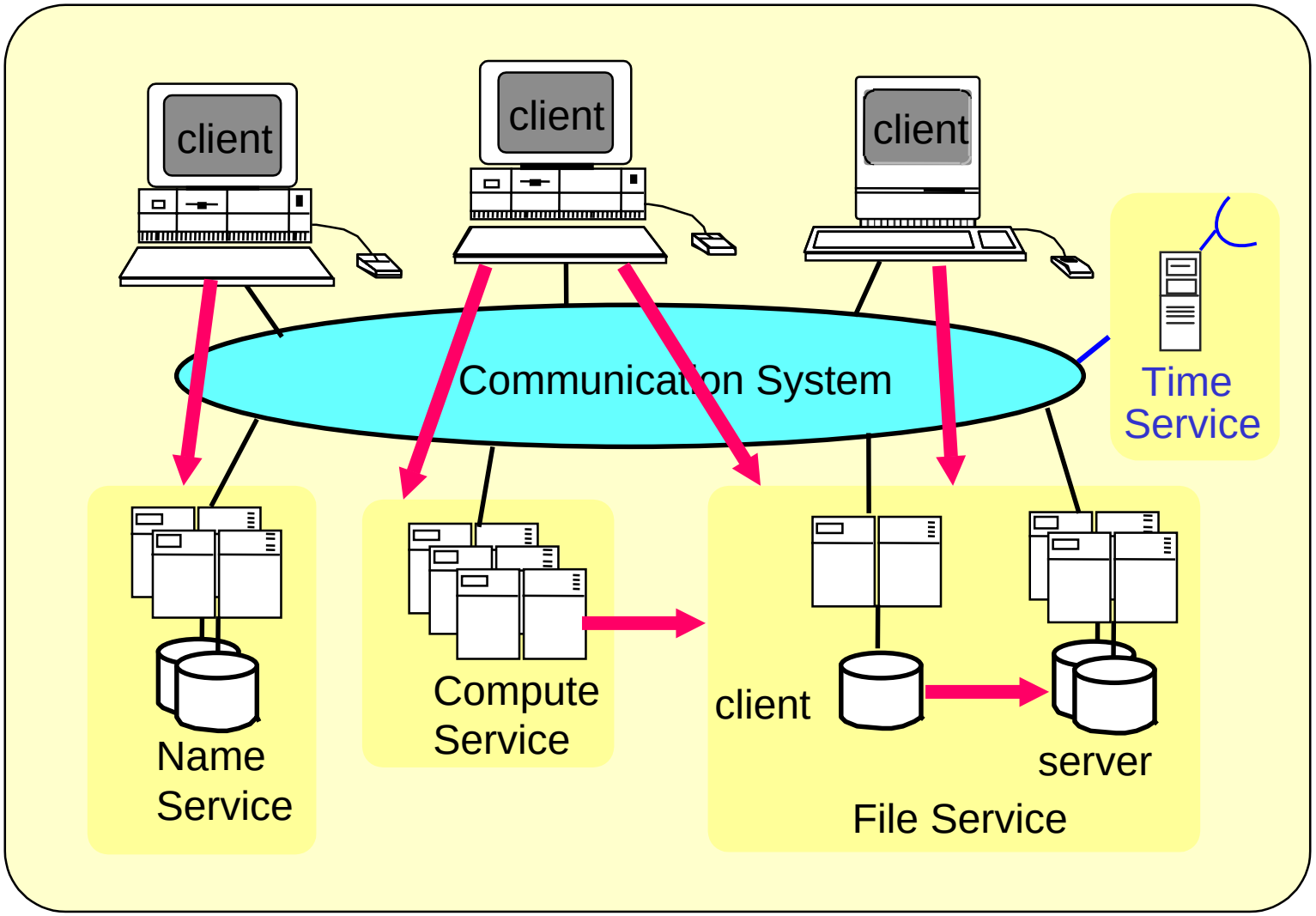
06-06798 Distributed Systems

Lecture 7:
Distributed File Systems

Overview

- Requirements for distributed file systems
  - transparency, performance, fault-tolerance, ...
- Design issues
  - possible options, architectures
  - file sharing, concurrent updates
  - caching
- Example
  - Sun NFS

