Distributed Systems:
Distributed File Systems – Part 2

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Distributed Systems: Andrew File System

Introduction

- Developed at Carnegie Mellon University as part of an IBM-CMU collaboration.
- The key objective was to provide scalability and security to support file sharing between up to 5000 concurrent users.
- 2 key design features:
  - Whole-file serving: Entire files and directories are transmitted to client computers
  - Whole-file caching: Once a copy or chunk of a file has been transferred it is stored in a permanent local cache.

Typical Scenario

- When the client issues an open command for a shared file it checks the cache.
  - A copy of the file is downloaded to the cache if it is not present.

- The copy is then opened and the resulting UNIX file descriptor is returned.

- Subsequent read, write and other operations are applied to the local copy.

- While the client issues a close command, the local copy is checked.
  - Changes cause the file to be transmitted back to the server.
  - The client copy is maintained.

Why go for upload/download?

- Based on observations about typical workloads in academic and other environments:
  - Files are small (less than 10k in size)
  - Reads are about 6 times more common than writes.
  - Sequential access is common, random access is rare.
  - Most files are accessed by only one user
  - Most shared files are modified by one user
  - Recently used files will most probably be used again

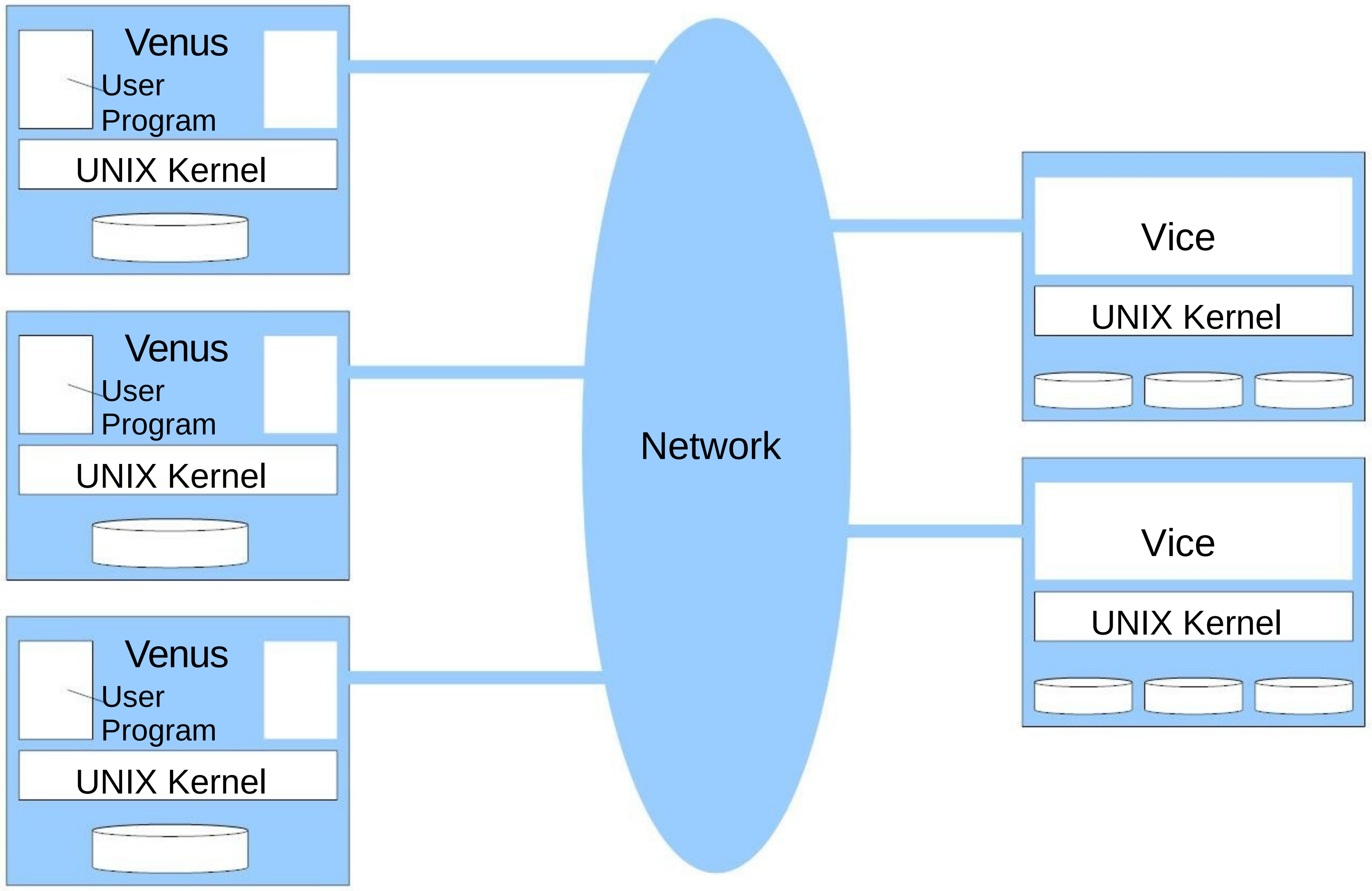
- Today, file sizes two magnitudes larger – but then so are network transmission speeds!

