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DISTRIBUTED SYSTEMS (COMP9243)

Lecture 10: Naming

① Basic Concepts
② Naming Services
③ Attribute-based Naming (aka Directory Services)
④ Distributed hash tables

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WHAT IS NAMING?

Systems manage a wide collection of entities of different kinds. They are identified by different kinds of names:

- Files (`/boot/vmlinuz`), Processes (`1, 14293`), Users (`chak, ikuz, cs9243`), Hosts (`weill, facebook.com`), ...

Examples of naming in distributed systems?
What's the difficulty?

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BASIC CONCEPTS

Name:

- String of bits or characters
- Refers to an entity

Entity:

- Resource, process, user, etc.
- Operations performed on entities at access points

Address:

- Access point named by an address
- Entity address = address of entity's access point
- Multiple access points per entity
- Entity's access points may change

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Identifier:

- Name that *uniquely* identifies entity
- Properties:
  ① Refers to at most one entity
  ② Entity referred to by at most one identifier
  ③ Always refers to same entity (i.e. no reuse)
- Allows easy comparison of references

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System-Oriented vs Human-Oriented Names

System-Oriented Names:

- ➜ Represented in machine readable form (32 or 64 bit strings)
- ➜ Structured or unstructured
- ✓ Easy to store, manipulate, compare
- ✗ Not easy to remember, hard for humans to use
- ➜ Example: inode (`0x00245dad`)

Human-Oriented Names:

- ➜ Variable length character strings
- ➜ Usually structured
- ➜ Often many human-oriented names map onto a single system-oriented name
- ✓ Easy to remember and distinguish between
- ✗ Hard for machine to process
- ➜ Example: URL (`http://www.cse.unsw.edu.au/~cs9243/lectures`)

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Name Spaces

Container for a set of related names

Structure options:

- ➜ Flat (only leaf nodes)
- ➜ Hierarchical (Strictly hierarchical, DAG, Multiple root nodes)
- ➜ Tag-based

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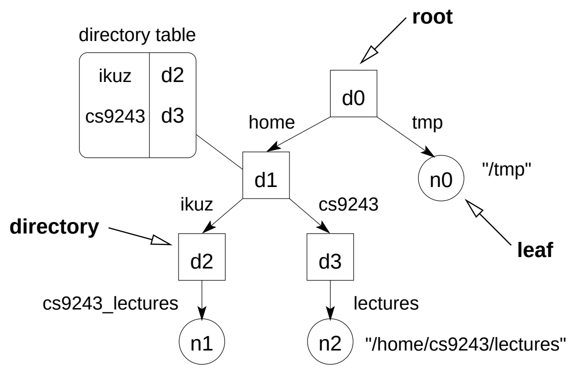

Path Names (in hierarchies):

- ➜ Sequence of edge labels
- ➜ Absolute: if first node in path name is a root node
- ➜ Relative: otherwise

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Aliasing:

- ➜ Alias: another name for an entity
- ➜ Hard link: two or more paths to an entity in the graph
- ➜ Soft link: leaf node stores a (absolute) path name to another node

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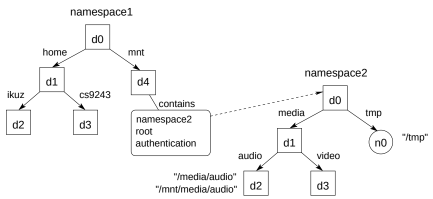
Merging:

➜ Mounting

- Directory node stores info about a directory node in other name space
- Need: protocol, server, path name, authentication and authorisation info, keys for secure communication, etc.



➜ Combining name spaces

- `http://www.cse.unsw.edu.au/~cs9243/naming-slides.pdf`
- Name Spaces: Protocol, DNS, File System

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Naming Services

A naming service provides a name space

Name Server:

➜ Naming service implemented by name servers

➜ Implements naming service operations

Operations:

➜ `Lookup`: resolve a path name, or element of a path name

➜ `Add`: add a directory or leaf node

➜ `Remove`: remove a subtree or leaf node

➜ `Modify`: modify the contents of a directory or leaf node

Client:

➜ Invokes naming service operations

Centralised vs Distributed Naming Service

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Name Resolution

The process of looking up a name

Resolution:

➜ Mapping a name onto the node referred to by the name

➜ Interested in the data stored by the node

Path Name Resolution:

