CS5412 / LECTURE 13: THE DANGERS OF GOSSIP

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REMINDER: GOSSIP

These protocols consume a fixed amount of background overhead. There are no load surges (but Bimodal Multicast can cause burst loads: *why?*)

Costs are quite low, like “on average, one message sent and one received per process, per second”. Message sizes are generally small.

Moreover, information spreads in time r * O(log N), where r is the gossip rate. For many purposes this actually very reasonable.

SO WHY NOT USE GOSSIP “EVERYWHERE”?

There are many tasks where the fit seems quite good.

Like checking to see if systems have hung processes, or monitoring loads, or tracking storage capacity on storage units.

The underlying values change slowly, so even a “slow” tracker will still be pretty accurate.

BUT THERE ARE SOME CAUTIONARY TALES

For example, gossip once caused all of Amazon S3 to crash!

This nearly resulted in a congressional inquiry! When S3 crashes, a great many companies also freeze up – any company that depends on the cloud depends on the S3 file system storage solution.

So… what is S3 and how does it use gossip?

AMAZON S3: THE “SIMPLE STORAGE SERVER”

S3 is a huge pool of storage nodes.

Plus, a “meta-data” server that keeps track of file names and where they can be found.

To store data, an application asks the meta-data service to allocate space, then sends the data to the appropriate storage servers.

WHY DO WE USE THE TERM “META-DATA”?

When you think about a file, you tend to think of the file name and the file contents. Like a key and a value.

But in fact files also have owners, permissions, create time, last access time, length (and perhaps, size on disk, which can be much smaller), etc.

We associate this data with the file. In Linux the inode plays this role. In S3 and other big-data systems, the meta-data service does it.

HOW DOES THE S3 META-DATA SERVICE TRACK SPACE AVAILABLE ON STORAGE UNITS?

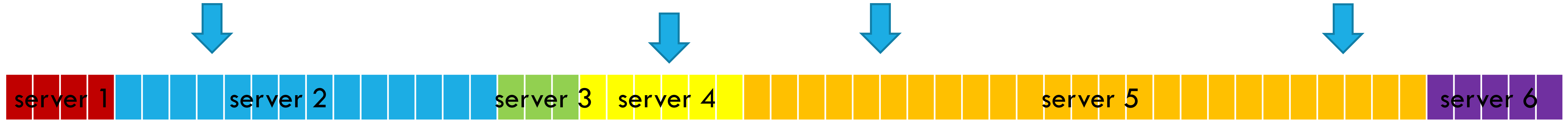
You might expect this to be easy, because the meta-data service does the allocations.

But in fact the meta-data service itself is sharded, so any single shard within it only knows (for sure) about files it is responsible for. Additionally, sometimes a server needs to take some storage offline.

To know the full state of the full S3 deployment we would need to sum across all meta-data services.

LOAD BALANCING

For each server, estimate current amount of free space. Line them up on a "space available" line.



For a new allocation, pick a random spot in this line. This spreads the incoming load around but will be biased to favor servers with more space.

GOSSIP IS USED FOR TRACKING STORAGE

Amazon used a gossip protocol in this role, specialized to S3 meta-data.

The basic idea is to use gossip to keep track of how much space each S3 storage node is reporting that it has available.

This is inexpensive and because each storage unit holds hundreds of gigabytes, the values don't change rapidly. A good match for gossip.

… UNTIL IT WENT WRONG!

Once upon a time, when S3 was working perfectly well, a storage server needed to take some storage offline.

Because of doing this, it suddenly went from having 20% excess capacity to being slightly over-full. This was not a bug – the servers actually have a tiny bit of reserve space, so “available capacity” could become slightly negative.

As it turns out, S3 storage servers reported space available as **signed** 32 bit integers. But the S3 meta-data service declared the same field to be a 32 bit **unsigned** integer. This was a marshalling bug.

"I HAVE -3 GB OF FREE CAPACITY"

Suppose that we have a signed integer that becomes negative, and then we interpret it as an unsigned integer?

