College of Information Studies
University of Maryland Hornbake Library Building College Park, MD 20742-4345

# Relational Databases

Week 13

LBSC 671

Creating Information Infrastructures

# Databases

- Database
  - Collection of data, organized to support access
  - Models some aspects of reality

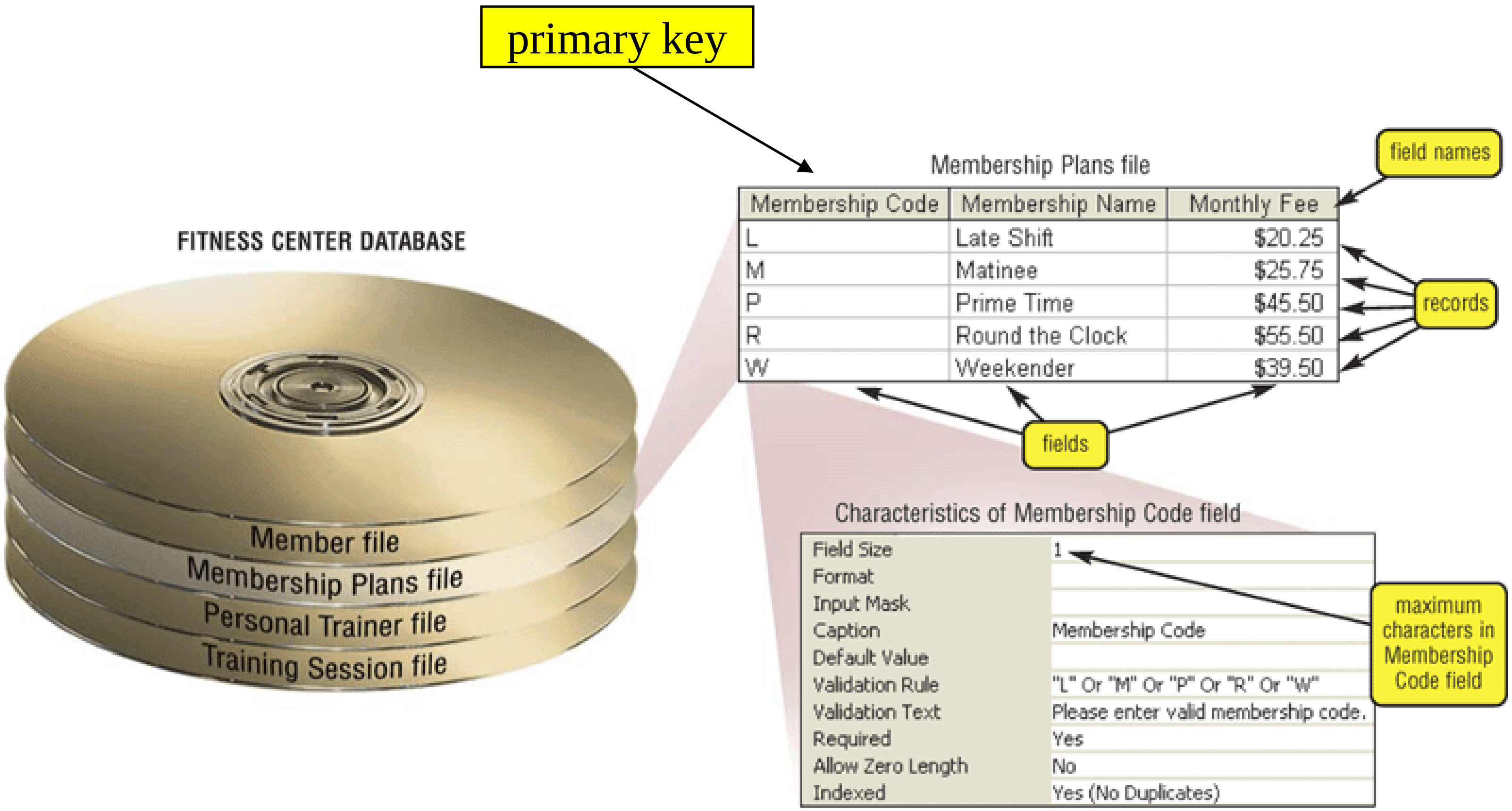
- DataBase Management System (DBMS)
  - Software to create and access databases

- Relational Algebra
  - Special-purpose programming language

# Structured Information

- Field An “atomic” unit of data
  - number, string, true/false, …
- Record A collection of related fields
- Table A collection of related records
  - Each record is one row in the table
  - Each field is one column in the table
- Primary Key The field that identifies a record
  - Values of a primary key must be unique
- Database A collection of tables

# A Simple Example



# Registrar Example

- Which students are in which courses?
- What do we need to know about the students?
  - first name, last name, email, department
- What do we need to know about the courses?
  - course ID, description, enrolled students, grades

# A “Flat File” Solution

| Student ID | Last Name | First Name | Department ID | Departmen | Course ID | Course description | Grades | email |
|---|---|---|---|---|---|---|---|---|
| 1 | Arrows | John | EE | EE | lbsc690 | Information Technology | 90 | jarrows@wam |
| 1 | Arrows | John | EE | Elec Engin | ee750 | Communication | 95 | ja_2002@yahoo |
| 2 | Peters | Kathy | HIST | HIST | lbsc690 | Informatino Technology | 95 | kpeters2@wam |
| 2 | Peters | Kathy | HIST | history | hist405 | American History | 80 | kpeters2@wma |
| 3 | Smith | Chris | HIST | history | hist405 | American History | 90 | smith2002@glue |
| 4 | Smith | John | CLIS | Info Sci | lbsc690 | Information Technology | 98 | js03@wam |

Discussion Topic

Why is this a bad approach?

