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. Scalability

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.
- 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 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
  - 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

Front End Program

Client

requests

Request Controller
(routes requests and
supervises their execution)

Transaction Server

Database System

Back-End
(Server)

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
  - 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, on-line retail, …
  - 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

Application Servers

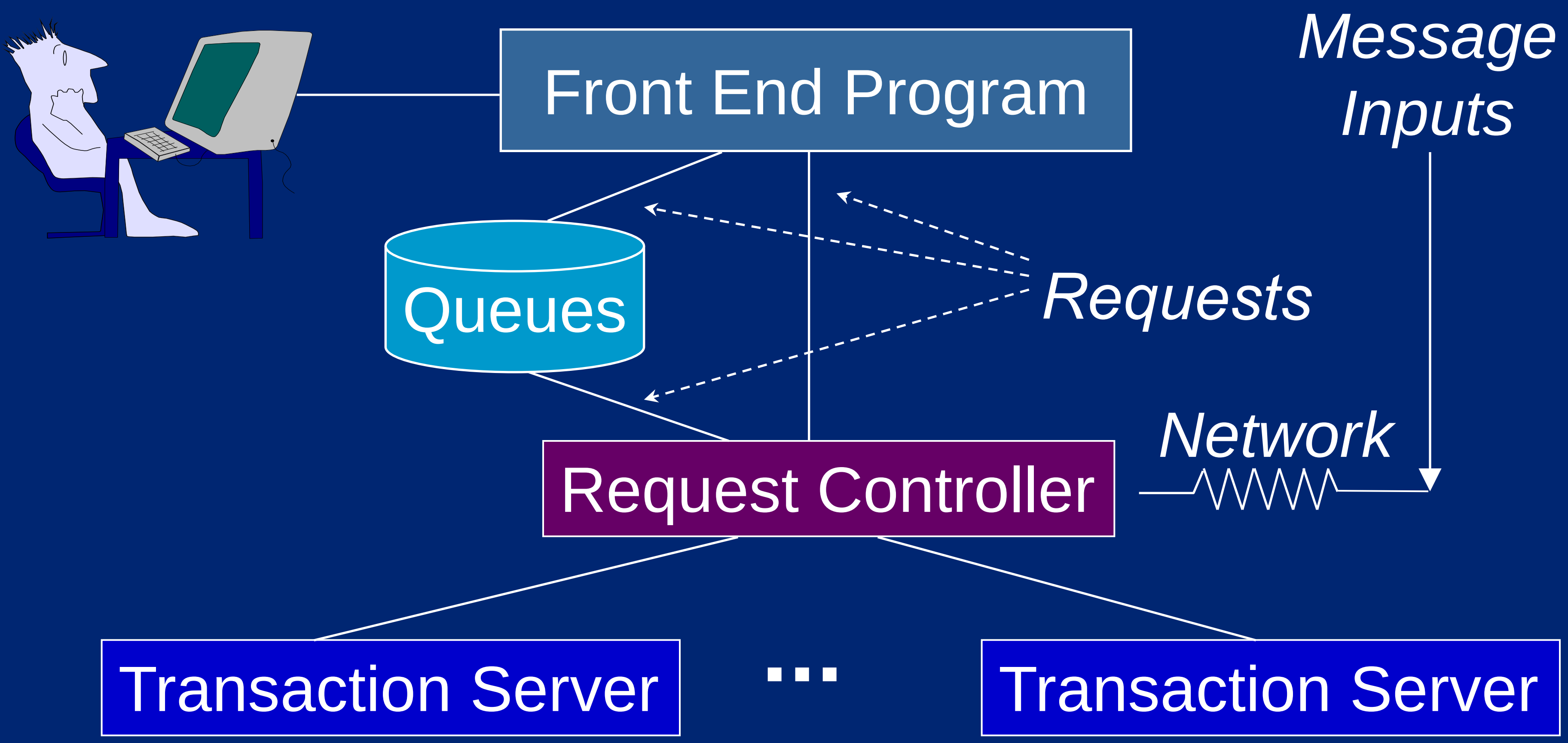
- A software product to create, execute and manage TP applications
- Formerly called *TP monitors*. Some people say App Server = TP monitor + web functionality.
- Programmer writes an app to process a single request. App Server scales it up to a large, distributed system
  - E.g. application developer 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)

