CPSC 504 – Background
(aka, all you need to know about databases to prepare for this course in two lectures)

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Administrative notes

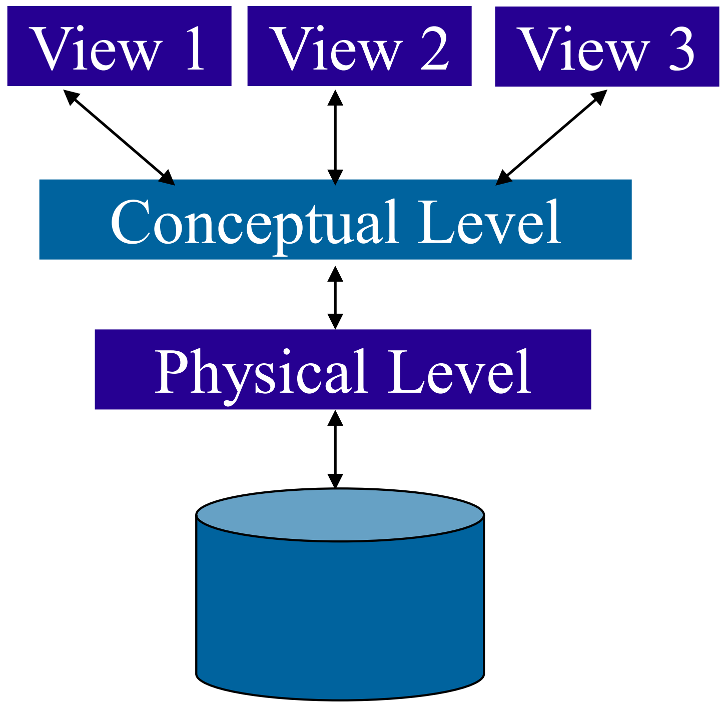
- Don’t forget to sign up for a presentation and a discussion
- Anyone having topics they’d like for student request days should send those to me
- Please sign up for the mailing list (majordomo@cs – “subscribe cpsc504”)
- The homework is on the web, due beginning of class January 24
    - General theory – trying to make sure you understand basics and have thought about it – not looking for one, true, answer.
    - State any assumptions you make
    - If you can’t figure out a detail, write an explanation as to what you did and why.
- Office hours?
- Canvas should be visible to everyone

Overview of the next two classes

- Entity Relationship (ER) diagrams
- Relational databases
- Object Oriented Databases (OODBs)
- XML
- Other data types
- Database internals (Briefly)
- Potpourri

Levels of Abstraction

- A major purpose of a DB management system is to provide an abstract view of the data.
- Three abstraction levels:
  - **Physical level**: how data is actually stored
  - **Conceptual (or Logical) level**: how data is perceived by the users
  - **External (or View) level**: describes part of the database to different users
    - Convenience, security, etc.
  - E.g., views of student, registrar, & database admin.



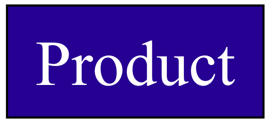
Schema and Instances

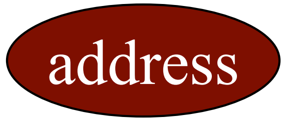
- We'll start with the **schema** – the logical structure of the database (e.g., students take courses)
  - **Conceptual (or logical) schema**: db design at the logical level
  - **Physical schema**: db design at the physical level; indexes, etc.
- Later we'll populate **instances** – content of the database at a particular point in time
  - E.g., currently there are no grades for CPSC 504
- **Physical Data Independence** –ability to modify physical schema without changing logical schema
  - Applications depend on the conceptual schema
- **Logical Data Independence** – Ability to change conceptual scheme without changing applications
  - Provided by views

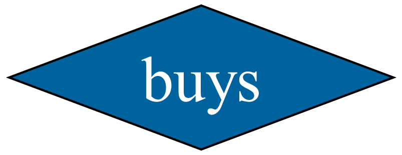
Conceptual Database Design

- What are the entities and relationships involved?
  - Entities are usually nouns, e.g., “course” “prof”
  - Relationships are statements about 2 or more objects. Often, verbs., e.g., “a prof teaches a course”
- What information about these entities and relationships should we store in the database?
- What integrity constraints or other rules hold?
- In relational databases, this is generally created in an **Entity-Relationship (ER) Diagram**