# Goals of “Normalization”

- Save space
  - Save each fact only once
- More rapid updates
  - Every fact only needs to be updated once
- More rapid search
  - Finding something once is good enough
- Avoid inconsistency
  - Changing data once changes it everywhere

# Relational Algebra

- Tables represent "relations"
  - Course, course description
  - Name, email address, department
- Named fields represent "attributes"
- Each row in the table is called a "tuple"
  - The order of the rows is not important
- Queries specify desired conditions
  - The DBMS then finds data that satisfies them

# A Normalized Relational Database

## Student Table

| Student ID | Last Name | First Name | Department ID | email |
|---|---|---|---|---|
| 1 | Arrows | John | EE | jarrows@wam |
| 2 | Peters | Kathy | HIST | kpeters2@wam |
| 3 | Smith | Chris | HIST | smith2002@glue |
| 4 | Smith | John | CLIS | js03@wam |

## Department Table

| Department ID | Department |
|---|---|
| EE | Electronic Engineering |
| HIST | History |
| CLIS | Information Stuides |

## Course Table

| Course ID | Course Description |
|---|---|
| lbsc690 | Information Technology |
| ee750 | Communication |
| hist405 | American History |

## Enrollment Table

| Student ID | Course ID | Grades |
|---|---|---|
| 1 | lbsc690 | 90 |
| 1 | ee750 | 95 |
| 2 | lbsc690 | 95 |
| 2 | hist405 | 80 |
| 3 | hist405 | 90 |
| 4 | lbsc690 | 98 |

# Approaches to Normalization

- For simple problems (like the homework)
  - Start with “binary relationships”
    - Pairs of fields that are related
  - Group together wherever possible
  - Add keys where necessary

- For more complicated problems
  - Entity relationship modeling (LBSC 670)

# Example of Join

Student Table

| Student ID | Last Name | First Name | Department ID | email |
|---|---|---|---|---|
| 1 | Arrows | John | EE | jarrows@wam |
| 2 | Peters | Kathy | HIST | kpeters2@wam |
| 3 | Smith | Chris | HIST | smith2002@glue |
| 4 | Smith | John | CLIS | js03@wam |

Department Table

| Department ID | Department |
|---|---|
| EE | Electronic Engineering |
| HIST | History |
| CLIS | Information Stuides |

"Joined" Table

| Student ID | Last Name | First Name | Department ID | Department | email |
|---|---|---|---|---|---|
| 1 | Arrows | John | EE | Electronic Engineering | jarrows@wam |
| 2 | Peters | Kathy | HIST | History | kpeters2@wam |
| 3 | Smith | Chris | HIST | History | smith2002@glue |
| 4 | Smith | John | CLIS | Information Stuides | js03@wam |

# Problems with Join

- Data modeling for join is complex
  - Useful to start with E-R modeling
- Join are expensive to compute
  - Both in time and storage space
- But it is joins that make databases relational
  - Projection and restriction also used in flat files

# Some Lingo

- "Primary Key" uniquely identifies a record
  - e.g. student ID in the student table
- "Compound" primary key
  - Synthesize a primary key with a combination of fields
  - e.g., Student ID + Course ID in the enrollment table
- "Foreign Key" is primary key in the <u>other</u> table
  - Note: it need not be unique in <u>this</u> table

# Project

New Table

| Student ID | Last Name | First Name | Department ID | Department | email |
|---|---|---|---|---|---|
| 1 | Arrows | John | EE | Electronic Engineering | jarrows@wam |
| 2 | Peters | Kathy | HIST | History | kpeters2@wam |
| 3 | Smith | Chris | HIST | History | smith2002@glue |
| 4 | Smith | John | CLIS | Information Stuides | js03@wam |

SELECT Student ID, Department

| Student ID | Department |
|---|---|
| 1 | Electronic Engineering |
| 2 | History |
| 3 | History |
| 4 | Information Stuides |

# Restrict

New Table

| Student ID | Last Name | First Name | Department ID | Department | email |
|---|---|---|---|---|---|
| 1 | Arrows | John | EE | Electronic Engineering | jarrows@wam |
| 2 | Peters | Kathy | HIST | History | kpeters2@wam |
| 3 | Smith | Chris | HIST | History | smith2002@glue |
| 4 | Smith | John | CLIS | Information Stuides | js03@wam |

WHERE Department ID = “HIST”

| Student ID | Last Name | First Name | Department ID | Department | email |
|---|---|---|---|---|---|
| 2 | Peters | Kathy | HIST | History | kpeters2@wam |
| 3 | Smith | Chris | HIST | History | smith2002@glue |

# The SELECT Command

- Project chooses columns
  - Based on their label
- Restrict chooses rows
  - Based on their contents
    - e.g. department ID = “HIST”
- These can be specified together
  - SELECT Student ID, Dept WHERE Dept = “History”

