers, has in filter table
Chains: 9827 Rules:36532

Summary: Open Source

Open Source Status

- Chain lookup fix
  - In iptables version 1.4.1
    - 50k chains, listing 5 min -> 0.5 sec
- Initial ruleset parsing fix
  - In iptables version 1.4.2-rc1
    - Production, reached 10 sec -> 0.046 sec
- IPTables::libiptc
  - Released on CPAN
- IPTables::SubnetSkeleton
  - Available via http://people.netfilter.org/hawk/

Summary: Goal reached?

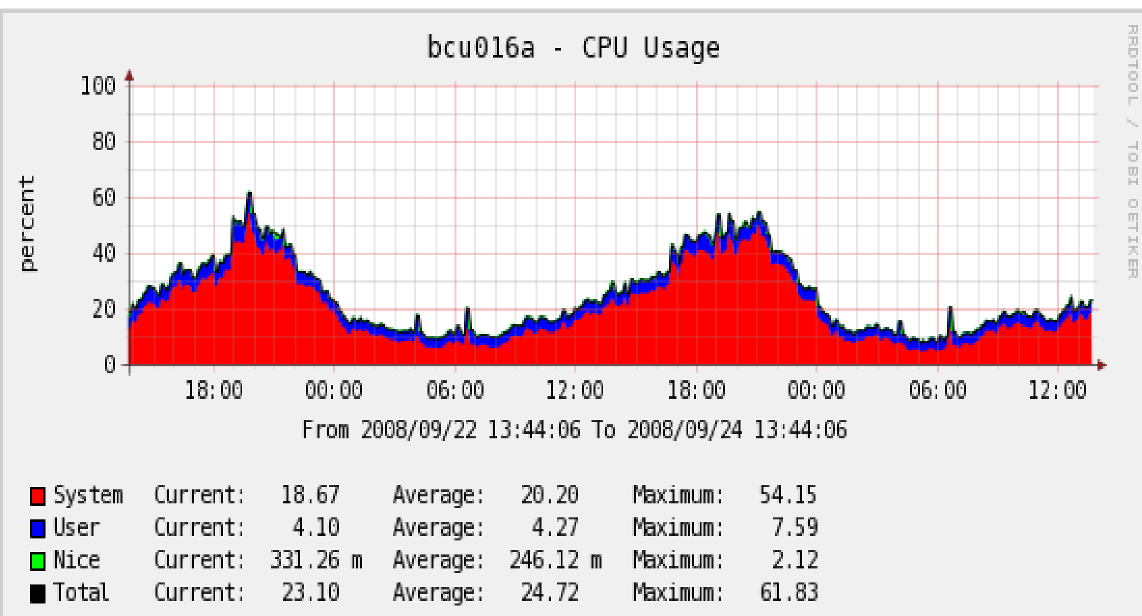
Goal of 5000 equipment,

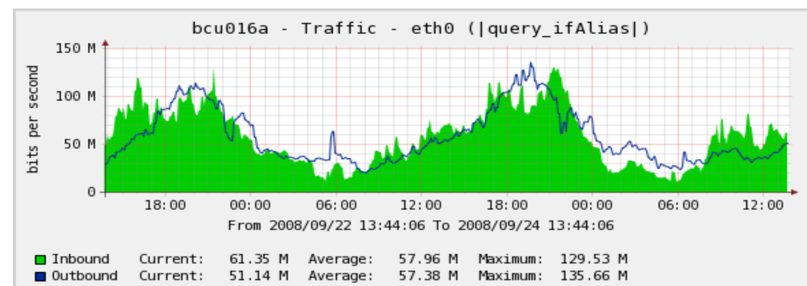
Production, reached 3400

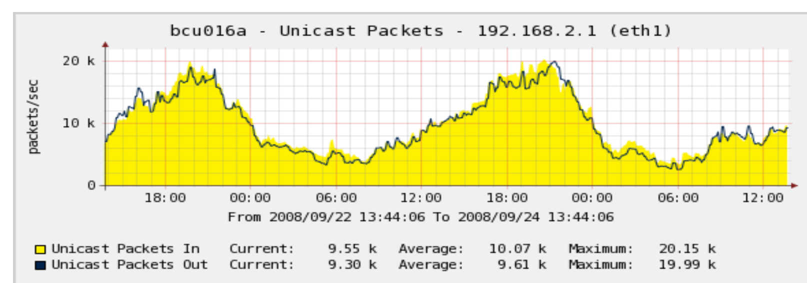
CPU load 30% average, 62% in peek.