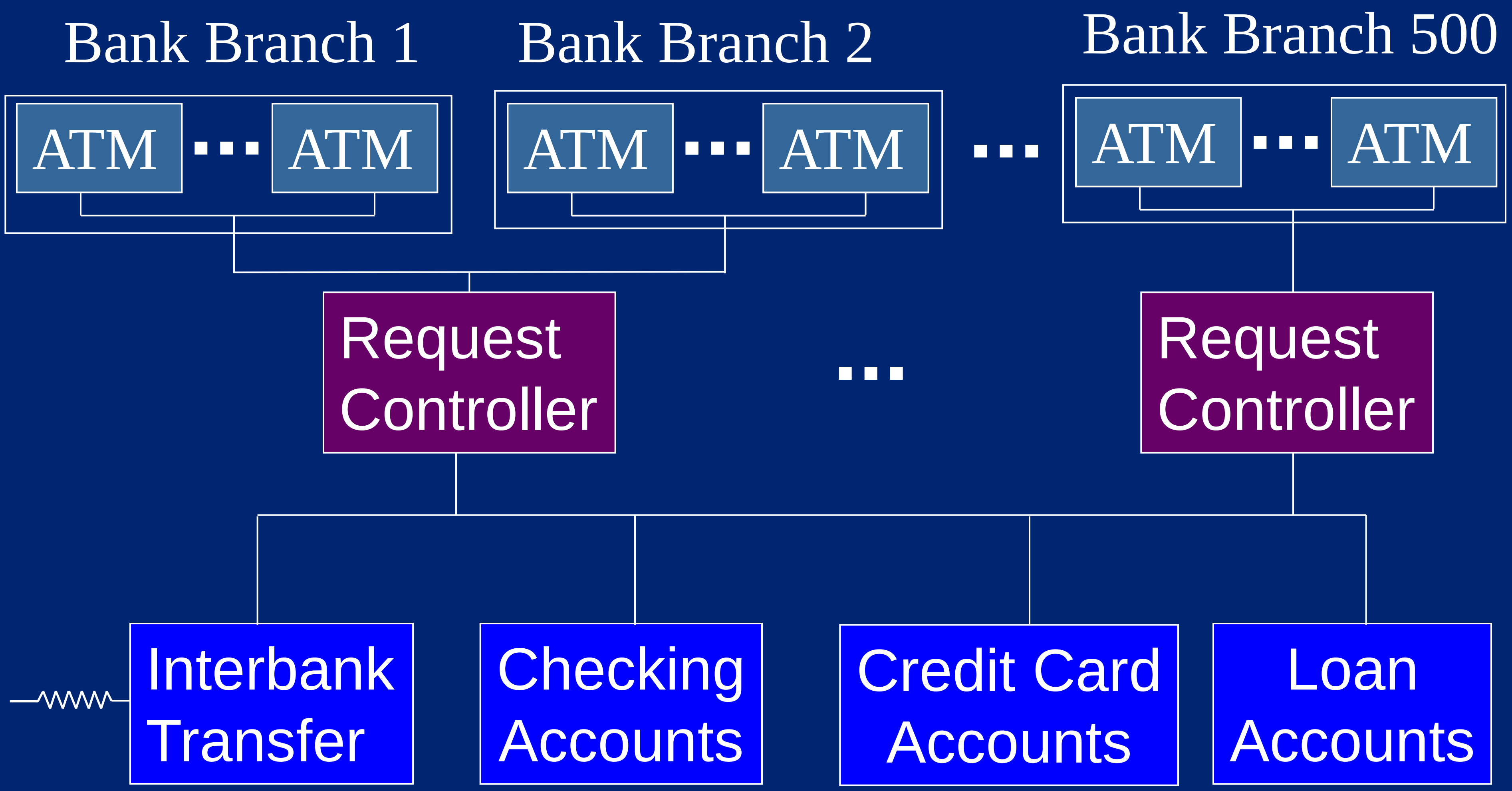
- Components include
  - An application programming interface (API) (e.g., Enterprise Java Beans)
  - Tools for program development
  - Tools for system management (app deployment, fault & performance monitoring, user mgmt, etc.)
- Enterprise Java Beans, IBM Websphere, Microsoft .NET (COM+), Oracle Weblogic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