# Restrict Operators

- Each SELECT contains a single WHERE
- Numeric comparison
  - <, >, =, <>, …
    - e.g., grade<80
- Boolean operations
  - e.g., Name = "John" AND Dept <> "HIST"

# Using Microsoft Access

- Create a database called M:\rides.mdb
  - File->New->Blank Database
- Specify the fields (columns)
  - "Create a Table in Design View"
- Fill in the records (rows)
  - Double-click on the icon for the table

# Creating Fields

- Enter field name
  - Must be unique, but only within the same table
- Select field type from a menu
  - Use date/time for times
  - Use text for phone numbers
- Designate primary key (right mouse button)
- Save the table
  - That's when you get to assign a table name

# Entering Data

- Open the table
  - Double-click on the icon
- Enter new data in the bottom row
  - A new (blank) bottom row will appear
- Close the table
  - No need to “save” – data is stored automatically

# Building Queries

- Copy ride.mdb to your M:\ drive
- “Create Query in Design View”
  - In “Queries”
- Choose two tables, Flight and Company
- Pick each field you need using the menus
  - Unclick “show” to <u>not</u> project
  - Enter a criterion to “restrict”
- Save, exit, and reselect to run the query

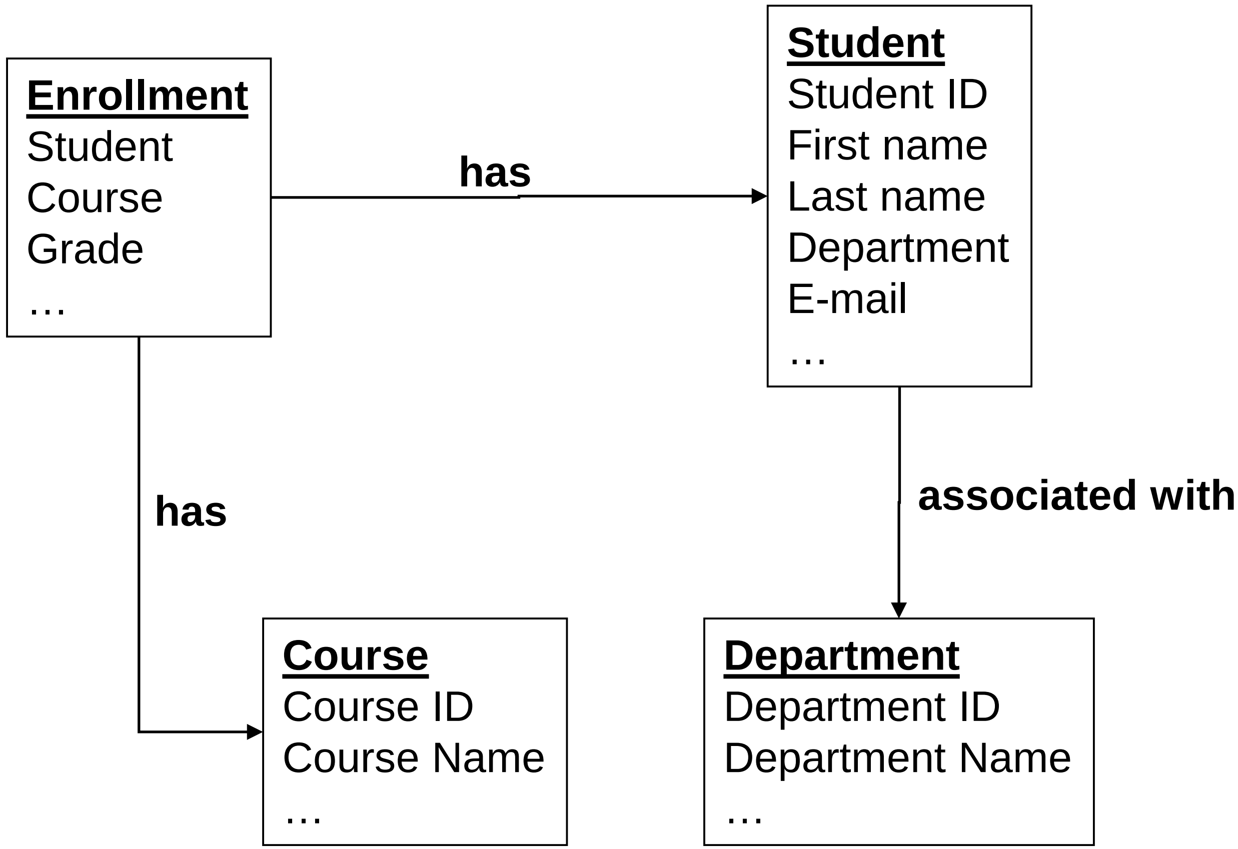
# Some Details About Access

- Joins are automatic if field names are same
  - Otherwise, drag a line between the fields
- Sort order is easy to specify
  - Use the menu
- Queries form the basis for reports
  - Reports give good control over layout
  - Use the report wizard - the formats are complex
- Forms manage input better than raw tables
  - Invalid data can be identified when input
  - Graphics can be incorporated

# Entity-Relationship Diagrams

- Graphical visualization of the data model
- Entities are captured in boxes
- Relationships are captured using arrows