The sign bit will be set. 2^31 is a large number!

In effect, small negative numbers will suddenly be interpreted as big positive numbers. Our server suddenly reports: *"I have 2147483645 gigabytes of free capacity!"*

SUDDENLY LOTS OF NEW FILES WERE SENT TO THIS STORAGE SERVER!

Since it was full, it refused the requests.

S3 <u>did</u> have logic to handle that situation. But it became a bottleneck.

S3 became … e x t r e m e l y . . .   s   l   o   w

IMAGINE THE SITUATION FOR S3 PRODUCT OWNERS AT AMAZON

One evening you are home with your family for Thanksgiving (pre-covid)

You get a call… its Jeff Bezos…

S3 is broken! Could you please go figure out why and fix it? So while everyone else is carving the turkey you log in… and see *millions* of errors being logged per second from 75 subsystems

IT TOOK AMAZON NEARLY A DAY TO FIGURE THIS OUT

S3 was actually working! It did store new files. But it was weirdly slow.

Higher level applications that depend on S3 began to have request timeouts, causing a cascade of failures.

This issue of one failure triggering other failures is a major problem see in the cloud and causes a whole series of outages all to happen at once.

FROM BAD… TO WORSE?

They eventually found the issue, and came up with a great idea!

They shut down the bad server. But nothing happened… Gossip is very slow to spread the word.

So then they noticed that meta-data server md1 was gossiping that server 53 had infinite space. They killed it.   Suddenly, md2 took over and started gossiping that 53 had infinite space…

ISSUES YOU SEE IN THIS STORY

With gossip, fresher data might not always spread faster than stale data

Gossip is very robust to servers being down, which means that just rebooting a single node won't fix anything.

Message serialization/deserialization doesn't necessarily check for type matches. In this case, it didn't… and so a signed integer can magically be reinterpreted as an unsigned integer.

A THOUGHT QUESTION

What's the best way to

- Count the number of nodes in a system?
- Compute the average load, or find the most loaded nodes, or least loaded nodes?

Options to consider

- Pure gossip solution
- Construct a service that actively tracks the nodes, or the load, etc?

… AND THE ANSWER IS

Gossip isn't very good for some of these tasks!

- There are gossip solutions for counting nodes, but they give approximate answers and run slowly
- Tricky to compute something like an average because of "re-counting" effect, (best algorithm: Kempe *et al)*

On the other hand, gossip works well for finding the c most loaded or least loaded nodes (constant c)

Gossip solutions run in time O(log N) and generally give probabilistic solutions

REMINDER: ASTROLABE

It creates a virtual tree of nodes.

At the leaf level, the tree tracks status for individual machines.

At the inner levels (these are “virtual” tables) aggregation queries are computed from the lower levels and shared. Lightly loaded leaf nodes run the inner-level gossip protocol

STATE MERGE: CORE OF ASTROLABE EPIDEMIC

swift.cs.cornell.edu

Name	Time	Load	Weblogic?	SMTP?	Word Version
swift	2011	2.0	0	1	6.2
falcon	1971	1.5	1	0	4.1
cardinal	2004	4.5	1	0	6.0