App Server Architecture, Pre-Web

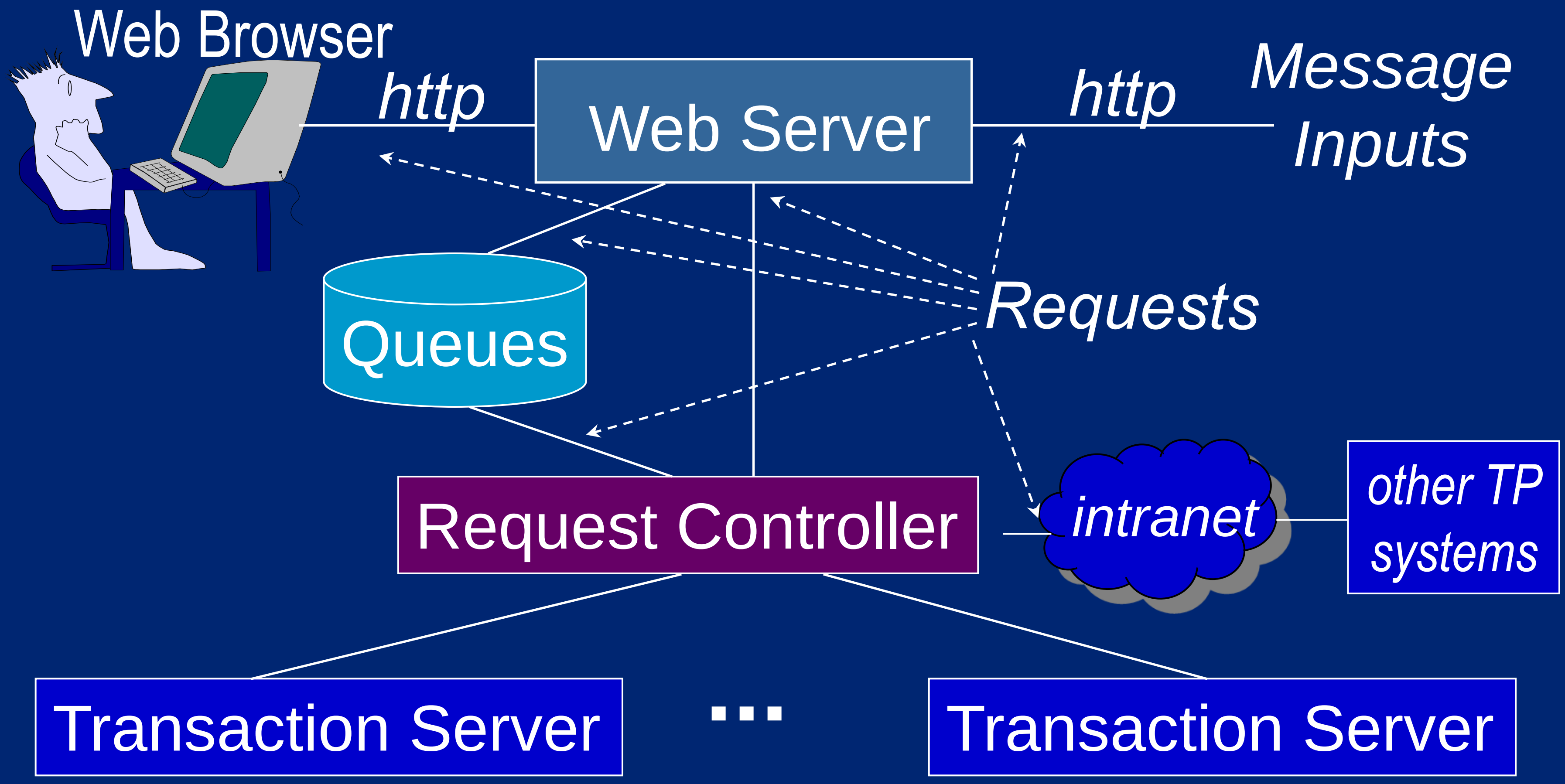
- Boxes below are distributed on an intranet