Distributed Service



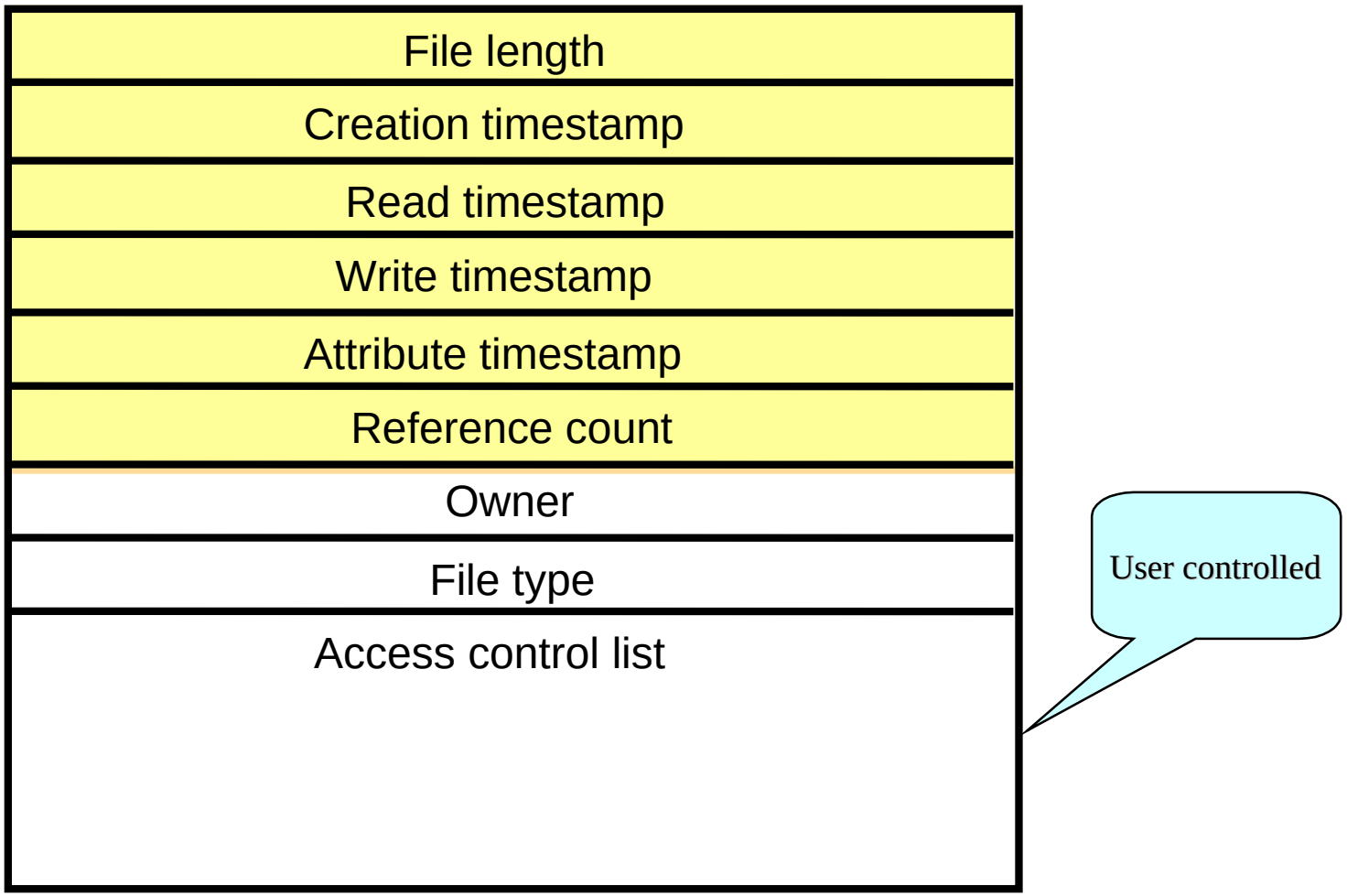
Distributed file service

- Basic service
  - persistent file storage of data and programs
  - operations on files (create, open, read,…)
  - multiple remote clients, within intranet
  - file sharing
  - typically one-copy update semantics, over RPC
- Many new developments
  - persistent object stores (storage of objects)
    - Persistent Java, Corba, …
  - replication, whole-file caching
  - distributed multimedia (Tiger video file server)

Characteristics of file systems

- Operations on files (=data + attributes)
  - create/delete
  - query/modify attributes
  - open/close
  - read/write
  - access control
- Storage organisation
  - directory structure (hierarchical, pathnames)
  - metadata (file management information)
    - file attributes
    - directory structure info, etc

File attributes



Layered structure of file system

Directory module:	relates file names to file IDs
File module:	relates file IDs to particular files
Access control module:	checks permission for operation requested
File access module:	reads or writes file data or attributes
Block module:	accesses and allocates disk blocks
Device module:	disk I/O and buffering

Concentrate on higher levels.