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falcon	1976	2.7	1	0	4.1
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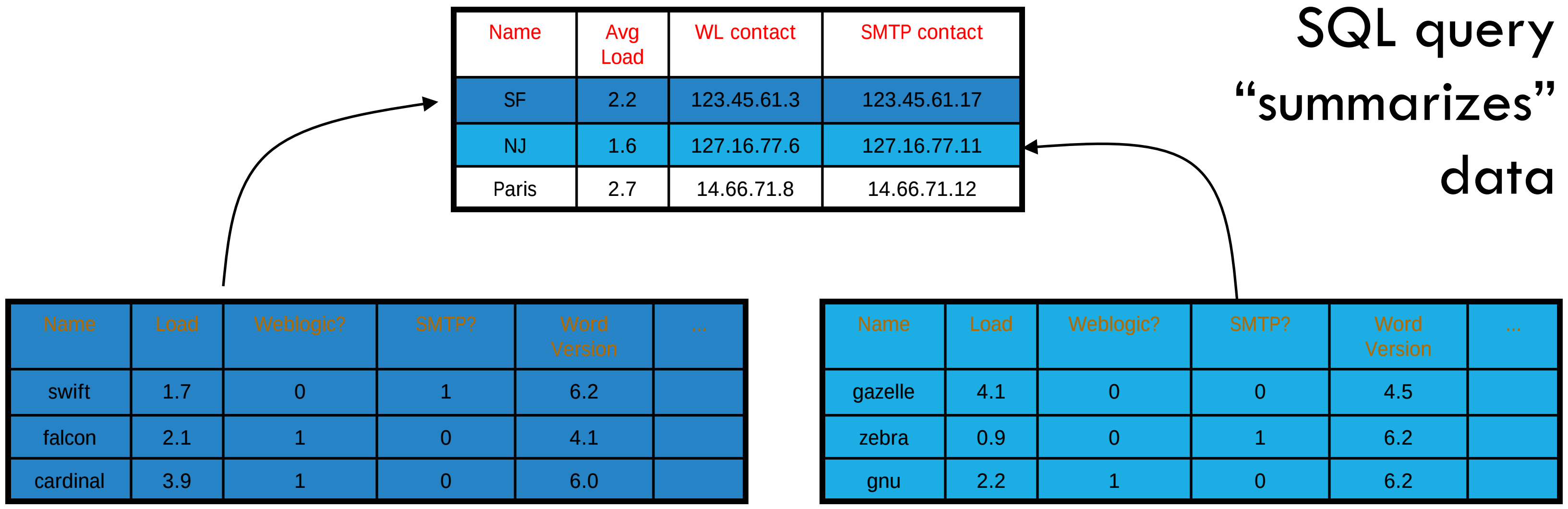
ASTROLABE BUILDS A HIERARCHY USING A P2P PROTOCOL THAT "ASSEMBLES THE PUZZLE" WITHOUT ANY SERVERS

Dynamically changing query output is visible system-wide

SQL query "summarizes" data



Name	Avg Load	WL contact	SMTP contact
SF	2.2	123.45.61.3	123.45.61.17
NJ	1.6	127.16.77.6	127.16.77.11
Paris	2.7	14.66.71.8	14.66.71.12

Name	Load	Weblogic?	SMTP?	Word Version	…
swift	1.7	0	1	6.2	
falcon	2.1	1	0	4.1	
cardinal	3.9	1	0	6.0	

San Francisco

Name	Load	Weblogic?	SMTP?	Word Version	…
gazelle	4.1	0	0	4.5	
zebra	0.9	0	1	6.2	
gnu	2.2	1	0	6.2	