Design Issues

- Andrew employs a large local cache (say 100Mb):
  - It is used to store local copies of the files that the user most commonly accesses.
  - This includes both shared code libraries and that user's personal files.
  - This means that, after the initial access, most shared files can be accessed at the same speed as local files.

- Unfortunately, this does not work for files such as databases which are frequently accessed and updated by multiple users.

AFS Design


Venus
User Program
UNIX Kernel
Venus
User Program
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Venus
User Program
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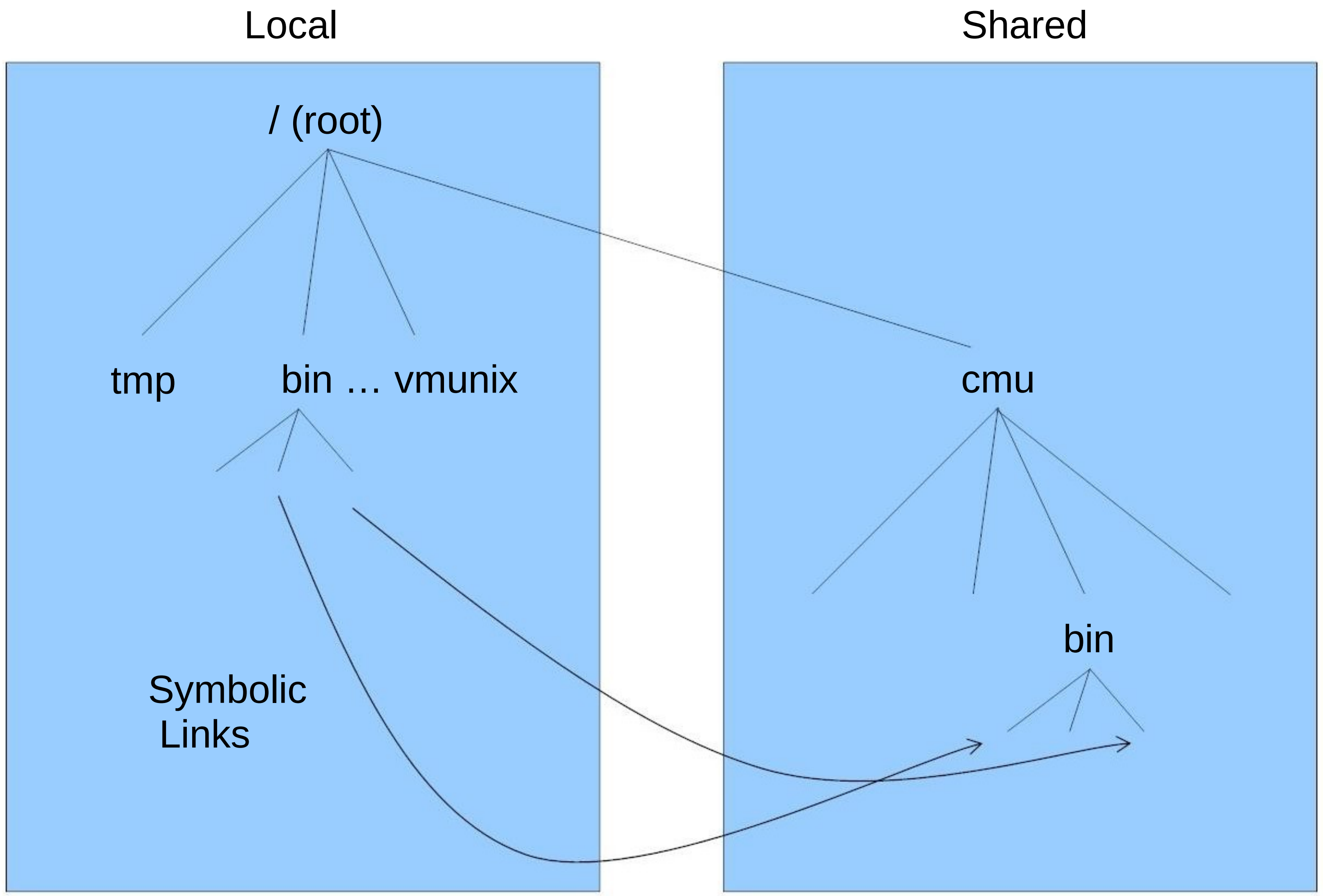
Network
Vice
UNIX Kernel
Vice
UNIX Kernel