# Registrar ER Diagram



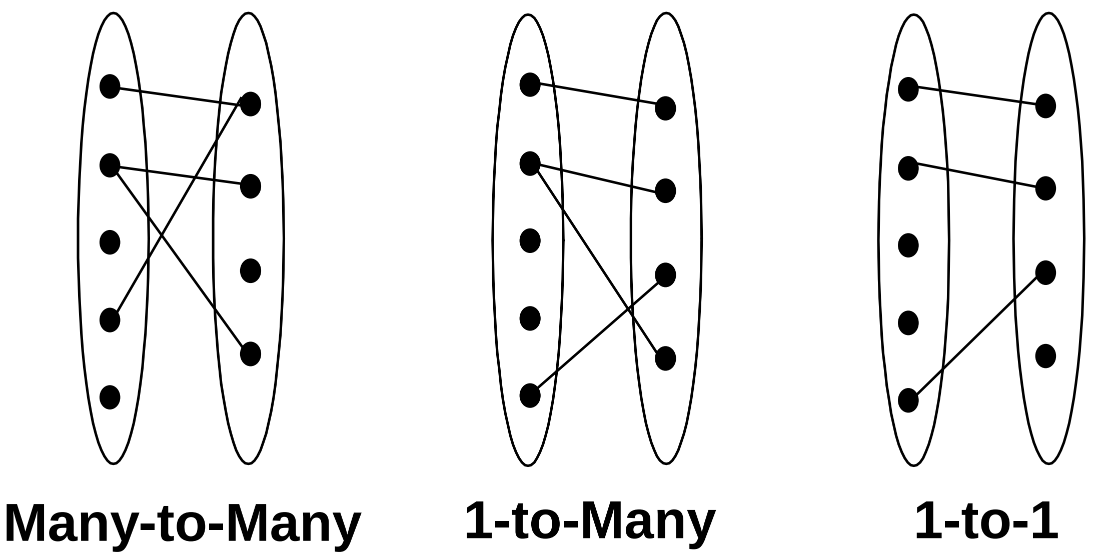
# Getting Started with E-R Modeling

- What **questions** must you answer?
- What **data** is needed to generate the answers?
  - Entities
    - Attributes of those entities
  - Relationships
    - Nature of those relationships
- How will the user interact with the system?
  - Relating the question to the available data
  - Expressing the answer in a useful form