New Jersey

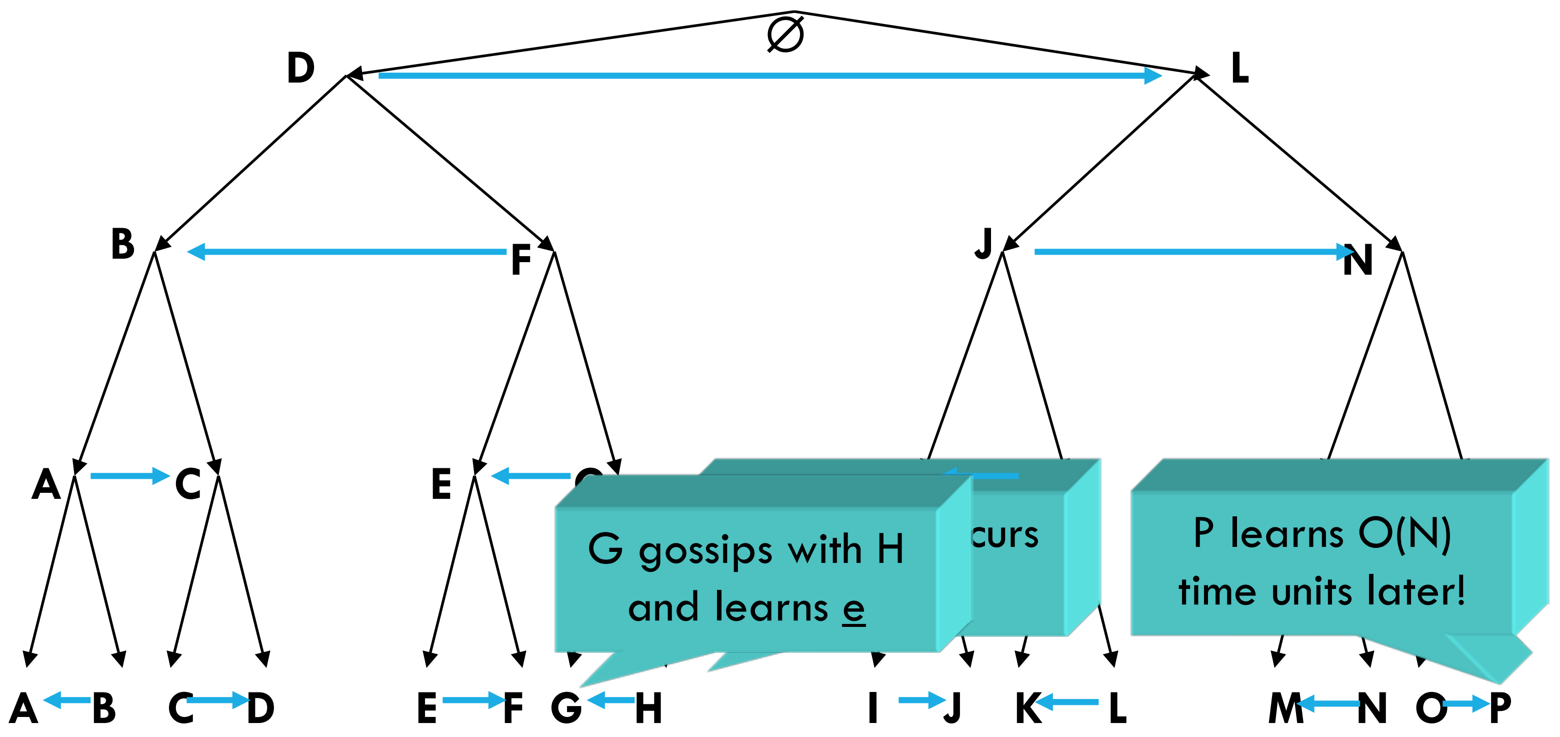
ANOTHER REALLY BAD STORY…

A company experimented with using Astrolabe

In their experiment, which was never deployed in practice, they had the idea that instead of the least loaded leaf nodes playing the inner gossip role, every node would have an equal role.

So they came up with a new kind of Astrolabe tree

AN UNFAIR AGGREGATION TREE


∅
D
L
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E
G
A B C D E F G H I J K L M N O P
curs
G gossips with H and learns e
P learns O(N) time units later!

WAIT! P LEARNS N TIME-STEPS LATER?

Wasn’t Astrolabe supposed to run in O(log N) time?

Why is it suddenly running in time O(N)?

WHAT WENT WRONG?

In this horrendous tree, each node has equal "work to do" but the information-space diameter is larger!

Astrolabe was actually benefitting from "instant" knowledge because the epidemic at each level is run <u>by someone elected from the level below</u>

INSIGHT: TWO KINDS OF SHAPE

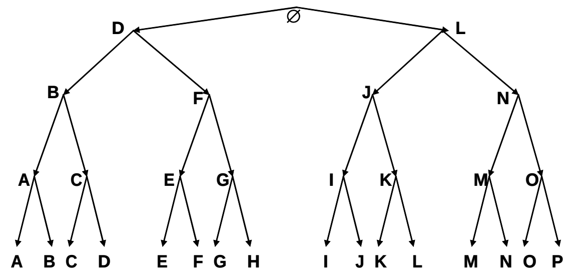
We've focused on the aggregation tree

But in fact should also think about the information flow tree

Our example was showing how an information flow tree can be slow.

