LOCATING DATA ON THE NETWORK: CONSISTENT HASHING, P2P NETWORKS, CHORD, AND DYNAMODB

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ATTRIBUTION

- These slides incorporate material from:
  - Christo Wilson, NEU (used with permission)
  - Kyle Jamieson, Princeton
  - Tanenbaum and Van Steen, 3rd edition

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READING

Please read section 3 of the “Algorithmic nuggets in content delivery” paper from Akamai

LOCATING ITEMS (AT SCALE) IS A PRETTY HARD PROBLEM

- Consider our metadata store:

Filename	Version	hashlist
kitten.jpg	1	[h0, h1, h2, h3, h4]
puppy.mp4	1	[h5,h6,h7,h8,h9]

- Let’s figure out about how many files a single server metadata store can store…

LET’S CHOOSE AN AWS INSTANCE TYPE

- General Purpose
- Compute Optimized
- Memory Optimized
- Accelerated Computing
- Storage Optimized
- Instance Features
- Measuring Instance Performance

LET'S PICK THE ARM-BASED MEMORY INSTANCE

R6g | R5 | R5a | R5b | R5n | R4 | X2gd | X1e | X1 | High Memory | z1d

Amazon EC2 R6g instances are powered by Arm-based AWS Graviton2 processors. They deliver up to 40% better price performance over current generation R5 instances for memory-intensive applications.

Features:

- Custom built AWS Graviton2 Processor with 64-bit Arm Neoverse cores
- Support for Enhanced Networking with Up to 25 Gbps of Network bandwidth
- EBS-optimized by default
- Powered by the AWS Nitro System, a combination of dedicated hardware and lightweight hypervisor
- With R6gd instances, local NVMe-based SSDs are physically connected to the host server and provide block-level storage that is coupled to the lifetime of the instance

MEMORY INSTANCE TYPES

Instance Size	vCPU	Memory (GiB)	Instance Storage	Network Bandwidth (Gbps)***	EBS Bandwidth (Mbps)
r6g.medium	1	8	EBS-Only	Up to 10	Up to 4,750
r6g.large	2	16	EBS-Only	Up to 10	Up to 4,750
r6g.xlarge	4	32	EBS-Only	Up to 10	Up to 4,750
r6g.2xlarge	8	64	EBS-Only	Up to 10	Up to 4,750
r6g.4xlarge	16	128	EBS-Only	Up to 10	4750
r6g.8xlarge	32	256	EBS-Only	12	9000
r6g.12xlarge	48	384	EBS-Only	20	13500
r6g.16xlarge	64	512	EBS-Only	25	19000
r6g.metal	64	512	EBS-Only	25	19000

Cost (per hour) of the r6g.16xlarge instance type: $3.2256

HOW MANY FILES CAN FIT INTO R6G.16XLARGE?

- 512GB of RAM
- Data requirements of each entry in the FileInfoMap?
  - Depends on size of the block...
  - Depends on distribution of file sizes…
    - Lots of small files? (e.g. C++, Java, Python, Go development)
    - Or big files? (audio or video files)
- Let’s see what the research literature says

TANENBAUM ET AL, 2004

File Size Distribution on UNIX Systems—Then and Now

Andrew S. Tanenbaum, Jorrit N. Herder*, Herbert Bos
Dept. of Computer Science
Vrije Universiteit
Amsterdam, The Netherlands
{ast@cs.vu.nl, jnherder@cs.vu.nl, herbertb@cs.vu.nl}

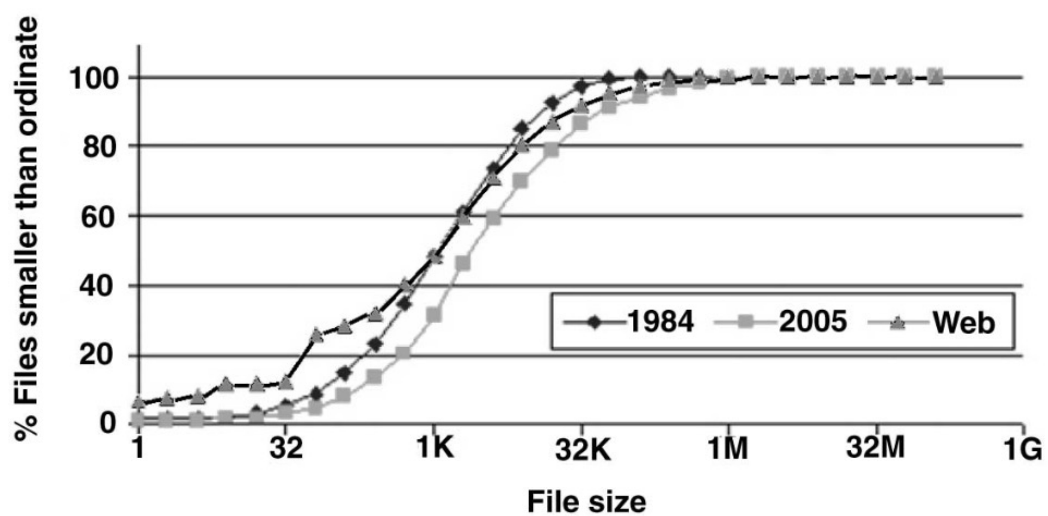


Fig. 2. Data of Fig. 1 shown graphically.