Entity / Relationship Diagrams

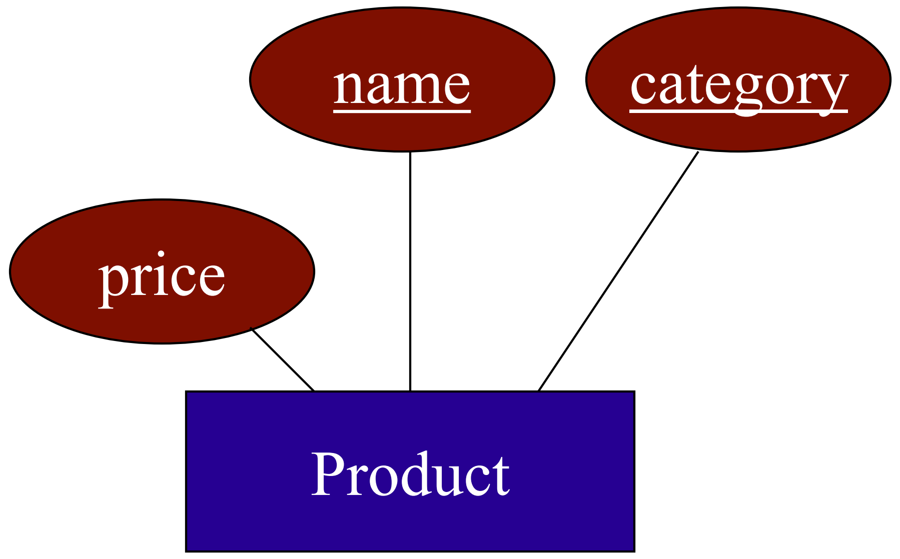
Entities 

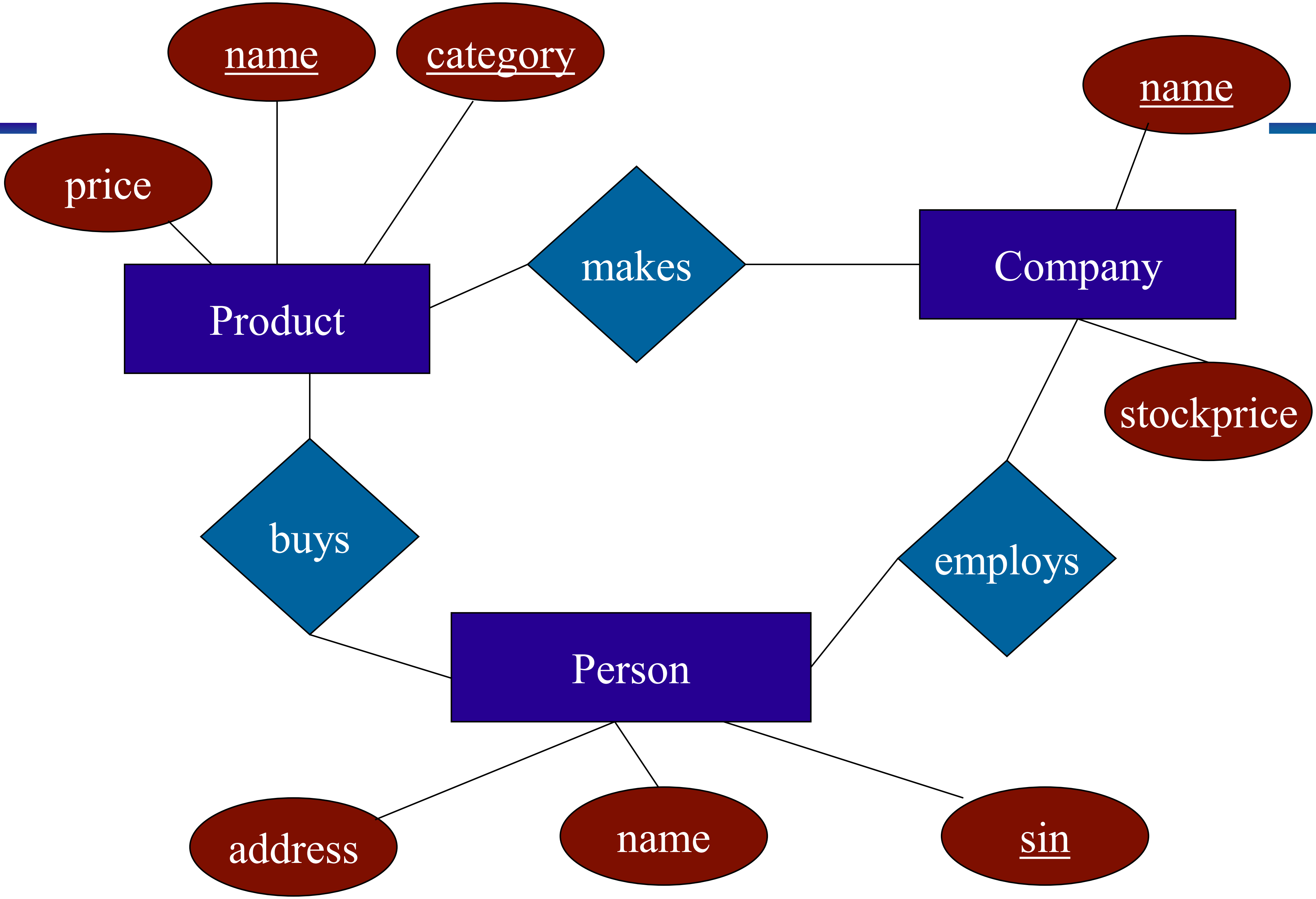
Attributes 

Relationships between entities 

Keys in E/R Diagrams

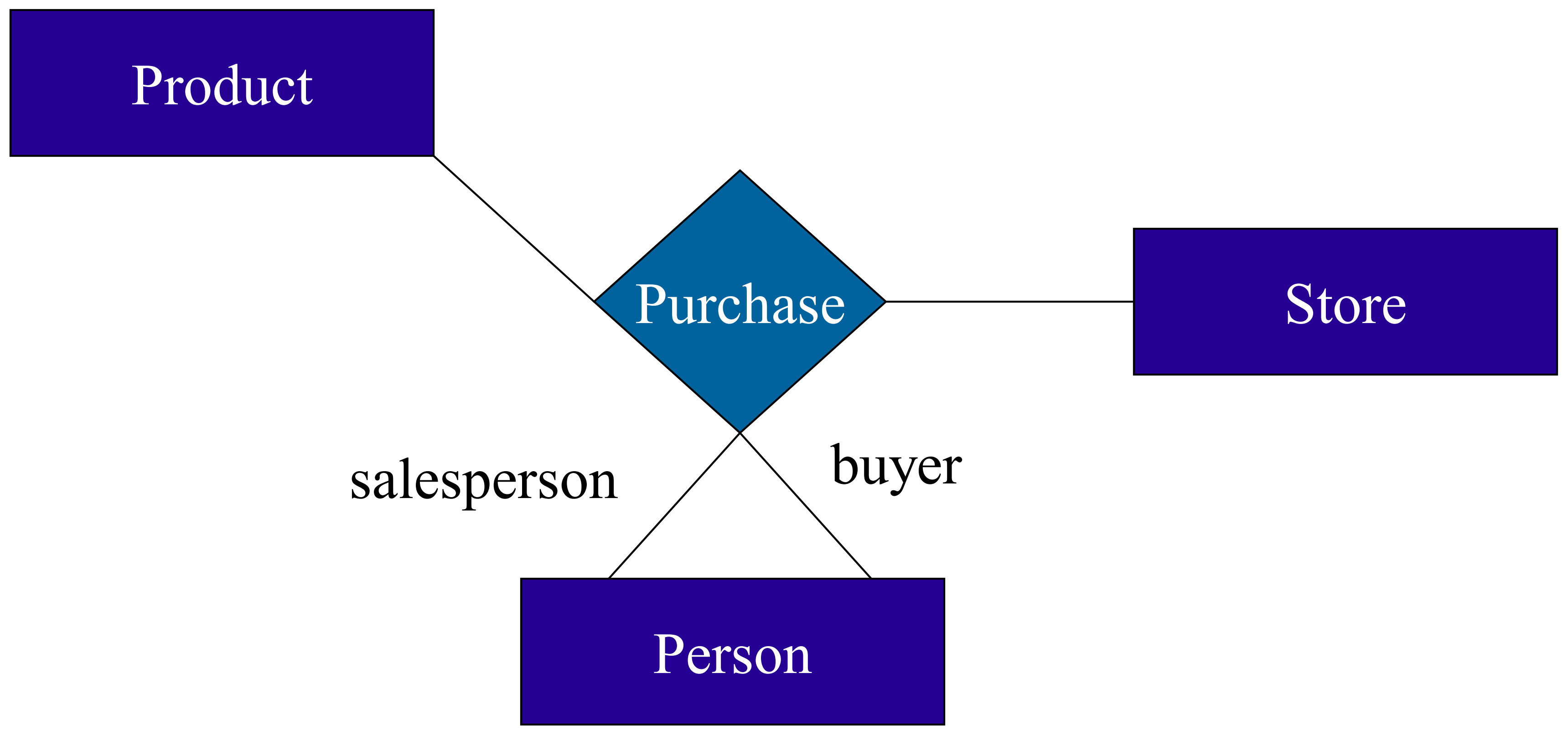
Every entity set must have a key which is identified by an underline



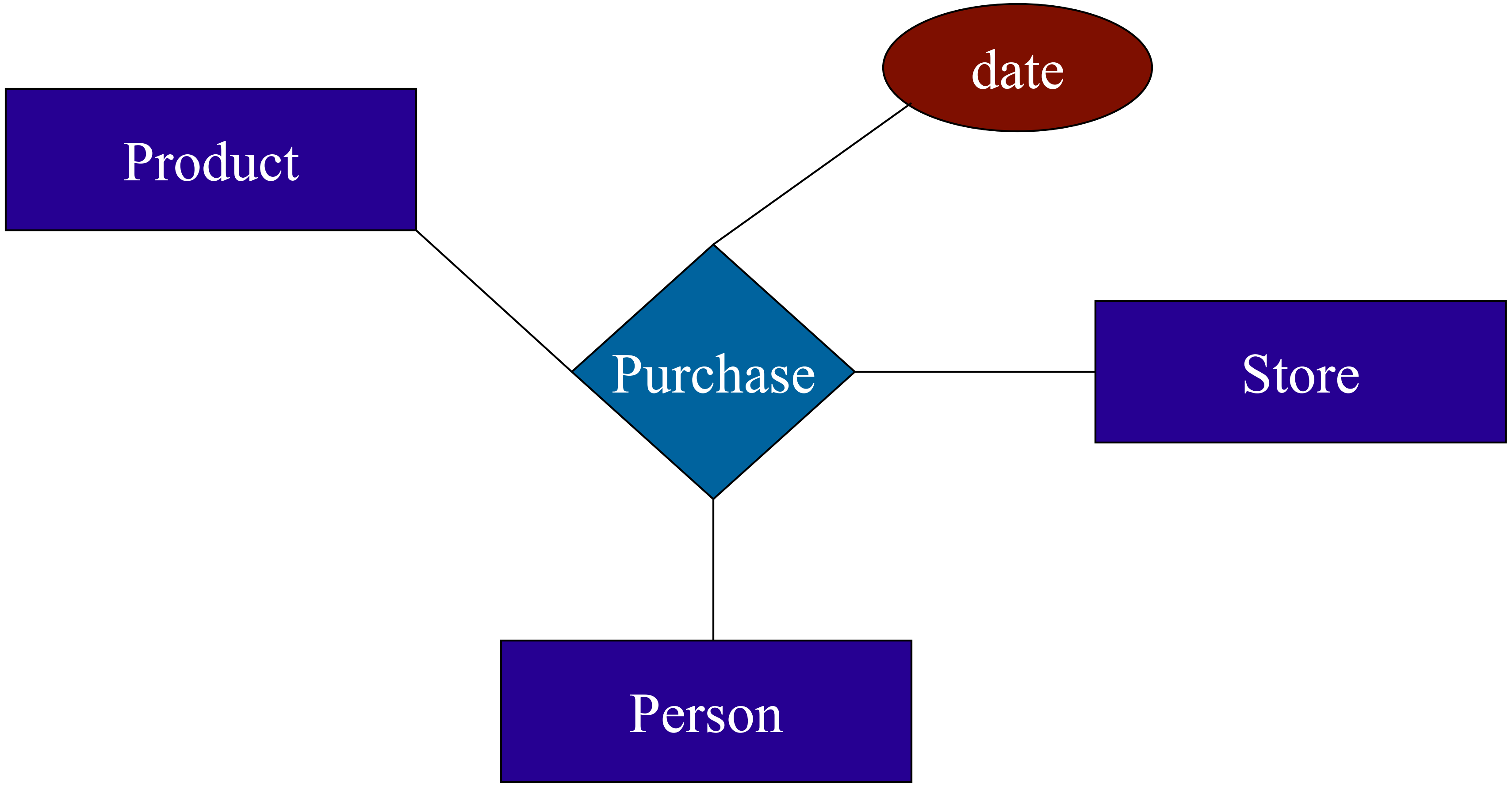

name
category
price
name
Product
makes
Company
stockprice
buys
employs
Person
address
name
sin

Roles in Relationships

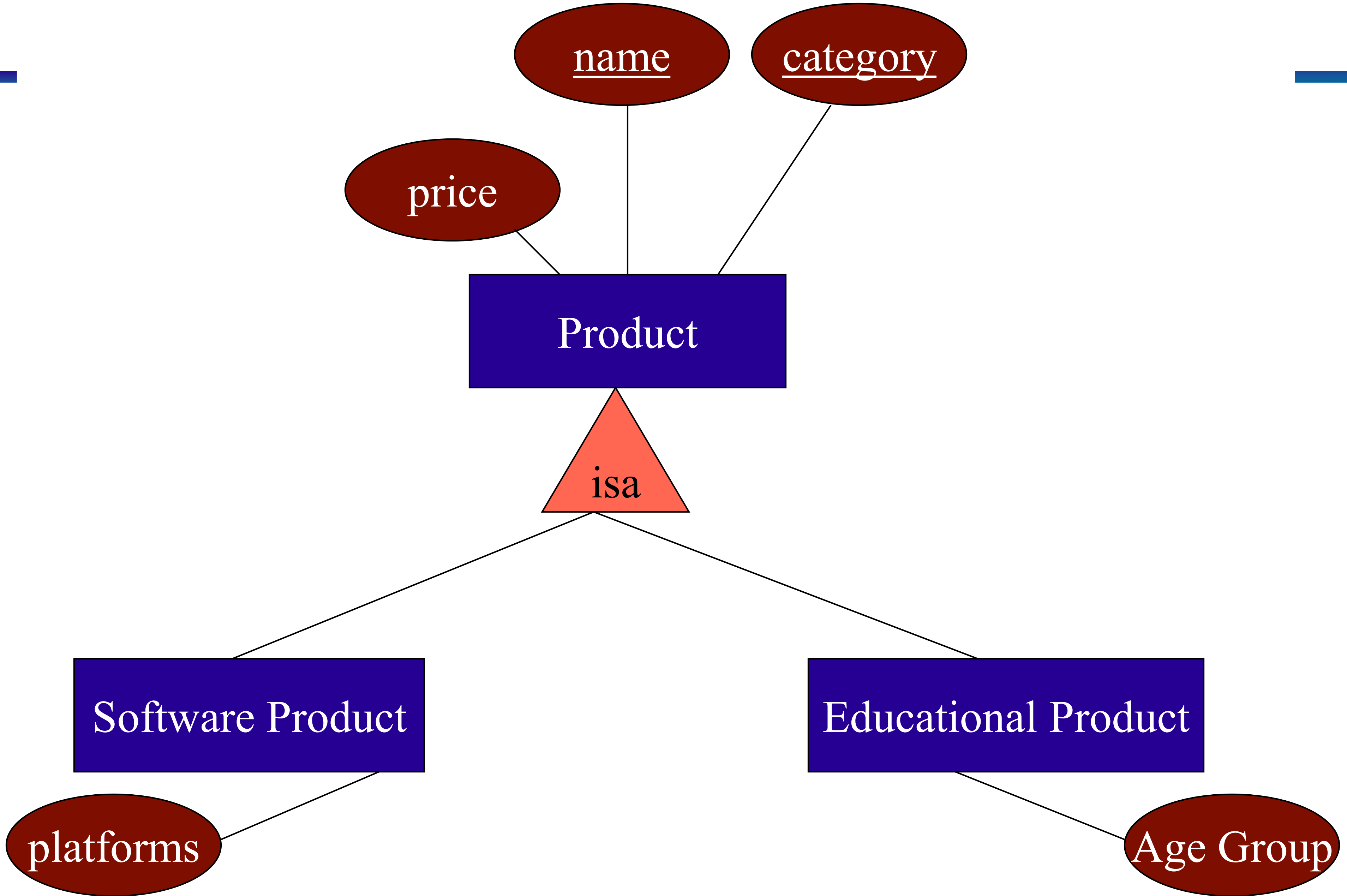
What if we need an entity set twice in one relationship?