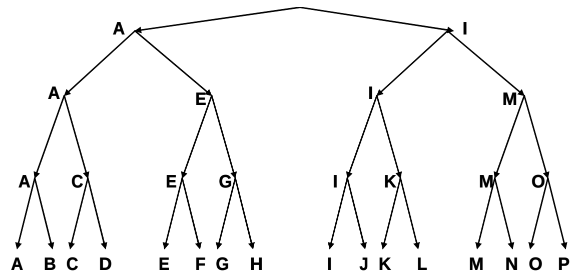
INFORMATION SPACE PERSPECTIVE

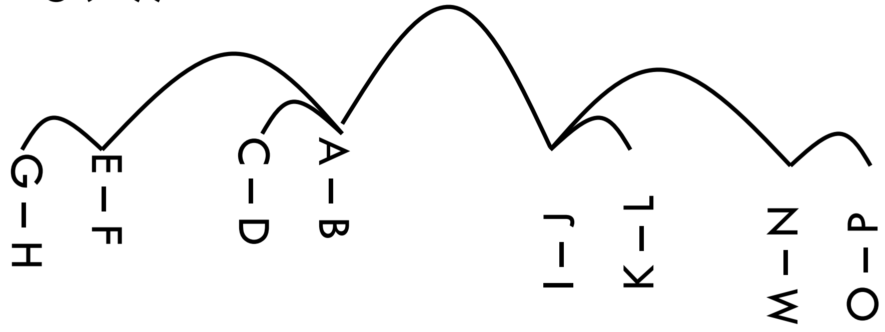
Bad aggregation graph: diameter O(n)



H – G – E – F – B – A – C – D – L – K – I – J – N – M – O – P

Astrolabe version: diameter O(log(n))





WHAT ABOUT THE UDP MULTICAST TRICK?

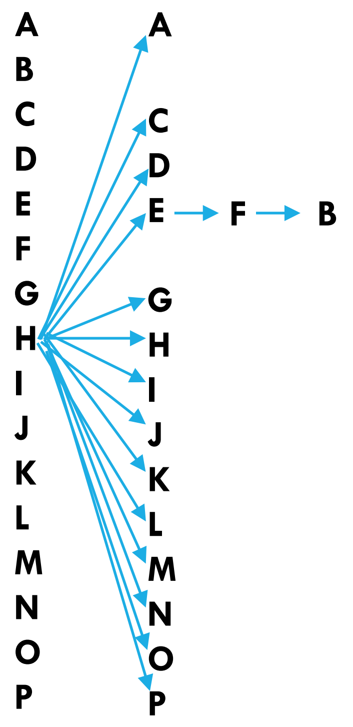
UDP multicast (like in Bimodal Multicast) really speeds up datacenter gossip multicast.

We could easily modify Astrolabe to do this too– now “most” nodes get infected right away, and we would have a bimodal query response time that would be very fast.

People have explored this, too.

INFORMATION SPACE PERSPECTIVE

UDP multicast causes a fast “all to most” exchange. Then a few stragglers need to catch up in the next gossip round or two:



In this UDP-multicast accelerated graph, we get a very accelerated covergence

BUT UDP MULTICAST CAN HAVE ISSUES TOO

Imagine a gossip system with 100,000 nodes using UDP multicast to accelerate reporting of important events.

Now suppose that the lights flicker or some other “system-wide” issue occurs and all 100,000 nodes remain operational but notice.

So now 100,000 machines all have news to report! They send 100,000 UDP multicast simultaneously… which is way more than we planned on!