AFS File Space



AFS Implementation

- Vice:
  - Implements a Flat File Service.
  - Groups files into volumes (e.g. system binaries, documentation, a users home directory) for ease of location and movement.
  - Each file is identified by a unique 96-bit file identifier (fid).

Volume number	File Handle	Uniquifier

- Venus:
  - Updates the local cache, downloading files as necessary.
  - Manages shared directory structure.
  - Resolves directories issued by clients to fids using a step-by-step lookup.
  - Maintains cache coherence via callback promises

AFS Cache Coherence

- Vice supplies a token, known as a callback promise, for each copy of a file that is transmitted to a Venus process.
  - It represents a promise that Vice will contact that Venus process should any other client modify that file.
  - Callback promises are stored locally, initially with a valid state.
- When a file is updated, the Vice server performs a callback.
  - It contacts each client that was issued a token and informs it that the file was updated.
  - This causes the callback promise to be changed to cancelled.
- When Venus receives and open request, it checks the callback promise.
  - If it is set to cancelled, then a fresh copy of the file is retrieved.

AFS Cache Coherence

- When a workstation is restarted, Venus imposes an additional check on all files in the cache:

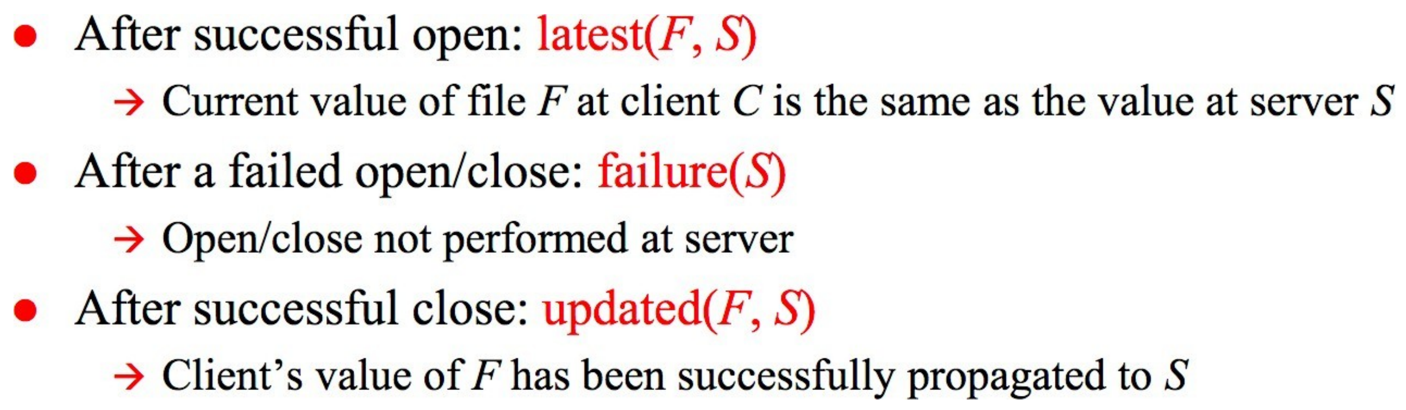
- Upon first access of a file, it submits a cache validation request to the server containing the files’ last modification timestamp.

- If the timestamp is correct, then the callback promise is validated.

- This validation also occurs if time T has elapsed since the communication with the server.