Attributes on Relationships



Subclasses in E/R Diagrams



Brief exercise

Take a few minutes to create an ER diagram with the person next to you

Summarizing ER diagrams

- Basics: entities, relationships, and attributes
- Also showed inheritance
- Has things other things like cardinality
  - Arrows mean different things in different versions; details not important for this class.
- Used to design databases...

But how do you store data in them?

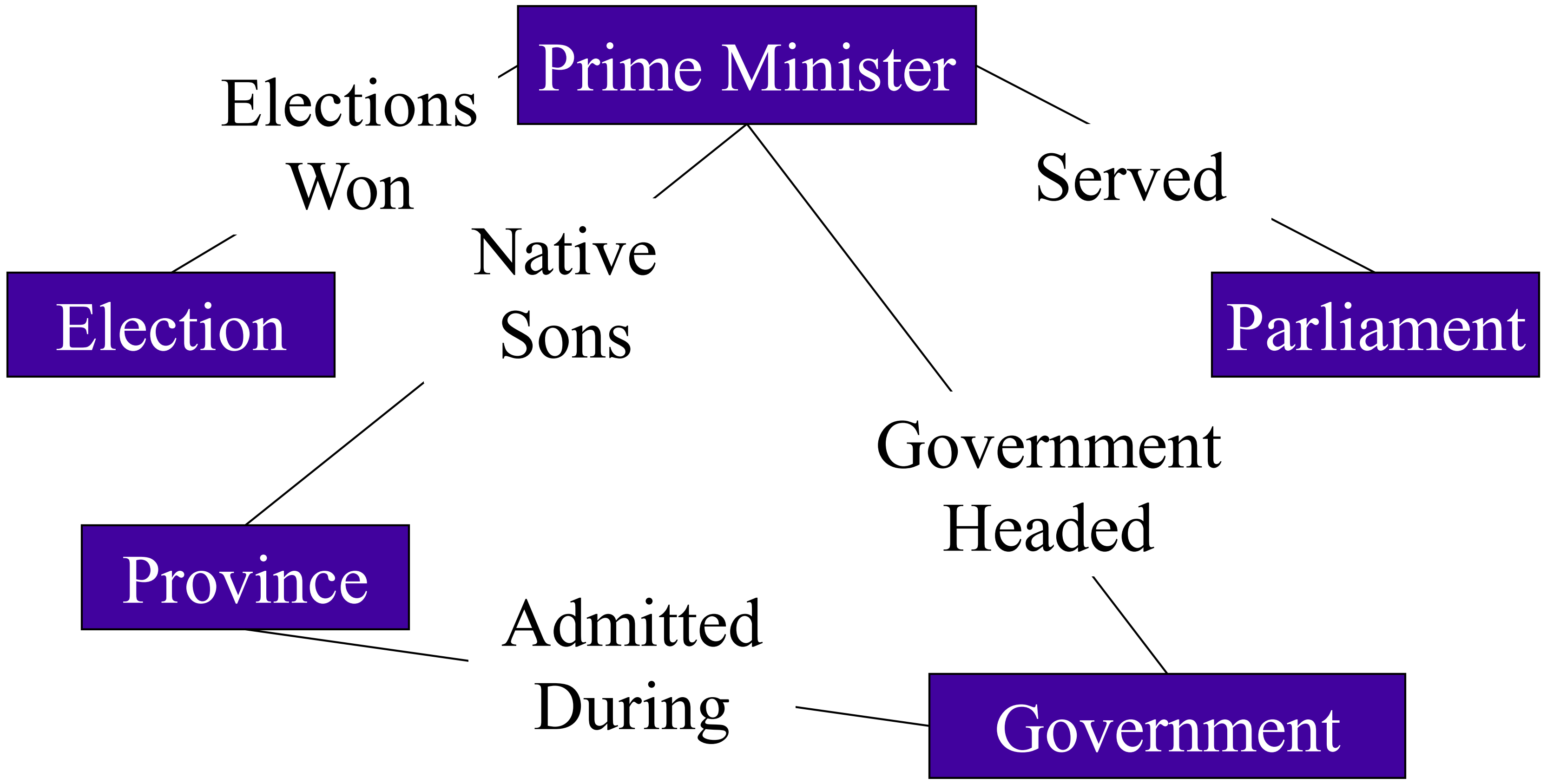
Overview of the next two classes

- Entity Relationship (ER) diagrams
- Relational databases
  - How did we get here?
  - What's in a relational schema?
  - From ER to relational
  - Query Languages
- Object Oriented Databases (OODBs)
- XML
- Other data types
- Database internals (Briefly)
- Potpourri

How did we get the relational model?

- Before the relational model, there were two main contenders
  - Network databases
  - Hierarchical databases
- Network databases had a complex data model
- Hierarchical databases integrated the application in the data model

Example Hierarchical Model

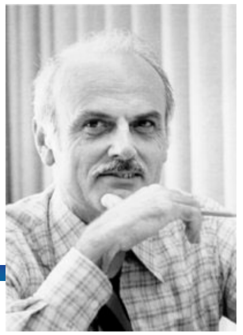


Example IMS (Hierarchical) query: Print the names of all the provinces admitted during a Liberal Government

```
DLITPLI:PROCEDURE (QUERY_PCB) OPTIONS (MAIN);

 DECLARE QUERY_PCB POINTER;
 /*Communication Buffer*/
 DECLARE 1 PCB BASED(QUERY_PCB),
  2 DATA_BASE_NAME CHAR(8),
  2 SEGMENT_LEVEL CHAR(2),
  2 STATUS_CODE CHAR(2),
  2 PROCESSING_OPTIONS CHAR(4),
  2 RESERVED_FOR_DLI FIXED BIRARY(31,0),
  2 SEGMENT_NAME_FEEDBACK CHAR(8)
  2 LENGTH_OF_KEY_FEEDBACK_AREA FIXED BINARY(31,0),
  2 NUMBER_OF_SENSITIVE_SEGMENTS FIXED BINARY(31,0),
  2 KEY_FEEDBACK_AREA CHAR(28);
 /* I/O Buffers*/
 DECLARE PRES_IO_AREA CHAR(65),
  1 PRESIDENT DEFINED PRES_IO_AREA,
  2 PRES_NUMBER CHAR(4),
  2 PRES_NAME CHAR(20),
  2 BIRTHDATE CHAR(8)
  2 DEATH_DATE CHAR(8),
  2 PARTY CHAR(10),
  2 SPOUSE CHAR(15);
 DECLARE SADMIT_IO_AREA CHAR(20),
  1 province_ADMITTED DEFINED SADMIT_IO_AREA,
  2 province_NAME CHAR(20);
 /* Segment Search Arguments */
 DECLARE 1 PRESIDENT_SSA STATIC UNALIGNED,
  2 SEGMENT_NAME CHAR(8) INIT('PRES '),
  2 LEFT_PARENTHESIS CHAR (1) INIT('('),
  2 FIELD_NAME CHAR(8) INIT ('PARTY '),
  2 CONDITIONAL_OPERATOR CHAR (2) INIT('='),
  2 SEARCH_VALUE CHAR(10) INIT ('Liberal '),
2 RIGHT_PARENTHESIS CHAR(1) INIT(')');
 DECLARE 1 province_ADMITTED_SSA STATIC UNALIGNED,
  2 SEGMENT_NAME CHAR(8) INIT('SADMIT ');
 /* Some necessary variables */
 DECLARE GU CHAR(4) INIT('GU '),
  GN CHAR(4) INIT('GN '),
  GNP CHAR(4) INIT('GNP '),
  FOUR FIXED BINARY (31) INIT (4),
  SUCCESSFUL CHAR(2) INIT(' '),
  RECORD_NOT_FOUND CHAR(2) INIT('GE');
 /*This procedure handles IMS error conditions */
 ERROR;PROCEDURE(ERROR_CODE);
  *
  *
  *
 END ERROR;
 /*Main Procedure */
 CALL PLITDLI(FOUR,GU,QUERY_PCB,PRES_IO_AREA,PRESIDENT_SSA);
 DO WHILE(PCB.STATUS_CODE=SUCCESSFUL);
  CALL PLITDLI(FOUR,GNP,QUERY_PCB,SADMIT_IO_AREA,province_ADMITTED_SSA);
  DO WHILE(PCB.STATUS_CODE=SUCCESSFUL);
   PUT EDIT(province_NAME)(A);
  CALL PLITDLI(FOUR,GNP,QUERY_PCB,SADMIT_IO_AREA,province_ADMITTED_SSA);
   END;
  IF PCB.STATUS_CODE NOT = RECORD_NOT_FOUND
   THEN DO;
    CALL ERROR(PCB.STATUS_CODE);
    RETURN;
    END;
   CALL PLITDLI(FOUR,GN,QUERY_PCB,PRES_IO_AREA,PRESDIENT_SSA);
  END;
  IF PCB.STATUS_CODE NOT = RECORD_NOT_FOUND
   THEN DO;
    CALL ERROR(PCB.STATUS_CODE);
    RETURN;
    END;
END DLITPLI;
```

Relational model to the rescue!