LIU ET AL, 2013

2013 13th IEEE/ACM International Symposium on Cluster, Cloud, and Grid Computing

Understanding Data Characteristics and Access Patterns in a Cloud Storage System

* *Ministry of* … *ystem Science*
† *Tsinghua National La* … *cience and Technology*

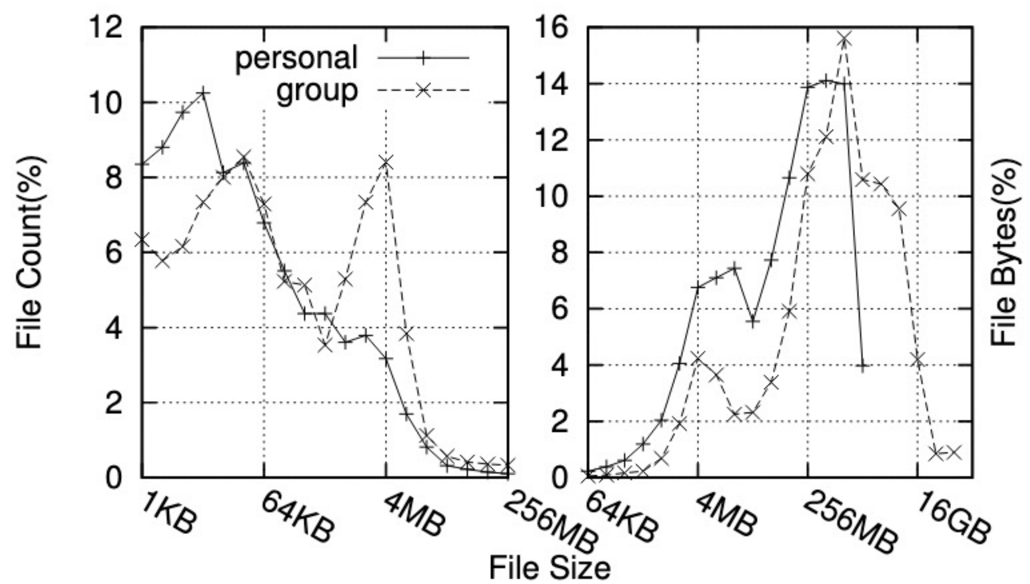


Figure 2. Bimodal file size distributions

A SIMPLE MODEL

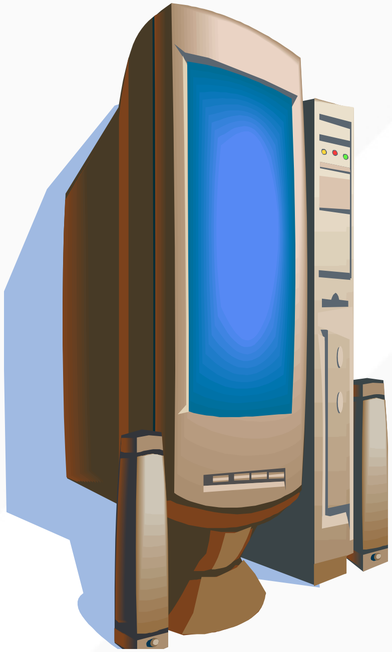
- File size distributions change over time and change depending on environment
- But to make it "easy", let's assume:
- 90% of files are small (64KB) and 10% are big (256MB)
- Let's use a 64KB block size
  - 90% of files need 1 hash in the hash list
    - 64 bytes for hash + 64 for filename and version = 128 bytes
  - 10% need 4000 hashes in the hash list
    - 4000*64 for hash + 64 for filename and version = 256 KB
- 0.9 * N * 128 + 0.1 * N * 256 KB = 512GB
- N(0.9*128 + 0.1*256KB) = 512GB
- N about 1.997 x 10^7 so just under 20 million

BUT WHAT IF YOU NEED MORE SPACE?

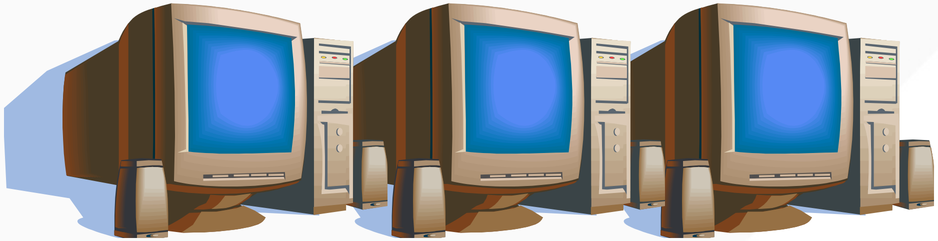
- What if you have more than 20 million files??

- You need *scale*

SCALING



Vertical Scaling
(bigger machines)



Horizontal Scaling
(more machines)

VERTICAL SCALING

- Get a machine with more RAM, more storage, a faster CPU, more CPUs, …
- Advantages:
  - Simple: Single machine abstraction
  - Simple: Only one IP address/hostname to consult
- Disadvantages:
  - Machines only get so big (have so much ram, etc)
  - What if the machine fails?

