CS514: Intermediate Course in Operating Systems

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Mobility is a huge topic

- Breaks existing applications
  - Anything bandwidth intensive or synchronous
- Opportunities for new applications
  - Location-specific (nearest Starbucks)
  - Ubiquity (short messaging)
  - Ad hoc networks
- Can't possibly give it justice in one lecture

Focus on a couple systems-level attempts

- What can the system do to support applications in mobile contexts, and how how effective is it?
- Coda (mobile file system)
  - CMU (AFS-based)
  - Application awareness
- Rover (mobility systems toolkit)
  - MIT
  - Application transparent

Characteristics of mobility

Disconnection (long or short, predictable or sudden)	Caching, hoarding, prefetching, DB/file inconsistencies
Variable and asymmetric bandwidth	Above, plus compression, prioritization, clever use of downlink
Expensive ($$$) BW	Above, plus user control
Battery, battery, and battery	Minimize transmissions (and also processing)
Weakened security (physical and radio)	User auth, encryption

Rover goals

- Philosophy is that applications know best how to deal with mobility
  - But there are general mechanisms that all applications can benefit from
- Provide a toolkit to applications
- Make it easier to write applications that deal with mobility issues
  - Reduce client/server communications requirements
  - Allow the user to effectively work offline

(Some slides care of Michael Ferguson)

Rover project

- Build Rover toolkit
- Build range of applications using Rover toolkit
  - Email
  - Calendar
  - Browser
- Evaluate effectiveness of Rover for supporting these applications

Conclusion: Success!

- Though Rover itself has not taken off…
- Applications easy to port
  - They say…
- Performs well
  - Compared to what?
- In my mind, they never really answer the question whether a toolkit/OS approach is better
  - This would be a hard question to answer…

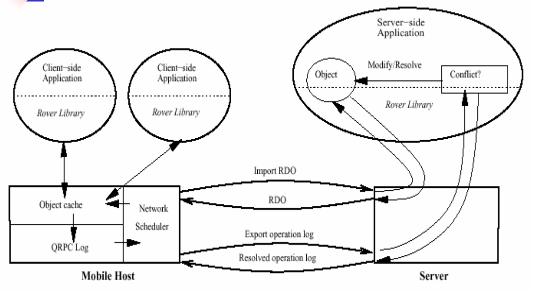
Two basic mechanisms

- Relocatable dynamic objects (RDO)
  - Code/data shipping, like simple agents or process migration
  - Allows dynamic control over processing versus communications tradeoff
- Queued remote procedure calls (QRPC)
  - Asynchronous RPCs
  - Allows offline operations without blocking

Rover operations

- *Import* objects onto client machine
  - RDO: contains data and operations on the data
- *Invoke* methods on those objects
- *Export* logs of method invocations to servers
  - Can also export RDOs
- Reconcile client data with server data

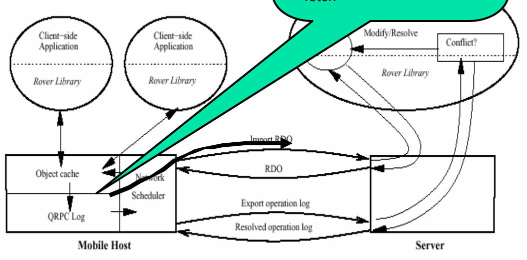
Rover operation



Import

Import call provides:
- Object ID (URN)
- Session ID
- callback routing arguments

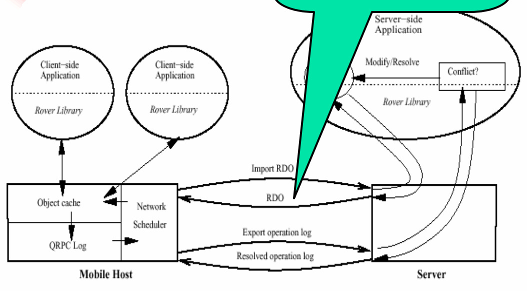
Import call returns a "promise"
Call is queued (QRPC) for lazy fetch