WILL THIS CAUSE A PROBLEM?

The network itself can handle the surge. It probably runs at around 75M messages per second, on the wire layer.

So 100,000 messages do get through.

But a standard Linux server, high-end hardware, can't receive more than 10,000 UDP messages per second. This becomes the bottleneck

90,000 UDP MESSAGES GET DROPPED

In fact those Linux servers need to work hard to receive but then drop so many messages. It causes a huge overload.

The whole data center grinds to a halt.

Lots of other services begin to get timeouts due to unresponsive servers, causing even more errors to report

IN FACT UDP MULTICAST STORMS ARE A FAMOUS THREAT IN DATACENTERS

Many years ago there were a number of products in the “message bus” and “data distribution system” space that used this feature.

To understand the issue (which has nothing to do with gossip!) it helps to understand how UDP multicast really works.

THE BASIC MECHANISMS

First, the IP system reserves a class of IP addresses for use in UDP multicast. They are "class D" addresses, and we can think of each one as a unique id plus a unique port number *shared by a set of receivers*.

For example, "Ken's Magic Message Bus" might reserve IP address D:224.10.20.30 port number 7890. Every server process in the KMMB service has this hard-wired in.

THE BASIC MECHANISMS

When a machine boots, the KMMB server instance launches. It creates a socket and *binds* this standard IP address and port to it.

This causes the NIC to begin to watch for messages that match. In addition, the top of rack switch and datacenter routers are informed that there is a new multicast listener on this segment of the network.

They make note of this.

CONCEPT: A BLOOM FILTER: A WAY TO TRACK SET MEMBERSHIP CHEAPLY (O(1) INCLUSION COST)

A Bloom filter is a set of (usually) 3 bit-vectors of some length (usually) 1K

To "remember" X, the filter computes hash(X), hash(X+1), hash(X+2) and sets the corresponding bit in vector 0, 1 and 2.

Later to answer the question "does this filter include X" we repeat but this time check the bits. Answer yes if all 3 bits are set, no if not.

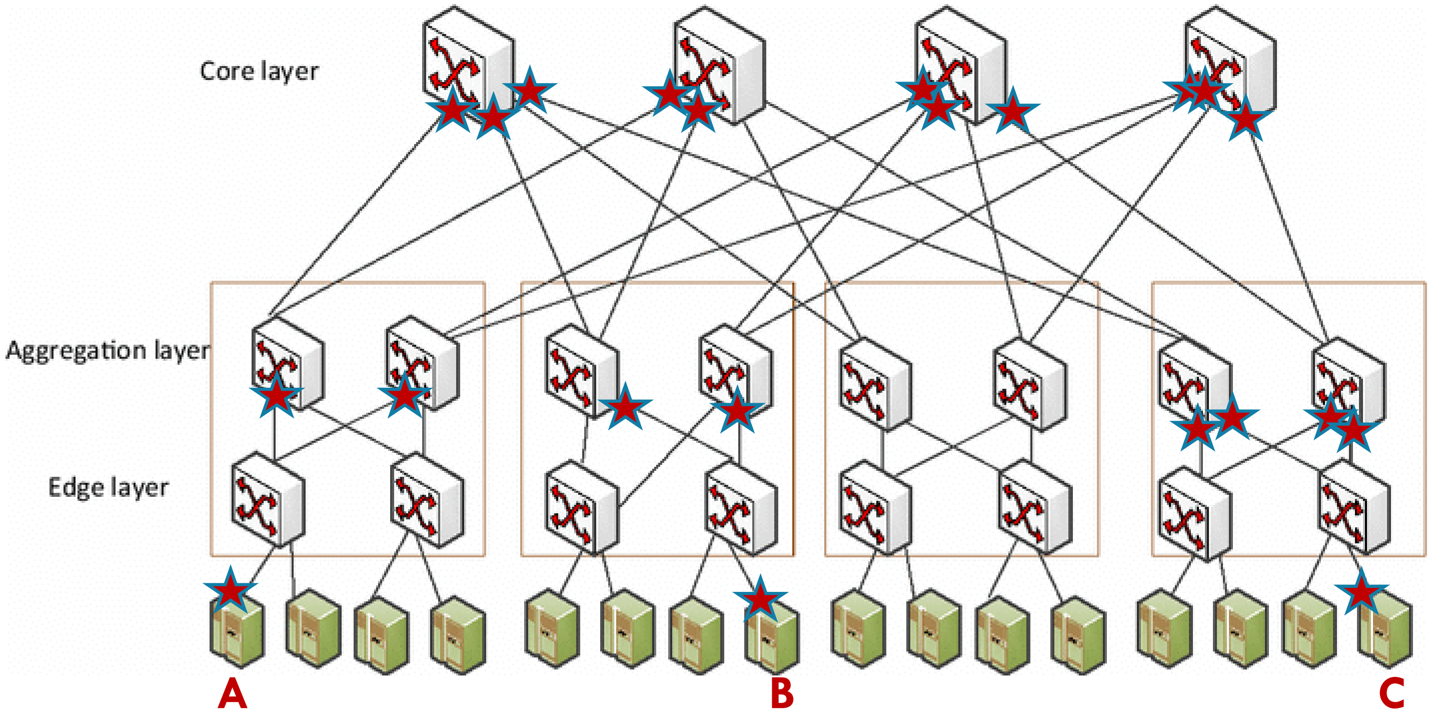
USE OF THESE FILTERS?