HORIZONTAL SCALING

- Form a *cluster* of 10, 100, 1000… servers that work together
- Advantages:
  - No one machine has to be very expensive/fancy
  - A failure of one machine doesn’t result in everything being lost
- Disadvantages:
  - How to find the data you’re looking for??
  - Performance is hard to reason about (subject of a future lecture, in fact)

HORIZONTAL SCALING ISSUES

- Probability of any failure in given period = $1-(1-p)^n$
  - p = probability a machine fails in given period
  - n = number of machines

- For **50K machines**, each with **99.99966% available**
  - **16%** of the time, **data center experiences failures**

- For **100K machines, failures 30%** of the time!

THE LOCATION PROBLEM

- Given a cluster C of *N* servers, how do we locate the specific server C_i responsible for a data item?

Filename	Version	hashlist
kitten.jpg	1	[h0, h1, h2, h3, h4]
puppy.mp4	1	[h5,h6,h7,h8,h9]

- E.g. For a logical metadata storage *service* spread across N machines, which machine has the hash list for kitten.jpg? For puppy.mp4?

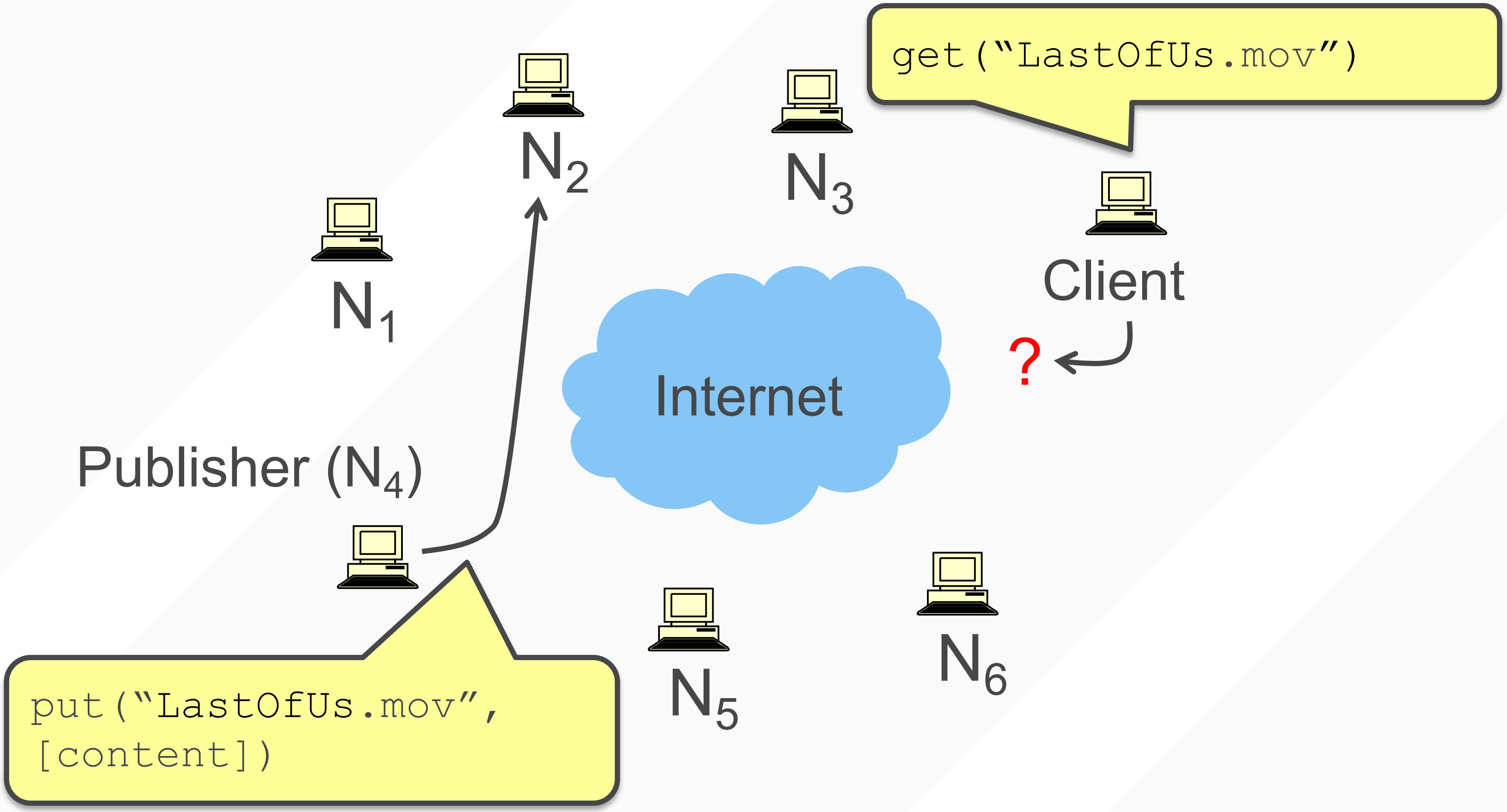
PEER TO PEER NETWORKS

- A distributed set of nodes sharing content, often based on “flat” names, is called a peer to peer network