CPU Xeon (Hyperthread) 3.2 Ghz, 1MB cache

In filter table Chains: 9827 Rules: 36532







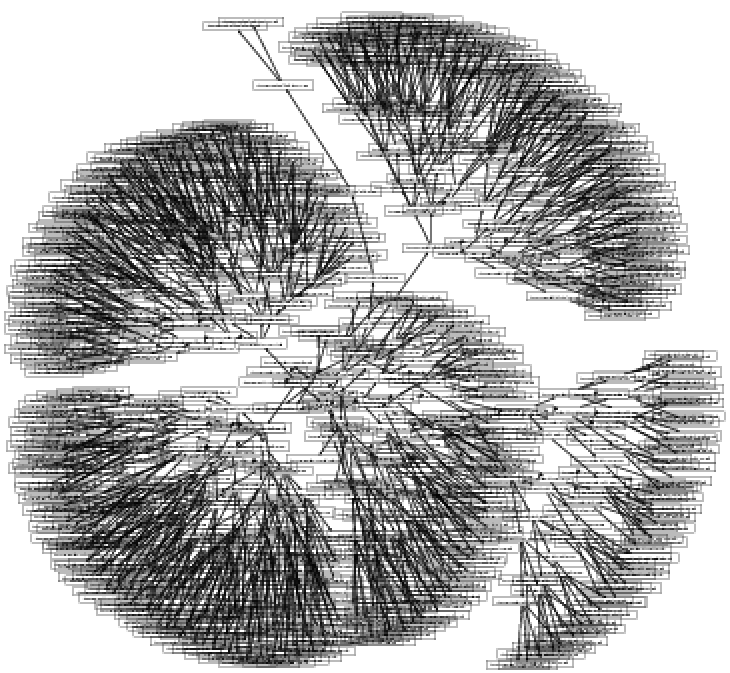
Remaining issue: Race condition

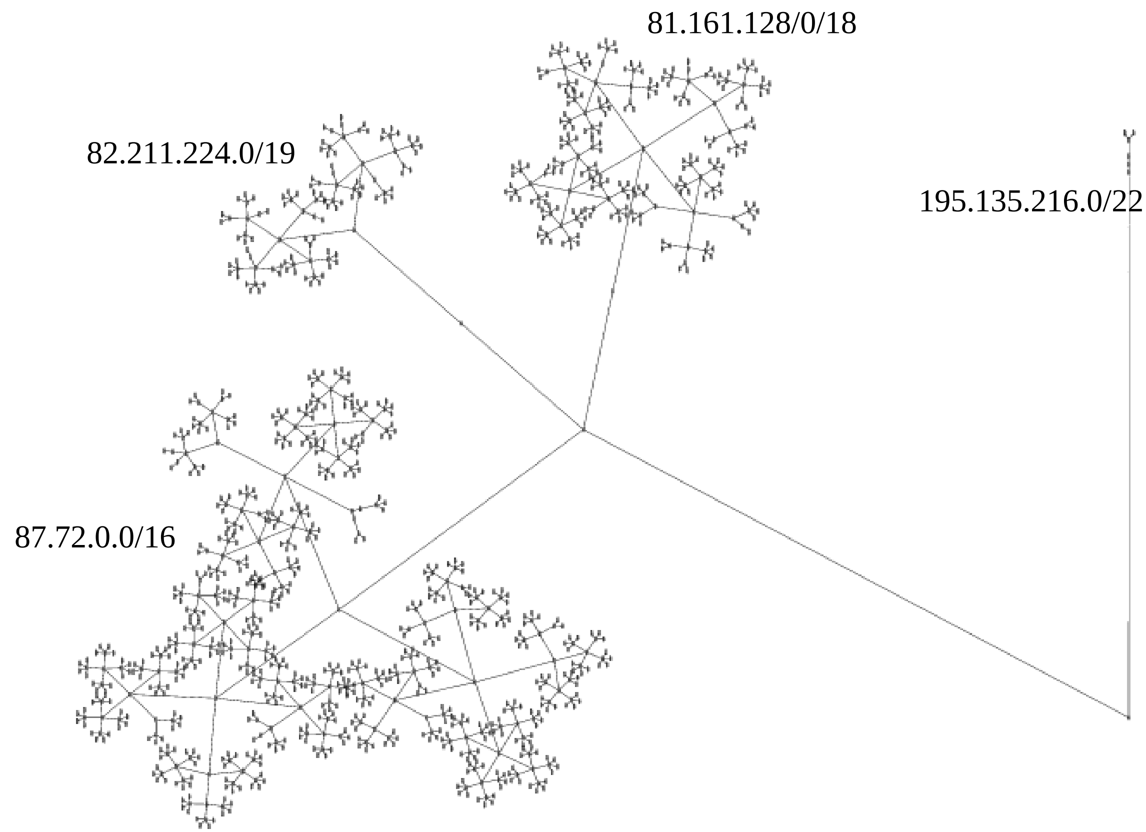
- Ruleset pull-out and commit system
  - Problem: Userspace race condition
    - Two processes pull-out ruleset
    - Process#1 commit
    - Process#2 commit ... what happens!?
      - if ruleset entries are the same, p#2 overwrite p#1 rules
        - possibly wrong counter updates
      - if ruleset entries differ, p#2 fail with an errno=EAGAIN
- My solution: Simple file lock (flock) in /var/lock/
- Discussion?
    - Don't lock on “-L” listing, because cannot use in a pipe