- Introduced by Edgar Codd (IBM) in 1970
- Most widely used model today.
  - Vendors: IBM, Informix, Microsoft, Oracle, Sybase, etc.
- Former Competitor: object-oriented model
  - ObjectStore, Versant, Ontos
  - A synthesis emerged: *object-relational model*
    - Informix Universal Server, UniSQL, O2, Oracle, DB2
- Recent competitor: XML data model

Key points of the relational model

- Exceedingly simple to understand – main abstraction is a table
- Query language separate from application language
  - General form is simple
  - Many bells and whistles

Structure of Relational Databases

- ***Relational database:*** a set of ***relations***
- ***Relation:*** made up of 2 parts:
  - ***Schema*** : specifies name of relation, plus name and **domain** (type) of each **field** (or **column** or **attribute**).
    - e.g., Student (*sid*: string, *name*: string, *major*: string).
  - ***Instance*** : a ***table***, with rows and columns.
    #Rows = cardinality, #fields = dimension / arity
- ***Relational Database Schema:*** collection of schemas in the database
- ***Database Instance:*** a collection of instances of its relations (e.g., currently no grades in CPSC 504)

Example of a Relation Instance

Product

Attribute names or columns

Name	Price	Category	Manufacturer
gizmo	$19.99	gadgets	GizmoWorks
Power gizmo	$29.99	gadgets	GizmoWorks
SingleTouch	$149.99	photography	Canon
MultiTouch	$203.99	household	Hitachi

Tuples or rows

Relation or table

Order of rows isn’t important

Formal Definition:

Product(Name: string, Price: double, Category: string, Manufacturer: string)

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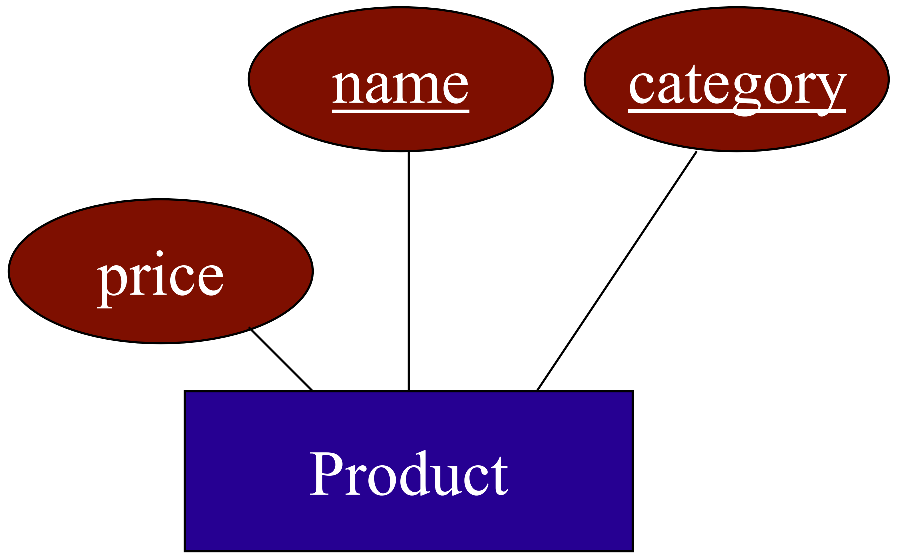
From E/R Diagrams to Relational Schema

- Entity set → relation
- Relationship → relation

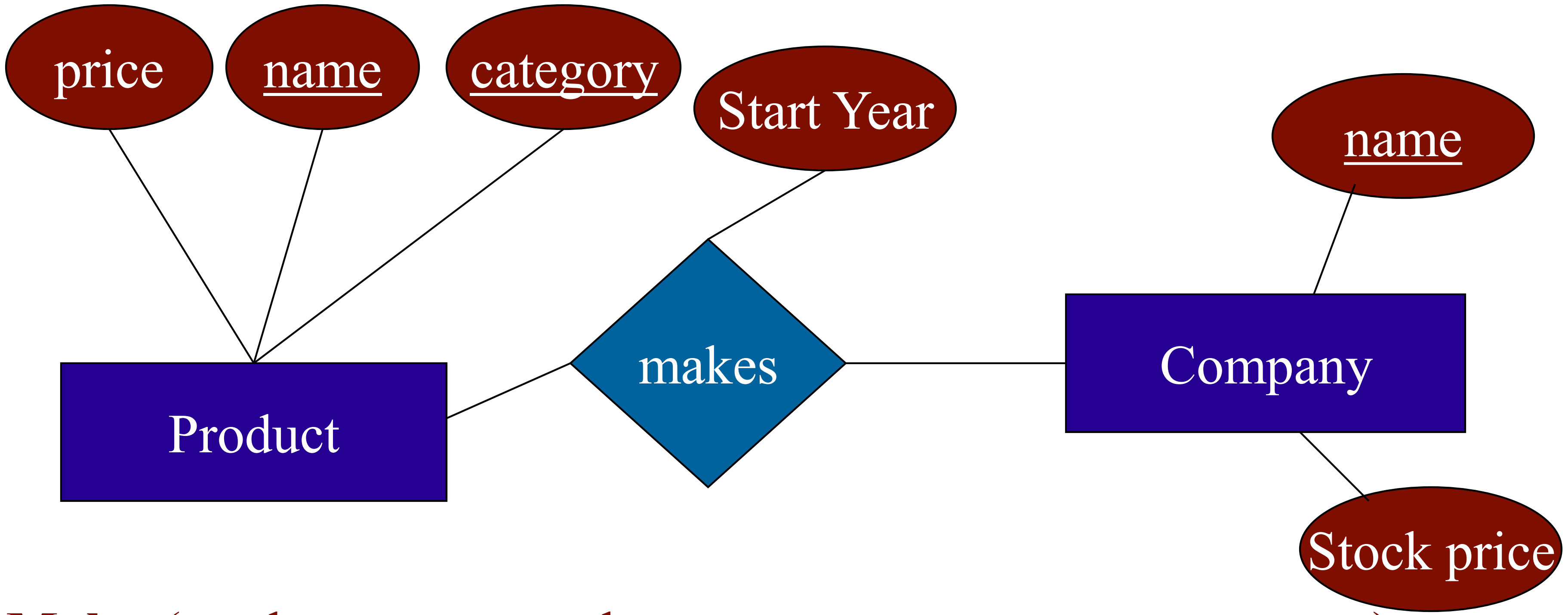
Entity Set to Relation



Product(<u>name, category</u>, price)

name	category	price
gizmo	gadgets	$19.99

Relationships to Relations



Makes(product-name, product-category, company-name, year)

Product-name	Product-Category	Company-name	Starting-year
gizmo	gadgets	gizmoWorks	1963

(watch out for attribute name conflicts)

When are two relations related?

- You guess they are
- I tell you so
- Constraints say so
  - A *key* is a set of attributes whose values are unique; we underline a key
    Product(<u>Name</u>, Price, Category, <u>Manfacturer</u>)
  - Foreign keys are a method for schema designers to tell you so
    - A foreign key states that an attribute is a reference to the key of another relation
      ex: Product.Manufacturer is foreign key of Company
    - Gives information and enforces constraint

Brief exercise

Translate the diagram that you did from ER to relational

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Relational Query Languages

- A major strength of the relational model: simple, powerful *querying* of data.
- Queries can be written intuitively; DBMS is responsible for efficient evaluation.
  - Precise semantics for relational queries.
  - Optimizer can re-order operations, and still ensure that the answer does not change.
- We'll look at 3: relational algebra, SQL, and Datalog

Querying – Relational Algebra

- *Select* (σ)- chose tuples from a relation
- *Project* (π)- chose attributes from relation
- *Join* ($\bowtie$) - allows combining of 2 relations
- *Set-difference* ($-$) Tuples in relation 1, but not in relation 2.
- *Union* ($\cup$)
- *Cartesian Product* ($\times$) Each tuple of R1 with each tuple in R2

Find products where the manufacturer is GizmoWorks

Product

Name	Price	Category	Manufacturer
Gizmo	$19.99	Gadgets	GizmoWorks
Powergizmo	$29.99	Gadgets	GizmoWorks
SingleTouch	$149.99	Photography	Canon
MultiTouch	$203.99	Household	Hitachi

?

$\Downarrow$

Name	Price	Category	Manufacturer
Gizmo	$19.99	Gadgets	GizmoWorks
Powergizmo	$29.99	Gadgets	GizmoWorks

Find products where the manufacturer is GizmoWorks

Product

Name	Price	Category	Manufacturer
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Powergizmo	$29.99	Gadgets	GizmoWorks
SingleTouch	$149.99	Photography	Canon
MultiTouch	$203.99	Household	Hitachi

Selection:

$\sigma_{\text{Manufacturer} = \text{'GizmoWorks'}}\text{Product}$

Name	Price	Category	Manufacturer
Gizmo	$19.99	Gadgets	GizmoWorks
Powergizmo	$29.99	Gadgets	GizmoWorks

Find name of all the products

Product

Name	Price	Category	Manufacturer
Gizmo	$19.99	Gadgets	GizmoWorks
Powergizmo	$29.99	Gadgets	GizmoWorks
SingleTouch	$149.99	Photography	Canon
MultiTouch	$203.99	Household	Hitachi

?

$\Downarrow$

Name
Gizmo
Powergizmo
SingleTouch
MultiTouch

Find name of all the products

Product

Name	Price	Category	Manufacturer
Gizmo	$19.99	Gadgets	GizmoWorks
Powergizmo	$29.99	Gadgets	GizmoWorks
SingleTouch	$149.99	Photography	Canon
MultiTouch	$203.99	Household	Hitachi

Projection:

$\pi_{\text{Name}}\text{Product}$

$\Downarrow$

Name
Gizmo
Powergizmo
SingleTouch
MultiTouch

Find the Name, Price, and Manufacturers of products whose price is greater than 100

Product

Name	Price	Category	Manufacturer
Gizmo	$19.99	Gadgets	GizmoWorks
Powergizmo	$29.99	Gadgets	GizmoWorks
SingleTouch	$149.99	Photography	Canon
MultiTouch	$203.99	Household	Hitachi

?