➜ Starts at a begin node (first element of the path name)

- Root node for absolute name
- Directory node for relative name

➜ Ends with data from (or a reference to) the last node (last element of path name)

Resolver:

➜ Does name resolution on behalf of client

➜ In client process, in client's kernel, process on client's machine

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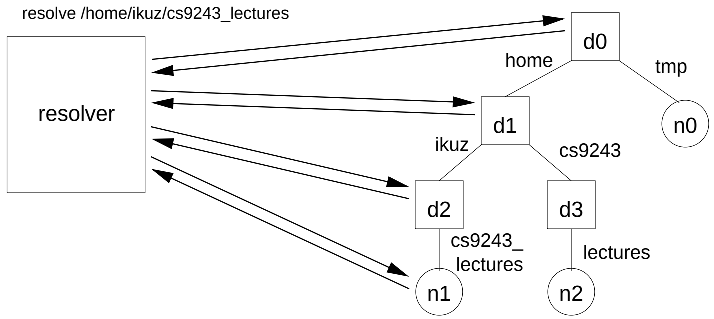
Iterative Resolution:



✗ Caching only at resolver

✗ Lots of communication

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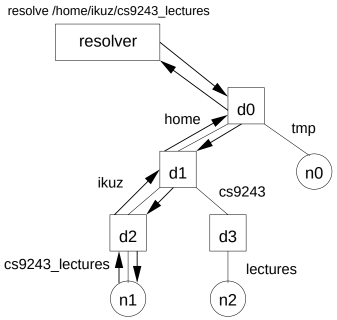
Recursive Resolution:



- ☑ Effective caching at name servers
- ☑ Reduced communication (if name servers close together)
- ☑ Name servers can be protected from external access
- ✗ Higher performance demand placed on servers

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Naming Service Implementation Issues

Performance and Scalability:

- ➜ Limit load on name servers
- ➜ Limit communication required
- ➜ Partitioning: split name space over multiple name servers
- ➜ Replication: copy (parts of) name space on multiple name servers

Fault Tolerance:

- ➜ Replication

Authoritative Name Server:

- ➜ Name server that stores an entity's original attributes

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Partitioning

Split name space over multiple servers

Structured Partitioning:

- ➜ split name space according to graph structure
- ➜ Name resolution can use zone hints to quickly find appropriate server
- ☑ Improved lookup performance due to knowledge of structure
- ✗ Rigid structure

Structure-free Partitioning:

- ➜ content placed on servers independent of name space
- ☑ Flexible
- ✗ Decreased lookup performance, increased load on root

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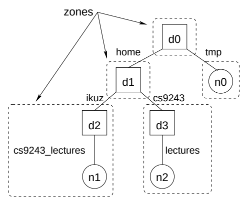

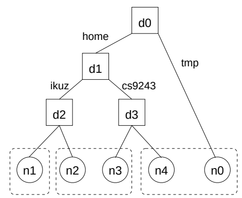

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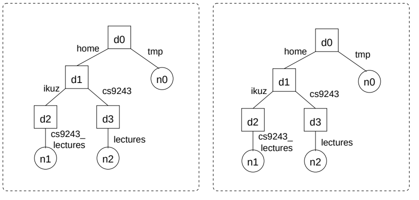
Replication

Copy name space to multiple servers

Full Replication:

- ➜ copy complete name space
- ☑ Fast performance
- ✗ Size (each server must store whole name space)
- ✗ Consistency (any change has to be performed at all replicas)
- ✗ Administration (who has rights to make changes where?)



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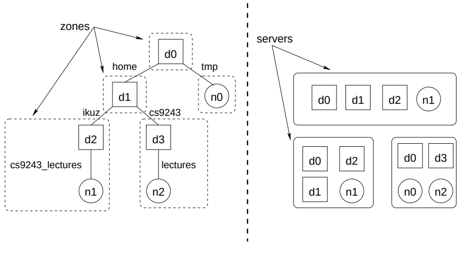
Partial replication:

- ➜ Replicate full name servers
- ➜ Replicate zones
- ☑ Improved performance, less consistency overhead
- ☑ Less administrative problems



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Caching:

- ➜ Cache query results
- ☑ No administrative problems
- ➜ Types of caches:
  - Directory cache: cache directory node information
  - Prefix cache: cache path name prefixes
  - Full-name cache: cache full names
- ➜ Cache implementations:
  - Process-local cache: in address space of process
  - Kernel cache: cache kept by kernel
  - User-process cache: separate shared service
- ➜ Cache updates and consistency
  - On use checking
  - Timeout
  - Invalidation
  - Slow propagation

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DNS (Domain Name System)

Structure:

- ➜ Hierarchical structure (tree)
- ➜ Top-level domains (TLD) (.com, .org, .net, .au, .nl, ...)
- ➜ *Zone*: a (group of) directory node
- ➜ *Resource records*: contents of a node
- ➜ *Domain*: a subtree of the global tree
- ➜ *Domain name*: an absolute path name

Type of record	Associated entity	Description
SOA	Zone	Holds information on the represented zone
A	Host	Contains an IP address of the host this node represents
MX	Domain	Refers to a mail server to handle mail addressed to this node
SRV	Domain	Refers to a server handling a specific service
NS	Zone	Refers to a name server that implements the represented zone
CNAME	Node	Symbolic link with the primary name of the represented node
PTR	Host	Contains the canonical name of a host
HINFO	Host	Holds information on the host this node represents
TXT	Any kind	Contains any entity-specific information considered useful

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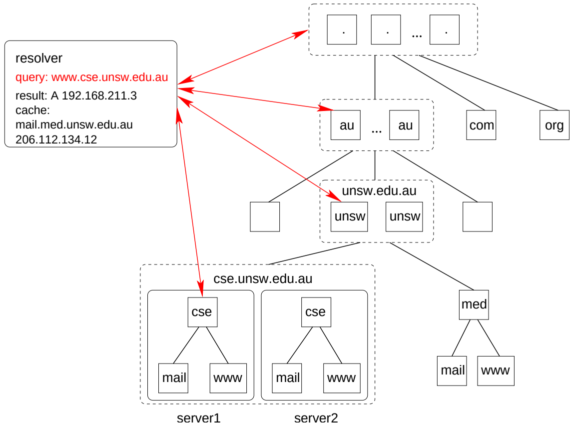

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Partitioning:

- ➜ Each zone implemented by a name server

Replication:

- ➜ Each zone replicated on at least two servers
- ➜ Updates performed on *primary*
- ➜ Contents transferred to *secondary* using *zone transfer*
- ➜ Higher levels have many more replicas (13 root servers: `A-M.root-servers.net`. Actually 386 replicas using anycast)

Caching:

- ➜ Servers cache results of queries
- ➜ Original entries have time-to-live field (TTL)
- ➜ Cached data is non-authoritative, provided until TTL expires

Name Resolution:

- ➜ Query sent to local server
- ➜ If cannot resolve locally then sent to root
- ➜ Resolved recursively or iteratively

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ATTRIBUTE-BASED NAMING (& LDAP)

White Pages vs Yellow Pages:

- ➜ White Pages: Name ↦ Phone number
- ➜ Yellow Pages: Attribute ↦ Set of entities with that attribute
- ➜ Example: X.500 and LDAP

Attribute-Based Names:

- ➜ Example: `/C=AU/O=UNSW/OU=CSE/CN=WWW Server/Hardware=Sparc/OS=Solaris/Server=Apache`
- ➜ Distinguished name (DN): set of attributes (distinguished attributes) that forms a canonical name for an entity

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Attribute-Based Naming:

- ➜ Lookup entities based on attributes
- ➜ Example: `search("&(C=AU)(O=UNSW)(OU=*)(CN=WWW Server)")`
- ➜ Attributes stored in *directory entry*, all stored in *directory*

Name Space:

- ➜ Flat: no structure in directory service
- ➜ Hierarchical: structured according to a hierarchy
- ➜ *Distinguished name* mirrors structure of name space
- ➜ All possible attribute types and name space defined by *schema*

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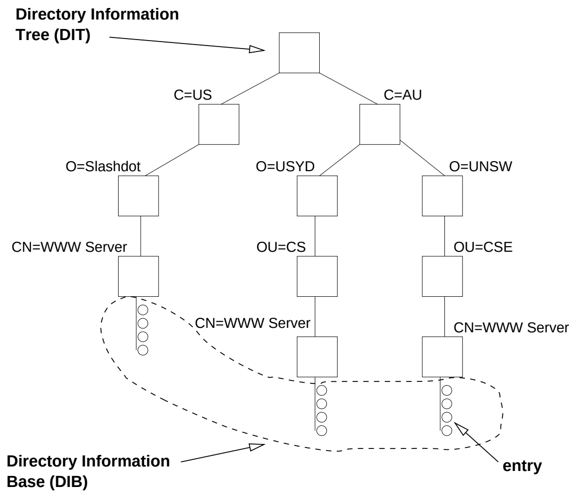