Distributed file system requirements

- Transparency (clients unaware of the distributed nature)
  - access transparency (client unaware of distribution of files, same interface for local/remote files)
  - location transparency (uniform file name space from any client workstation)
  - mobility transparency (files can be moved from one server to another without affecting client)
  - performance transparency (client performance not affected by load on service)
  - scaling transparency (expansion possible if numbers of clients increase)

Distributed file system requirements

- Concurrent file updates (changes by one client do not affect another)
- File replication (for load sharing, fault-tolerance)
- Heterogeneity (interface platform-independent)
- Fault-tolerance (continues to operate in the face of client and server failures)
- Consistency (*one-copy-update* semantics or slight variations)
- Security (access control)
- Efficiency (performance comparable to conventional file systems)

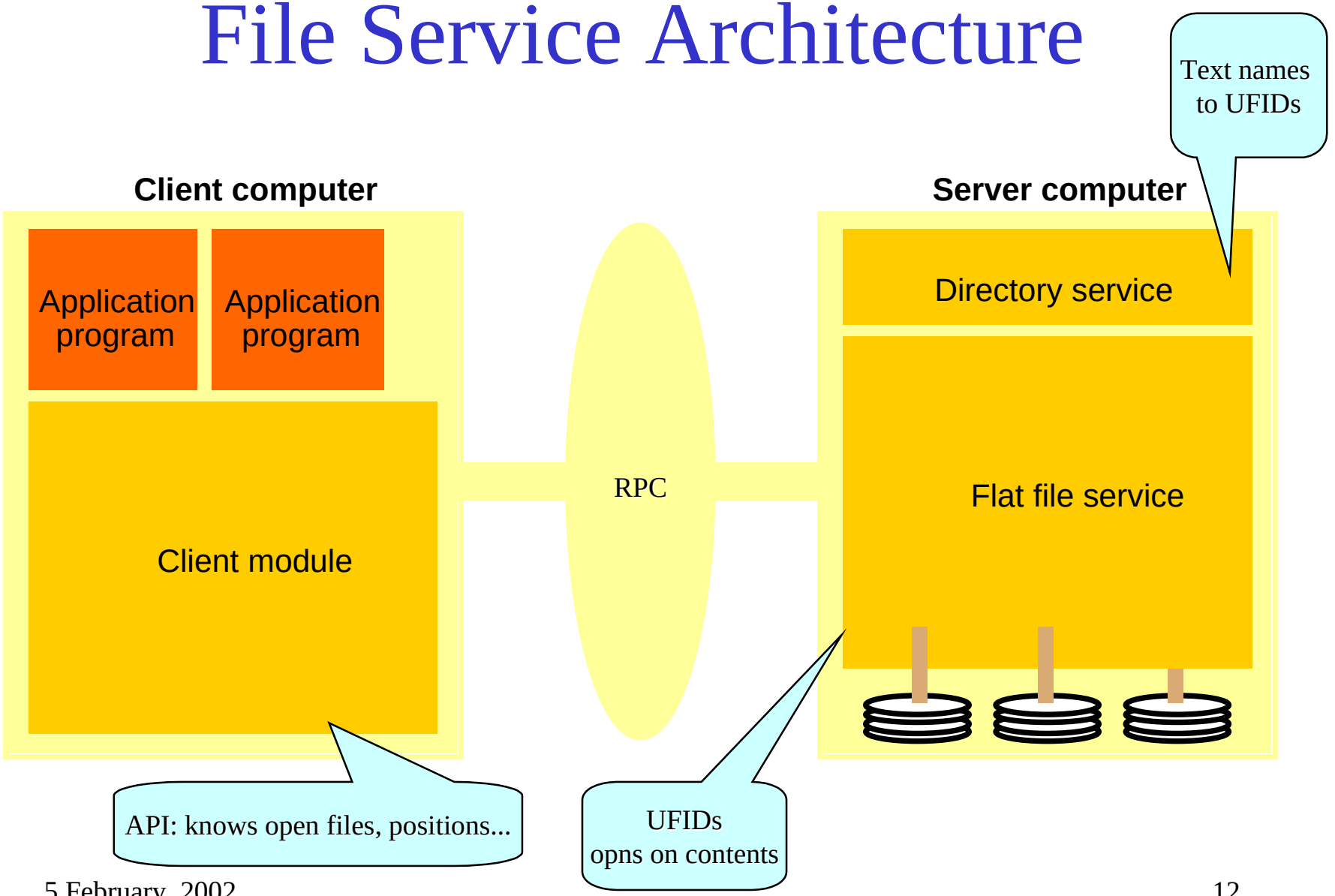
File Service Design Options

- Stateful
  - server holds information on open files, current position, file locks
  - open before access, close after
  - better performance - shorter message, read-ahead possible
  - server failure - lose state
  - client failure - tables fill up
  - can provide file locks

File Service Design Options

- Stateless
  - no state information held by server
  - file operations idempotent, must contain all information needed (longer message)
  - simpler file server design
  - can recover easily from client or server crash
  - locking requires extra lock server to hold state

File Service Architecture



File server architecture

Components (for openness):

- Flat file service
  - operations on file contents
  - unique file identifiers (UFIDs)
  - translates UFIDs to file locations