$\Downarrow$

Name	Price	Manufacturer
SingleTouch	$149.99	Canon
MultiTouch	$203.99	Hitachi

Find the Name, Price, and Manufacturers of products whose price is greater than 100

Product

Name	Price	Category	Manufacturer
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Powergizmo	$29.99	Gadgets	GizmoWorks
SingleTouch	$149.99	Photography	Canon
MultiTouch	$203.99	Household	Hitachi

Selection + Projection:

$\pi_{\text{Name, Price, Manufacturer}}\,(\sigma_{\text{Price} > 100}\text{Product})$

Name	Price	Manufacturer
SingleTouch	$149.99	Canon
MultiTouch	$203.99	Hitachi

Find names and prices of products that cost less than $200 and have Japanese manufacturers

Product

Name	Price	Category	Manufacturer
Gizmo	$19.99	Gadgets	GizmoWorks
Powergizmo	$29.99	Gadgets	GizmoWorks
SingleTouch	$149.99	Photography	Canon
MultiTouch	$203.99	Household	Hitachi

Company

Cname	StockPrice	Country
GizmoWorks	25	USA
Canon	65	Japan
Hitachi	15	Japan

?

$\Downarrow$

Name	Price
SingleTouch	$149.99

Find names and prices of products that cost less than $200 and have Japanese manufacturers

Product

Name	Price	Category	Manufacturer
Gizmo	$19.99	Gadgets	GizmoWorks
Powergizmo	$29.99	Gadgets	GizmoWorks
SingleTouch	$149.99	Photography	Canon
MultiTouch	$203.99	Household	Hitachi

Company

Cname	StockPrice	Country
GizmoWorks	25	USA
Canon	65	Japan
Hitachi	15	Japan

$$\pi_{\text{Name, Price}}((\sigma_{\text{Price} < 200}\text{Product}) \bowtie_{\text{Manufacturer} = \text{Cname}} (\sigma_{\text{Country} = \text{'Japan'}}\text{Company}))$$

Name	Price
SingleTouch	$149.99

The SQL Query Language

- Structured Query Language
- The standard relational query language
- Developed by IBM (System R) in the 1970s
- Standards:
  - SQL-86
  - SQL-89 (minor revision)
  - SQL-92 (major revision, current standard)
  - SQL-99 (major extensions)

SQL

- Data Manipulation Language (DML)
  - Query one or more tables
  - Insert/delete/modify tuples in tables
- Data Definition Language (DDL)
  - Create/alter/delete tables and their attributes
- Transact-SQL
  - Idea: package a sequence of SQL statements → server

SQL basics

- Basic form: (many many more bells and whistles in addition)

Select attributes

From relations (possibly multiple, joined)

Where conditions (selections)

SQL – Selections

```
SELECT   *
FROM     Company
WHERE    country="Canada" AND stockPrice > 50
```

Some things allowed in the WHERE clause:

attribute names of the relation(s) used in the FROM.
comparison operators: =, <>, <, >, <=, >=
apply arithmetic operations: stockPrice*2
operations on strings (e.g., "||" for concatenation).
Lexicographic order on strings.
Pattern matching: s LIKE p
Special stuff for comparing dates and times.

SQL – Projections

Select only a subset of the attributes

```
SELECT   name, stock price
FROM     Company
WHERE    country="Canada" AND stockPrice > 50
```

Rename the attributes in the resulting table

```
SELECT   name AS company, stockPrice AS price
FROM     Company
WHERE    country="Canada" AND stockPrice > 50
```

SQL – Joins

```
SELECT   name, store
FROM     Person, Purchase
WHERE    name=buyer AND city=“Vancouver”
                   AND product=“gizmo”
```

Product (name, price, category, manufacturer)
Purchase (buyer, seller, store, product)
Company (name, stock price, country)
Person(name, phone number, city)

Selection: $\sigma_{\text{Manufacturer = 'GizmoWorks'}}$(Product)

Product

Name	Price	Category	Manufacturer
Gizmo	$19.99	Gadgets	GizmoWorks
Powergizmo	$29.99	Gadgets	GizmoWorks
SingleTouch	$149.99	Photography	Canon
MultiTouch	$203.99	Household	Hitachi

$\Downarrow$

What’s the SQL?

Name	Price	Category	Manufacturer
Gizmo	$19.99	Gadgets	GizmoWorks
Powergizmo	$29.99	Gadgets	GizmoWorks

Selection: $\sigma_{\text{Manufacturer = 'GizmoWorks'}}$(Product)

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SingleTouch	$149.99	Photography	Canon
MultiTouch	$203.99	Household	Hitachi

```
SELECT   *
FROM     Product
WHERE    Manufacturer = 'GizmoWorks'
```

Name	Price	Category	Manufacturer
Gizmo	$19.99	Gadgets	GizmoWorks
Powergizmo	$29.99	Gadgets	GizmoWorks

Selection + Projection: $\pi_{\text{Name, Price, Manufacturer}}(\sigma_{\text{Price > 100}}\text{Product})$

Product

Name	Price	Category	Manufacturer
Gizmo	$19.99	Gadgets	GizmoWorks
Powergizmo	$29.99	Gadgets	GizmoWorks
SingleTouch	$149.99	Photography	Canon
MultiTouch	$203.99	Household	Hitachi

What's the SQL?

$\Downarrow$

Name	Price	Manufacturer
SingleTouch	$149.99	Canon
MultiTouch	$203.99	Hitachi

Selection + Projection:

$\pi_{\text{Name, Price, Manufacturer}}(\sigma_{\text{Price} > 100}\text{Product})$

Product

Name	Price	Category	Manufacturer
Gizmo	$19.99	Gadgets	GizmoWorks
Powergizmo	$29.99	Gadgets	GizmoWorks
SingleTouch	$149.99	Photography	Canon
MultiTouch	$203.99	Household	Hitachi

```
SELECT  Name, Price,
Manufacturer
FROM    Product
WHERE   Price > 100
```

Name	Price	Manufacturer
SingleTouch	$149.99	Canon
MultiTouch	$203.99	Hitachi

$\pi_{\text{Name, Price}}((\sigma_{\text{Price} < 200}\text{Product}) \bowtie_{\text{Manufacturer} = \text{Cname}} (\sigma_{\text{Country} = \text{'Japan'}}\text{Company}))$

Product

Name	Price	Category	Manufacturer
Gizmo	\$19.99	Gadgets	GizmoWorks
Powergizmo	\$29.99	Gadgets	GizmoWorks
SingleTouch	\$149.99	Photography	Canon
MultiTouch	\$203.99	Household	Hitachi

Company

Cname	StockPrice	Country
GizmoWorks	25	USA
Canon	65	Japan
Hitachi	15	Japan

What's the SQL?

Name	Price
SingleTouch	\$149.99

English: find the name and price of all Japanese products that cost less than \$200

$$\pi_{\text{Name, Price}}((\sigma_{\text{Price <= 200}}\text{Product}) \bowtie_{\text{Manufacturer = Cname}} (\sigma_{\text{Country = 'Japan'}}\text{Company}))$$

Product

Name	Price	Category	Manufacturer
Gizmo	$19.99	Gadgets	GizmoWorks
Powergizmo	$29.99	Gadgets	GizmoWorks
SingleTouch	$149.99	Photography	Canon
MultiTouch	$203.99	Household	Hitachi

Company

Cname	StockPrice	Country
GizmoWorks	25	USA
Canon	65	Japan
Hitachi	15	Japan

```
SELECT  Name, Price
FROM    Product, Company
WHERE   Country = 'Japan' AND
        price <= 200 AND
        Manufacturer = Cname
```

Name	Price
SingleTouch	$149.99

Querying – Datalog (Our final query language)

- Enables recursive queries
- More convenient for analysis
- Some people find it easier to understand
- Without recursion but with negation it is equivalent in power to relational algebra and SQL
- Limited version of Prolog (no functions)

Datalog Rules and Queries

A Datalog rule has the following form:

head :- atom1, atom2, …, atom,…

You can read this as then :- if ...

Arithmetic comparison or interpreted predicate

ExpensiveProduct(N) :- Product(N,P,C,M) & P > \$10

CanadianProduct(N) :- Product(N,P,C,M)&Company(M,SP, “Canada”)

IntlProd(N) :- Product(N,P,C,M)& Company (M2, SP, C2)&

$\underbrace{\text{NOT Company(M, SP, “Canada”)}}_{\text{Negated subgoal}}$

(sometimes you’ll see &’s between atoms and sometimes &; both mean “and”)

Relations:

Product (name, price, category, maker)

Purchase (buyer, seller, store, product)

Company (name, stock price, country)

Person (name, phone number, city)

Conjunctive Queries

- A subset of Datalog
- Only relations appear in the right hand side of rules
- No negation
- Functionally equivalent to Select, Project, Join queries
- Very popular in modeling relationships between databases

Selection: $\sigma_{\text{Manufacturer = 'GizmoWorks'}}$(Product)

Product

Name	Price	Category	Manufacturer
Gizmo	$19.99	Gadgets	GizmoWorks
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SingleTouch	$149.99	Photography	Canon
MultiTouch	$203.99	Household	Hitachi

What's the Datalog?

Name	Price	Category	Manufacturer
Gizmo	$19.99	Gadgets	GizmoWorks
Powergizmo	$29.99	Gadgets	GizmoWorks

Selection:

$\sigma_{\text{Manufacturer = 'GizmoWorks'}}$(Product)

Product

Name	Price	Category	Manufacturer
Gizmo	$19.99	Gadgets	GizmoWorks
Powergizmo	$29.99	Gadgets	GizmoWorks
SingleTouch	$149.99	Photography	Canon
MultiTouch	$203.99	Household	Hitachi

$\Downarrow$

Q(n,p,c,'GizmoWorks):-Product(n,p,c,'GizmoWorks')

Name	Price	Category	Manufacturer
Gizmo	$19.99	Gadgets	GizmoWorks
Powergizmo	$29.99	Gadgets	GizmoWorks

Selection + Projection: $\pi_{\text{Name, Price, Manufacturer}}(\sigma_{\text{Price} > 100}\text{Product})$

Product

Name	Price	Category	Manufacturer
Gizmo	$19.99	Gadgets	GizmoWorks
Powergizmo	$29.99	Gadgets	GizmoWorks
SingleTouch	$149.99	Photography	Canon
MultiTouch	$203.99	Household	Hitachi

What’s the Datalog?

