CIS 330:
Applied Database Systems

27 Aug 2004: Introduction

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Course Goals

- Understand the functionality of modern database systems
- Understand where database systems fit into an enterprise data management infrastructure
- Design and build data-driven applications websites

- Learn several important tools:
  - Database System: Microsoft SQL Server
  - Application Server: Apache Tomcat
  - Data Modeling tool: DeZign for Databases
- Learn several important technologies
  - JDBC, JSP, Servlets, XML/XSLT/XPath, web services, J2EE

Instructor

- Alan Demers
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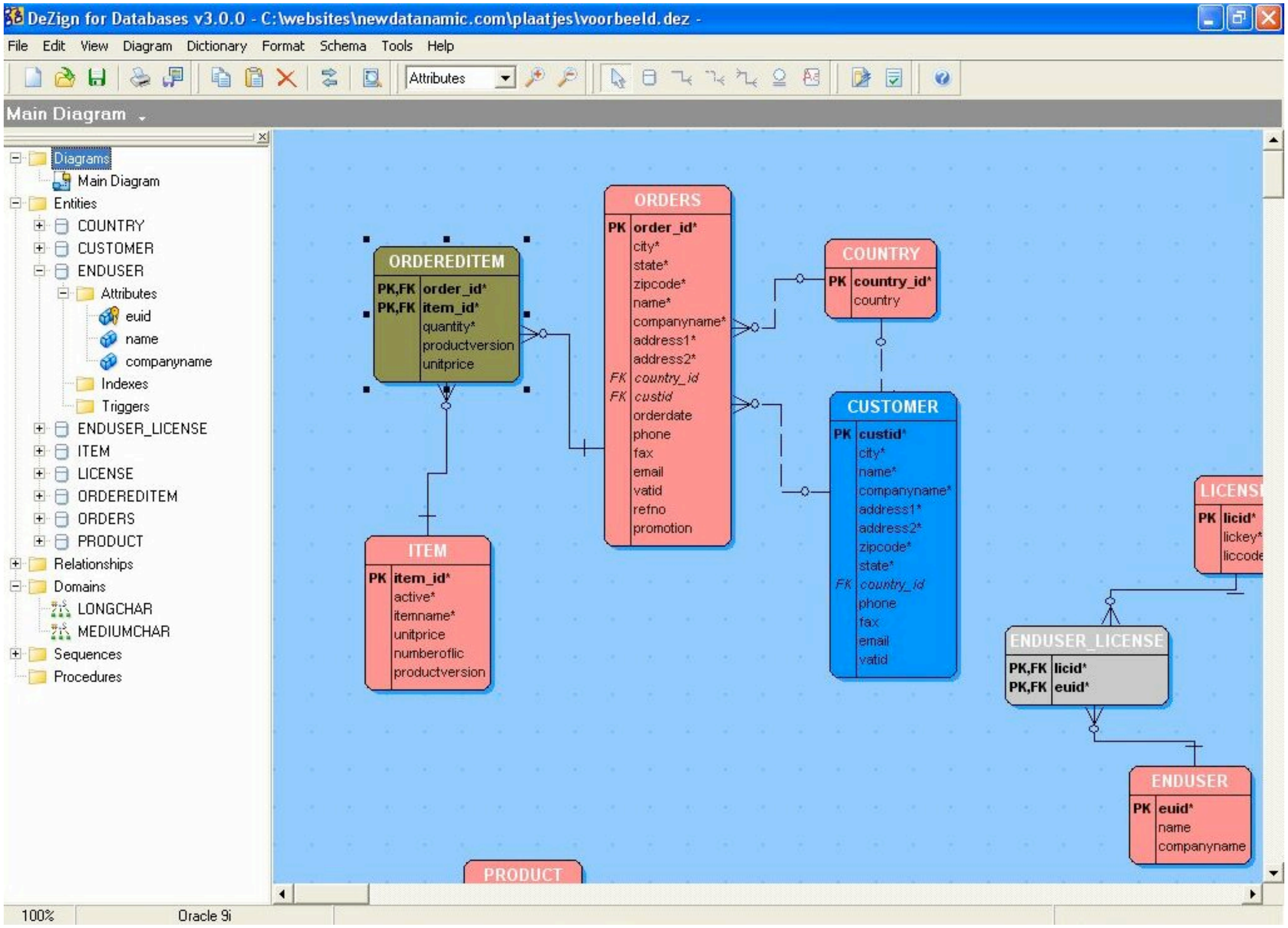
- Office hours:
  - TTh, 1:00-2:00, Upson Hall 4115
  - Always welcome to ask questions via email (ademers@cs.cornell.edu)
  - Ask questions after the lecture

