# 1. Introduction

CSE 593 Transaction Processing

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## Outline





## 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
- Download a video clip and pay for it
- Play a bid at an on-line auction



## 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?

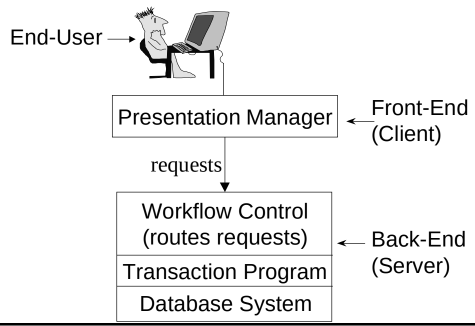
- It's at the core of electronic commerce
- Most medium-to-large businesses use TP for their production systems. The business can't operate without it.
- It's a *huge* slice of the computer system market — over $50B/year. Probably the single largest application of computers.



## 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

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## 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

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## 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

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## 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.)

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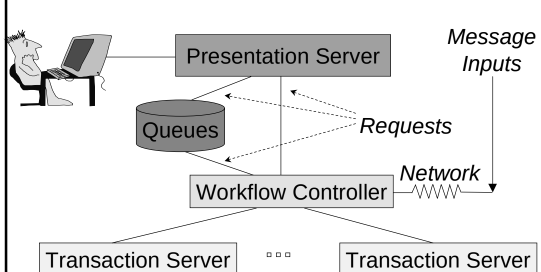
## App Server Architecture, pre-Web

- Boxes below are distributed on an intranet

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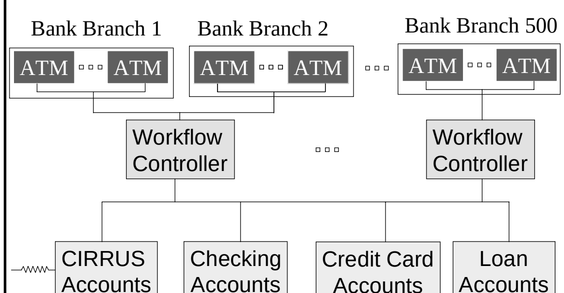
## Automated Teller Machine (ATM) Application Example

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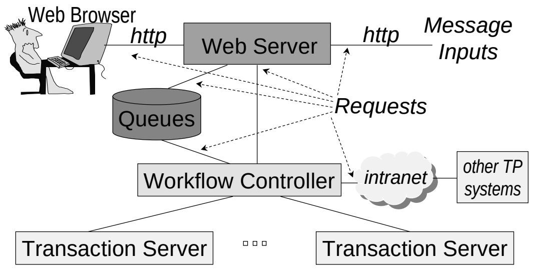
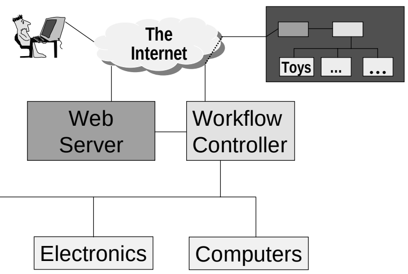
## Application Server Architecture






## Internet Retailer






## 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 Database System and Application Server



## Outline

✓1. The Basics
2. ACID Properties
3. Atomicity and Two-Phase Commit
4. Availability
5. Performance
6. 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)

```
T1: Start
    . . .
      Dispense Money
    Commit
```

System crashes
Transaction aborts
Money is dispensed

```
T1: Start
    . . .
    Commit
Dispense Money
```

System crashes

*Deferred operation never gets executed*



## Reading Uncommitted Output Isn't Undoable

```
T1:  Start
     . . .
     Display output
     . . .
     If error, Abort
```

User reads output
…
User enters input

Brain transport

```
T2:  Start
     Get input from display
     . . .
     Commit
```



## 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 has a lot to say 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

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



## Consistency Preservation Example

$T_1$: Start;
  A = Read(x);
  A = A - 1;
  Write(y, A);
 Commit;

$T_2$: Start;
  B = Read(x);
  C = Read(y);
  If (B > C+1) then B = B - 1;
  Write(x, B);
 Commit;

- Consistency predicate is x > y.
- Serial executions preserve consistency. Interleaved executions may not.
- H = $r_1[x]\ r_2[x]\ r_2[y]\ w_2[x]\ w_1[y]$
  - 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; | $T_2$: Start; |
| --- | --- |
| A = Read(x); | B = Read(x); |
| A = A + 1; | B = B + 1; |
| Write(x, A); | Write(y, B); |
| Commit; | Commit; |