Name	Price	Manufacturer
SingleTouch	$149.99	Canon
MultiTouch	$203.99	Hitachi

Selection + Projection: $\pi_{\text{Name, Price, Manufacturer}}(\sigma_{\text{Price} > 100}\text{Product})$

Product

Name	Price	Category	Manufacturer
Gizmo	$19.99	Gadgets	GizmoWorks
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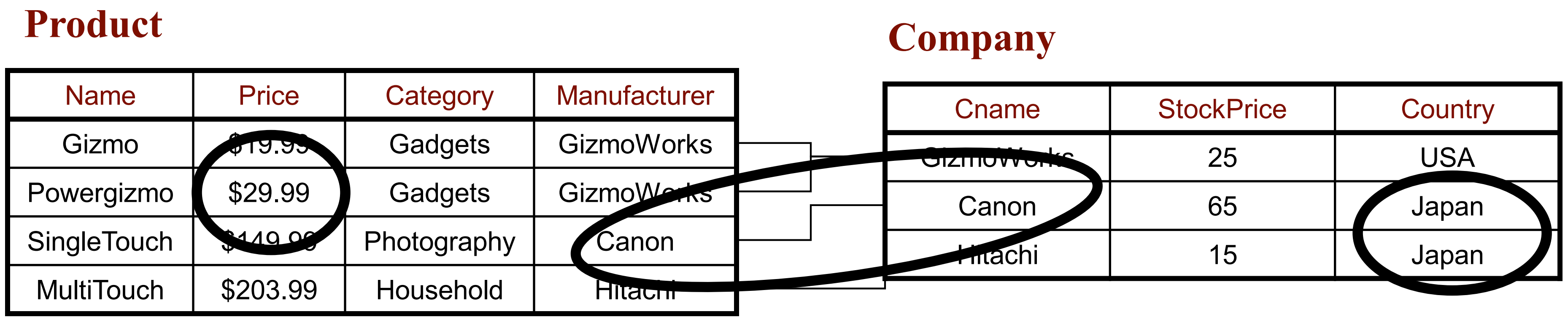
MultiTouch	$203.99	Household	Hitachi

Q(n,p,m):-Product(n,p,c,m), p > 100

Name	Price	Manufacturer
SingleTouch	$149.99	Canon
MultiTouch	$203.99	Hitachi

$\pi_{Name,Price}((\sigma_{Price < 200} Product) \bowtie_{Manufacturer = Cname} (\sigma_{Country = 'Japan'} Company))$



Product

Name	Price	Category	Manufacturer
Gizmo	$19.99	Gadgets	GizmoWorks
Powergizmo	$29.99	Gadgets	GizmoWorks
SingleTouch	$149.99	Photography	Canon
MultiTouch	$203.99	Household	Hitachi

Company

Cname	StockPrice	Country
GizmoWorks	25	USA
Canon	65	Japan
Hitachi	15	Japan

Name	Price
SingleTouch	$149.99

What's the Datalog?

English: find the name and price of all Japanese products that cost less than $200

$\pi_{\text{Name,Price}}((\sigma_{\text{Price} < 200}\text{Product}) \bowtie_{\text{Manufacturer} = \text{Cname}} (\sigma_{\text{Country} = \text{'Japan'}}\text{Company}))$

Product

Name	Price	Category	Manufacturer
Gizmo	$19.99	Gadgets	GizmoWorks
Powergizmo	$29.99	Gadgets	GizmoWorks
SingleTouch	$149.99	Photography	Canon
MultiTouch	$203.99	Household	Hitachi

Company

Cname	StockPrice	Country
GizmoWorks	25	USA
Canon	65	Japan
Hitachi	15	Japan

Q(n,p):- Product(n,p,c,**m**),
Company(**m**,s,co), p < 200

Name	Price
SingleTouch	$149.99

Exercise: using this schema or any other, write 2 queries in Datalog and in English

A Datalog rule has the following form:

head :- atom1, atom2, …, atom,…

You can read this as then :- if ...

Arithmetic comparison or interpreted predicate

ExpensiveProduct(N) :- Product(N,P,C,M) & P > \$10

CanadianProduct(N) :- Product(N,P,C,M)&Company(M,SP, “Canada”)

IntlProd(N) :- Product(N,P,C,M)& Company (M2, SP, C2)&

$\underbrace{\text{NOT Company(M, SP, “Canada”)}}_{\text{Negated subgoal}}$

(sometimes you’ll see &’s between atoms and sometimes &; both mean “and”)

Relations:

Product (name, price, category, maker)

Purchase (buyer, seller, store, product)

Company (name, stock price, country)

Person (name, phone number, city)

Bonus Relational Goodness: Views

Views are stored queries treated as relations, Virtual views are not physically stored. Materialized views are stored

They are used (1) to define conceptually different views of the database and (2) to write complex queries simply.

View: purchases of telephony products:

```
CREATE VIEW  telephony-purchases AS
  SELECT product, buyer, seller, store
  FROM  Purchase, Product
  WHERE  Purchase.product = Product.name
           AND  Product.category = “telephony”
```

Summarizing/Rehashing Relational DBs

- Relational perspective: Data is stored in relations. Relations have attributes. Data instances are tuples.
- SQL perspective: Data is stored in tables. Tables have columns. Data instances are rows.
- Query languages
  - Relational algebra – mathematical base for understanding query languages
  - SQL – most commonly used
  - Datalog – based on Prolog, very popular with theoreticians
- Bonus! Views allow complex queries to be written simply

Outline

- Entity Relationship (ER) diagrams
- Relational databases
- Object Oriented Databases (OODBs)
- XML
- Other data types
- Database internals (Briefly)
- Potpourri

Object-Oriented DBMS’s

- Started late 80’s
- Main idea:
  - Toss the relational model!
  - Use the OO model – e.g., C++ classes
- Standards group: ODMG = Object Data Management Group.
- OQL = Object Query Language, tries to imitate SQL in an OO framework.

The OO Plan

ODMG imagines OO-DBMS vendors implementing an OO language like C++ with extensions (OQL) that allow the programmer to transfer data between the database and “host language” seamlessly.

A brief diversion: the impedance mismatch

OO Implementation Options

- Build a new database from scratch (O_2)
  - Elegant extension of SQL
  - Later adopted by ODMG in the OQL language
  - Used to help build XML query languages
- Make a programming language persistent (ObjectStore)
  - No query language
  - Niche market
- We’ll see a few others

ODL

- ODL defines *persistent* classes, whose objects may be stored permanently in the database.
  - ODL classes look like Entity sets with binary relationships, plus methods.
  - ODL class definitions are part of the extended, OO host language.

ODL – remind you of anything?

```
interface  Person
   (extent People key sin)
 {    attribute  string    sin;
      attribute  string    dept;
      attribute  string    name;}
```

```
interface  Course
   (extent Crs key cid)
 {    attribute  string  cid;
      attribute  string  cname;
      relationship Person instructor;
      relationship Set<Student> stds
             inverse takes;}
```

```
interface  Student extends Person
   (extent Students)
 {    attribute  string  major;
      relationship Set<Course> takes inverse stds;}
```

Why did OO Fail?

- Why are relational databases so popular?
  - Very simple abstraction; don’t have to think about programming when storing data.
  - Very well optimized
- Relational db are very well entrenched – OODBs had not enough advantages, and no good exit strategy (we’ll see more about this later)

Merging Relational and OODBs

- Object-oriented models support interesting data types – not just flat files.
  - Maps, multimedia, etc.
- The relational model supports very-high-level queries.
- Object-relational databases are an attempt to get the best of both.
- All major commercial DBs today have OR versions – full spec in SQL99, but your mileage may vary.

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XML

- eXtensible Markup Language
- XML 1.0 – a recommendation from W3C, 1998
- Roots: SGML (from document community - works great for them; from db perspective, very nasty).
- After the roots: a format for sharing *data*