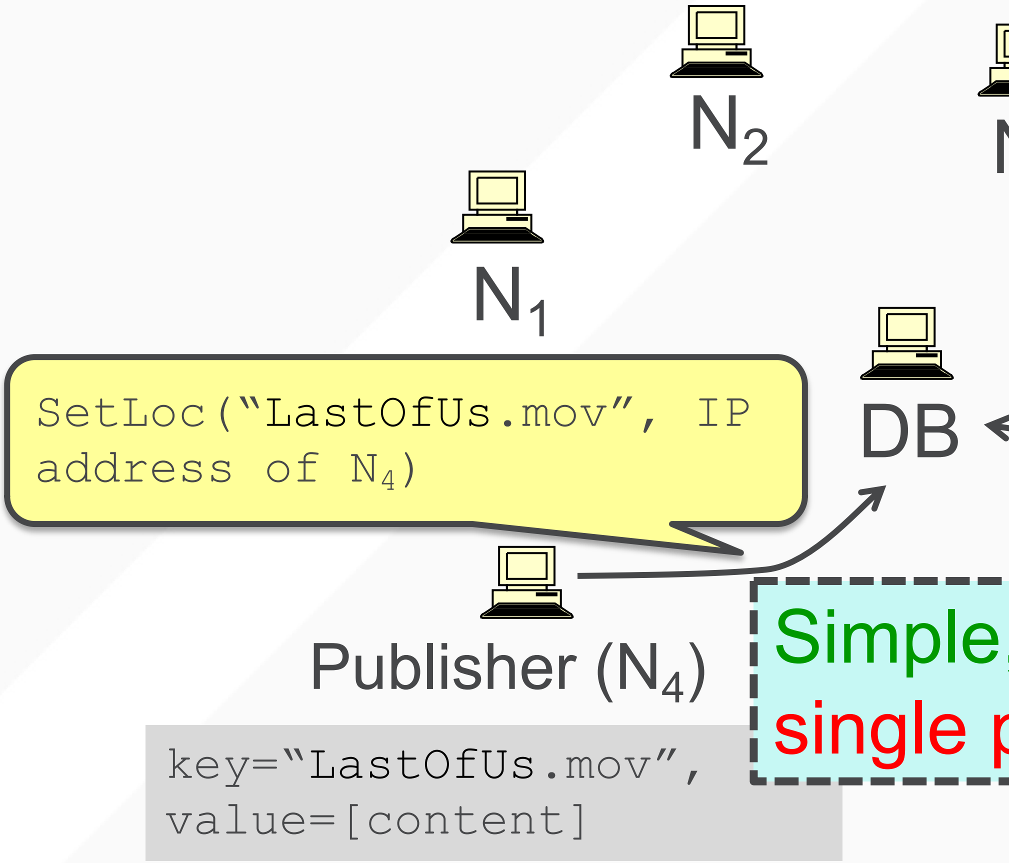
WHAT IS “FLAT” NAMING?

- The name doesn’t give you an indication of where the data is located
- Flat:
  - MAC address: 00:50:56:a3:0d:2a
- Vs hierarchical:
  - IP address: 206.109.2.12/24
  - DNS name: starbase.neosoft.com

FLAT NAME LOOKUP PROBLEM

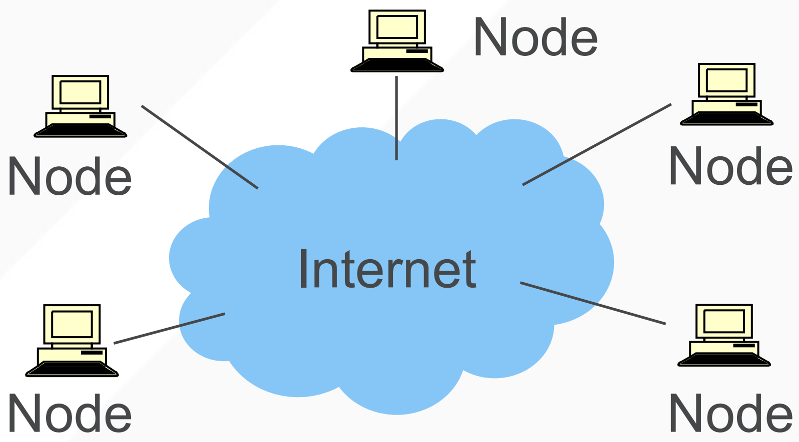


CENTRALIZED LOOKUP (NAPSTER)