- Directory service
  - mapping between text names to UFIDs
- Client module
  - API for file access, one per client computer
  - holds state: open files, positions
  - knows network location of flat file & directory server

Flat file service RPC interface

- Used by client modules, not user programs
  - *FileId* (UFID) uniquely identifies file
  - invalid if file not present or inappropriate access
  - *Read/Write*; *Create/Delete*; *Get/SetAttributes*
- No open/close! (unlike UNIX)
  - access immediate with *FileId*
  - *Read/Write* identify starting point
- Improved fault-tolerance
  - operations idempotent except Create, can be repeated (at-least-once RPC semantics)
  - stateless service

Flat file service operations

Read(FileId, i, n) -> Data — throws *BadPosition*	If $1 \leq i \leq Length(File)$: Reads a sequence of up to *n* items from a file starting at item *i* and returns it in *Data*.
Write(FileId, i, Data) — throws *BadPosition*	If $1 \leq i \leq Length(File)+1$: Writes a sequence of *Data* to a file, starting at item *i*, extending the file if necessary.
Create() -> FileId	Creates a new file of length 0 and delivers a UFID for it.
Delete(FileId)	Removes the file from the file store.
GetAttributes(FileId) -> Attr	Returns the file attributes for the file.
SetAttributes(FileId, Attr)	Sets the file attributes (only owner, file type and access control list; rest maintained by flat file service).

Access control

- In UNIX file system
  - access rights are checked against the access mode (read, write, execute) in open
  - user identity checked at login time, cannot be tampered with
- In distributed systems
  - access rights must be checked at server
    - RPC unprotected
    - forging identity possible, a security risk
  - user id typically passed with every request (e.g. Sun NFS)
  - stateless