Course Mechanics

- Homepage will have all the relevant material
- Slides will be online before each lecture
- Every student who is enrolled in the class will receive a loaner laptop
  - Laptops will be distributed next week
  - You need to be officially enrolled in order to receive a laptop!

- Course Outline: See Webpage

Software: DeZign for Databases



Prerequisites and Grading

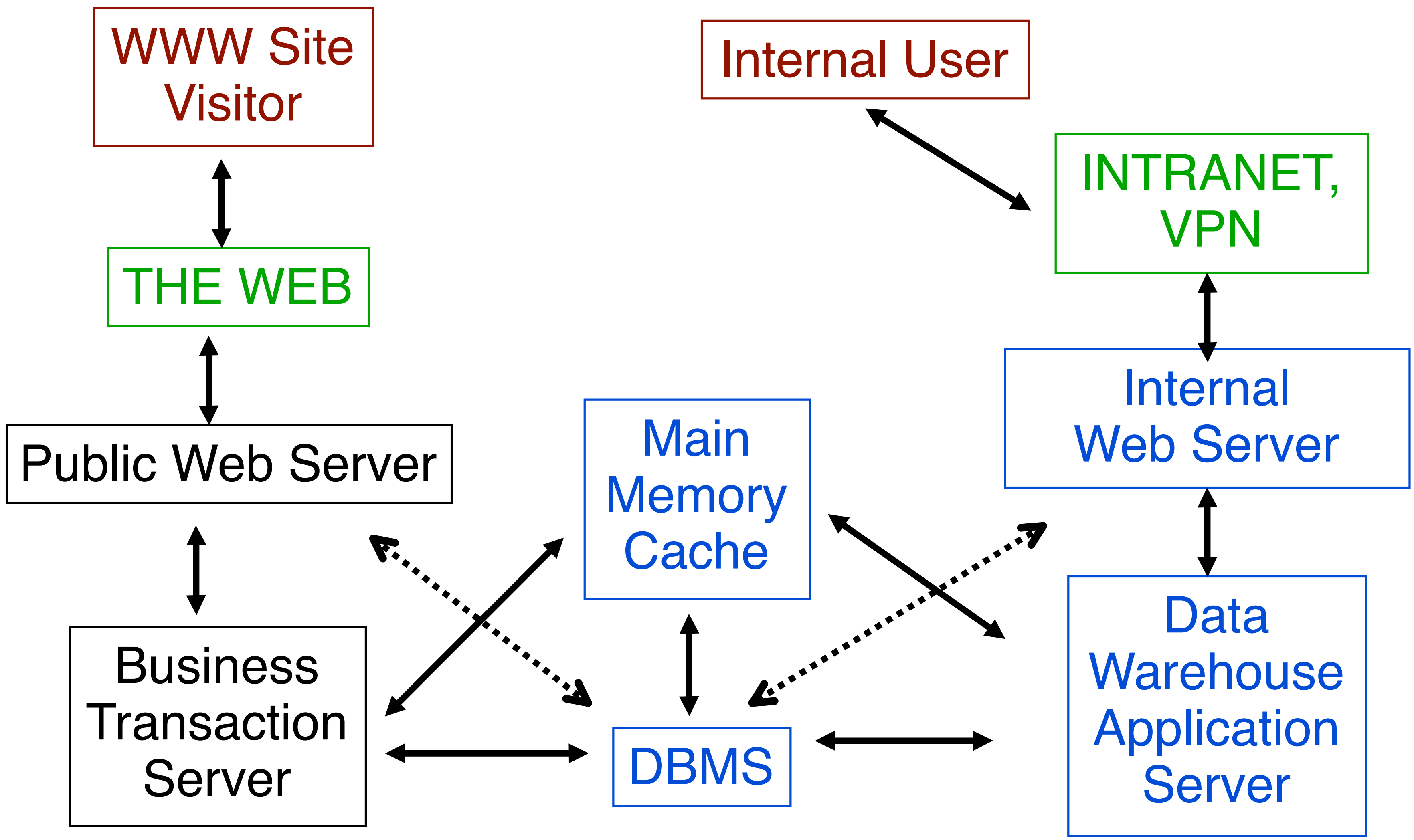
- Prerequisites:
  - CS211; if you don't have CS211, talk to me after class