Import

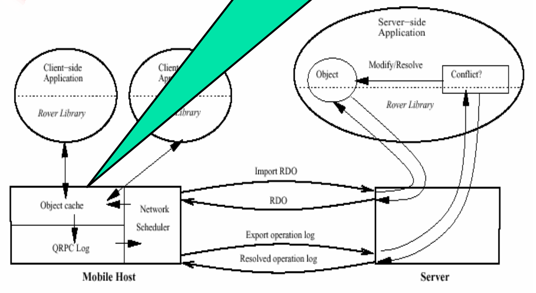
When imported object arrives:
- Callback routine is called
- Object is put into the cache
- RDO may invoke a thread

Object may be locked at server



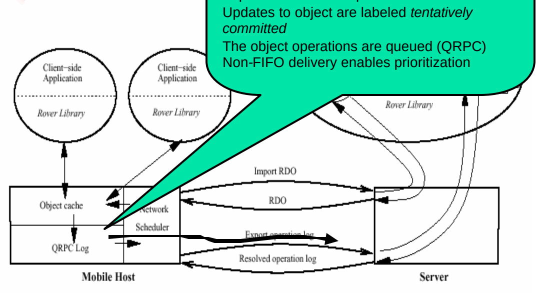
Invoke

Application invokes methods on received object
Each operation is stored
Changes in object indicated by version vectors

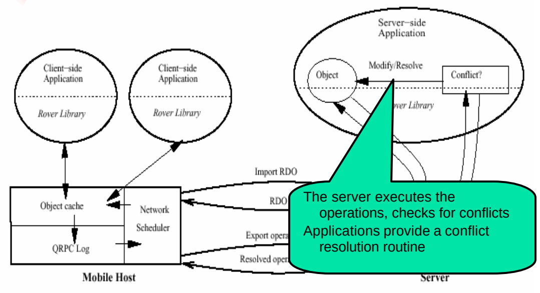


Export

Export call provides:
Object ID (URN)
Session ID
callback routing
arguments
Export call returns a "promise"
Updates to object are labeled *tentatively committed*
The object operations are queued (QRPC)
Non-FIFO delivery enables prioritization



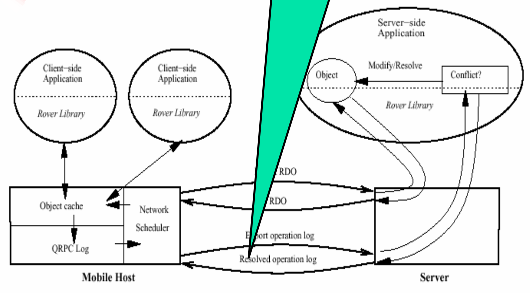
Export



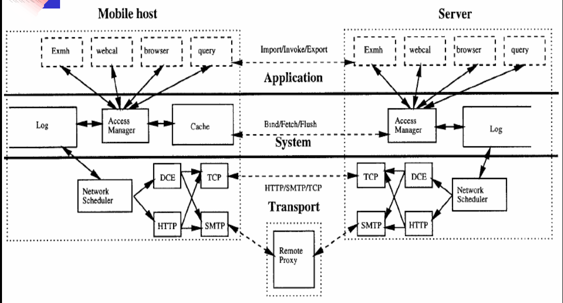
The server executes the operations, checks for conflicts
Applications provide a conflict resolution routine

Export

Revolved operations are returned to the client
After callback, client marks objects as *committed*

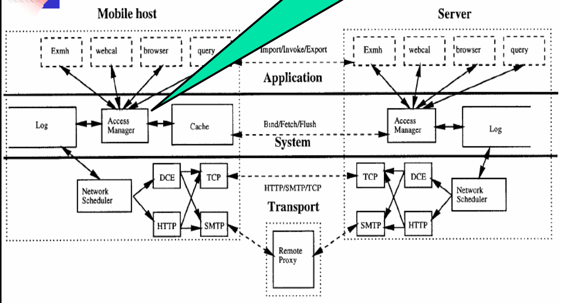


Rover Architecture



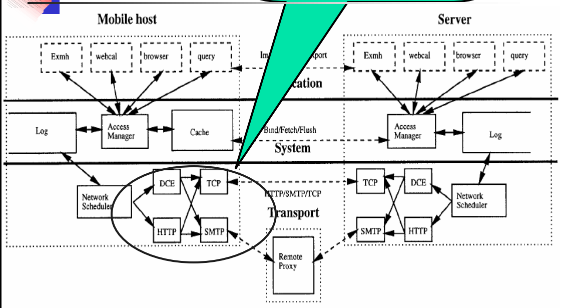
Rover Arch

All applications run over a single Rover process
Communicate via Local RPC
Allows prioritization across applications