Directory structure

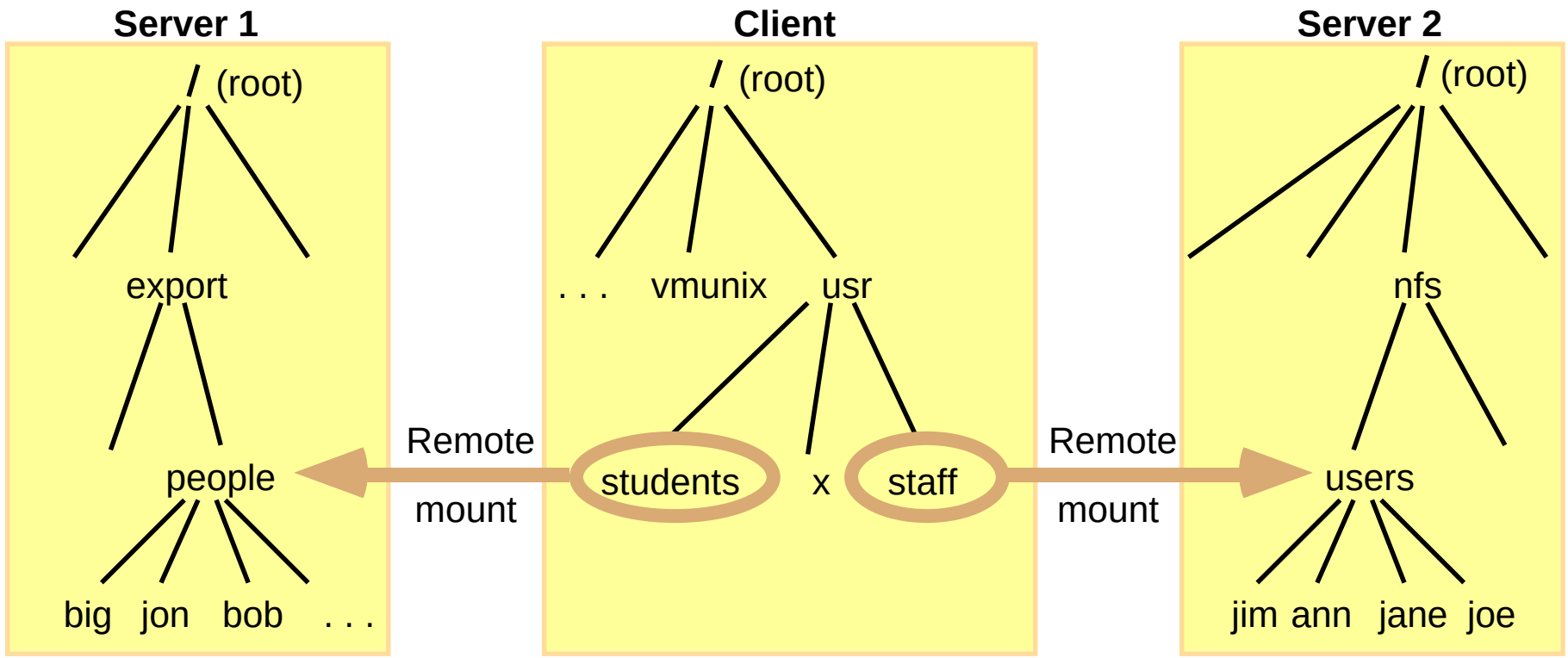
- Hierarchical
  - tree-like, pathnames from root
  - (in UNIX) several names per file (*link* operation)
- Naming system
  - implemented by client module, using directory service
  - root has well-known UFID
  - locate file following path from root

File names

Text name (=directory pathname+file name)

- hostname:local name
  - not mobility transparent
- uniform name structure (same name space for all clients)
- remote mount (e.g. Sun NFS)
  - remote directory inserted into local directory
  - relies on clients maintaining consistent naming conventions across all clients
    - all clients must implement same local tree
    - must mount remote directory into the same local directory

Remote mount



Note: The file system mounted at */usr/students* in the client is actually the sub-tree located at */export/people* in Server 1; the file system mounted at */usr/staff* in the client is actually the sub-tree located at */nfs/users* in Server 2.

Directory service

- Directory
  - conventional file (client of the flat file service)
  - mapping from text names to UFIDs
- Operations
  - require *FileId*, machine readable UFID as parameter
  - locate file (*LookUp*)
  - add/delete file (*AddName/UnName*)
  - match file names to regular expression (*GetNames*)

Directory service operations

Lookup(Dir, Name) -> FileId — throws *NotFound*	Locates the text name in the directory and returns the relevant UFID. If *Name* is not in the directory, throws an exception.
AddName(Dir, Name, File) — throws *NameDuplicate*	If *Name* is not in the directory, adds (*Name*, *File*) to the directory and updates the file's attribute record. If *Name* is already in the directory: throws an exception.
UnName(Dir, Name) — throws *NotFound*	If *Name* is in the directory: the entry containing *Name* is removed from the directory. If *Name* is not in the directory: throws an exception.
GetNames(Dir, Pattern) -> NameSeq	Returns all the text names in the directory that match the regular expression *Pattern*.