- Grading:
  - 20 (smaller and larger) homework assignments (no groups), total of 60%.
  - Two exams:
    - Midterm: 15%
    - Final: 20%
  - Class participation: 5%

Introduction

- Three-tier architectures
- Introduction to database systems

The Big Picture



Enterprise Architectures

Three separate types of functionality:

- Data management
- Application logic
- Presentation

- The system architecture determines whether these three components reside on a single system (“tier) or are distributed across several tiers

Single-Tier Architectures

- All functionality combined into a single tier, usually on a mainframe
  - User access through dumb terminals

- Advantages:
  - Easy maintenance and administration
- Disadvantages:
  - Today, users expect graphical user interfaces.
  - Centralized computation of all of them is too much for a central system

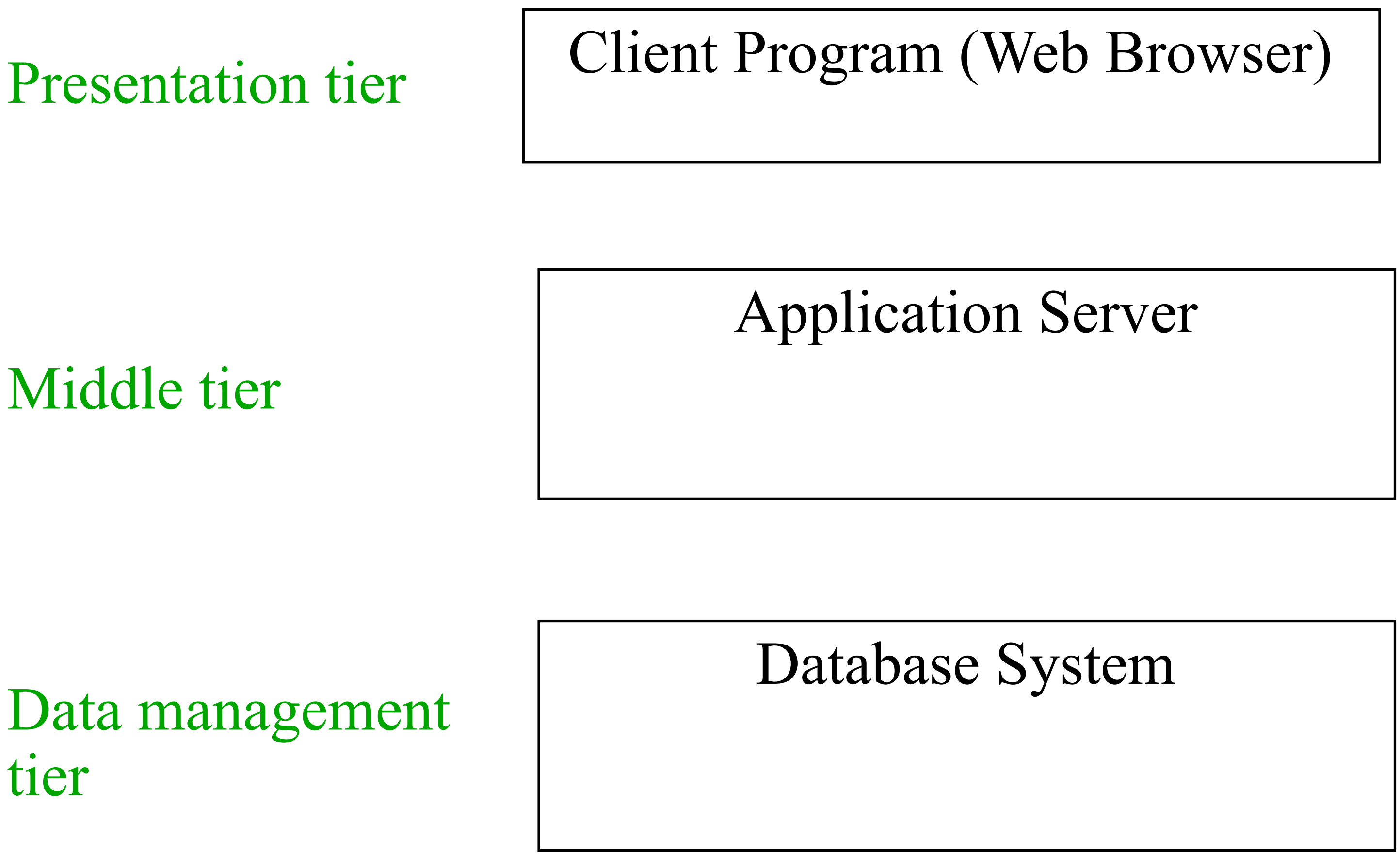
Client-Server Architectures

- Work division: Thin client
  - Client implements only the graphical user interface
  - Server implements business logic and data management
- Work division: Thick client
  - Client implements both the graphical user interface and the business logic
  - Server implements data management

Client-Server Architectures (Contd.)

- Disadvantages of thick clients
  - No central place to update the business logic
  - Security issues: Server needs to trust clients
    - Access control and authentication needs to be managed at the server
    - Clients need to leave server database in consistent state
    - One possibility: Encapsulate all database access into stored procedures
  - Does not scale to more than several 100s of clients
    - Large data transfer between server and client
    - More than one server creates a problem: x clients, y servers: x*y connections

The Three-Tier Architecture



The Three Layers

- Presentation tier
  - Primary interface to the user