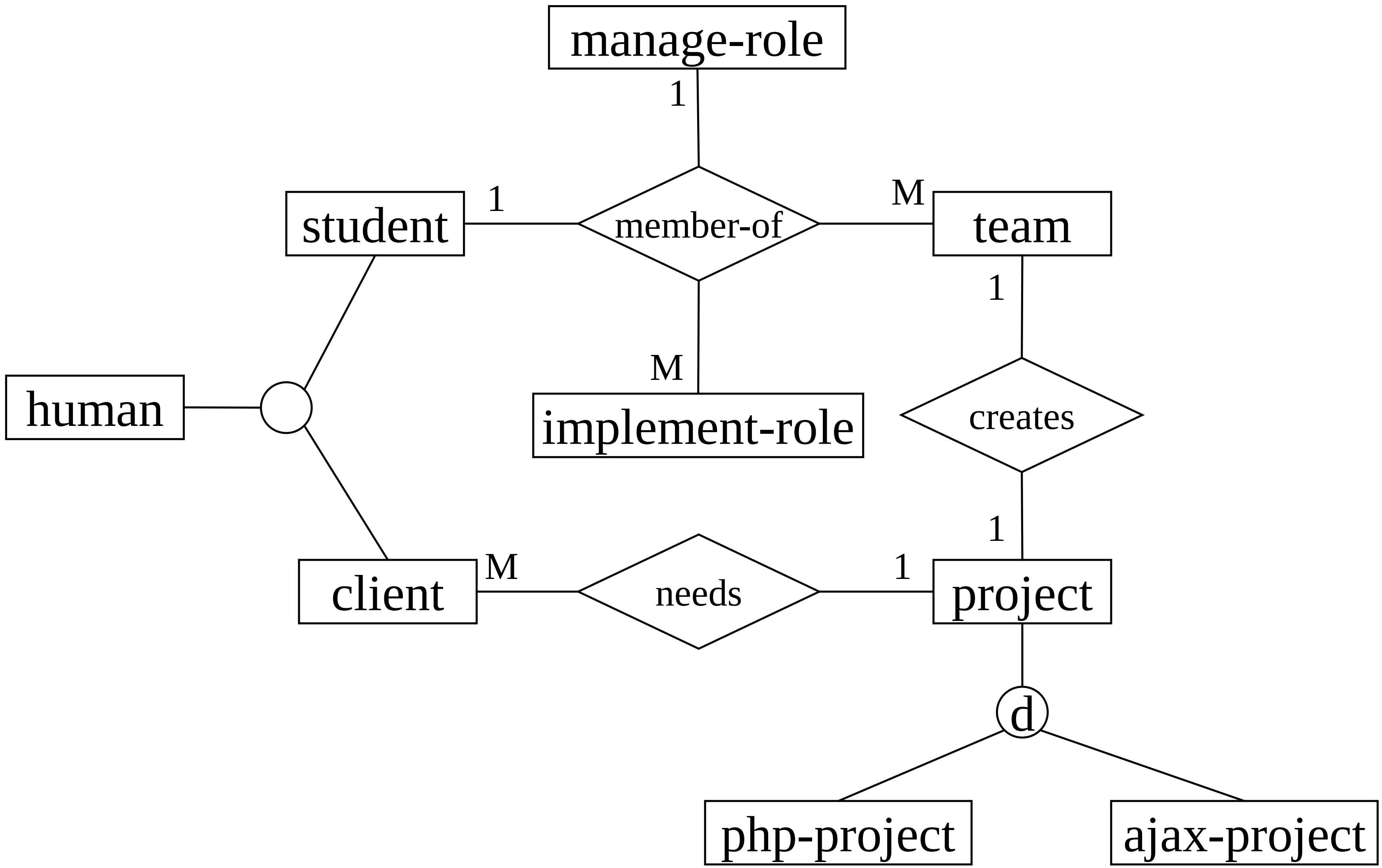
# Components of E-R Diagrams

- Entities
  - Types
    - Subtypes (disjoint / overlapping)
  - Attributes
    - Mandatory / optional
  - Identifier
- Relationships
  - Cardinality
  - Existence
  - Degree

# Types of Relationships



# Project Team E-R Example



# Making Tables from E-R Diagrams

- Pick a primary key for each entity
- Build the tables
  - One per entity
  - Plus one per M:M relationship
  - Choose terse but memorable table and field names
- Check for parsimonious representation
  - Relational “normalization”
  - Redundant storage of computable values
- Implement using a DBMS

# Normalized Table Structure

- Persons: id, fname, lname, userid, password
- Contacts: id, ctype, cstring
- Ctlabels: ctype, string
- Students: id, team, mrole
- Iroles: id, irole
- Rlabels: role, string
- Projects: team, client, pstring

# Normalization

- 1NF: Single-valued indivisible (atomic) attributes
  - Split “Doug Oard” to two attributes as (“Doug”, “Oard”)
  - Model M:M implement-role relationship with a table
- 2NF: Attributes depend on complete primary key
  - (id, impl-role, name)->(id, name)+(id, impl-role)
- 3NF: Attributes depend directly on primary key
  - (id, addr, city, state, zip)->(id, addr, zip)+(zip, city, state)

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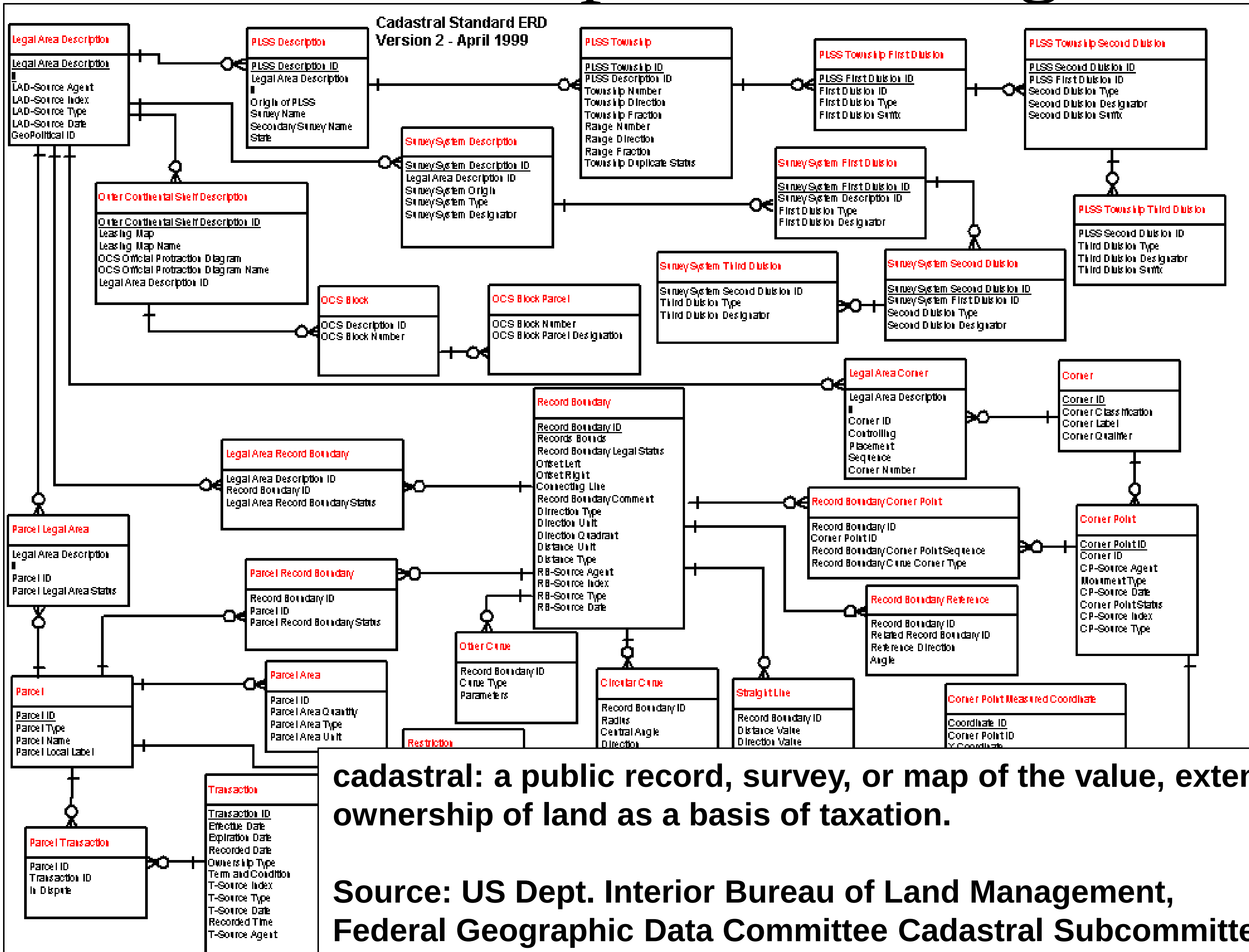
- 4NF: Divide independent M:M tables
  - (id, role, courses) -> (id, role) + (id, courses)
- 5NF: Don’t enumerate derivable combinations