The End

Goodbye

and thank you for accepting the patches...





Extra slides

- Bonus slides
  - if time permits
  - or funny questions arise

libiptc: scalability issues

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Major:

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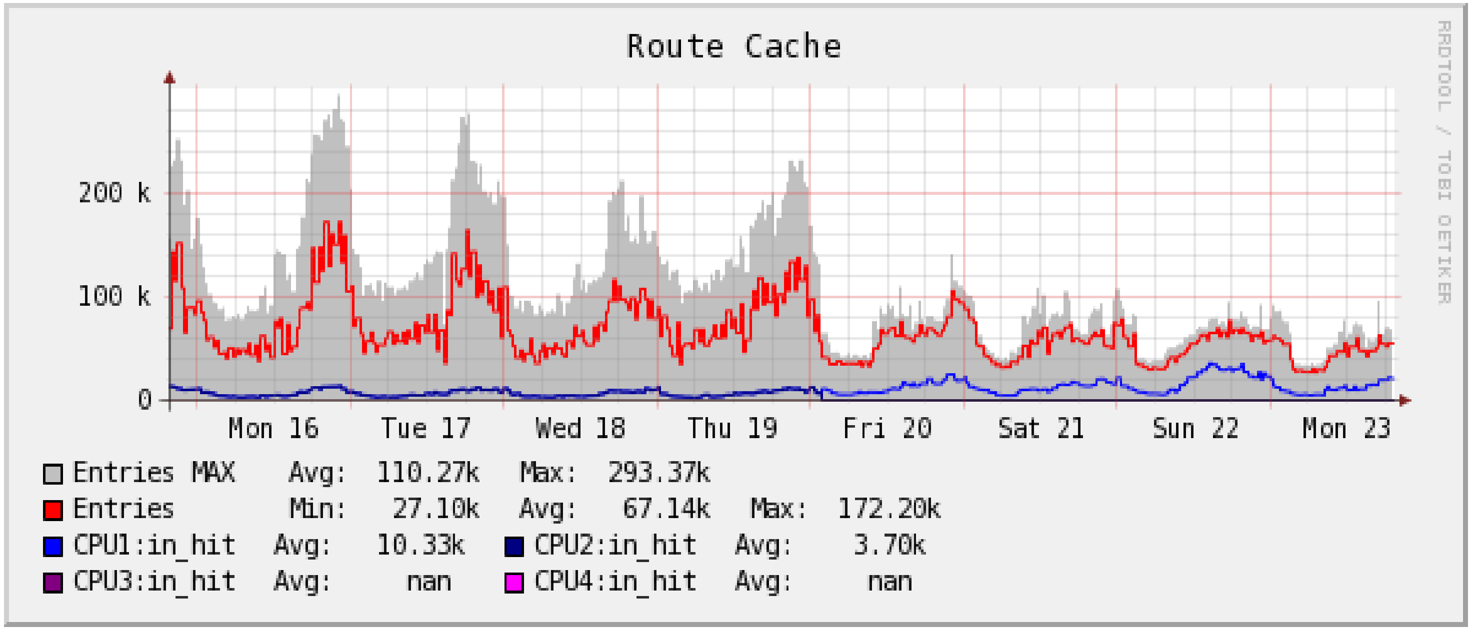
- Chain name lookup slow