  - Needs to adapt to different display devices (PC, PDA, cell phone, voice access?)
- Middle tier
  - Implements business logic (implements complex actions, maintains state between different steps of a workflow)
  - Accesses different data management systems
- Data management tier
  - One or more standard database management systems

Example 1: Airline reservations

- Build a system for making airline reservations
- What is done in the different tiers?
- Database System
  - Airline info, available seats, customer info, etc.
- Application Server
  - Logic to make reservations, cancel reservations, add new airlines, etc.
- Client Program
  - Log in different users, display forms and human-readable output

Example 2: Course Enrollment

- Build a system using which students can enroll in courses
- Database System
  - Student info, course info, instructor info, course availability, pre-requisites, etc.
- Application Server
  - Logic to add a course, drop a course, create a new course, etc.
- Client Program
  - Log in different users (students, staff, faculty), display forms and human-readable output

Three-Tier Architecture: Advantages

- Heterogeneous systems
  - Tiers can be independently maintained, modified, and replaced
- Thin clients
  - Only presentation layer at clients (web browsers)
- Integrated data access
  - Several database systems can be handled transparently at the middle tier
  - Central management of connections
- Scalability
  - Replication at middle tier permits scalability of business logic
- Software development
  - Code for business logic is centralized
  - Interaction between tiers through well-defined APIs: Can reuse standard components at each tier

Technologies

Client Program
(Web Browser)

HTML
Javascript
XSLT

Application Server
(Tomcat, Apache)

XML, JSP,
Servlets
Cookies, EJB,
XPath, web
services

Database System
(Microsoft SQL Server)

SQL,
Stored
Procedures

Why Database Systems?

