Transactions and Replication

CSE 490H

Philip A. Bernstein

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1. The Basics - What's a Transaction?

- The *execution* of a program that performs an administrative function by accessing a *shared database*, usually on behalf of an *on-line* user.

<u>Examples</u>

- Reserve an airline seat. Buy an airline ticket
- Withdraw money from an ATM.
- Verify a credit card sale.
- Order an item from an Internet retailer
- Place a bid at an on-line auction
- Submit a corporate purchase order

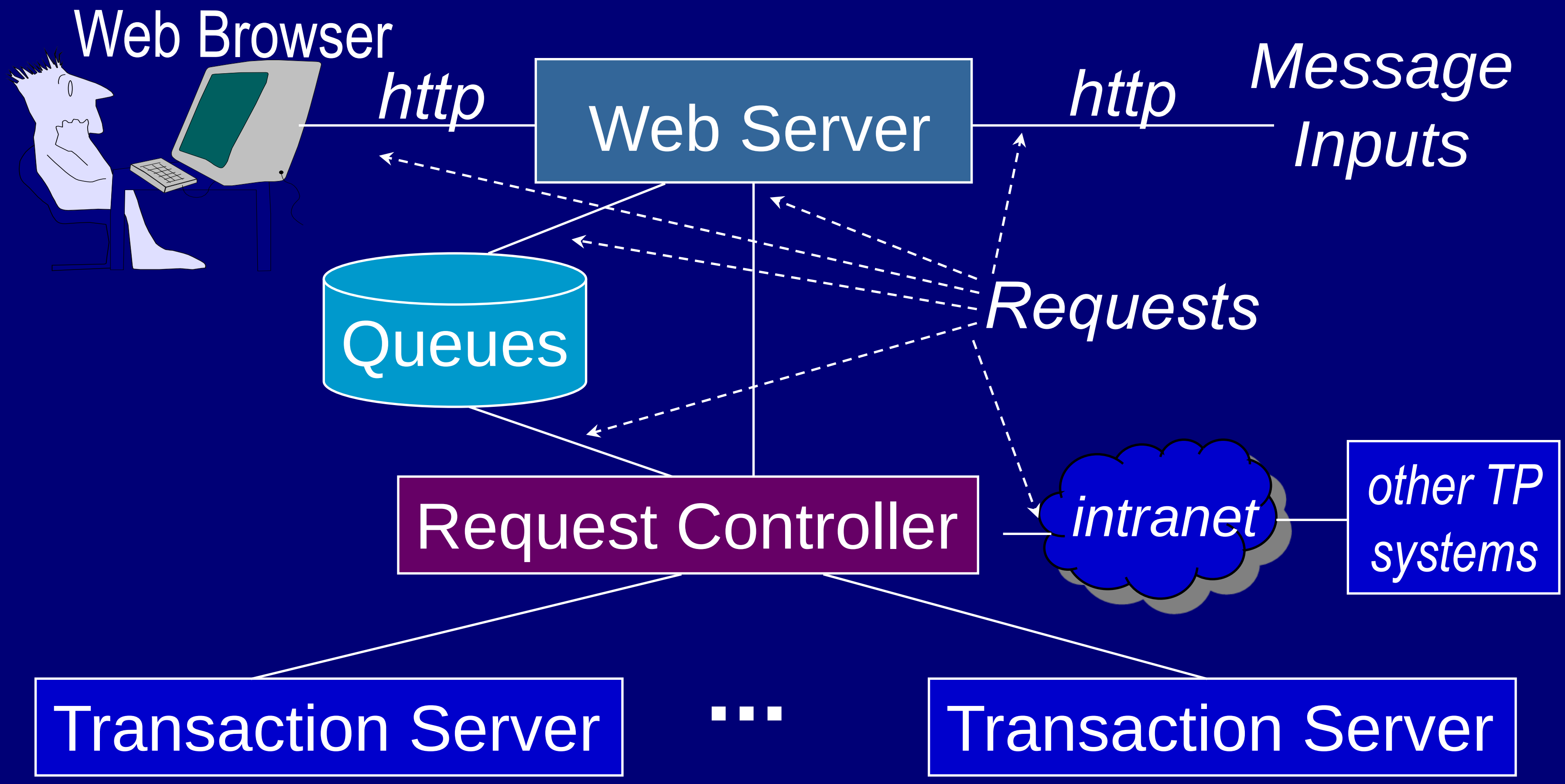
The "ities" are What Makes Transaction Processing (TP) Hard

- Reliability - system should rarely fail
- Availability - system must be up all the time
- Response time - within 1-2 seconds
- Throughput - thousands of transactions/second
- Scalability - start small, ramp up to Internet-scale
- Security – for confidentiality and high finance
- Configurability - for above requirements + low cost
- Atomicity - no partial results
- Durability - a transaction is a legal contract
- Distribution - of users and data

What Makes TP Important?