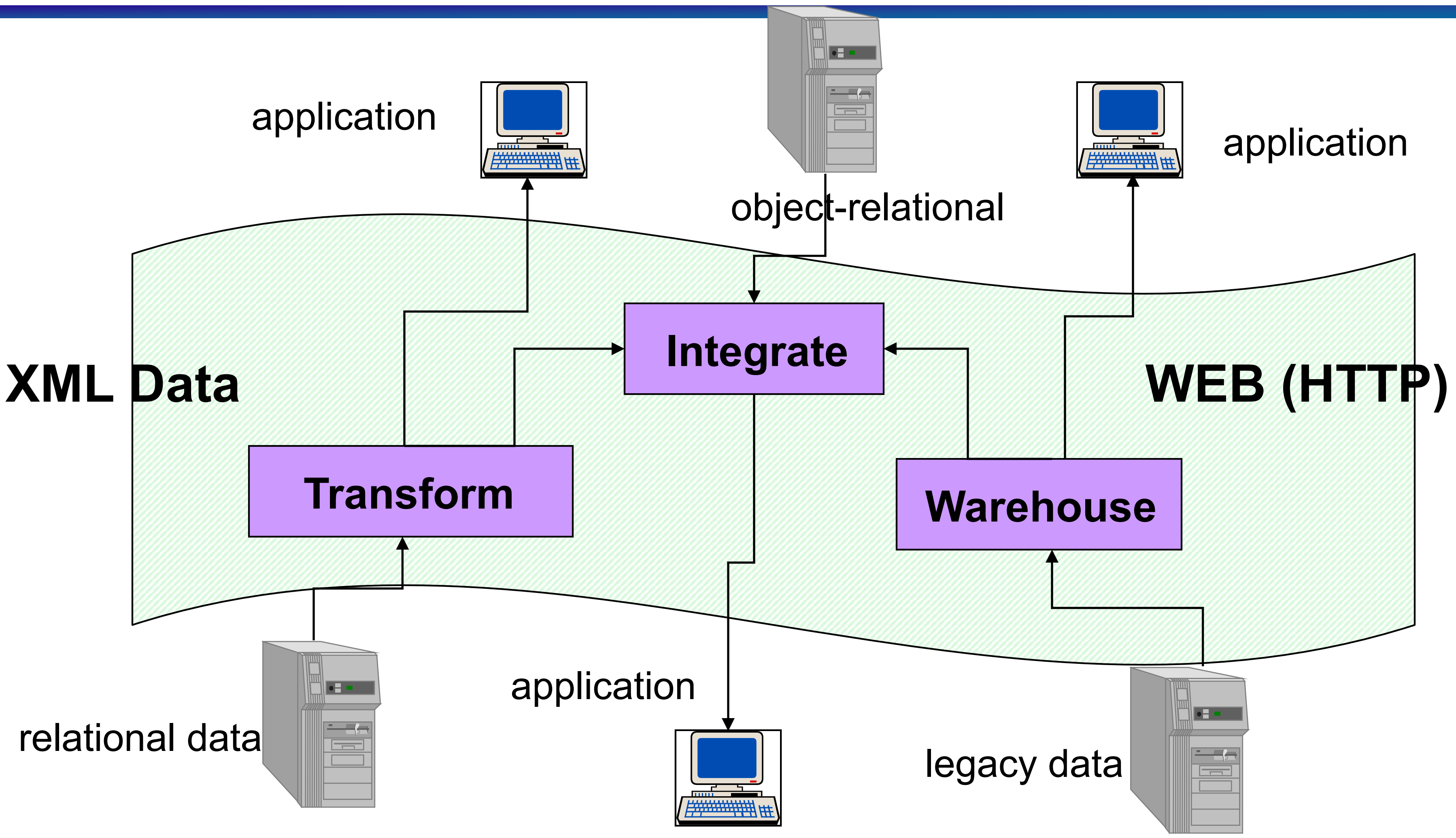
XML is self-describing

- Schema elements become part of the data
  - In XML <persons>, <name>, <phone> are part of the data, and are repeated many times
  - Relational schema: persons(name,phone) defined separately for the data and is fixed
- Consequence: XML is very flexible

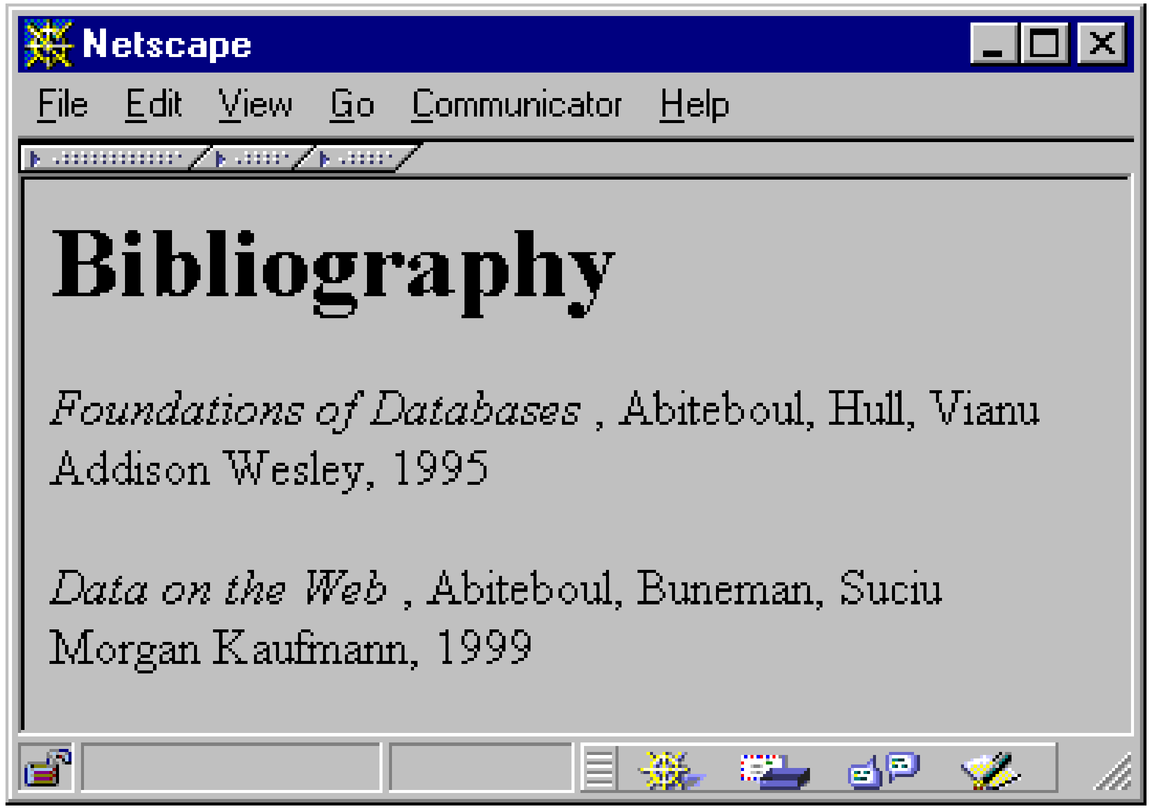
Why XML is of Interest to Us

- XML is *semistructured* and *hierarchical*
- XML is just syntax for data
  - Note: we have no syntax for relational data
- This is exciting because:
  - Can translate *any* data to XML
  - Can ship XML over the Web (HTTP)
  - Can input XML into any application
  - Thus: data sharing and exchange on the Web

XML Data Sharing and Exchange



From HTML to XML



Bibliography

Foundations of Databases , Abiteboul, Hull, Vianu
Addison Wesley, 1995

Data on the Web , Abiteboul, Buneman, Suciu
Morgan Kaufmann, 1999

HTML describes the presentation

HTML

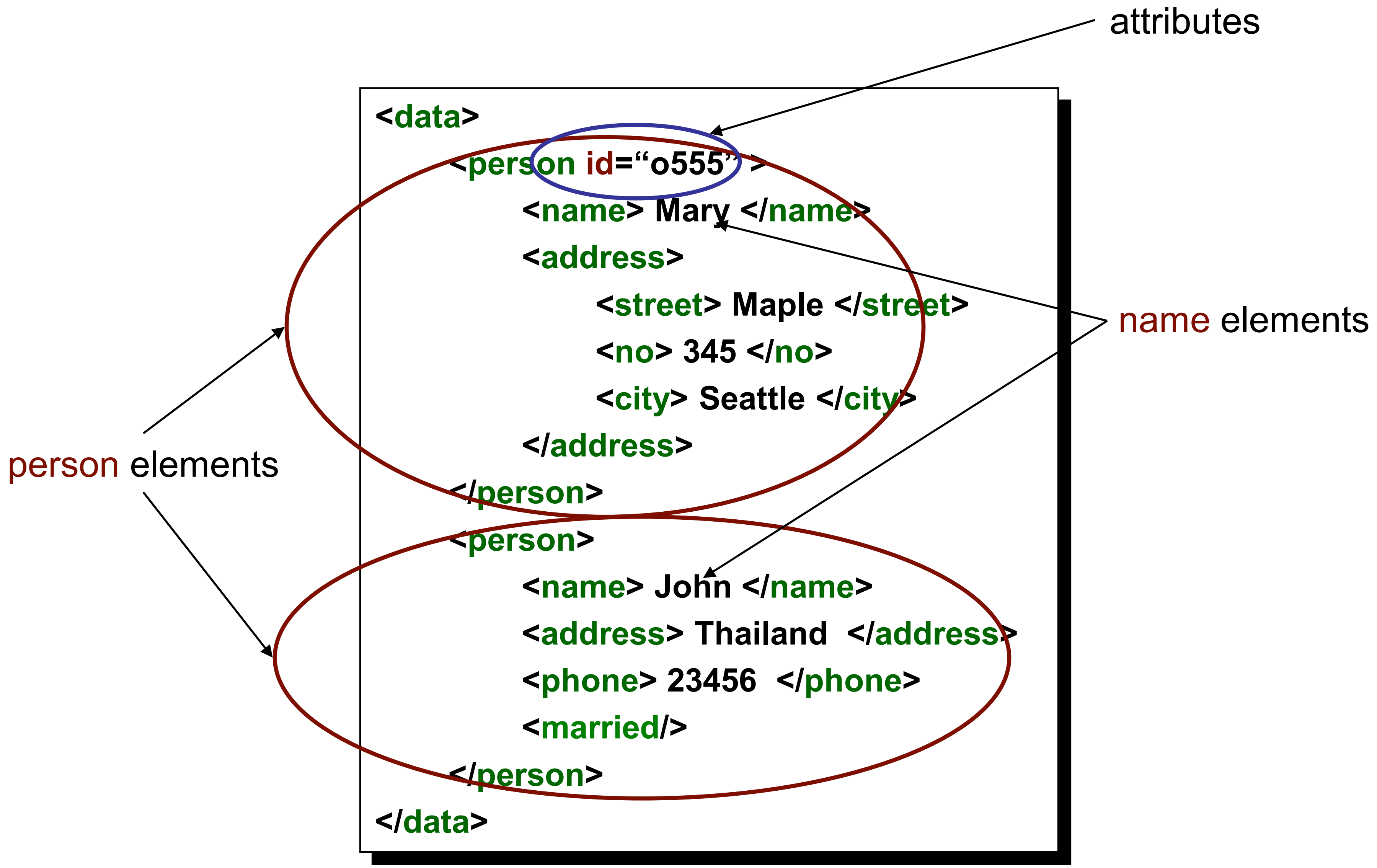
```
<h1> Bibliography </h1>
<p> <i> Foundations of Databases </i>
        Abiteboul, Hull, Vianu
        <br> Addison Wesley, 1995
<p> <i> Data on the Web </i>
        Abiteoul, Buneman, Suciu
        <br> Morgan Kaufmann, 1999
```