The NIC uses a Bloom filter to recognize incoming IP multicast packets it should accept.

The TOR switch uses a Bloom filter to track which rack has machines listening for a particular IP multicast address.

The fat-tree of datacenter routers uses this to remember which subnetworks have a machine listening for an IP multicast address.

EXAMPLE: NODES A, B AND C ARE IN IP MULTICAST GROUP OF KMMB



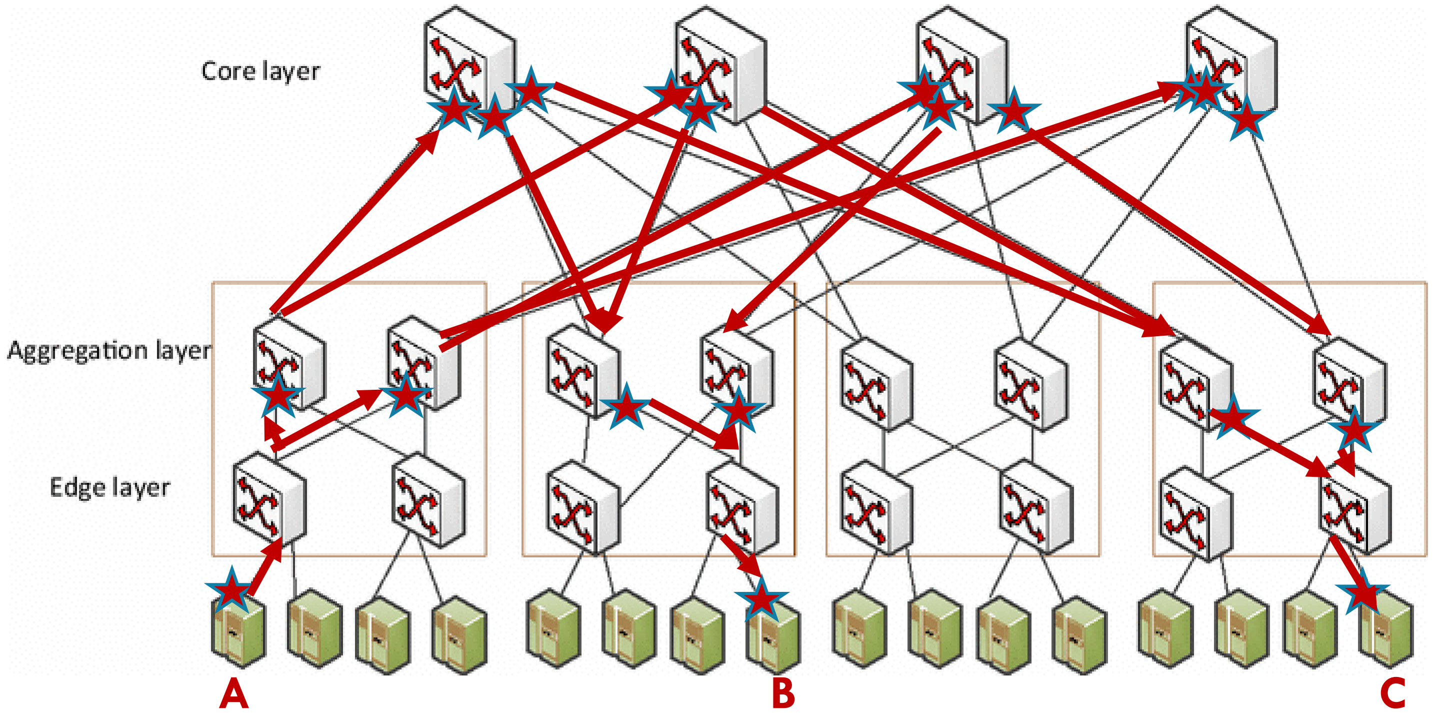
A SENDS A MULTICAST

Suppose we want to publish some event from A to KMMB?

A prepares a UDP packet, puts the special address in it, and calls sendto

At each stage it will be forwarded towards any receivers

EXAMPLE: NODES A, B AND C ARE IN IP MULTICAST GROUP OF KMMB



BLOOM FILTER ROLE?

At the "line rate" of the network (75M packets/second) we have very little time to decide where to forward copies.

The Bloom filter can be implemented in hardware (the hashing policy is the expensive step) and runs fast enough to make the decision before the switch or router exceeds its available time

So we get a very clean UDP multicast that might show up multiple times per receiver, but won't bother non-receivers…

SOME USES

Maybe KMMB is super popular. Each user has their own instance.

Also, very useful for tracking debug data and network management properties. If nobody is listening, the network itself automatically discards the UDP packets!

… so perhaps we see a “linear adoption”. Maybe for every 500 machines we see one additional thing using UDP multicast.

WHAT DOES THIS TELL US?

When the datacenter was small, it worked awesomely.

But suppose our datacenter has 1M computers – just yesterday Jeff Bezos gave the order and we doubled the size!