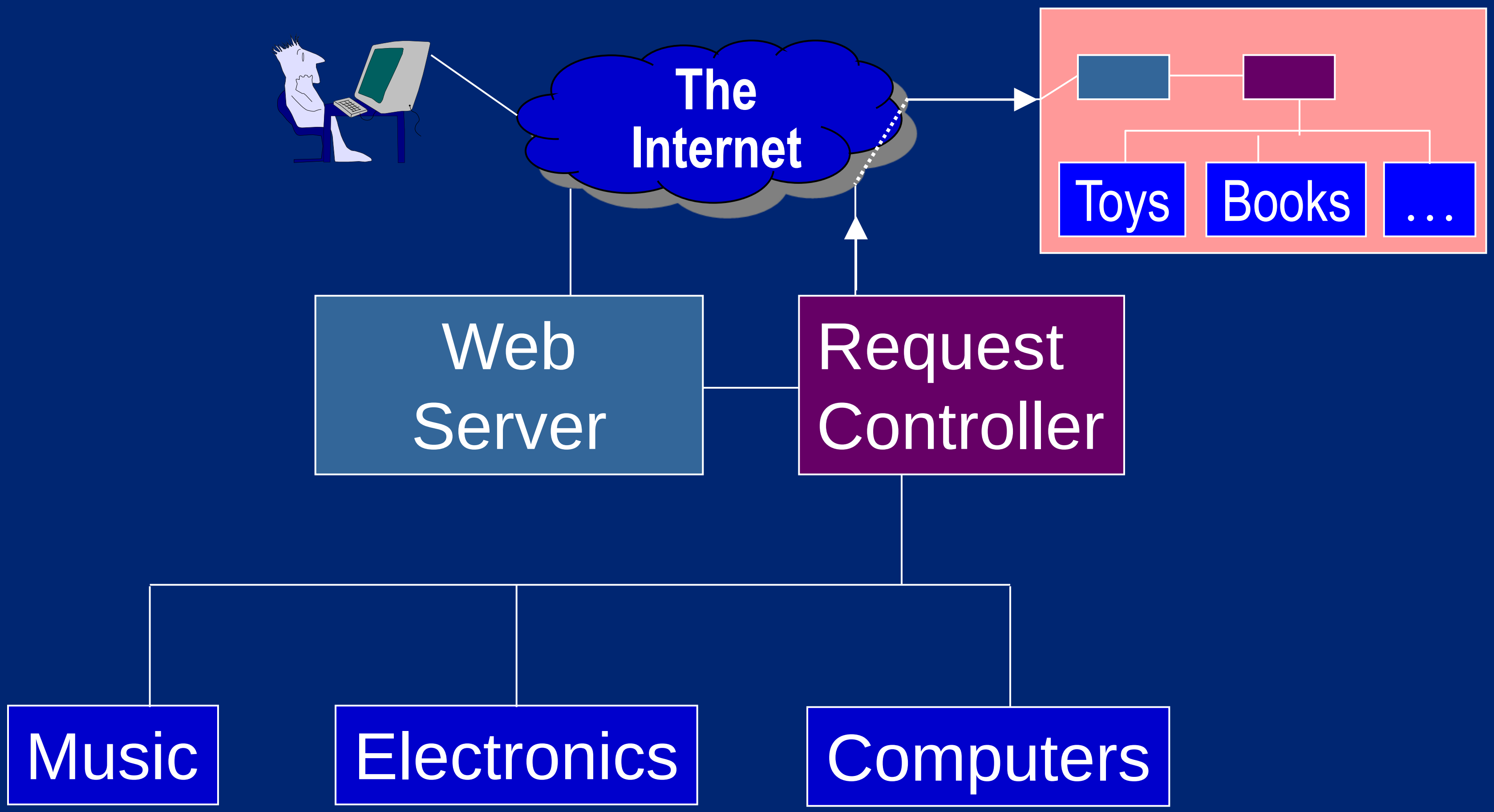
Automated Teller Machine (ATM) Application Example