AFS Update Semantics

- Attempts to approximate to one-copy semantics for UNIX file access.
  - Full one-copy semantics requires that a write results in all cached copies of a file being updated before another operation is applied to that file.
- For a client C operating on a file F the following guarantees are maintained:



- After successful open: latest(*F*, *S*)
  - → Current value of file *F* at client *C* is the same as the value at server *S*
- After a failed open/close: failure(*S*)
  - → Open/close not performed at server
- After successful close: updated(*F*, *S*)
  - → Client's value of *F* has been successfully propagated to *S*

Other Aspects

- Threads
  - Venus and Vice are multi-threaded
- Read-only replicas
  - Multiple read-only copies of volumes containing frequently used (read) files (e.g. /bin) are maintained on different servers.
- Bulk transfers
  - The 64k limit on file transfer size reduces network overheads

AFS Review

	FFS	AFS
Objective	Reference Architecture	Scalable and Secure
Security	Directory Service/RPC	RPC-based
	Encryption	Private key algorithm
Naming	Location Transparency	Location Indepence
File Access	Remote Access Model + Cache	Upload / Download + Cache
Cache-Update Policy	Write-Through	Callback Promise (token)
	N/A	Write-on-close
Consistency	N/A	Timestamp-based
Service Type	Stateless	Stateful
Replication	N/A	Read-only

Peer to Peer Networks

What is P2P?

- Peer-to-Peer (P2P) Systems:
  - A set of networked devices that have **equal responsibility** and which **share resources and workload** as necessary.
  - Each device is both a **client** and a **server**.
  - There is no (or little) centralised control.

- Examples of Peer-to-Peer Systems:
  - File Sharing Applications e.g. Gnutella, BitTorrent, Kazaa, …
  - Instant Messengers and Telephony e.g. Skype, Yahoo, MSN
  - Data Processing Services e.g. Seti@Home

- Peer-to-Peer Systems **most effective** when used to store very large collections of immutable data

- Their design **diminishes their effectiveness** for applications that store and update mutable data

Characteristics of P2P Systems

- Aim of P2P Systems:
  - To deliver a service that is fully decentralised and self-organising, dynamically balancing the storage and processing loads between all the participating computers as computers join and leave the service.
- Key Characteristics:
  - Every user contributes resources to the service.
  - While resources differ, all nodes in a P2P system have the same functional capabilities and responsibilities.
  - Their correct operation does not depend on the existence of any centrally-administered systems.
  - They can be designed to offer a limited degree of anonymity to the providers and users of resources.
- Key Problem:
  - How to deal with the placement and accessing of shared resources in a manner that balances the workload and ensures availability, but does not add undue overheads?

Placement of Resources

- Deciding at which node(s) a resource should be located
  - Can be managed by the P2P application, or left to nature (the users)
- Examples:
  - Andrew File System
    - Consists of a set of file servers that decide how many copies of a file are needed to meet demand and where those copies should be located.
    - Users are not aware of the existence of multiple copies of the file (location independence).
  - Napster, Gnutella
    - Each user runs the application (peer) and decides which file(s) will be located at their node.
    - Copies are created in an ad-hoc way - each user downloads the files that they want (and then shares them).
    - Users are aware of the number of copies that they have access to.

Accessing (Locating) Resources

- In (centralised) managed environments: searching is not a problem:
  - We know where all the copies of a file are
  - We can develop algorithms that employ knowledge of the placement scheme that has been used.
- In P2P environments: resources are distributed over a diverse set of nodes.
  - How do we find the resource we are looking for?
  - We need to perform some kind of search!
- In such ad-hoc environments we have a problem:
  - We do not know where the resource is located
  - We may not even know what nodes exist!
  - While a number techniques have been developed to handle this, locating resources in a P2P system is still a hot topic of research…

Types of P2P Systems

- Three main types of P2P system:
  - Centralized systems: peer connects to server which coordinates and manages communication
    - e.g. SETI@home

centralised discovery
centralised communication

  - Decentralized systems: peers run independently with no central services.
    - Discovery is decentralized and communication takes place between the peers. e.g. Gnutella, Pastry

decentralised discovery
decentralised communication

  - Hybrid systems: peers connect to a server to discover other peers
    - peers manage the communication themselves (e.g. Napster).
    - This is also called 'Brokered P2P'.

centralised discovery
decentralised communication

Peer-to-Peer Middleware Systems

P2P Middleware Systems

- With the growing popularity of P2P systems, P2P researchers worked to develop generalized versions of the first P2P system
  - that utilise existing routing, naming, data replication and security techniques in new ways to provide a reliable resource sharing layer over an unreliable and untrusted collection of computers and networks
- Aims:
  - To be application independent
  - scalability: to share resources, storage and data present in computers at the edges of the internet on a global scale
- They provide reference architecture that allowed researchers to focus on specific P2P issues.
- These systems are commonly knows as P2P Middleware Systems.