Route cache perf

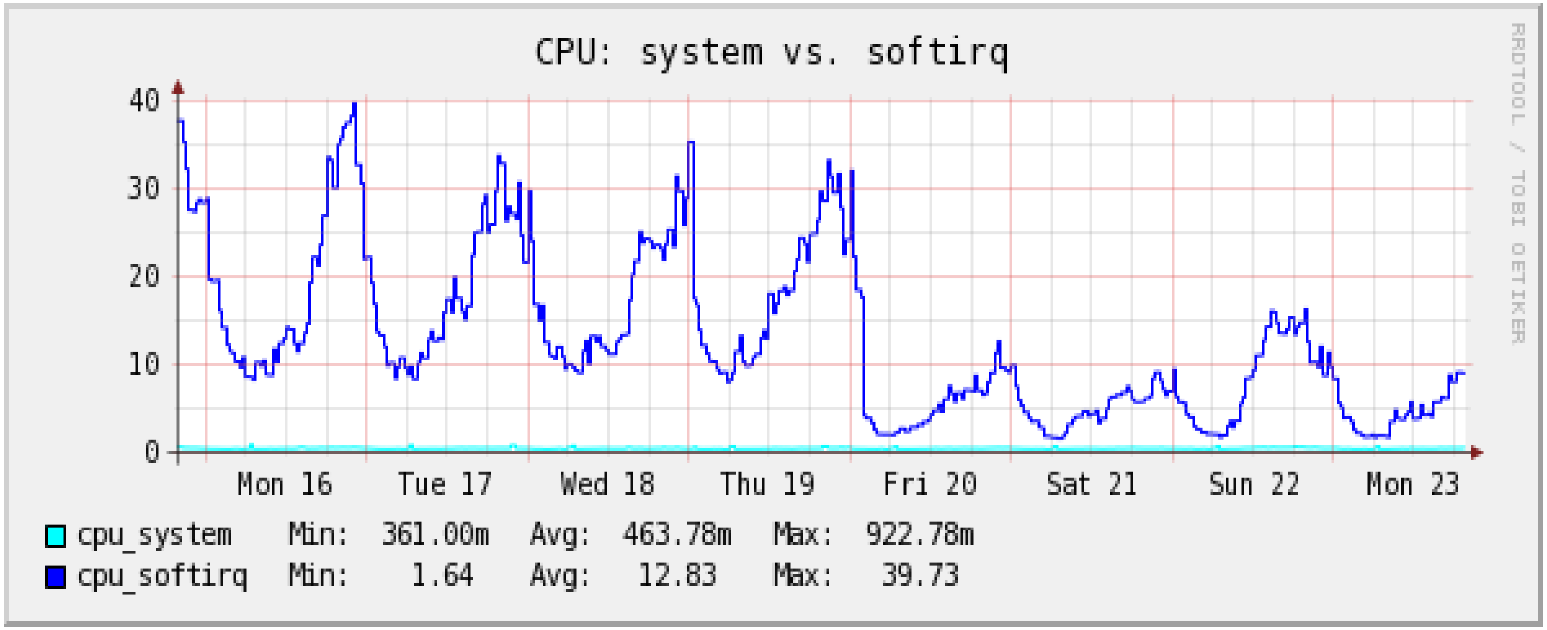
Improved route cache

- Kernel 2.6.15 --> 2.6.25
  - Thanks to Eric Dumazet



CPU util softirq

- Softirq CPU usage dropped
  - Kernel 2.6.15 --> 2.6.25
    - Patrick McHardy, improved conntrack locking



More libiptc stats

Machine with the most customers,

Customers:2105	Equipment: 3477	
In filter table	Chains: 9827	Rules: 36532
In mangle table	Chains: 2770	Rules:14275

“Init” time: 0.10719919s

“is_chain” time: 0.00001473s

BSD pf firewalling

My *limited* knowledge of

- Open/FreeBSD's firewall facility: pf (packet filter)
  - Don't have chains with rules like iptables: Uses one list/chain
  - To compensate, they have an “ipset” like facility called “tables”
    - Quite smart using a radix tree.
  - Has a basic ruleset-optimizer, performs four tasks:
    - remove duplicate rules
    - remove rules that are a subset of another rule
    - combine multiple rules into a table when advantageous
    - re-order the rules to improve evaluation performance

Don't think pf would solve my categorization needs

- I could not use “ipset”, for the same reasons cannot use pf “tables”