Discuss with your neighbor: What functionality is required from database systems in the following application scenarios:

- EBay (www.ebay.com)
- Barnes and Noble (www.bn.com)
- General Motors (www.gm.com)
- The Protein Data Bank (http://www.rcsb.org/pdb)
- Sprint (www.sprint.com)
- Your cell phone

Why Store Data in a DBMS?

- Benefits
  - Transactions (concurrent data access, recovery from system crashes)
  - High-level abstractions for data access, manipulation, and administration
  - Data integrity and security
  - Performance and scalability

Digression – What Is a Transaction?

The execution of a program that performs a function by accessing a database.

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.

Transactions

- A transaction is an atomic sequence of actions
- Each transaction must leave the system in a consistent state (if system is consistent when the transaction starts).
- The ACID Properties:
  - Atomicity
  - Consistency
  - Isolation
  - Durability

Example Transaction: Online Store

Your purchase transaction:

- Atomicity: Either the complete purchase happens, or nothing
- Consistency: The inventory and internal accounts are updated correctly
- Isolation: It does not matter whether other customers are also currently making a purchase
- Durability: Once you have received the order confirmation number, your order information is permanent, even if the site crashes

Transactions (Contd.)

A transaction will *commit* after completing all its actions, or it could *abort* (or be aborted by the DBMS) after executing some actions.

Example Transaction: ATM

You withdraw money from the ATM machine

- Atomicity
- Consistency
- Isolation
- Durability

Commit versus Abort?

What are reasons for commit or abort?

Transactions: Examples

Give examples of transactions in the following applications. Which of the ACID properties are needed?

- EBay (www.ebay.com)
- Barnes and Noble (www.bn.com)
- General Motors (www.gm.com)
- The Protein Data Bank (http://www.rcsb.org/pdb)
- Sprint (www.sprint.com)
- Your cell phone

What Makes Transaction Processing Hard

- Reliability - system should rarely fail
- Availability - system must be up all the time
- Response time - within a few 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

Reliability and Availability

- Reliability - system should rarely fail
- Availability - system must be up all the time

Downtime	Availability
1 hour/day	95.8%
1 hour/week	99.41%
1 hour/month	99.86%
1 hour/year	99.9886%
1 minute/day	99.9988%
1 hour/20years	99.99942%
1 minute/week	99.99983%

Performance

- Response time - within 1-2 seconds
- Throughput - thousands of transactions/second
- Scalability - start small, ramp up to Internet-scale

What Makes TP Important?

- It is 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 is 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

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

Concurrency Control for Isolation

(Start: A=$100; B=$100)

Consider two transactions:

- T1: START, A=A+100, B=B-100, COMMIT
- T2: START, A=1.06*A, B=1.06*B, COMMIT

The first transaction is transferring $100 from B's account to A's account. The second transaction is crediting both accounts with a 6% interest payment.

Database systems try to do as many operations concurrently as possible, to increase performance.

Example (Contd.)

(Start: A=$100; B=$100)

- Consider a possible interleaving (schedule):

T1: A=A+$100, B=B-$100 COMMIT
T2: A=1.06*A, B=1.06*B COMMIT
End result: A=$106; B=$0

- Another possible interleaving:

T1: A=A+100, B=B-100 COMMIT
T2: A=1.06*A, B=1.06*B COMMIT
End result: A=$112; B=$6

The second interleaving is incorrect! Concurrency control of a database system makes sure that the second schedule does not

Ensuring Atomicity

- DBMS ensures atomicity (all-or-nothing property) even if the system crashes in the middle of a transaction.
- Idea: Keep a log (history) of all actions carried out by the DBMS while executing :
  - Before a change is made to the database, the corresponding log entry is forced to a safe location.
  - After a crash, the effects of partially executed transactions are undone using the log.