- It’s at the core of electronic commerce
- Most medium-to-large businesses use TP for their production systems. The business can’t operate without it.
- It’s a *huge* slice of the computer system market. One of the largest applications of computers.

TP System Architecture



System Characteristics

- Typically < 100 transaction types per application
- Transaction size has high variance. Typically,
  - 0-30 disk accesses
  - 10K - 1M instructions executed
  - 2-20 messages
- A large-scale example: airline reservations
  - hundreds of thousands of active display devices
  - plus indirect access via Internet
  - tens of thousands of transactions per second, peak

Availability

- Fraction of time system is able to do useful work
- Some systems are *very* sensitive to downtime
  - airline reservation, stock exchange, telephone switching
  - downtime is front page news

Downtime	Availability
1 hour/day	95.8%
1 hour/week	99.41%
1 hour/month	99.86%
1 hour/year	99.9886%
1 hour/20years	99.99942%

- Contributing factors
  - failures due to environment, system mgmt, h/w, s/w
  - recovery time

2. The ACID Properties

- Transactions have 4 main properties
  - Atomicity - all or nothing
  - Consistency - preserve database integrity
  - Isolation - execute as if they were run alone
  - Durability - results aren't lost by a failure

Atomicity

- All-or-nothing, no partial results.
  - E.g. in a money transfer, debit one account, credit the other. Either debit and credit both run, or neither runs.
  - Successful completion is called *Commit*.
  - Transaction failure is called *Abort.*
- Commit and abort are irrevocable actions.
- An Abort *undoes* operations that already executed
  - For database operations, restore the data's previous value from before the transaction
  - But some real world operations are not undoable. They require special treatment
    Examples - transfer money, print ticket, fire missile

Consistency

- Every transaction should maintain DB consistency
  - Referential integrity - E.g. each order references an existing customer number and existing part numbers
  - The books balance (debits = credits, assets = liabilities)
- ☝ *Consistency preservation is a property of a transaction, not of the TP system*
  (unlike the A, I, and D of ACID)
- If each transaction maintains consistency,
  then serial executions of transactions do too.

Isolation

- Intuitively, the effect of a set of transactions should be the same as if they ran independently
- Formally, an interleaved execution of transactions is *serializable* if its effect is equivalent to a serial one.
- Implies a user view where the system runs each user's transaction stand-alone.
- Of course, transactions in fact run with lots of concurrency, to use device parallelism.

Durability

- When a transaction commits, its results will survive failures (e.g. of the application, OS, DB system … even of the disk).
- Makes it possible for a transaction to be a legal contract.
- Implementation is usually via a log
  - DB system writes all transaction updates to its log
  - To commit, it adds a record "commit(T_i)" to the log
  - When commit(T_i) is on disk, T_i is committed.
  - System waits for disk ack before acking to user

3. Atomicity and Two-Phase Commit

- Distributed systems make atomicity harder
- Suppose a transaction updates data managed by two DB systems.
- One DB system could commit the transaction, but a failure could prevent the other system from committing.
- The solution is the two-phase commit protocol.
  - Abstract “DB system” by *resource manager*
  - Could be a SQL DBMS, message mgr, queue mgr, file system, OO DBMS, etc.

Two-Phase Commit

- Main idea - all resource managers (RMs) save a durable copy of the transaction's updates before any of them commit.
- If one RM fails after another commits, the failed RM can still commit after it recovers.
- The protocol to commit transaction T
  - Phase 1 - T's coordinator asks all participant RMs to "prepare T". Each participant RM replies "prepared" after T's updates are durable.
  - Phase 2 - After receiving "prepared" from *all* participant RMs, the coordinator tells all participant RMs to commit.

