1. Introduction

CSEP 545 Transaction Processing
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Outline
1. The Basics
2. ACID Properties
3. Atomicity and Two-Phase Commit
4. Performance
5. Styles of System

1.1 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.

Examples
• 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
• Connect to video-on-demand and pay for it

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 Infrastructure

• User’s viewpoint
  – Enter a request from a browser or other display device
  – The system performs some application-specific work, which includes database accesses
  – Receive a reply (usually, but not always)
• The TP system ensures that each transaction
  – is an independent unit of work
  – executes exactly once, and
  – produces permanent results.
• TP system makes it easy to program transactions
• TP system has tools to make it easy to manage
TP System Infrastructure … Defines System and Application Structure

End-User → Presentation Manager (Client)

 Workflow Control (routes requests and supervises their execution)

Transaction Program

Database System

Front-End

Back-End

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
  – 150,000 active display devices
  – plus indirect access via Internet travel agents
  – thousands of disk drives
  – 3000 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

<table>
<thead>
<tr>
<th>Downtime</th>
<th>Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 hour/day</td>
<td>95.8%</td>
</tr>
<tr>
<td>1 hour/week</td>
<td>99.41%</td>
</tr>
<tr>
<td>1 hour/month</td>
<td>99.86%</td>
</tr>
<tr>
<td>1 hour/year</td>
<td>99.9866%</td>
</tr>
<tr>
<td>1 hour/20years</td>
<td>99.99942%</td>
</tr>
</tbody>
</table>

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

Application Servers

• A software product to create, execute and manage TP applications
• Formerly called TP monitors. Some people say
  App Server = TP monitor + web functionality.
• Programmer writes an app to process a single request.
  App Server scales it up to a large, distributed system
  – E.g. application developer writes programs to debit a checking
    account and verify a credit card purchase.
  – App Server helps system engineer deploy it to 10s/100s of
    servers and 10Ks of displays
  – App Server helps system engineer deploy it on the Internet,
    accessible from web browsers

Application Servers (cont’d)

• Components include
  – an application programming interface (API) (e.g.,
    Enterprise Java Beans)
  – tools for program development
  – tools for system management (app deployment,
    fault & performance monitoring, user mgmt, etc.)
• Enterprise Java Beans, IBM Websphere,
  Microsoft .NET (COM+), BEA Weblogic,
  Oracle Application Server

App Server Architecture, pre-Web

• Boxes below are distributed on an intranet
Automated Teller Machine (ATM) Application Example

Bank Branch 1

ATM >>> ATM

Workflow Controller

CIRRUS Accounts

Checking Accounts

Credit Card Accounts

Loan Accounts

Bank Branch 2

ATM >>> ATM

Workflow Controller

Bank Branch 500

ATM >>> ATM

Workflow Controller

CIRRUS Accounts

Checking Accounts

Credit Card Accounts

Loan Accounts

Application Server Architecture

Web Browser

http

Web Server

http

Message Inputs

Requests

intranet

other TP systems

Workflow Controller

Transaction Server

Transaction Server

Internet Retailer

The Internet

Web Server

Workflow Controller

Music

Electronics

Computers

Web Services

• Interface and protocol standards to do application server functions over the internet.

The Internet

Web Service

Workflow Controller

Music

Electronics

Computers

Enterprise Application Integration

• A software product to route requests between independent application systems. Often include
  – A queuing system
  – A message mapping system
  – Application adaptors (SAP, PeopleSoft, etc.)
• EAI and Application Servers address a similar problem, with different emphasis
• IBM Websphere MQ, TIBCO, Vitria, SeeBeyond

ATM Example with an EAI System

Bank Branch 1

ATM >>> ATM

Queues

ATM >>> ATM

EAI Routing

Bank Branch 2

ATM >>> ATM

Queues

ATM >>> ATM

EAI Routing

Bank Branch 500

ATM >>> ATM

Queues

EAI Routing

CIRRUS Accounts

Checking Accounts

Credit Card Accounts

Loan Accounts
Workflow Systems

• A software product that executes multi-transaction long-running scripts (e.g. process an order)
• Product components
  – A workflow script language
  – Workflow script interpreter and scheduler
  – Workflow tracking
  – Message translation
  – Application and queue system adaptors
• Transaction vs. document centric
• Structured processes vs. case management
• IBM Websphere MQ Workflow, Microsoft BizTalk, Vitria, Oracle Workflow, FileNET, Documentum

System Software Vendor’s View

• TP is partly a component product problem
  – Hardware
  – Operating system
  – Database system
  – Application Server
• TP is partly a system engineering problem
  – Getting all those components to work together to produce a system with all those “ilities”.
• This course focuses primarily on the Database System and Application Server

Outline

✓ 1. The Basics
  2. ACID Properties
  3. Atomicity and Two-Phase Commit
  4. Performance
  5. Styles of System

1.2 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.
  Examples - transfer money, print ticket, fire missile

Example - ATM Dispenses Money
(a non-undoable operation)

System crashes
Transaction aborts
Money is dispensed

Deferred operation
never gets executed
Reading Uncommitted Output Isn’t Undoable

Compensating Transactions

- A transaction that reverses the effect of another transaction (that committed). For example,
  - “Adjustment” in a financial system
  - Annul a marriage
- Not all transactions have complete compensations
  - E.g. Certain money transfers (cf. “The Firm”)
  - E.g. Fire missile, cancel contract
  - Contract law talks a lot about appropriate compensations
- A well-designed TP application should have a compensation for every transaction type

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.

