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?

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

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
**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)

**NAME SPACES**

Container for a set of related names

**Structure options:**
- Flat (only leaf nodes)
- Hierarchical (Strictly Hierarchical, DAG, Multiple root nodes)
- Tag-based

**Path Names (in hierarchies):**
- Sequence of edge labels
- **Absolute:** if first node in path name is a root node
- **Relative:** otherwise

**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

**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
  - Name Spaces: Protocol, DNS, File System

**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**
**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

Iterative Resolution:

Recursive Resolution:

**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
**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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**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?)

**Partial Replication:**
- Replicate full name servers
- Replicate zones
  - Improved performance, less consistency overhead
  - Less administrative problems
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

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

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
**LDAP & Attribute-Based Naming**

**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

**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

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

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

**Searching and Lookup in a Distributed Directory**

**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
X.500 AND LDAP

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**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

ADDRESS RESOLUTION OF UNSTRUCTURED NAMES

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

DISTRIBUTED HASH TABLES

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**Simple Solution: Broadcasting:**
- Resolver broadcasts query to every node
- Only nodes that have access point will answer

**Example – ARP:**
- 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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**Hash table (key value store) as overlay network:**

**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?
**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 → successor(key)

**A simple lookup:**
- Use successors function
- Recursive RPCs until node with key is found
- $O(n)$ cost

**A scalable lookup:**
- Routing table at every node: finger table
- $i$th entry is successor($n + 2^{-i}$)
- $finger[1]$ is successor
- Lookup greatest node id in table < $k$
- Ask it to lookup the key
- Exponentially smaller jumps
Adding a node:

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

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: \( O(\log n) \).
- \( O(\log n) \) nodes contacted for lookup
- \( 1/2\log n \) average

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

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