Application Server Architecture

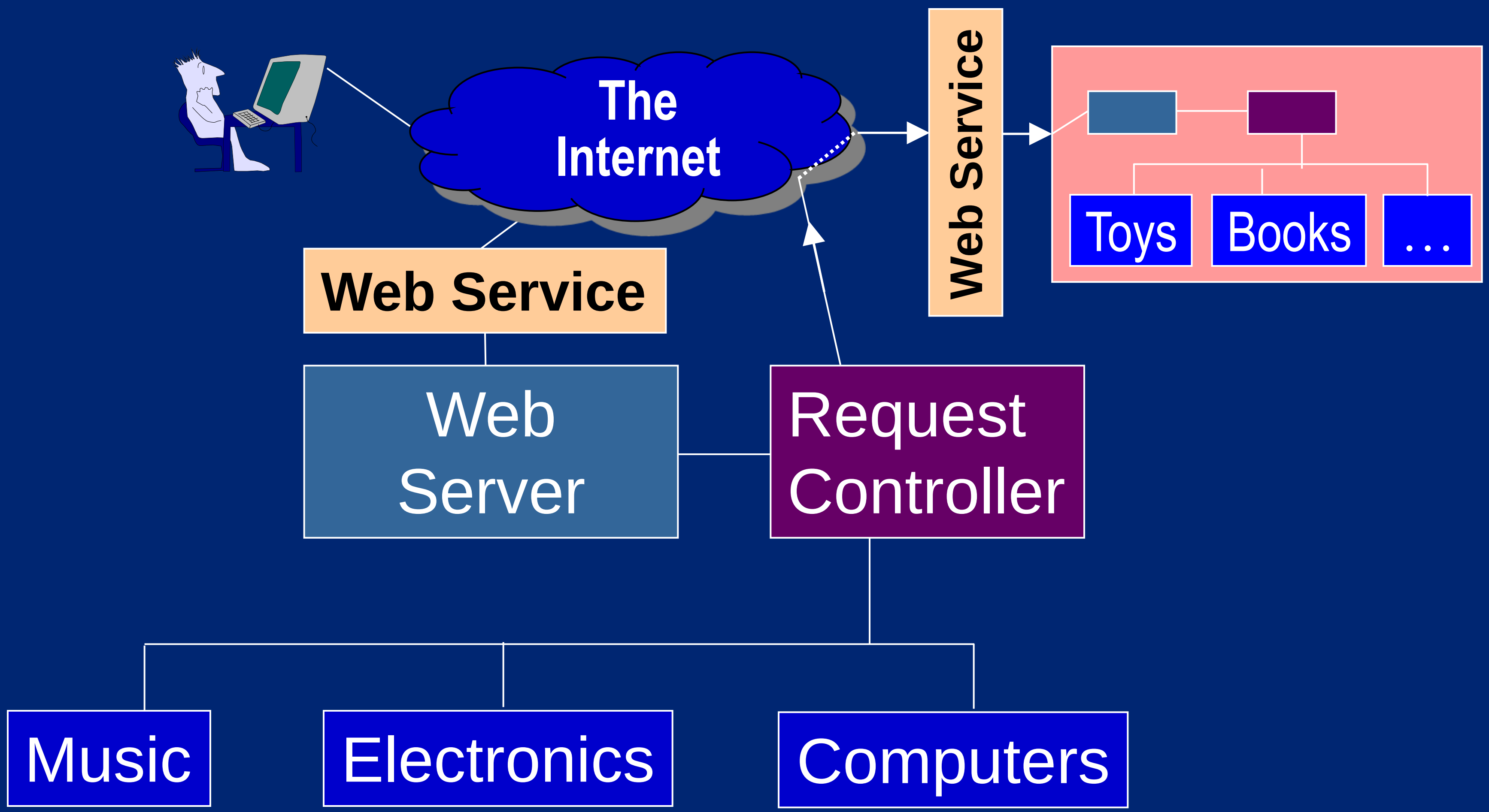


Internet Retailer



Service Oriented Architecture (SOA)

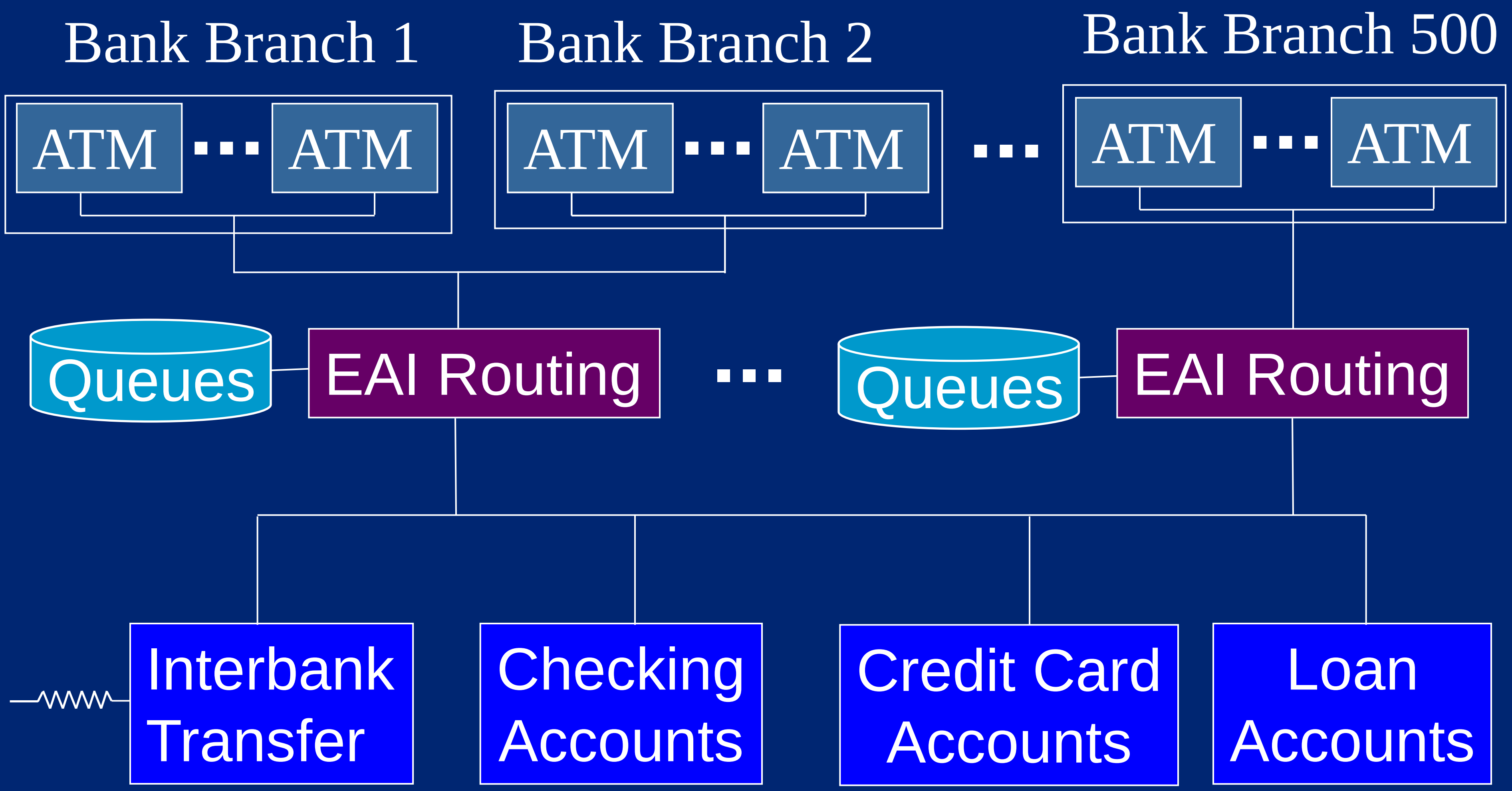
- Web services - interface and protocol standards to do app server functions over the internet.