Recovery

- A DBMS logs all elementary events on stable storage. This data is called the log.
- The log contains everything that changes data: Inserts, updates, and deletes.
- Reasons for logging:
  - Need to UNDO transactions
  - Recover from a systems crash

Recovery: Example

(Simplified process)

- Insert customer data into the database
- Check order availability
- Insert order data into the database
- Write recovery data (the log) to stable storage
- Return order confirmation number to the customer

Why Store Data in a DBMS?

- Benefits
  - Transactions (concurrent data access, recovery from system crashes)
  - High-level abstractions for data access, manipulation, and administration
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  - Performance and scalability

Data Model

- A data model is a collection of concepts for describing data.
- Examples:
  - ER model (used for conceptual modeling)
  - Relational model, object-oriented model, object-relational model (actually implemented in current DBMS)

The Relational Data Model

A relational database is a set of relations. Turing Award ("Nobel Prize" in CS) for Codd in 1980 for his work on the relational model

- Example relation:

  Customers(cid: integer, name: string, byear: integer, state: string)

cid	name	byear	state
1	Jones	1960	NY
2	Smith	1974	CA
3	Smith	1950	NY

The Relational Model: Terminology

- Relation instance and schema
- Field (column)
- Record or tuple (row)
- Cardinality

cid	name	byear	state
1	Jones	1960	NY
2	Smith	1974	CA
3	Smith	1950	NY

Customer Relation (Contd.)

- In your enterprise, you are more likely to have a schema similar to the following:

  Customers(cid, identifier, nameType, salutation, firstName, middleNames, lastName, culturalGreetingStyle, gender, customerType, degrees, ethnicity, companyName, departmentName, jobTitle, primaryPhone, primaryFax, email, website, building, floor, mailstop, addressType, streetNumber, streetName, streetDirection, POBox, city, state, zipCode, region, country, assembledAddressBlock, currency, maritalStatus, bYear, profession)

Product Relation

- Relation schema:
  Products(pid: integer, pname: string, price: float, category: string)
- Relation instance:

pid	pname	price	category
1	Intel PIII-700	300.00	hardware
2	MS Office Pro	500.00	software
3	IBM DB2	5000.00	software
4	Thinkpad 600E	5000.00	hardware

Transaction Relation

- Relation schema:
  Transactions(
    tid: integer,
    tdate: date,
    cid: integer,
    pid: integer)

- Relation instance:

tid	tdate	cid	pid
1	1/ 1/ 2000	1	1
1	1/ 1/ 2000	1	2
2	1/ 1/ 2000	1	4
3	2/ 1/ 2000	2	3
3	2/ 1/ 2000	2	4

The Object-Oriented Data Model

- Richer data model. Goal: Bridge impedance mismatch between programming languages and the database system.
- Example components of the data model: Relationships between objects directly as pointers.
- Result: Can store abstract data types directly in the DBMS
  - Pictures
  - Geographic coordinates
  - Movies
  - CAD objects

Object-Oriented DBMS

- Advantages: Engineering applications (CAD and CAM and CASE computer aided software engineering), multimedia applications.
- Disadvantages:
  - Technology not as mature as relational DMBS
  - Not suitable for decision support, weak security
  - Vendors are much smaller companies and their financial stability is questionable.

Object-Oriented DBMS (Contd.)