Some Notation

- \( r_i[x] = \text{Read}(x) \text{ by transaction } T_i \)
- \( w_i[x] = \text{Write}(x) \text{ by transaction } T_i \)
- \( c_i = \text{Commit} \text{ by transaction } T_i \)
- \( a_i = \text{Abort} \text{ by transaction } T_i \)
- A history is a sequence of such operations, in the order that the database system processed them.

Consistency Preservation Example

\[
\begin{align*}
T_1: \text{Start};
& A = \text{Read}(x); \\
& A = A - 1; \\
& \text{Write}(y, A); \\
& \text{Commit};
\end{align*}
\]

\[
\begin{align*}
T_2: \text{Start};
& B = \text{Read}(x); \\
& C = \text{Read}(y); \\
& \text{If } (B > C + 1) \text{ then } B = B - 1; \\
& \text{Write}(x, B); \\
& \text{Commit};
\end{align*}
\]

- Consistency predicate is \( x > y \).
- Serial executions preserve consistency. Interleaved executions may not.
- \( H = r_1[x] \cdot r_1[x] \cdot r_2[y] \cdot w_2[x] \cdot w_2[y] \)
  - e.g. try it with \( x=4 \) and \( y=2 \) initially

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.
A Serializability Example

T_1: Start;
A = Read(x);
A = A + 1;
Write(x, A);
Commit;

T_2: Start;
B = Read(x);
B = B + 1;
Write(y, B);
Commit;

- H = r_1[x] r_2[x] w_1[x] c_1 w_2[y] c_2
- H is equivalent to executing T_1 followed by T_2
- Note, H is not equivalent to T_1 followed by T_2
- Also, note that T_1 started before T_2 and finished before T_2, yet the effect is that T_2 ran first.

Serializability Examples (cont’d)

- Client must control the relative order of transactions, using handshakes
  (wait for T_1 to commit before submitting T_2).
- Some more serializable executions:
  r_1[x] r_2[y] w_2[y] w_1[x] = T_1 T_2 = T_2 T_1
  r_1[y] r_2[y] w_2[y] w_1[x] = T_1 T_2 ≠ T_2 T_1
  r_1[x] r_2[y] w_2[y] w_1[y] = T_2 T_1 ≠ T_1 T_2
- Serializability says the execution is equivalent to some serial order, not necessarily to all serial orders

Non-Serializable Examples

- r_1[x] r_2[x] w_3[x] w_1[x] (race condition)
  - e.g., T_1 and T_2 are each adding 100 to x
- r_1[x] r_2[y] w_1[x] w_2[y]
  - e.g., each transaction is trying to make x = y, but the interleaved effect is a swap
- r_1[x] r_2[y] w_1[x] r_2[x] r_2[y] c_2 w_2[y] c_1 (inconsistent retrieval)
  - e.g., T_1 is moving $100 from x to y.
  - T_2 sees only half of the result of T_1
- Compare to the OS view of synchronization

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_j)” to the log
  - when the commit record is on disk, the transaction is committed.
  - system waits for disk ack before acking to user

1.3 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, OO DBMS, etc.)

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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 the transaction”. Participant RMs 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

Application Program
Resource Manager
Transaction Manager (TM)
Other Transaction Managers

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.

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1.4 Performance Requirements

• Measured in max transaction per second (tps) or per minute (tpm), and dollars per tps or tpm.
• Dollars measured by list purchase price plus 5 year vendor maintenance (“cost of ownership”)
• Workload typically has this profile:
  – 10% application server plus application
  – 30% communications system (not counting presentation)
  – 50% DB system
• TP Performance Council (TPC) sets standards
• TPC A & B (‘89-’95), now TPC C & W

TPC-A/B — Bank Tellers

• Obsolete (a retired standard), but interesting
• Input is 100 byte message requesting deposit/withdrawal
• Database tables = {Accounts, Tellers, Branches, History}

Start
Read message from terminal (100 bytes)
Read+write account record (random access)
Write history record (sequential access)
Read+write teller record (random access)
Read+write branch record (random access)
Write message to terminal (200 bytes)
Commit

• End of history and branch records are bottlenecks

The TPC-C Order-Entry Benchmark

<table>
<thead>
<tr>
<th>Table</th>
<th>Rows/Whse</th>
<th>Bytes/row</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warehouse</td>
<td>1</td>
<td>89</td>
</tr>
<tr>
<td>District</td>
<td>10</td>
<td>95</td>
</tr>
<tr>
<td>Customer</td>
<td>30K</td>
<td>655</td>
</tr>
<tr>
<td>History</td>
<td>30K</td>
<td>46</td>
</tr>
<tr>
<td>Order</td>
<td>30K</td>
<td>24</td>
</tr>
<tr>
<td>New-Order</td>
<td>9K</td>
<td>8</td>
</tr>
<tr>
<td>OrderLine</td>
<td>300K</td>
<td>54</td>
</tr>
<tr>
<td>Stock</td>
<td>100K</td>
<td>306</td>
</tr>
<tr>
<td>Item</td>
<td>100K</td>
<td>82</td>
</tr>
</tbody>
</table>