Enterprise Application Integration (EAI)

- A software product to route requests between independent application systems. It often includes
  - A queuing system
  - A message mapping system
  - Application adaptors (SAP, Oracle PeopleSoft, etc.)
- EAI and Application Servers address a similar problem, with different emphasis
- Examples
  - IBM Websphere MQ, TIBCO, Vitria, Sun SeeBeyond

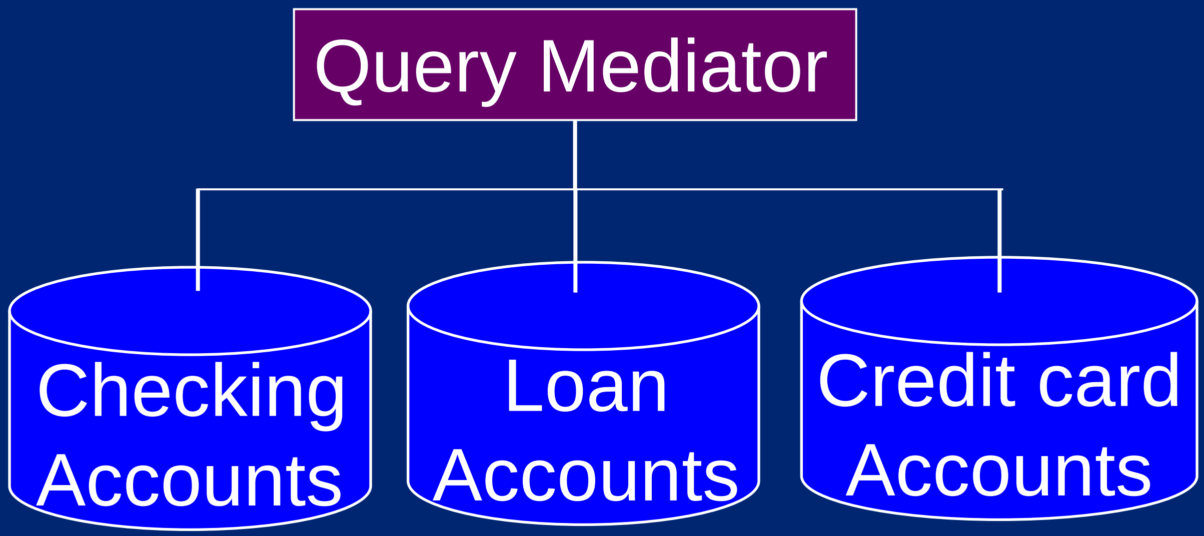
ATM Example with an EAI System



Workflow, or Business Process Mgmt

- 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-centric vs. document-centric
- Structured processes vs. case management
- Examples: IBM Websphere MQ Workflow, Microsoft BizTalk, SAP, Vitria, Oracle Workflow, IBM FileNET, EMC Documentum, TIBCO

Data Integration Systems (Enterprise Information Integration)



- Heterogeneous query systems (mediators). It's database system software, but …
- It's similar to EAI with more focus on data transformations than on message mgmt.