Vendors:

- Gemstone (www.gemstone.com)
- Objectivity (www.objy.com)
- ObjectStore (www.objectstore.net)
- POET (www.poet.com)
- Versant (www.versant.com, merged with POET)

Organizations:

- OMG: Object Management Group (www.omg.org)

Object-Relational DBMS

- Mixture between the object-oriented and the object-relational data model
  - Combines ease of querying with ability to store abstract data types
  - Conceptually, the relational model, but every field
- All major relational vendors are currently extending their relational DBMS to the object-relational model

Query Languages

We need a high-level language to describe and manipulate the data

Requirements:

- Precise semantics
- Easy integration into applications written in C++/Java/Visual Basic/etc.
- Easy to learn
- DBMS needs to be able to efficiently evaluate queries written in the language

Relational Query Languages

- The relational model supports simple, powerful querying of data.
  - Precise semantics for relational queries
  - Efficient execution of queries by the DBMS
  - Independent of physical storage

SQL: Structured Query Language

- Developed by IBM (System R) in the 1970s
- ANSI standard since 1986:
  - SQL-86
  - SQL-89 (minor revision)
  - SQL-92 (major revision, current standard)
  - SQL-99 (major extensions)
- More about SQL in the next lecture

Example Query

- Example Schema:
  Customers(
      cid: integer,
      name: string,
      byear: integer,
      state: string)

cid	name	byear	state
1	Jones	1960	NY
2	Smith	1974	CA
3	Smith	1950	NY

- Query:
  SELECT
      Customers.cid,
  Customers.name,
      Customers.byear,
  Customers.state
  FROM Customers
  WHERE Customers.cid = 3

cid	name	byear	state
3	Smith	1950	NY

Example Query

SELECT
  Customers.cid,
  Customers.name,
  Customers.byear,
  Customers.state

FROM Customers

WHERE
  Customers.cid = 1

cid	name	byear	state
1	Jones	1960	NY
2	Smith	1974	CA
3	Smith	1950	NY

cid	name	byear	state
1	Jones	1960	NY

Why Store Data in a DBMS?

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  - Transactions (concurrent data access, recovery from system crashes)
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  - Performance and scalability

Integrity Constraints

- Integrity Constraints (ICs): Condition that must be true for any instance of the database.
  - ICs are specified when schema is defined.
  - ICs are checked when relations are modified.
  - A legal instance of a relation is one that satisfies all specified ICs.
  - DBMS should only allow legal instances.
- Example: Domain constraints.

Primary Key Constraints

- A set of fields is a superkey for a relation if no two distinct tuples can have same values in all key fields.
- A set of fields is a key if the set is a superkey, and none of its subsets is a superkey.
- Example:
  - {cid, name} is a superkey for Customers
  - {cid} is a key for Customers
- Where do primary key constraints come from?

Primary Key Constraints (Contd.)

- Can there be more than one key for a relation?
- What is the maximum number of superkeys for a relation with k fields?

Where do ICs Come From?

- ICs are based upon the semantics of the real-world enterprise that is being described in the database relations.
- We can check a database instance to see if an IC is violated, but we can NEVER infer that an IC is true by looking at an instance.
  - An IC is a statement about all possible instances!
  - From example, we know state cannot be a key, but the assertion that cid is a key is given to us.
- Key and foreign key ICs are very common; a DBMS supports more general ICs.

Security

- Secrecy: Users should not be able to see things they are not supposed to.
  - E.g., A student can't see other students' grades.
- Integrity: Users should not be able to modify things they are not supposed to.
  - E.g., Only instructors can assign grades.
- Availability: Users should be able to see and modify things they are allowed to.

Why Store Data in a DBMS?

- Benefits
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  - High-level abstractions for data access, manipulation, and administration
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DBMS and Performance

- Efficient implementation of all database operations
- Indexes: Auxiliary structures that allow fast access to the portion of data that a query is about
- Smart buffer management
- Query optimization: Finds the best way to execute a query
- Automatic high-performance concurrent query execution, query parallelization

Summary Of DBMS Benefits

- Transactions
  - ACID properties, concurrency control, recovery
- High-level abstractions for data access
  - Data models
- Data integrity and security
  - Key constraints, foreign key constraints, access control
- Performance and scalability
  - Parallel DBMS, distributed DBMS, performance tuning