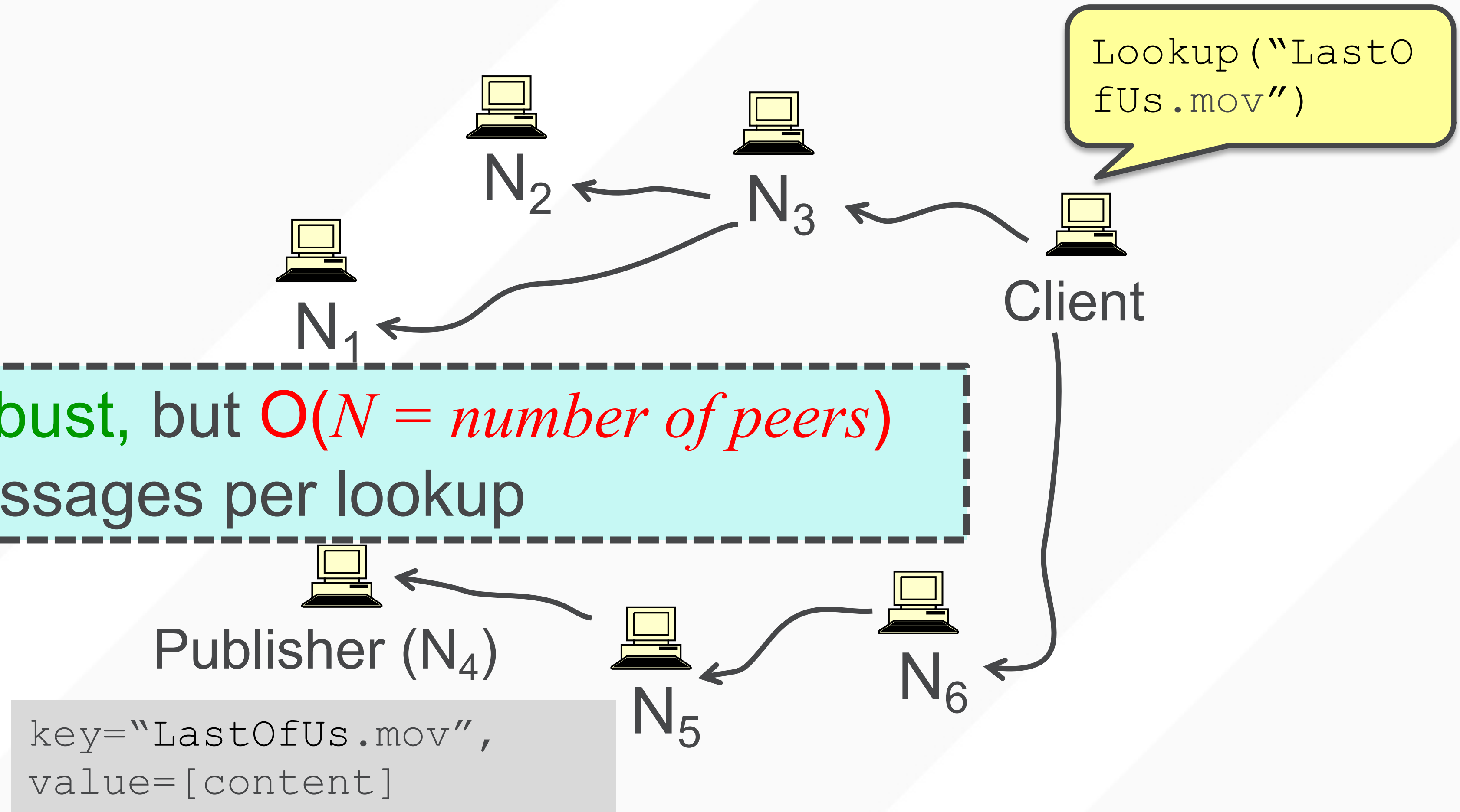
Simple, but O(N) state and a single point of failure