P2P Middleware Systems

- P2P Middleware systems are based on 2nd generation architectures:
  - Every node in the system is a peer.
  - Some special infrastructure nodes included to improve network performance.
  - Peer nodes connect to infrastructure nodes (which may also be peers), and route searches via these infrastructure nodes.
- Perhaps the most central issue in P2P research is the issue of resource discovery (searching).
  - algorithms used to carry out the search within P2P middleware systems are known as routing overlay algorithms

Routing Overlays - basic idea

- P2P routing overlays are used to locate objects.
  - The middleware is a layer that is responsible for routing requests from any node to the node that holds the target resource.
  - However, P2P systems allow for the migration of resources between nodes.
  - As a result, the term overlay is used to clarify that it is an application layer routing mechanism (it is not a network layer mechanism like IP routing).
  - The first system to employ routing overlays was the Plaxton Mesh. Others to follow include Pastry and Tapestry.

- Routing overlays ensure that any node can access any resource by routing each request through a sequence of nodes.
  - It exploits knowledge at each of them in order to locate the resource.
  - Because P2P systems can store replicas, the routing algorithm must maintain the location of all copies.
  - It then delivers requests to the nearest “live” node

Routing Overlay - basic idea

- The main task of a routing overlay is:
  - Clients wishing to invoke an operation on a resource submit a request, which includes a GUID (unique identifier) for the resource, to the routing overlay algorithm.
    - Globally Unique IDentifiers (GUID)
  - It directs the request to a node on which a replica (or the original) of the resource resides.
- In addition the routing overlay is responsible for:
  - Creating GUID's for all new resources
  - Announcing the existence of the new resources to ensure that the resource is reachable by all clients.
  - Handling the removal of references to shared resources that are no longer in the system
  - managing the addition/removal of nodes to/from the system.

Routing Overlays - Resource GUIDS

- In a P2P System, resources are identified by a globally unique identifier (GUID) that is location independent.
  - For object-based resources the GUID is calculated using a hash function, such as SHA-1.
  - This hash is derived from some/all of the resources state. This means that clients receiving the resource can check the validity of the hash (self certifying aspect)
  - Uniqueness is verified by searching for another object with the same GUID.
- GUID's are used to determine the placement of objects, and to retrieve them
- Because of this, routing overlay routing systems are sometimes constructed using Distributed Hash Tables (DHT -this is reflected in the simple API or operations that is used to access and add resources)
- The DHT layer takes responsibility for:
  - choosing a location for each resource
  - storing it (with replicas to ensure availability)
  - providing access to it via a get() operation.

Routing Overlays - Distributed Hash Tables (DHT)

- DHTs form an infrastructure that can be used to build peer-to-peer networks.

- Question: GUID’s are used to determine the placement of objects, and to retrieve them - Within the DHT model, how does
  this happen.

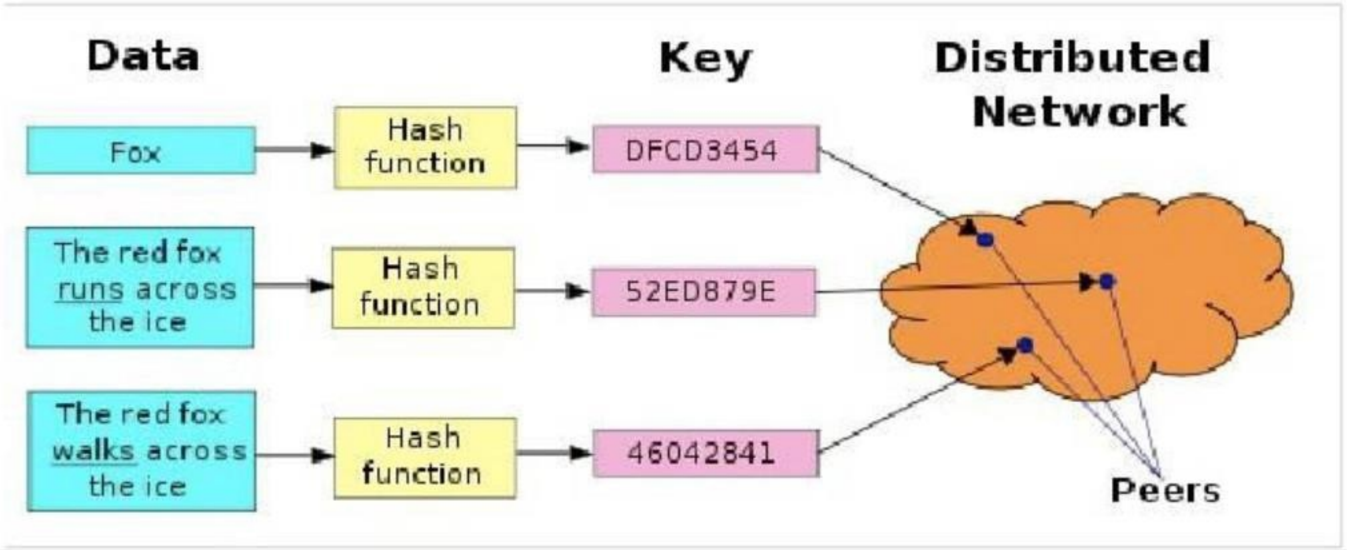
- Answer: A data item with GUID X is stored at the node whose GUID is numerically closest to X, and at the r hosts with GUIDs numerically closest to X.
    - where r is a replication factor chosen to ensure a very high probability of availability