Transactional Middleware

- In summary, there are *many* variations that package different combinations of middleware features
  - Application Server
  - Enterprise Application Integration
  - Business process management (aka Workflow)
  - Enterprise Server Bus
- New ones all the time, that defy categorization

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. Scalability

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
  - 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

- $r_i[x]$ = 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 -1> C) 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

Serializability Example 1

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

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

- H = $r_1[x]$ $r_2[y]$ $w_1[x]$ c_1 $w_2[y]$ c_2
- H is equivalent to executing
  - T_1 followed by T_2
  - T_2 followed by T_1

Serializability Example 2

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_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

- 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. Performance

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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". 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

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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
  - http://www.tpc.org
- TPC A & B (‘89-’95), now TPC C & E

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

TPC-C Order-Entry for Warehouse

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

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
  - Some high-end system sales require custom benchmarks

Current TPC-C Numbers

- All numbers are sensitive to date submitted
- Systems
  - cost $60K (Dell/HP) - $12M (Oracle/IBM)
  - mostly Oracle/DB2/MS SQL on Unix variants/Windows
  - $0.40 - $5 / tpmC
- Example of high throughput
  - Oracle, 30M tpmC, $30.0M, $1/tpmC, Oracle/Solaris
- Example of low cost
  - HP ProLiant, 290K tpmC, $113K, $0.39/tpmC, Oracle/Linux

TPC-E

- Approved in 2007
- Models a stock trading app for brokerage firm
- Should replace TPC-C, it's database-centric
- More complex but less disk IO per transaction

TPC-E

- 33 tables in four sets
  - Market data (11 tables)
  - Customer data (9 tables)
  - Broker data (9 tables)
  - Reference data (4 tables)
- Scale
  - 500 customers per tpsE

TPC-E Transactions

- Activities
  - Stock-trade, customer-inquiry, feeds from markets, market-analysis
- tpsE = number of Trade-Result transaction per sec
- Trade-Result
  - Completes a stock market trade
  - Receive from market exchange confirmation & price
  - Update customer‘s holdings
  - Update broker commission
  - Record historical information

TPC-E Transactions

Name	Access	Description
Broker-Volume	RO	DSS-type medium query
Customer-Position	RO	"What am I worth?"
Market-Feed	RW	Processing of Stock Ticker
Market-Watch	RO	"What's the market doing?"
Security-Detail	RO	Details about a security
Trade-Lookup	RO	Look up historical trade info
Trade-Order	RW	Enter a stock trade
Trade-Result	RW	Completion of a stock trade
Trade-Status	RO	Check status of trade order
Trade-Update	RW	Correct historical trade info

Current TPC-E Numbers

- Systems
  - Cost $60K - $2.3M
  - Almost all are MS SQL on Windows
  - $130 - $250 / tpsE
- Example of high throughput
  - IBM, 4.5k tpsE, $645k, $140/tpsE, MS SQL/Windows
- Example of low cost
  - IBM, 2.9K tpsE, $371K, $130/tpsE, MS SQL/Windows

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1.5 Scalability

- Techniques for better performance
  - Textbook, Chapter 2, Section 6
- Scale-up
  - Caching
  - Resource Pooling
- Scale-out
  - Partitioning
  - Replication

Caching

- Key idea
  - Use more memory
  - Keep a copy of data from its permanent home
  - Accessing a cached copy is fast
- Key issues
  - Which data to keep
    - Popular read-only data
  - Cache replacement
  - What if original data is updated
    - Invalidations
    - Timeouts

Caching

- Applied at multiple levels
  – Database and application server
- Updates
  – Write through
    - Better cache coherence
  – Write back
    - Batching and write absorption
- Example products
  – Memcached, MS Velocity

Resource Pooling

- Key idea
  - If a logical resource is expensive to create and cheap to access, then manage a pool of the resource
- Examples
  - Session pool
  - Thread pool

Partitioning

- To add system capacity, add server machines
- Sometimes, you can just relocate some server processes to different machines
- But if an individual server process overloads one machine, then you need to partition the process
  - Example – One server process manages flights, cars, and hotel rooms. Later, you partition them in separate processes.
  - We need mapping from resource name to server name

Partitioning: Routing

- Sometimes, it's not enough to partition by resource type, because a resource is too popular
  - Example: flights
- Partition popular resource based on value ranges
  - Example – flight number 1-1000 on Server A, flight number 1000-2000 on Server B, etc.
  - Request controller has to direct its calls based on parameter value (e.g. flight number)
  - This is called parameter-based routing
    - E.g., range, hashing, dynamic