PEER-TO-PEER (P2P) NETWORKS



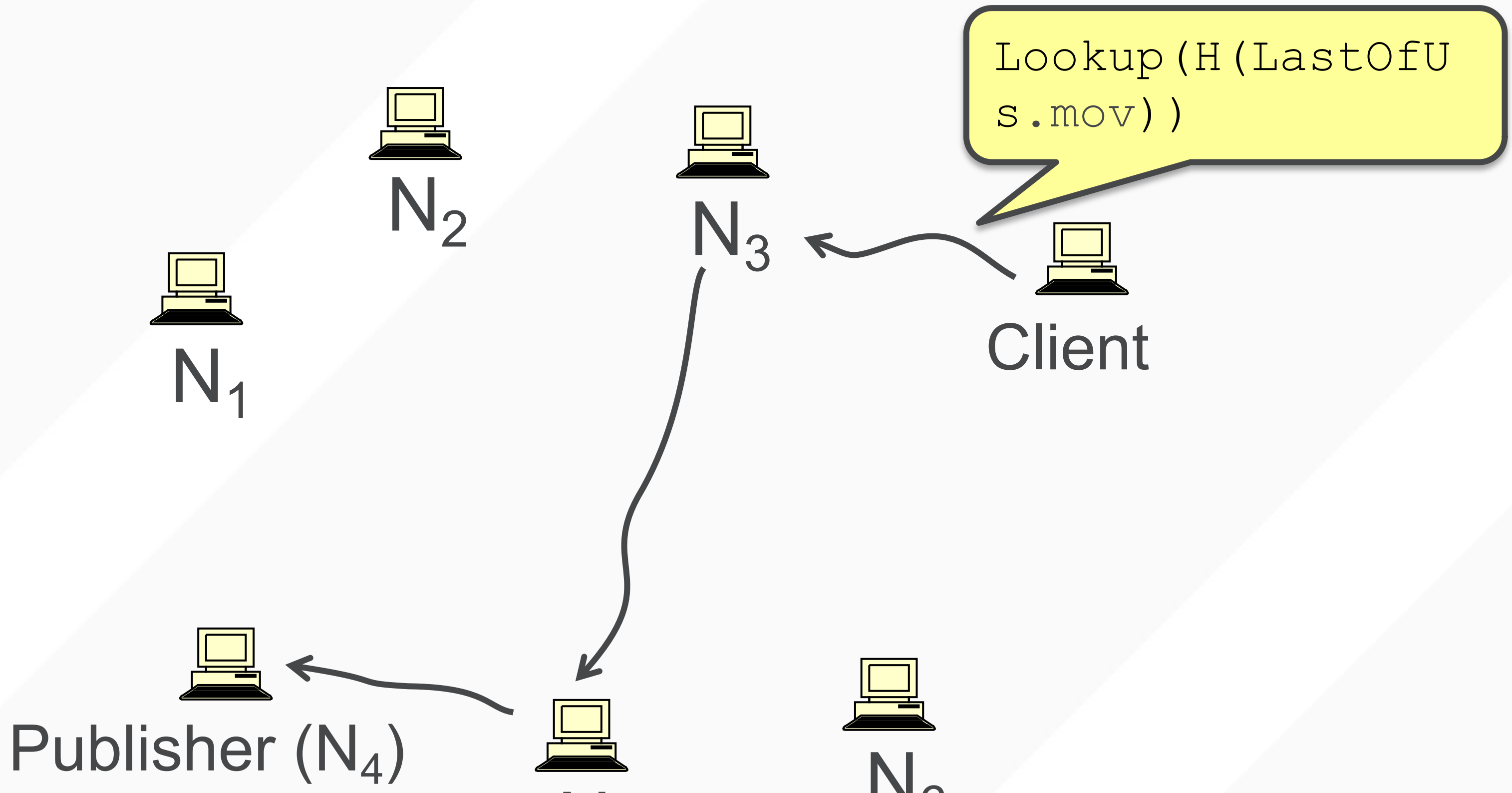
- A **distributed** system architecture:
  - **No centralized control**
  - Nodes are **roughly symmetric** in function
- **Large** number of **unreliable** nodes (could be reliable too)

FLOODED QUERIES (ORIGINAL GNUTELLA)



Robust, but O(N = *number of peers*) messages per lookup

ROUTED DHT QUERIES (DYNAMODB AND SURFSTORE)



Can we make it robust, reasonable state, reasonable number of hops?

SYSTEMATIC FLAT NAME LOOKUPS VIA DHTS

- Local hash table:

```
key = Hash(name)
put(key, value)
get(key) → value
```

- **Service:** Constant-time insertion and lookup

How can I do (roughly) this across millions of hosts on the Internet or within a giant datacenter application?
Distributed Hash Table (DHT)

WHAT IS A DHT (AND WHY)?

- Distributed Hash Table:

```
key = hash(data)
lookup(key) → IP addr
send-RPC(IP address, put, key, data)
send-RPC(IP address, get, key) → data
```

- **Partitioning data** in truly **large-scale distributed systems**
  - Tuples in a global database engine
  - Data blocks in SurfStore
  - Files in a P2P file-sharing system

SUMMARY OF IDEA

- We're going to rely on hashing to map keys to servers
  - That way, to find a key (e.g. filename), just hash the name you're looking for and consult just that server!
  - Cool… let's see how that works in practice…

STRAWMAN: MODULO HASHING (E.G. HASHMAP)

- Consider problem of data partition:
  - Given **object id X**, choose one of ***k*** servers to use

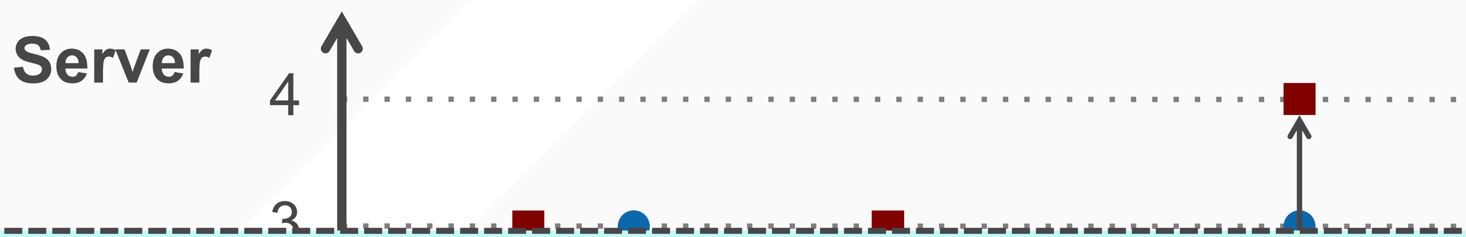
- Suppose instead we use **modulo hashing:**
  - Place ***X*** on server ***i* = hash(*X*) mod *k***

- What happens if a server fails or joins ($k \leftarrow k\pm1$)?
  - or different clients have **different estimate** of k?