Distributed Hash Table Operations

- put(GUID, data)
  - The data is stored in replicas at all nodes responsible for the object identified by GUID
- remove(GUID)
  - Deletes all references to GUID and the associated data
- data = get(GUID)
  - The data associated with GUID is retrieved from one of the nodes responsible for it.

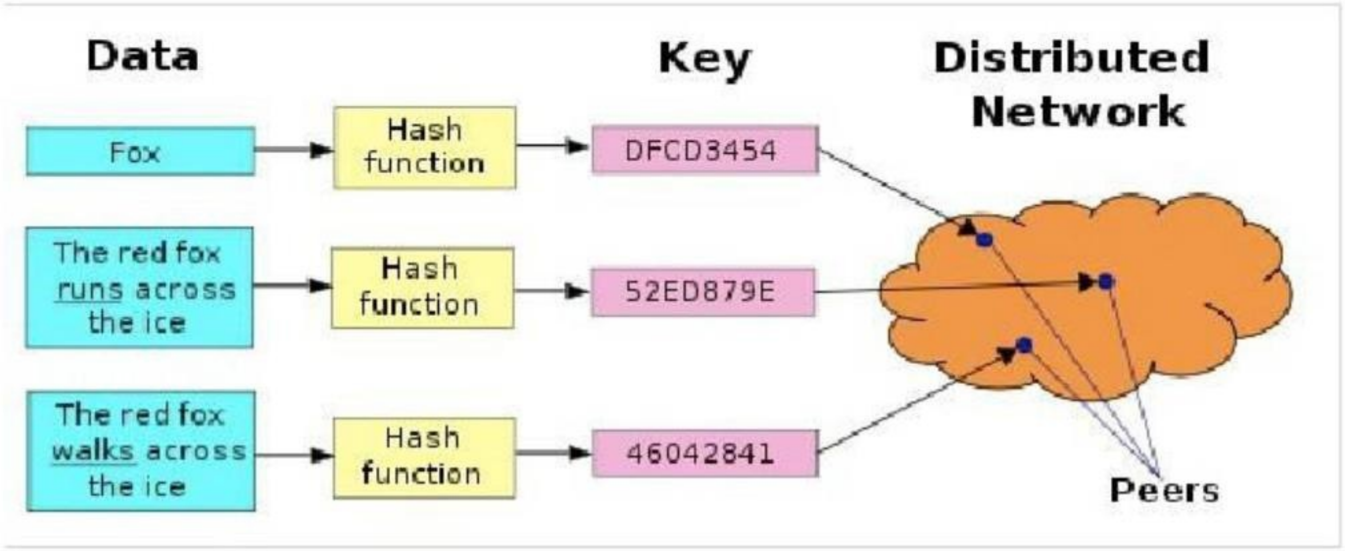
Distributed Hash Tables (DHT's)

- Networks that use DHTs include:
  - BitTorrent
- provide a lookup service similar to a hash table
  - (key, value) pairs are stored in the DHT
  - any participating node can efficiently retrieve the value (data) associated with a given key



Distributed Hash Tables (DHT's)

- Responsibility for maintaining the mapping from keys to values (data) is distributed among the nodes
  - can scale to extremely large numbers of nodes
  - handle continual node arrivals, departures, and failures.



DHT’s - Properties

- Decentralization: the nodes collectively form the system without any central coordination.
- Scalability: the system should function efficiently even with thousands or millions of nodes.
- Fault tolerance: the system should remain reliable even with nodes continuously joining, leaving, and failing
  - mainly through the replication of objects

Thank you