Rover Arch

Network scheduler can select TCP or SMTP (mail) for transport
Latter for batching lower priority requests
(Interim solution)



Implementation

- RDOs are Tcl/tk objects
- Transported in HTTP
  - Using CERN's Web Common Library
  - Server uses CGI scripts

Applications

- Mail reader (based on Exmh Tcl/Tk)
- Calendar (based on Ical Tcl/Tk calendar)
- Web browser proxy (new application)

Mail Reader

- Parts of GUI and messages sent as RDOs
- RDOs used for prefetching and application-specific consistency (inconsistent folder changes)

Calendar

- Each calendar item (appointment or notice) is an RDO
- Item imported, changed tentatively, and exported and committed
- Routines for conflict resolution
  - Error notice, or give some users priority

Web browser proxy

- Implements "click ahead"
  - During disconnection, clicks are queued for later download
  - User has access to list of queued clicks
    - List is an RDO
- Does prefetching

Some thoughts on Rover

- Rover is a nice proof-of-concept for how to deal with mobility
- But Rover itself of limited value
  - Tcl/Tk based RDOs probably overtaken by Java
  - Use of SMTP a bad choice (they know this)
  - Probably hard to automatically prioritize among disparate applications
    - User would prefer to control this based on immediate circumstances
    - Not clear there is much value to running Rover as a single, system service

Some thoughts on Rover

- Email not the best proof-of-concept application
  - Already fundamentally asynchronous, so not much different with Rover
- Click-ahead sounds like a bad idea to me
  - I'd rather control when clicks happen…
- Calendar is a decent proof-of-concept application

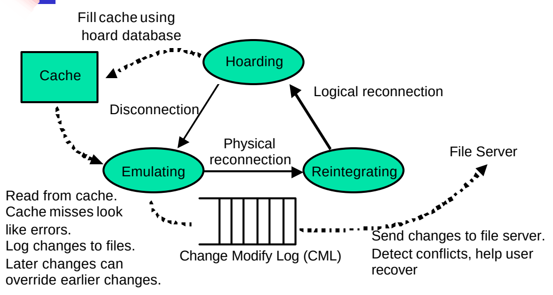
Surprising conclusion

- From the Rover paper:
  - "*The largest, most important, drawback of the Rover approach is that application designers must think carefully about how application functions should be divided between a client and a server*"
- Funny…this struck me as probably the main advantage of Rover!!!
  - Provides a nice model for how to think about disconnection, asynchrony, and consistency

Coda File System

- Unlike Rover, makes disconnection issues transparent to the application (and, to some extent, the user)
  - Coda transparently propagates file modifications and handles conflicts

Disconnected operation states on client (Venus)


Fill cache using hoard database
Cache
Hoarding
Logical reconnection
Disconnection
Physical reconnection
File Server
Emulating
Reintegrating
Read from cache. Cache misses look like errors. Log changes to files. Later changes can override earlier changes.
Change Modify Log (CML)
Send changes to file server. Detect conflicts, help user recover

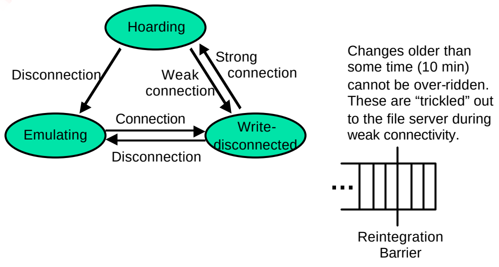
Conflict resolution

- Code resolves most directory conflicts
- For files, requires application-specific resolvers
- Unresolvable files are presented to user in a manual repair tool
  - User sees an "explosion" of inconsistent files in a directory tree
  - Use diff and grep to resolve