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Directory Services

A directory service implements a directory

Operations:

- `Lookup`: resolve a distinguished name
- `Add`: add an entity
- `Remove`: remove an entity
- `Modify`: modify the attributes of an entity
- `Search`: search for entities that have particular attributes
- Search can use partial knowledge
- Search does not have to include distinguished attributes
- Most important qualities: allow browsing and allow searching

Client:

- Invokes directory service operations

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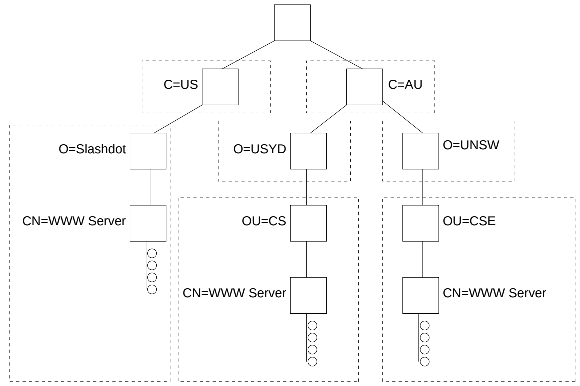
Distributed Directory Service

Partitioning:

- Partitioned according to name space structure (e.g., hierarchy)



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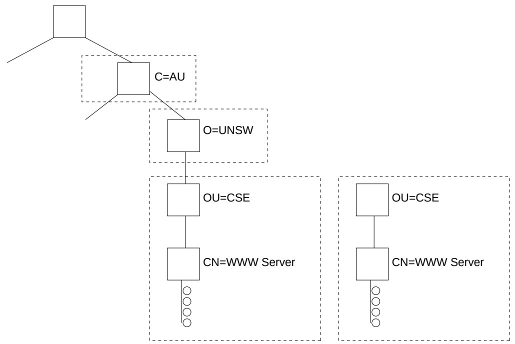
Replication:

- Replicate whole directory
- Replicate partitions
- Read/Write and read only replicas (e.g. primary-backup)
- Catalog and cache replicas



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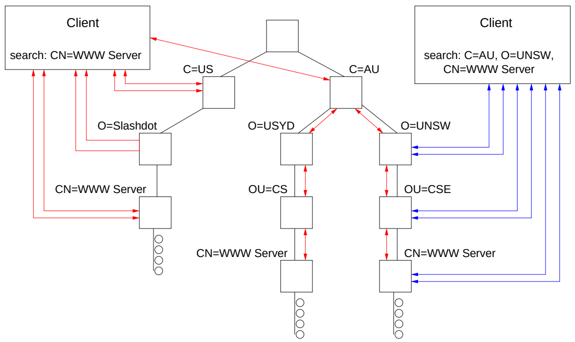
Searching and Lookup in a Distributed Directory



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Approaches:

- ➜ Chaining (recursive)
- ➜ Referral (iterative)
- ➜ Multicasting (uncommon)

Performance of Searching:

- ➜ Searching whole name space: must visit each directory server
- ✗ bad scalability
- ➜ Limit searches by specifying *context*
- ➜ Catalog: stores copy of subset of DIB information in each server
- ➜ Main problem: multiple attributes mean multiple possible decompositions for partitioning BUT only one decomposition can be implemented

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X.500 and LDAP

X.500:

- ➜ ISO standard
- ➜ Global DIT
- ➜ Defines DIB, DIB partitioning, and DIB replication

LDAP (Lightweight Directory Access Protocol):

- ➜ X.500 access over TCP/IP
  - X.500 is defined for OSI Application layer
- ➜ Textual X.500 name representation
- ➜ Popular on Internet
- ➜ Also X.500 free implementations (e.g. openldap)
- ➜ Used in Windows for Active Directory

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Address Resolution of Unstructured Names

Unstructured Names:

- ➜ Practically random bit strings
- ➜ Example: random key, hash value
- ➜ No location information whatsoever
- ➜ How to find corresponding address of entity?