File sharing

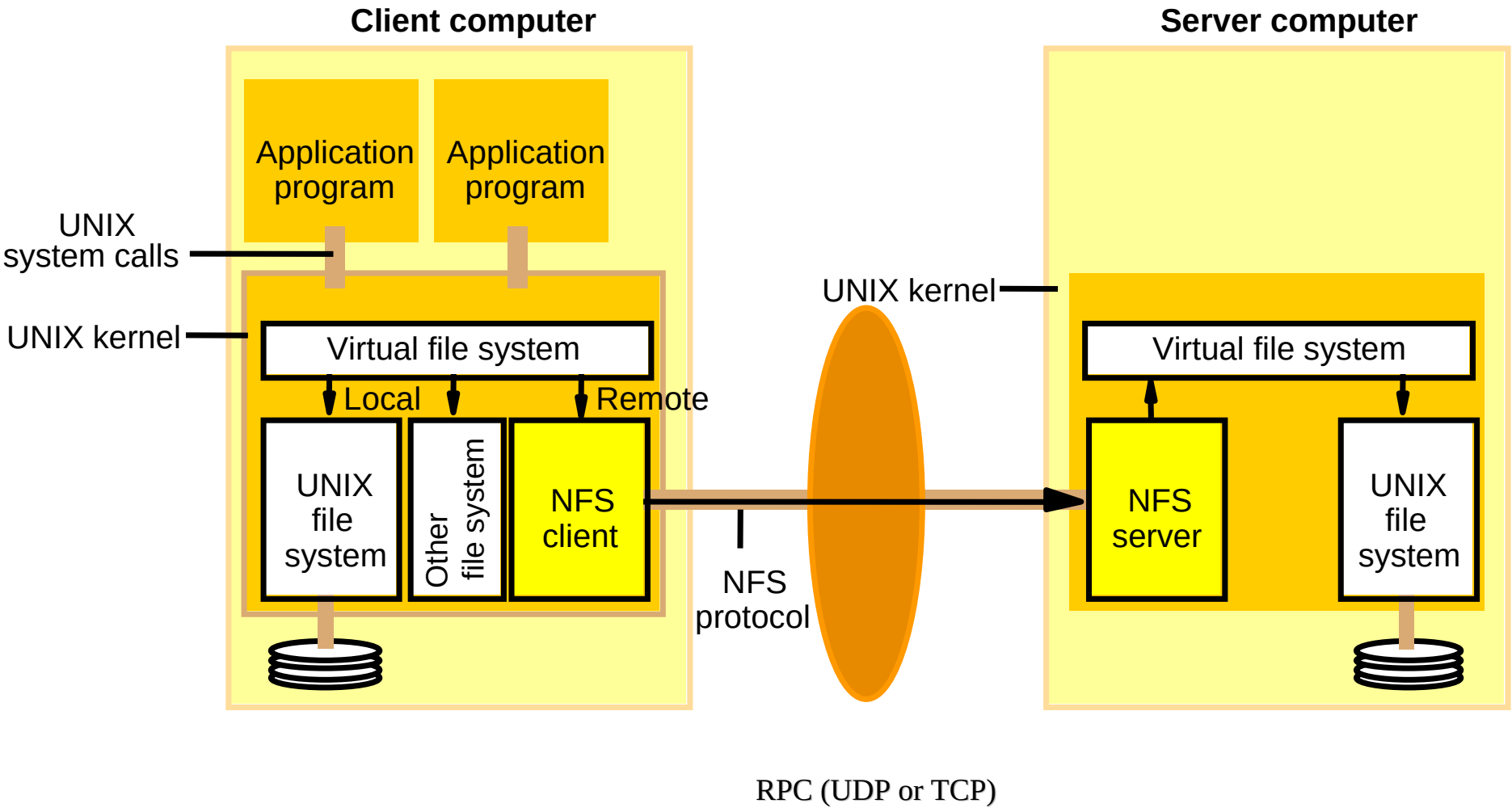
Multiple clients share the same file for read/write access.

- One-copy update semantics
  - every read sees the effect of all previous writes
  - a write is immediately visible to clients who have the file open for reading
- Problems!
  - caching: maintaining consistency between several copies difficult to achieve
  - serialise access by using file locks (affects performance)
  - trade-off between consistency and performance

Example: Sun NFS (1985)

- Structure of flat file & client & directory service
- NFS protocol
  - RPC based, OS independent (originally UNIX)
- NFS server
  - stateless (no open/close)
  - no locks or concurrency control
  - no replication with updates
- Virtual file system, remote mount
- Access control (user id with each request)
  - security loophole (modify RPC to impersonate user…)
- Client and server caching