PROBLEMS WITH MODULO HASHING

$h(x) = x + 1 \pmod 4$

Add one machine: $h(x) = x + 1 \pmod 5$



All entries get remapped to new nodes!
→ Need to move objects over the network

We need a different hashing approach that doesn't change everything when a server comes or goes…

CONSISTENT HASHING [KARGER '97]

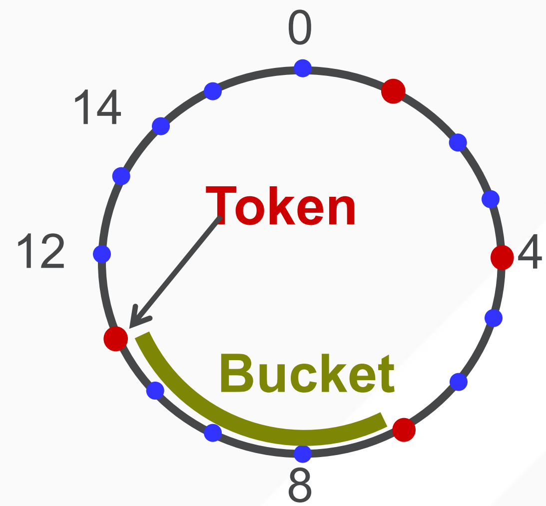
- **Key identifier** = hash(key)

- **Node identifier** = hash(server's IP address) or hash(server's hostname) or hash(server's identity)

- Same hash function maps two *different* types of data to the same ID space!

CONSISTENT HASHING

- Assign *n* *tokens* to random points on mod 2^k circle; hash key size = *k*
- Hash object to random circle position
- Put object in closest clockwise bucket
  - *successor* (key) → bucket



- Desired features –
  - Balance: No bucket has "too many" objects
  - Smoothness: Addition/removal of token minimizes object movements for other buckets

EXAMPLE FROM AKAMAI PAPER (SECTION 3)

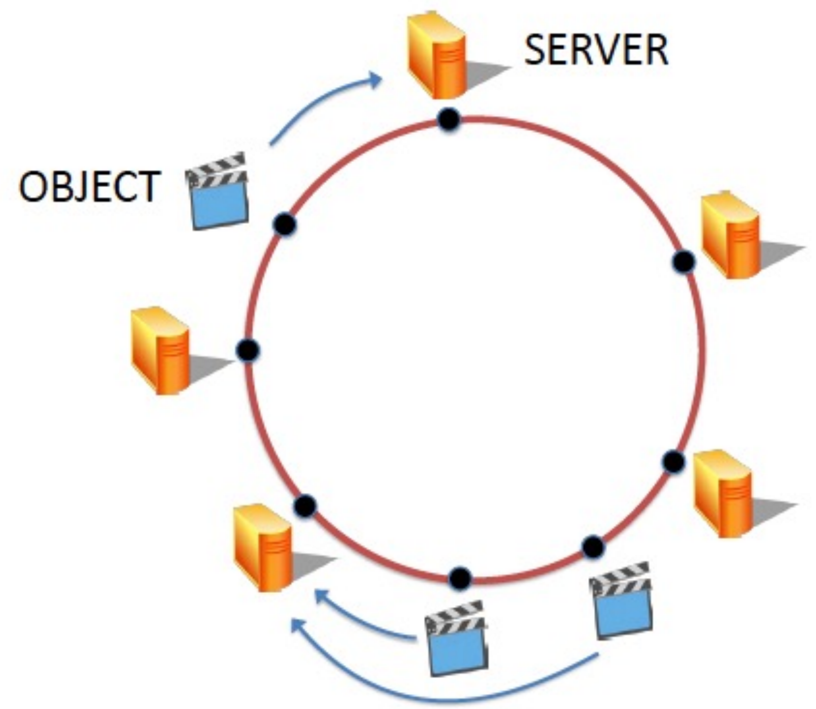
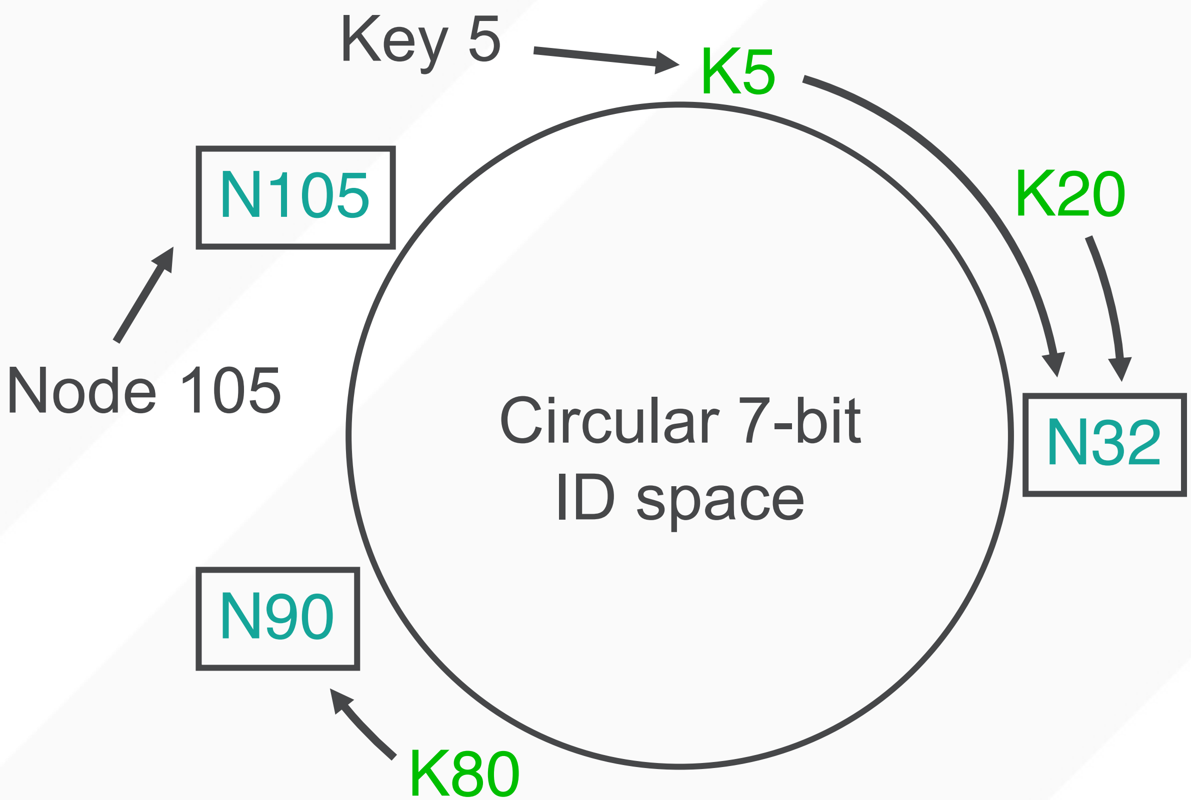