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Simple Solution: Broadcasting:

- Resolver broadcasts query to every node
- Only nodes that have access point will answer

Example – ARP:

Protocol to resolve MAC addresses from IP addresses.

- Resolver broadcasts:
  Who has 129.94.242.201? Tell 129.94.242.200
- 129.94.242.201 answers to 129.94.242.200:
  129.94.242.201 is at 00:15:C5:FB:AD:95

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Distributed Hash Tables

Hash table (key value store) as overlay network:

- `put(key, value)`, `value = get(key)`, `remove(key)`

Example: look up unstructured host names:

```
put(weill, 129.94.242.49)
put(beethoven, 129.94.172.11)
put(maestro, 129.94.242.33)

address = get(beethoven)
```

- How high is performance cost of lookup?

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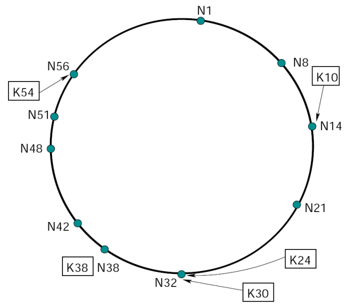
Chord: Distributed Hash Table

General Structure:



- keys and node IP addresses mapped to identifier
- consistent hashing (SHA-1 m-bits)
- key assigned to first node with $id > key \rightarrow$ `successor(key)`

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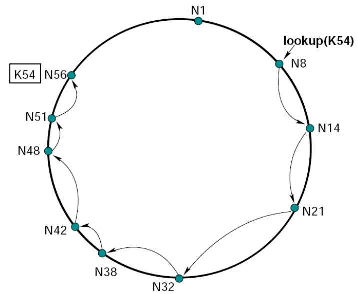
A simple lookup:



- use successors function
- recursive RPCs until node with key is found
- $O(n)$ cost

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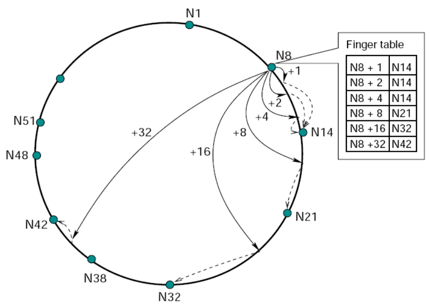
A scalable lookup:



- ➜ routing table at every node: *finger table*
- ➜ ith entry is $successor(n + 2^{i-1})$
- ➜ $finger[1]$ is successor

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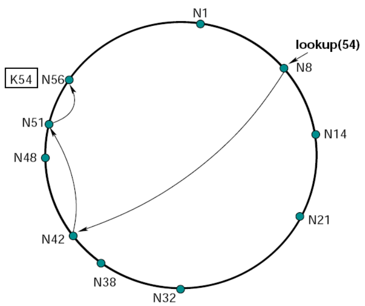

- ➜ lookup greatest node id in table $< k$
- ➜ ask it to lookup the key
- ➜ exponentially smaller jumps

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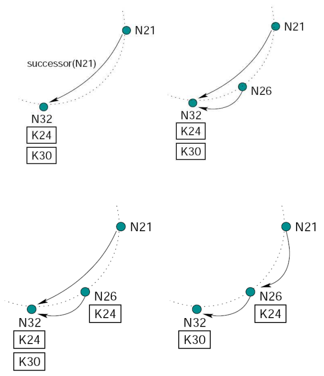
Adding a node:



- ➜ `stabilize`: ensure successor pointers up-to-date
- ➜ `fix_fingers`: ensure that finger tables updated

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Dealing with node failure:

- ➜ successor list: r successors to handle $r - 1$ failures
- ➜ higher level must handle loss of data relating to failure

Analysis:

- ➜ finger table size: $O(logn)$.
- ➜ $O(logn)$ nodes contacted for lookup
- ➜ $1/2logn$ average

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HOMEWORK

➜ How could you use a DHT to implement a directory service?

➜ How could you use a DHT to implement a file system?

Hacker's edition:

➜ Use an existing DHT implementation to implement a simple file system.

➜ Implement the DHT yourself

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READING LIST

Domain Names - Implementation and Specification RFC 1035 DNS

The Lightweight Directory Access Protocol: X.500 Lite LDAP

Chord: A Scalable Peer-to-peer Lookup Protocol for Internet Applications Chord