Two-Phase Commit
System Architecture

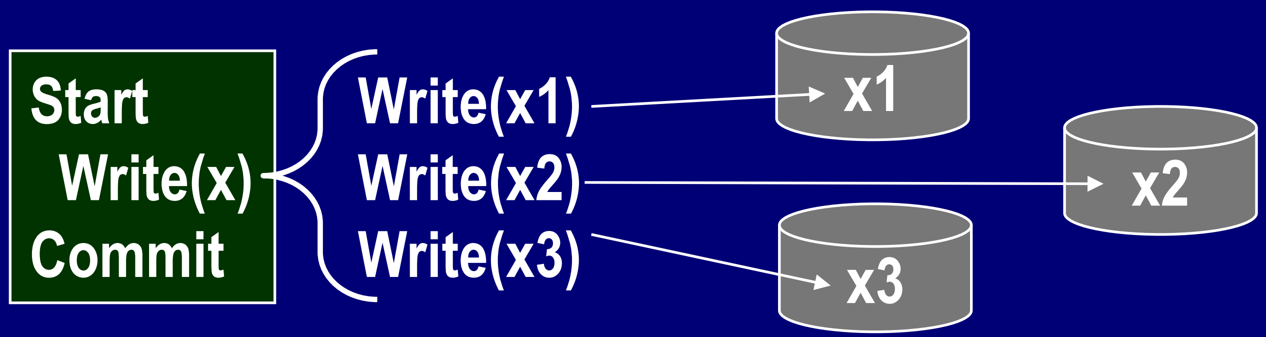
1. Start transaction returns a unique *transaction identifier*
2. Resource accesses include the transaction identifier. For each transaction, RM registers with TM
3. When application asks TM to commit, the TM runs two-phase commit.

4. Replication Basics

- Replication - using multiple copies of a server or resource for better availability and performance.
  - Replica and Copy are synonyms
- If you're not careful, replication can lead to
  - worse performance - updates must be applied to all replicas and synchronized
  - worse availability - some algorithms require multiple replicas to be operational for any of them to be used

Synchronous Replication

- Replicas function just like a non-replicated resource
  - Txn writes data item x. System writes all replicas of x.
  - Synchronous – replicas are written within the update txn
  - Asynchronous – One replica is updated immediately. Other replicas are updated later



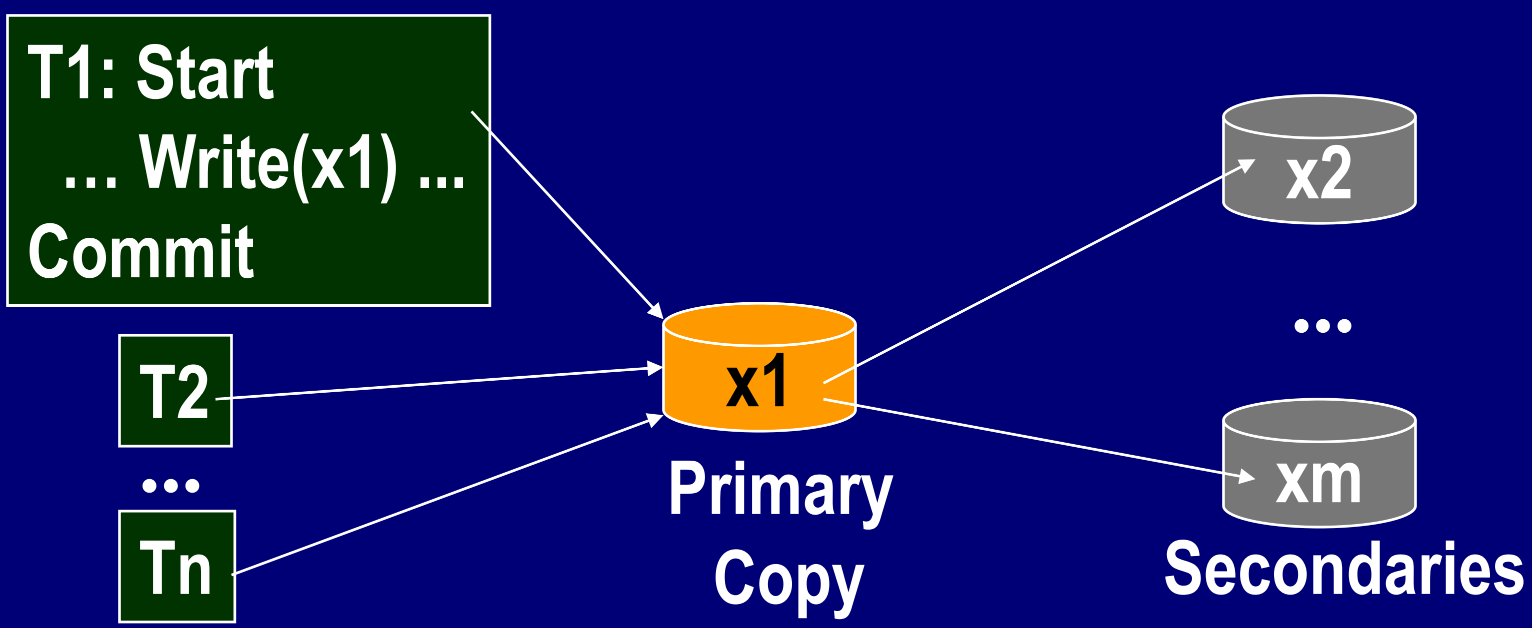
- Problems with synchronous replication
  - Expensive due to 2-phase commit
  - Can't control when updates are applied to replicas