NFS architecture



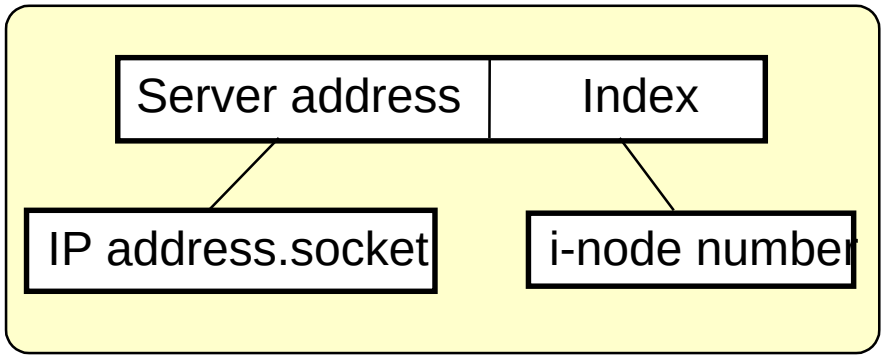
File identifier (*FileId*)

Simple Solution

– i-node (number identifying file within file system)

– file migration requires finding and changing all *FileId*s

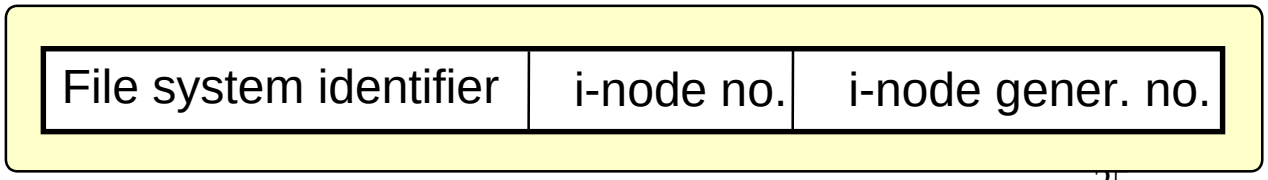
– UNIX reuses i-node numbers after file deleted (i-node gen. no)



NFS file handle

Virtual file system uses i-node if local, file handle if remote.

File handle



Caching in NFS

- Indispensable for performance
- Caching
  - retains recently used data (file pages, directories, file attributes) in cache
  - updates data in cache for speed
  - block size typically 8kbytes
- Server caching
  - cache in server memory (UNIX kernel)
- Client caching
  - cache in client memory, local disk

Server caching

- Store data in server memory
- Read-ahead: anticipate which pages to read
- Delayed write
  - update in cache; write to disk periodically (UNIX *sync* to synchronise cache) or when space needed
  - which contents seen by users depends on timing
- Write through
  - cache and write to disk (reliable, poor performance)
- Write on close
  - write to disk only when commit received (fast but problems with files open for a long time)

Client caching

- Potential consistency problems!
  - different versions, portions of files, … since writes delayed
  - clients poll server to check if copy still valid
- Timestamp method
  - tag with latest time of validity check and modification time
  - copy valid if time since last check less than freshness interval, or modification time on server the same
  - choose freshness interval adaptively, 3-30 sec for files, 30-60 sec for directories
  - for small freshness interval, potential heavy load on network

Client caching

- Reads
  - perform validity check whenever cache entry used
  - if not valid, request data from server
  - several optimisations to reduce traffic
  - recent updates not always visible (timing!)
- Writes
  - when page modified, marked as dirty
  - dirty pages flushed asynchronously, periodically (client's synch) and on close
- Not truly *one-copy update* semantics...

New developments

- **AFS**, Andrew file system (CMU 1986)
  - whole-file serving (64kbytes), whole-file caching (on local client disk, 100s of recently used files)
- **NFS** protocol (precise one-copy update semantics)
  - Spritely NFS: extend with open/close with state info held at server, add server callbacks to notify about cache entries
- **WebNFS** (Internet programs can interact with NFS server directly, bypassing mount)
- **xFS** (serverless network, file serving responsibility distributed across LAN)

Summary

- File service
  - crucial to the running of a distributed system
  - performance, consistency and easy recovery essential
- Design issues
  - separate flat file service from directory service and client module
  - stateless for performance and fault-tolerance
  - caching for performance
  - concurrent updates difficult with caching
  - approximation of one-copy update semantics