• TPC-C uses heavier weight transactions
TPC-C Transactions

- **New-Order**
  - Get records describing a warehouse, customer, & district
  - Update the district
  - Increment next available order number
  - Insert record into Order and New-Order tables
  - For 5-15 items, get Item record, get/update Stock record
  - Insert Order-Line Record
- **Payment, Order-Status, Delivery, Stock-Level** have similar complexity, with different frequencies
- tpmC = number of New-Order transaction per min.

Comments on TPC-C

- Enables apples-to-apples comparison of TP systems
- Does not predict how your application will run, or how much hardware you will need, or which system will work best on your workload
- Not all vendors optimize for TPC-C.
  - IBM has claimed DB2 is optimized for a different workload, so they only started publishing TPC numbers a few years ago.

Typical TPC-C Numbers

- $3 - $50 / tpmC. Most are under $20 / tpmC.
  - Top 24 price/performance results on MS SQL Server & Windows.
  - One of the top 56 is Oracle, Linux, BEA Tuxedo
- System cost $36K (Dell) - $12M (Fujitsu)
- Examples of high throughput
  - HP ProLiant cluster, 709K tpmC, $10.6M, $150/tpmC (MS SQL, MS COM+)
  - IBM 428K tpmC, $7.6M, $18/hpmC (Oracle, WebSphere)
- Examples of low cost (all use MS SQL Server, COM+)
  - HP ProLiant cluster, 411K tpmC, $5.3M, $13/tpmC
  - Dell, 16.7K tpmC, $47K, $3/tpmC
- Results are very sensitive to date published.

TPC-W – Web Retailer

- Introduced 12/99.
- Features - dynamic web page generation, multiple browser sessions, secure UI & payments (via secure socket layer)
- Profiles - shop (WIPS), browse (WIPSb), order (WIPSo)
- Tables – {Customer, Order, Order-Line, Item, Author, CreditCardTxns, Address, Country}
- Transactions – HomeWeb, ShoppingCart, AdminRequest, AdminConfirm, CustomerRegister, BuyRequest, BuyConfirm, OrderInquiry, OrderDisplay, Search, SearchResult, NewProducts, BestSellers, ProductDetail,

TPC-W (cont’d)

- Scale factor: 1K – 10M items (in the catalog).
- Web Interactions per sec (WIPS) @ ScaleFactor
  - IBM: 21K WIPS@10K items; $33 / WIPS; $690K total
  - Dell: 8K WIPS@10K items; $25 / WIPS; $190K total

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1.5 Styles of Systems

- TP is System Engineering
- Compare TP to other kinds of system engineering …
- Batch processing - Submit a job and receive file output.
- Time sharing - Invoke programs in a process, which may interact with the process’s display
- Real time - Submit requests that have a deadline
- Client/server - PC calls a server over a network to access files or run applications
- Decision support - Submit queries to a shared database, and process the result with desktop tools
- TP - Submit a request to run a transaction

TP vs. Batch Processing (BP)

- A BP application is usually uniprogrammed so serializability is trivial. TP is multiprogrammed.
- BP performance is measured by throughput. TP is also measured by response time.
- BP can optimize by sorting transactions by the file key. TP must handle random transaction arrivals.
- BP produces new output file. To recover, re-run the app.
- BP has fixed and predictable load, unlike TP.
- But, where there is TP, there is almost always BP too.
  - TP gathers the input. BP post-processes work that has weak response time requirements
  - So, TP systems must also do BP well.

TP vs. Timesharing (TS)

- TS is a utility with highly unpredictable load. Different programs run each day, exercising features in new combinations.
- By comparison, TP is highly regular.
- TS has less stringent availability and atomicity requirements. Downtime isn’t as expensive.

TP vs. Real Time (RT)

- RT has more stringent response time requirements. It may control a physical process.
- RT deals with more specialized devices.
- RT doesn’t need or use a transaction abstraction
  - usually loose about atomicity and serializability
- In RT, response time goals are usually more important than completeness or correctness. In TP, correctness is paramount.

TP and Client/Server (C/S)

- Is commonly used for TP, where client prepares requests and server runs transactions
- In a sense, TP systems were the first C/S systems, where the client was a terminal

TP and Decision Support Systems (DSSs)

- DSSs run long queries, usually with lower data integrity requirements than TP.
- A.k.a. data warehouse (DSS is the more generic term.)
- TP systems provide the raw data for DSSs.
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What’s Next?

• This chapter covered TP system structure and properties of transactions and TP systems
• The rest of the course drills deeply into each of these areas, one by one.