# A More Complex ER Diagram




**cadastral: a public record, survey, or map of the value, extent, and ownership of land as a basis of taxation.**

**Source: US Dept. Interior Bureau of Land Management, Federal Geographic Data Committee Cadastral Subcommittee**
**http://www.fairview-industries.com/standardmodule/cad-erd.htm**

# Database “Programming”

- Natural language
  - Goal is ease of use
    - e.g., Show me the last names of students in CLIS
  - Ambiguity sometimes results in errors

- Structured Query Language (SQL)
  - Consistent, unambiguous interface to any DBMS
  - Simple command structure:
    - e.g., SELECT Last name FROM Students WHERE Dept=CLIS
  - Useful standard for inter-process communications

- Visual programming (e.g., Microsoft Access)
  - Unambiguous, and easier to learn than SQL

# Structured Query Language

DESCRIBE Flight;

**Flight : Table**

| Field Name | Data Type |
|---|---|
| Flight Number | Text |
| Origin | Text |
| Destination | Text |
| Departure Time | Date/Time |
| Arrival Time | Date/Time |
| Available Seats | Number |
| Company Name | Text |
| Price | Currency |

# Structured Query Language

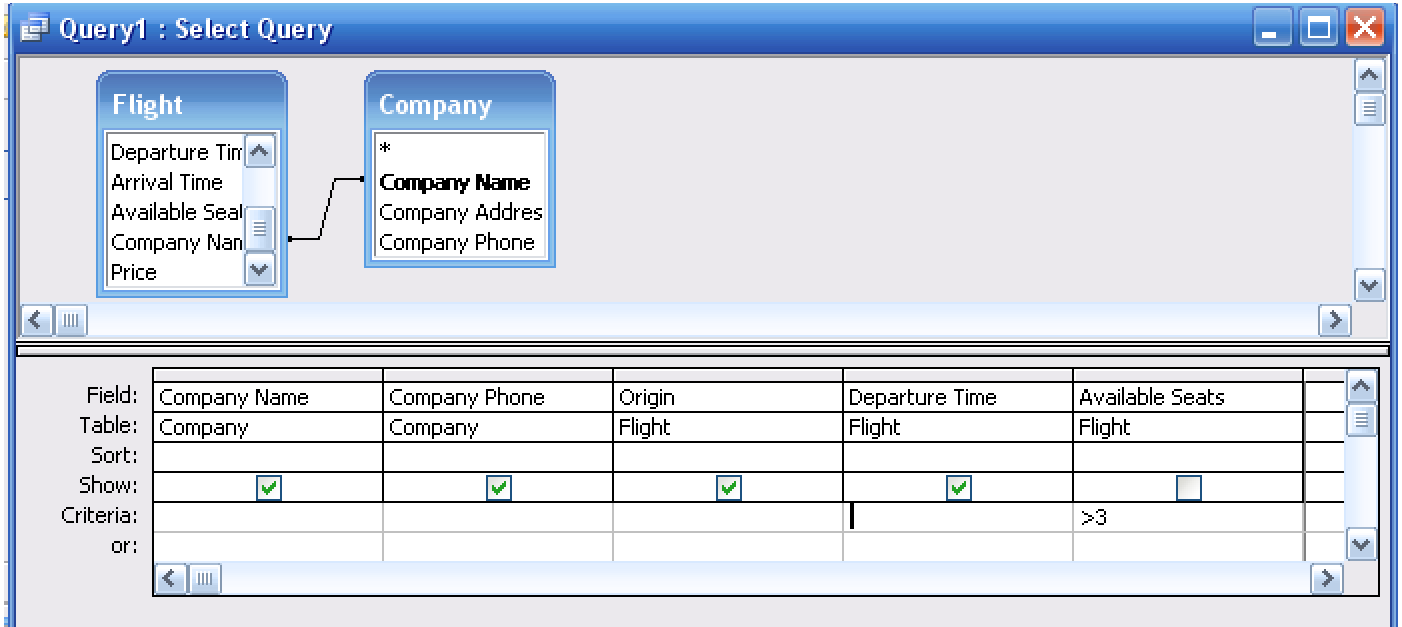
SELECT * FROM Flight;