Asynchronous Replication

- Asynchronous replication
  - Each transaction updates one replica.
  - Updates are propagated later to other replicas.
- Primary copy: Each data item has a primary copy
  - All transactions update the primary copy
  - Other copies are for queries and failure handling
- Multi-master: Transactions update different copies
  - Useful for disconnected operation, partitioned network, mobile
  - Useful when weak consistency is good enough
- Both approaches ensure that
  - Updates propagate to all replicas
  - If new updates stop, replicas converge to the same state
- We focus here on primary copy

5. Primary-Copy Replication

- Designate one replica as the <u>primary copy</u> (<u>publisher</u>)
- Transactions may update only the primary copy
- Updates to the primary are sent later to <u>secondary</u> replicas (<u>subscribers</u>) in the order they were applied to the primary



Update Propagation

- Collect updates at the primary using triggers or by post-processing the log
  - Triggers: on every update at the primary, a trigger fires to store the update in the update propagation table.
  - Log post-processing: "sniff" the log to generate update propagations
- Log post-processing (vs. triggers)
  - Saves triggered update overhead during on-line txn.
  - But R/W log synchronization has a (small) cost
  - Requires admin (what if the log sniffer fails?)
- Optionally identify updated fields to compress log
- Most DB systems support this today.

Failure & Recovery Handling

- Secondary failure - nothing to do till it recovers
  - At recovery, apply the updates it missed while down
  - Needs to determine which updates it missed, just like non-replicated log-based recovery
  - If down for too long, may be faster to get a whole copy
- Primary failure
  - Normally, secondaries wait till the primary recovers
  - Can get higher availability by electing a new primary
    - Hold that thought ….

Communications Failures

- Secondaries can’t distinguish a primary failure from a communication failure that partitions the network.
- If the secondaries elect a new primary and the old primary is still running, there will be a reconciliation problem when they’re reunited. This is multi-master.
- To avoid this, one partition must know it’s the only one that can operate. It can’t communicate with other partitions to figure this out.
- Could make a static decision.
  E.g., the partition that has the primary wins.
- Dynamic solutions are based on Majority Consensus

Majority Consensus

- Whenever a set of communicating replicas detects a replica failure or recovery, they test if they have a majority (more than half) of the replicas.
- If so, they can elect a primary
- Only one set of replicas can have a majority.
- Doesn’t work with an even number of copies.
  – Useless with 2 copies
- Quorum consensus
  – Give a weight to each replica
  – The replica set that has a majority of the weight wins
  – E.g. 2 replicas, one has weight 1, the other weight 2

Electing a New Primary

- A secondary S that detects primary's failure starts a new election by sending invitations to all secondaries
  - Other secondaries reply with their replica identifier
  - If S gets replies from a majority, it selects the largest replica identifier as the winner
  - If not, it tells everyone to wait for more recoveries
- What if replicas fail and recover during the election?
  - Use Paxos. S includes a unique epoch number in its invitation.
  - A recipient accepts the invitation only if it hasn't accepted another invitation with higher epoch
  - S backs off on retries, to avoid an arms race

After Electing a New Primary

- All replicas must now check that they have the same updates from the failed primary
- During the election, each replica reports the id of the last log record it received from the primary
- The most up-to-date replica sends its latest updates to (at least) the new primary.
- Could still lose an update that committed at the primary and wasn't forwarded before the primary failed … but solving it requires synchronous replication (2-phase commit to propagate updates to replicas)

Conclusion

- Primary copy is just one replication
- Other models
  - Multi-master replication
  - Shared storage
- All 3 models are used commercially