1M / 1500 = 660. Our Bloom Filter bit vectors only had 1024 bits. So now most of them will be set. Yesterday with 500,000 machines this wasn't the case – only 330 were set, per vector.

FALSE POSITIVES

As we scale up the data center, more and more of the UDP packets are going to be forwarded to more and more machines, due to Bloom Filter matches.

In effect we go from the network filtering out “no receiver” packets to forwarding them, many copies each, on every link.

This overloads the network and it becomes lossy. It may also overload individual machines if some machines are listening for many IP multicast addresses

WE CALL THESE MULTICAST STORMS

The term refers to an all-to-all message pattern that overwhelms the entire data center.

Basically, a single event ended up crashing the whole datacenter within seconds!

THESE PROBLEM HAVE ACTUALLY BEEN SEEN!

One result is that most modern data centers disable UDP multicast.

Either trying to use it always gives errors or, more common, when you try to use it they automatically set up TCP connections and route your messages over TCP.

For smaller multicast groups this works… but you can't make 100,000 TCP connections from one node to 100,000 other nodes. So we can't use the UDP speedup feature in most datacenter systems.

SUMMARY

Gossip is tricky! UDP multicast is tricky too! In fact everything except TCP seems to be risky!

A gossip mechanism will have constant, low overheads and very predictable delay, provided that the information sharing graph is of low diameter.

But small mistakes can yield gossip solutions that actually malfunction in major ways, potentially shutting down entire datacenters!