Flight : Table

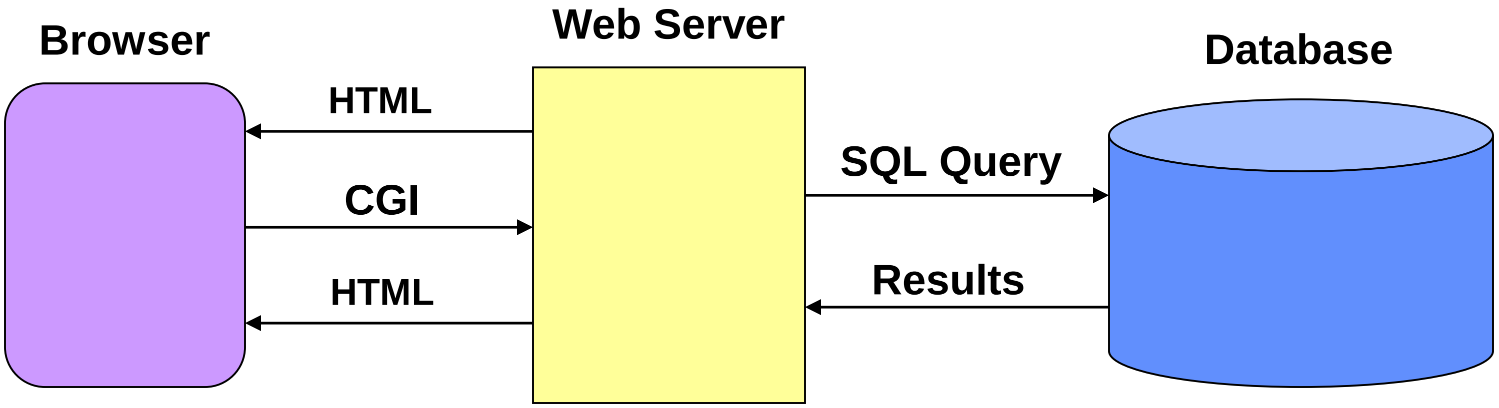
| | Flight Number | Origin | Destination | Departure Time | Arrival Time | Available Seats | Company Name | Price |
|---|---|---|---|---|---|---|---|---|
| ▶ | CA210 | DC | Austin | 6:00:00 AM | 11:00:00 AM | 0 | Cal Air | $200.00 |
| | CA345 | San Jose | San Diego | 9:00:00 AM | 10:30:00 AM | 20 | Cal Air | $100.00 |
| | FT900 | Chicago | New York | 2:00:00 PM | 5:00:00 PM | 1 | Fancy Trans | $200.00 |
| | GJ405 | DC | San Jose | 12:30:00 PM | 8:45:00 PM | 10 | Green Jet | $340.00 |
| | GJ908 | New York | Austin | 8:00:00 AM | 12:00:00 PM | 2 | Green Jet | $250.00 |
| | TP123 | New York | San Jose | 7:00:00 AM | 11:00:00 AM | 2 | Trans Planet | $400.00 |
| * | | | | | | 0 | | $0.00 |

# Structured Query Language

```
SELECT Company.CompanyName, Company.CompanyPhone,
    Flight.Origin, Flight.DepartureTime
FROM Flight,Company
WHERE Flight.CompanyName=Company.CompanyName
  AND Flight.AvailableSeats>3;
```



# Putting the Pieces Together



# Why Database-Generated Pages?

- Remote access to a database
  - Client does not need the database software
- Serve rapidly changing information
  - e.g., Airline reservation systems
- Provide multiple “access points”
  - By subject, by date, by author, …
- Record user responses in the database

# Issues to Consider

- Benefits of Databases
  - Multiple views
  - Data reuse
  - Scalable
  - Access control

- Costs of Databases
  - Formal modeling
  - Complex (learn, design, implement, debug)
  - Brittle (relies on multiple communicating servers)
  - Not crawlable