- $H = r_1[x]\ r_2[x]\ w_1[x]\ c_1\ w_2[y]\ c_2$
- H is equivalent to executing $T_2$ followed by $T_1$
- 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:
  $r_1[x]\ r_2[y]\ w_2[y]\ w_1[x] \equiv T_1\ T_2 \equiv T_2\ T_1$
  $r_1[y]\ r_2[y]\ w_2[y]\ w_1[x] \equiv T_1\ T_2 \not\equiv T_2\ T_1$
  $r_1[x]\ r_2[y]\ w_2[y]\ w_1[y] \equiv T_2\ T_1 \not\equiv T_1\ T_2$
- Serializability says the execution is equivalent to *some* serial order, not necessarily to *all* serial orders



## Non-Serializable Examples

- $r_1[x]\ r_2[x]\ w_2[x]\ w_1[x]$ (*race condition*)
  - e.g. $T_1$ and $T_2$ are each adding 100 to x
- $r_1[x]\ r_2[y]\ w_2[x]\ w_1[y]$
  - e.g. each transaction is trying to make x = y, but the interleaved effect is a swap
- $r_1[x]\ r_1[y]\ w_1[x]\ r_2[x]\ r_2[y]\ c_2\ w_1[y]\ c_1$ (*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($T_i$)" to the log
  - when the commit record is on disk, the transaction is committed.
  - system waits for disk ack before acking to user



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✓2. ACID Properties
3. Atomicity and Two-Phase Commit
4. Availability
5. Performance
6. Styles of System

## 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.)

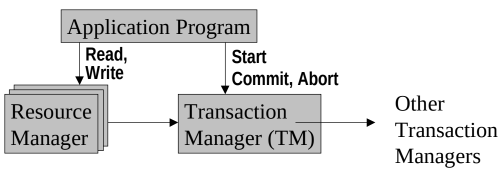


## Two-Phase Commit

- Main idea - all resource managers (RMs) save a <u>durable</u> copy of the transaction’s updates <u>before</u> 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




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 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



## 1.5 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 has this profile:
  - 10% application server plus application
  - 30% communications system (not counting presentation)
  - 50% DB system
- TP Performance Council (*TPC*) sets standards
  - http://www.tpc.org.
- 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

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## The TPC-C Order-Entry Benchmark

| Table | Rows/Whse | Bytes/row |
|---|---|---|
| Warehouse | 1 | 89 |
| District | 10 | 95 |
| Customer | 30K | 655 |
| History | 30K | 46 |
| Order | 30K | 24 |
| New-Order | 9K | 8 |
| OrderLine | 300K | 54 |
| Stock | 100K | 306 |
| Item | 100K | 82 |

- TPC-C uses heavier weight transactions

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## 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.

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## 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. E.g., IBM has claimed DB2 is optimized for a different workload, so they have only recently published TPC numbers

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## Typical TPC-C Numbers

- \$10 - \$50 / tpmC. Uniform spread across the range.
  - Top 49 price/performance results on MS SQL Server & Win 2000.
  - Fujitsu at \$21. Sybase at \$27. IBM DB2 at \$32. Oracle at \$36
- System cost \$153K (Intergraph) - \$14.2M (IBM)
- Examples of high throughput
  - Compaq 550K tpmC, \$10.4M, \$21/tpmC (MS SQL, MS COM+)
  - IBM 441K tpmC, \$14.2M, \$32/tpmC (IBM DB2, MS COM+)
- Examples of low cost (all use MS SQL Server, COM+)
  - Compaq, 20.2K tpmC, \$201K, \$10/tpmC
  - Dell, 30.2K tpmC, \$335K, \$11/tpmC
  - HP, 33.1K tpmC, \$393K, \$12/tpmC
- Results are <u>very</u> sensitive to date published.

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## TPC/W – Web Retailer

- Introduced 12/99. One published measurement so far.
- Features - DB accesses to generate dynamic web pages, secure UI, secure payments (via secure socket layer (SSL))
- Scale factor: 1K – 10M items (in the catalog).
- Web Interactions per sec (WIPS) @ ScaleFactor
  - IBM: 1262 WIPS@ 10,000; \$277 / WIPS; \$350K total
- 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,

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## 1.6 TP is System Engineering

- Compare it to other kinds of system engineering …
- Batch processing - S*ubmit* 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.