Figure 4: Consistent hashing first maps both objects and buckets (servers) to the unit circle. An object is then mapped to the next server that appears on the circle in clockwise order.

CONSISTENT HASHING [KARGER '97]



Key is stored at its successor: node with next-higher ID

CONSISTENT HASHING AND LOAD BALANCING

- Each node owns **$1/n^{th}$** of the ID space in expectation
  - Says nothing of request load per bucket

- If a node fails, its successor takes over bucket
  - **Smoothness goal ✓:** Only localized shift, not O(n)
  - But now successor owns **two** buckets: **$2/n^{th}$ of key space**
    - The failure has **upset the load balance**

VIRTUAL NODES

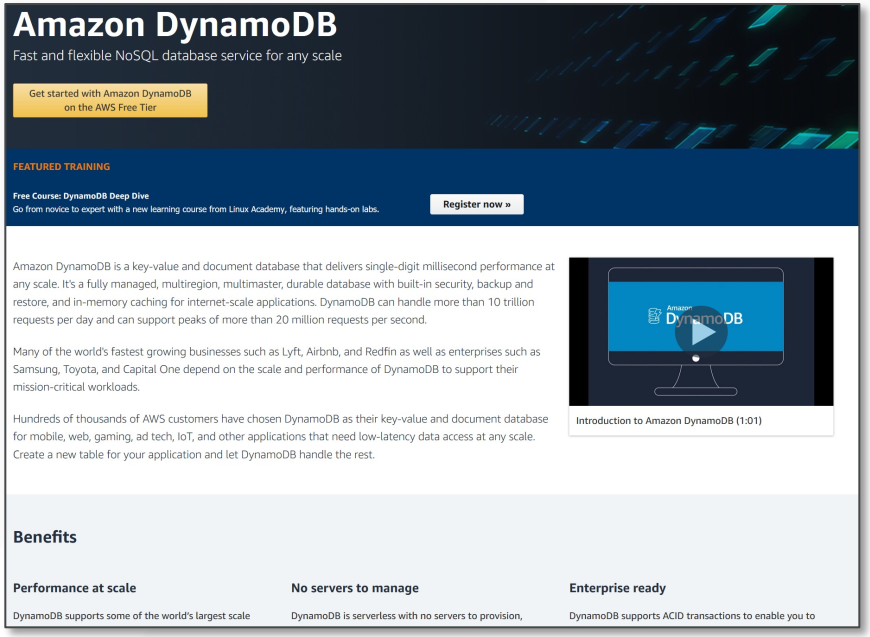
- **Idea:** Each **physical node** now maintains **v > 1 tokens**
  - Each token corresponds to a ***virtual node***

- Each virtual node owns an expected **1/(vn)th** of ID space

- **Upon a physical node's failure, v** successors take over, each now stores **(v+1)/v×1/nth** of ID space

- **Result: Better load balance** with larger v

DYNAMODB



- Amazon's DynamoDB data store is based on this concept of consistent hashing

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