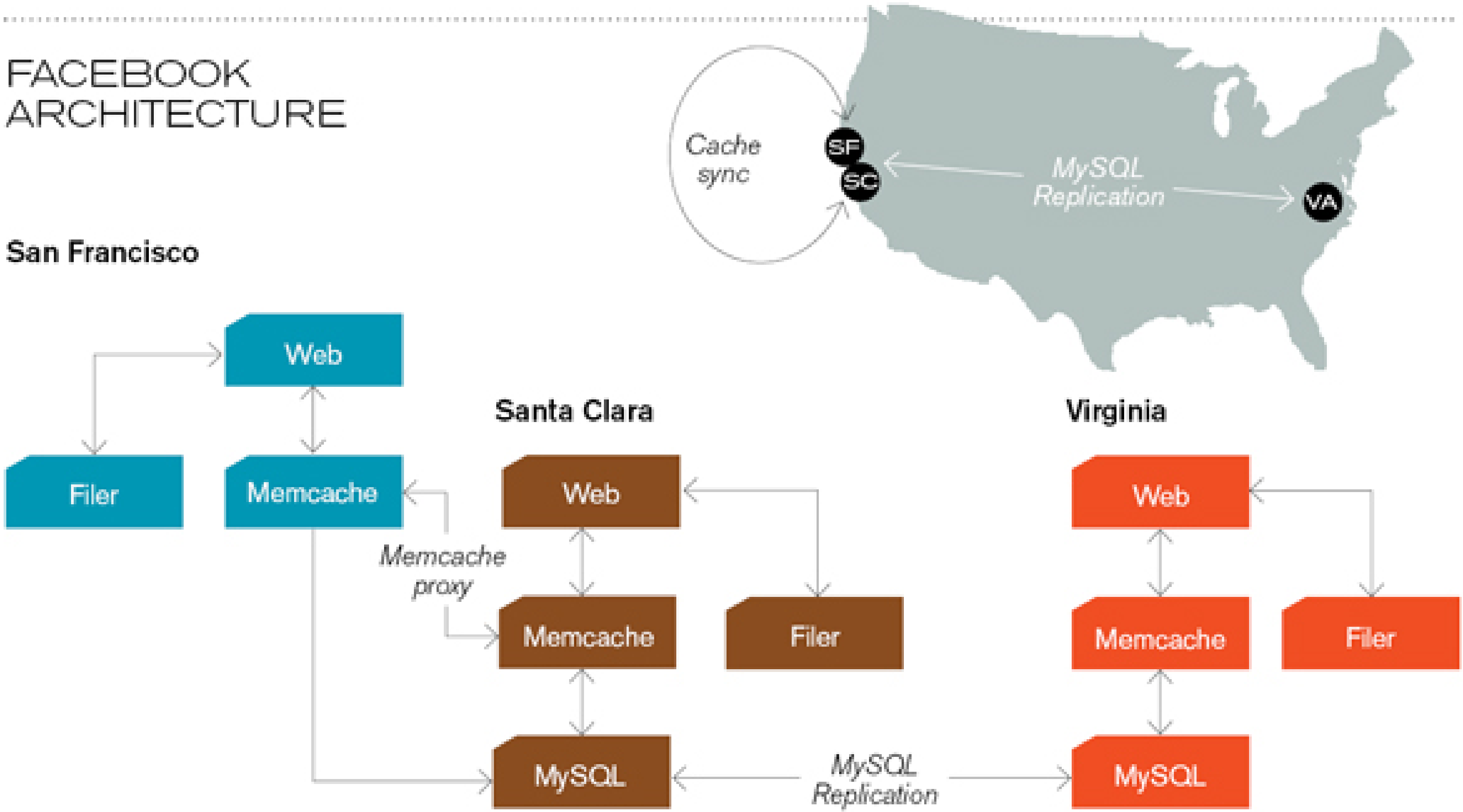
# Key Ideas

- Databases are a good choice when you have
  - Lots of data
  - A problem that contains inherent relationships
- Design before you implement
- Join is the most important concept
  - Project and restrict just remove undesired stuff

# Databases in the Real World

- Some typical database applications:
  - Banking (e.g., saving/checking accounts)
  - Trading (e.g., stocks)
  - Airline reservations

- Characteristics:
  - Lots of data
  - Lots of concurrent access
  - Must have fast access
  - “Mission critical”




**Caching servers:** 15 million requests per second, 95% handled by memcache (15 TB of RAM)

**Database layer:** 800 eight-core Linux servers running MySQL (40 TB user data)

Source: Technology Review (July/August, 2008)

# Database Integrity

- Registrar database must be internally consistent
  - Enrolled students must have an entry in student table
  - Courses must have a name
- What happens:
  - When a student withdraws from the university?
  - When a course is taken off the books?

# Integrity Constraints

- Conditions that must always be true
  - Specified when the database is designed
  - Checked when the database is modified
- RDBMS ensures integrity constraints are respected
  - So database contents remain faithful to real world
  - Helps avoid data entry errors

# Referential Integrity

- Foreign key values must exist in other table
  - If not, those records cannot be joined
- Can be enforced when data is added
  - Associate a primary key with each foreign key
- Helps avoid erroneous data
  - Only need to ensure data quality for primary keys

# Concurrency

- Thought experiment: You and your project partner are editing the same file…
  - Scenario 1: you both save it at the same time
  - Scenario 2: you save first, but before it's done saving, your partner saves

**Whose changes survive?**
**A) Yours B) Partner's C) neither D) both E) ???**

# Concurrency Example

- Possible actions on a checking account
  - Deposit check (read balance, write new balance)
  - Cash check (read balance, write new balance)
- Scenario:
  - Current balance: $500
  - You try to deposit a $50 check and someone tries to cash a $100 check at the same time
  - Possible sequences: (what happens in each case?)

| | | |
|---|---|---|
| **Deposit: read balance** | **Deposit: read balance** | **Deposit: read balance** |
| **Deposit: write balance** | **Cash: read balance** | **Cash: read balance** |
| **Cash: read balance** | **Cash: write balance** | **Deposit: write balance** |
| **Cash: write balance** | **Deposit: write balance** | **Cash: write balance** |

# Database Transactions

- Transaction: sequence of grouped database actions
  - e.g., transfer $500 from checking to savings
- "ACID" properties
  - **Atomicity**
    - All-or-nothing
  - **Consistency**
    - Each transaction must take the DB between consistent states.
  - **Isolation:**
    - Concurrent transactions must appear to run in isolation
  - **Durability**
    - Results of transactions must survive even if systems crash

# Making Transactions

- Idea: keep a log (history) of all actions carried out while executing transactions
  - Before a change is made to the database, the corresponding log entry is forced to a safe location


- Recovering from a crash:
  - Effects of partially executed transactions are undone
  - Effects of committed transactions are redone

# Before You Go

On a sheet of paper, answer the following (ungraded) question (no names, please):

What was the muddiest point in today's class?