Problem with disconnected states approach

- Reintegration would consume bandwidth resources…users couldn't do anything useful immediately upon reconnect
- Solutions:
  - New states for weak connectivity
  - Rapid cache validation (version stamps for directories, not just files)
    - Cached by clients
  - "User patience threshold"…model to predict if a user would rather wait for a large file not in the cache, or be given an error

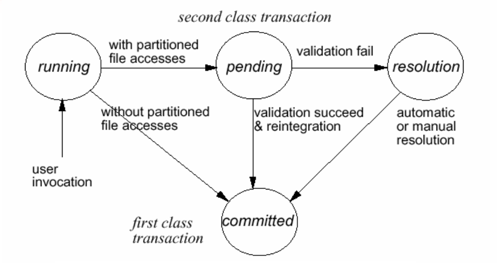
Weak connectivity operation states on Venus


Hoarding
Disconnection
Weak connection
Strong connection
Emulating
Connection
Write-disconnected
Disconnection
Changes older than some time (10 min) cannot be over-ridden. These are "trickled" out to the file server during weak connectivity.
…
Reintegration Barrier

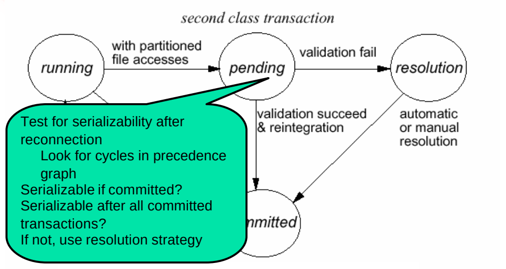
Isolation-Only Transactions

- Coda emulation of UNIX file system has benefit of backwards compatibility
- UNIX lacks notion of read-write file conflicts
  - Where an application is using a file as input, and that file is modified
    - Windows, on the other hand, locks the file
- This limitation is exacerbated by disconnected operation
- Coda deals with this by checking for possible read-write inconsistencies after reconnection

State machine for IOT

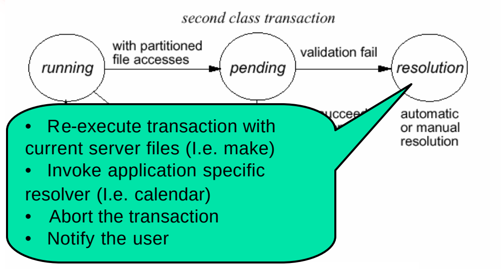

second class transaction
running
with partitioned file accesses
pending
validation fail
resolution
without partitioned file accesses
validation succeed & reintegration
automatic or manual resolution
user invocation
first class transaction
committed

Pending validation


second class transaction
running
with partitioned file accesses
pending
validation fail
resolution
validation succeed & reintegration
automatic or manual resolution
mmitted

Test for serializability after reconnection
    Look for cycles in precedence graph
Serializable if committed?
Serializable after all committed transactions?
If not, use resolution strategy

Resolution Strategies



- Re-execute transaction with current server files (I.e. make)
- Invoke application specific resolver (I.e. calendar)
- Abort the transaction
- Notify the user

Some thoughts on Coda

- File system is the wrong level of abstraction for many applications
  - Calendar, database
  - I agree with Rover on this
- As a user, I think Coda running "under the hood" would be confusing, sometimes annoying
  - If file is shared, I'd rather deal with resolution explicitly (version control, etc.)
  - If file is not shared, I'd rather control when "synchronization" takes place

Other interesting work

- Bayou (Xerox Parc)
- "Peer-to-peer" ad hoc network write conflict resolution
  - Group document editing, calendar, etc.
- Basic idea, "anti-entropy": peers do pairwise comparison of writes, try to revolve conflicts
  - Determine conflict by trying the write on neighbors version, conflict exists if result is different
  - Eventually all peers reach an agreed state

Other interesting work

- Broadcast disks
- Based on fact that radio reception much less expensive than radio transmission
  - Archarya et. al., SIGMOD95
- Continuous broadcast of "disks", clients keep the ones they want
  - Broadcast index at set times so that clients know when to receive
- Variations to support caching, consistency
  - Broadcast version changes