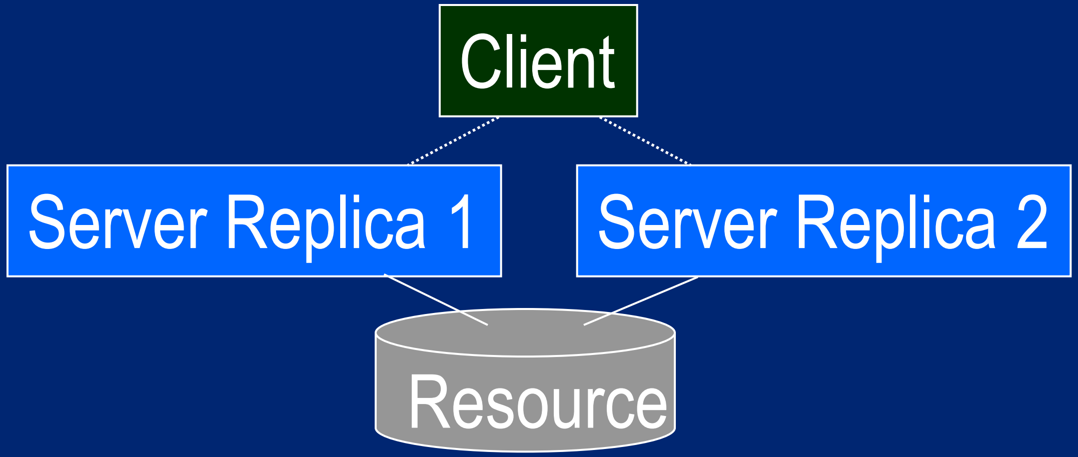
Replication

- 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

Replicated Server

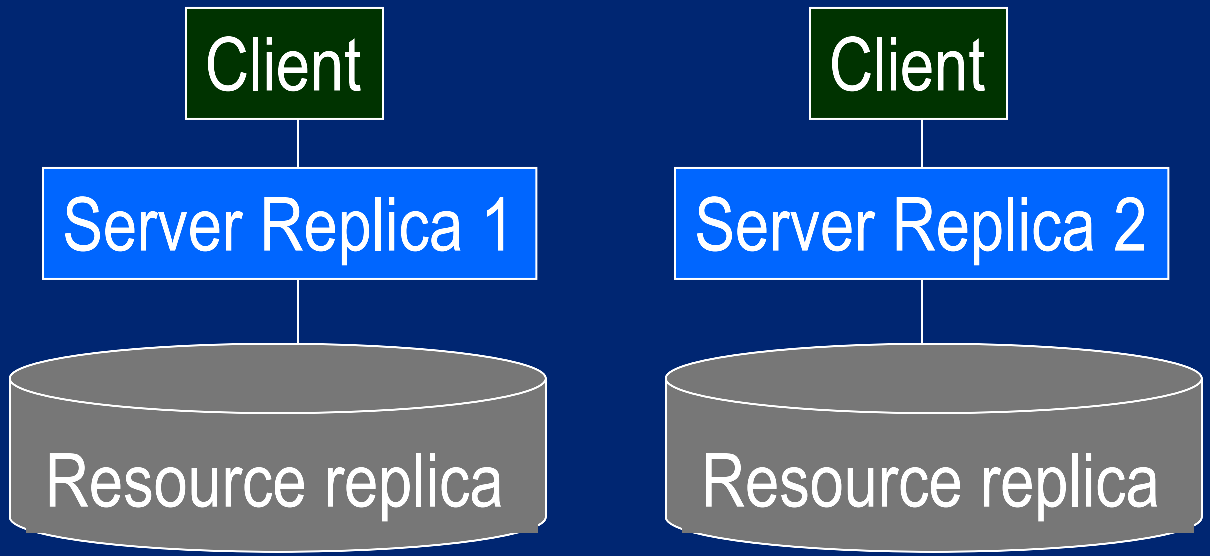
- Can replicate servers on a common resource
  - Data sharing - DB servers communicate with shared disk



- Helps availability for process (not resource) failure
- Requires a replica cache coherence mechanism, so this helps performance only if
  - Little conflict between transactions at different servers or
  - Loose coherence guarantees (e.g. read committed)

Replicated Resource

- To get more improvement in availability, replicate the resources (too)
- Also increases potential throughput
- This is what's usually meant by replication



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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.

Next Steps

- We covered
  - Chapter 1
  - Chapter 2, Section 6
- Assignment 1
- Teams for the project