XML

```
<bibliography>
      <book>    <title> Foundations… </title>
                <author> Abiteboul </author>
                <author> Hull </author>
                <author> Vianu </author>
                <publisher> Addison Wesley </publisher>
                <year> 1995 </year>
      </book>
      …
</bibliography>
```

XML describes the content

XML Document



```
<data>
    <person id="o555" >
        <name> Mary </name>
        <address>
            <street> Maple </street>
            <no> 345 </no>
            <city> Seattle </city>
        </address>
    </person>
    <person>
        <name> John </name>
        <address> Thailand  </address>
        <phone> 23456  </phone>
        <married/>
    </person>
</data>
```

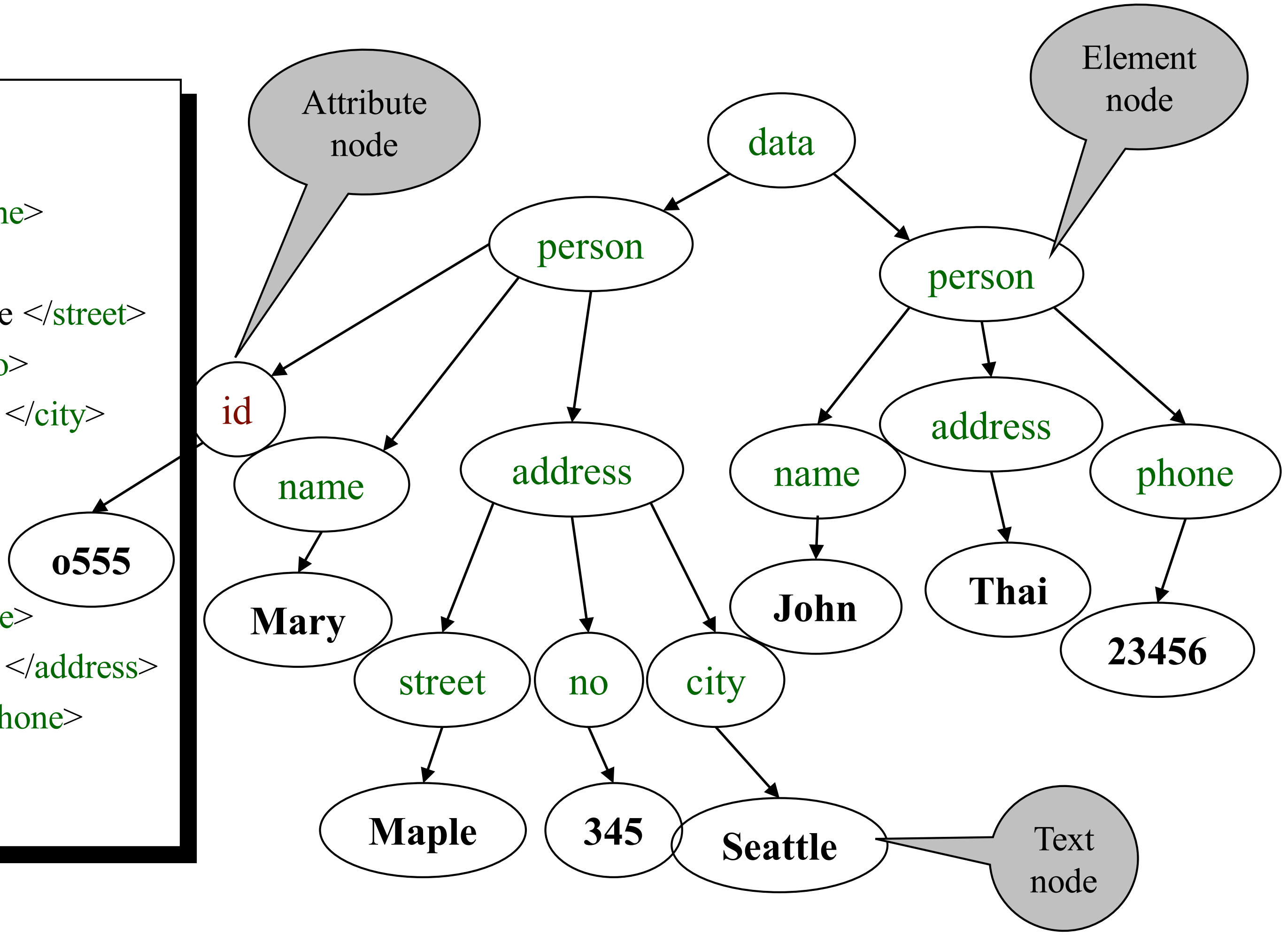
XML Terminology

- Elements
  - enclosed within tags:
    - <person> … </person>
  - nested within other elements:
    - <person> <address> … </address> </person>
  - can be empty
    - <married></married> abbreviated as <married/>
  - can have Attributes
    - <person id="0005"> … </person>

- XML document has as single ROOT element

XML as a Tree !!

```
<data>
        <person id="o555" >
                <name> Mary </name>
                <address>
                        <street> Maple </street>
                        <no> 345 </no>
                        <city> Seattle </city>
                </address>
        </person>
        <person>
                <name> John </name>
                <address> Thailand  </address>
                <phone> 23456  </phone>
        </person>
</data>
```



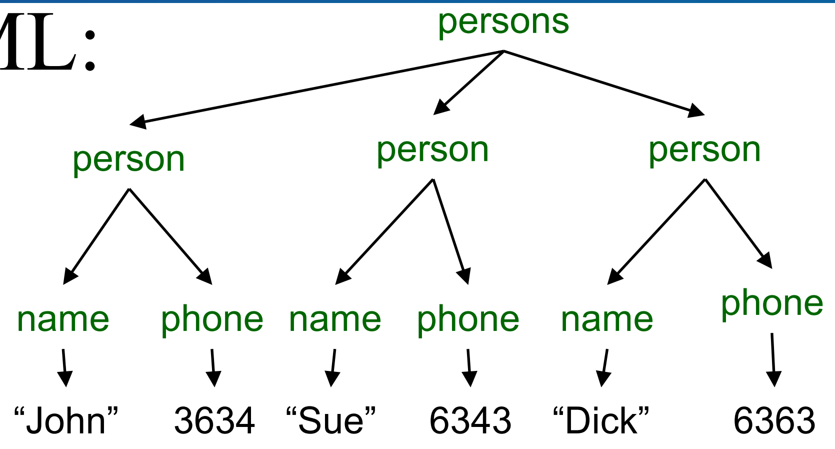
Minor Detail: Order matters !!!

Relational Data as XML

person

name	phone
John	3634
Sue	6343
Dick	6363

XML:



```
<persons>
      <person> <name>John</name>
                      <phone> 3634</phone>
       </person>
       <person> <name>Sue</name>
                       <phone> 6343</phone>
       </person>
       <person> <name>Dick</name>
                       <phone> 6363</phone>
       </person>
</persons>
```

XML is semi-structured

- Missing elements:

```
<person>   <name> John</name>
           <phone>1234</phone>
 </person>

<person>  <name>Joe</name>
</person>                          ← no phone !
```

- Could represent in a table with nulls

name	phone
John	1234
Joe	-

XML is semi-structured

- Repeated elements

```
<person> <name> Mary</name>
         <phone>2345</phone>
         <phone>3456</phone>
</person>
```

← two phones !

- Impossible in tables:

name	phone	
Mary	2345	3456

???

XML is semi-structured

- Elements with different types in different objects

```
<person> <name>  <first> John </first>
                  <last> Smith </last>      ← structured name !
           </name>
           <phone>1234</phone>
</person>
```

- Heterogeneous collections:
  - <persons> can contain both <person>s and <customer>s

Summarizing XML

- XML has first class elements and second class attributes
- XML is semi-structured
- XML is nested
- XML is a tree
- XML is a buzzword

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Other data formats

- Key-value pairs
- Makefiles
- Forms
- Application code

What format is your data in?

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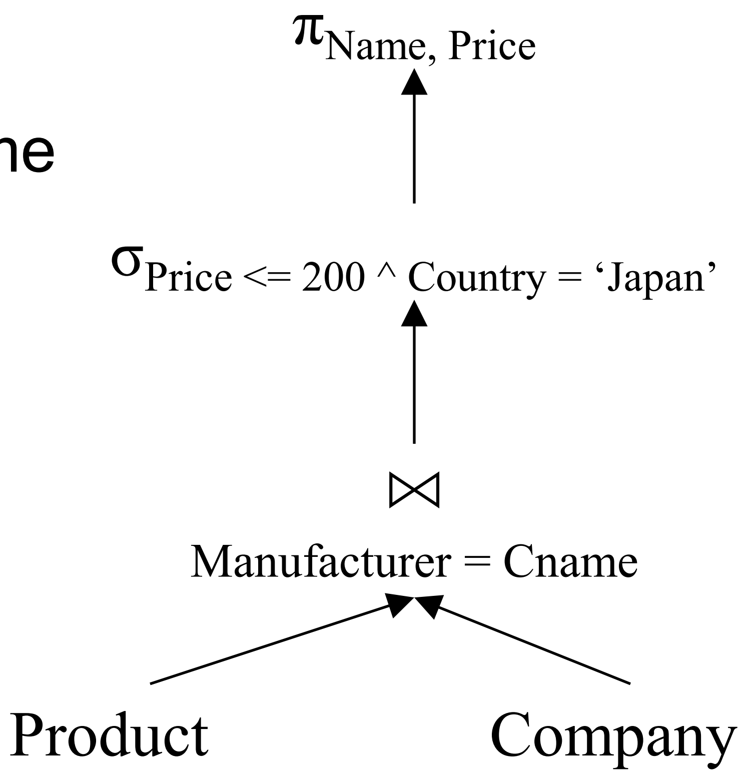
  - Transaction Processing
- Potpourri

How SQL Gets Executed: Query Execution Plans

Select Name, Price

From Product, Company

Where Manufacturer = Cname
    AND Price <= 200
    AND Country = ‘Japan’


$\pi_{\text{Name, Price}}$
$\sigma_{\text{Price <= 200 ^ Country = ‘Japan’}}$
$\bowtie$
Manufacturer = Cname
Product
Company

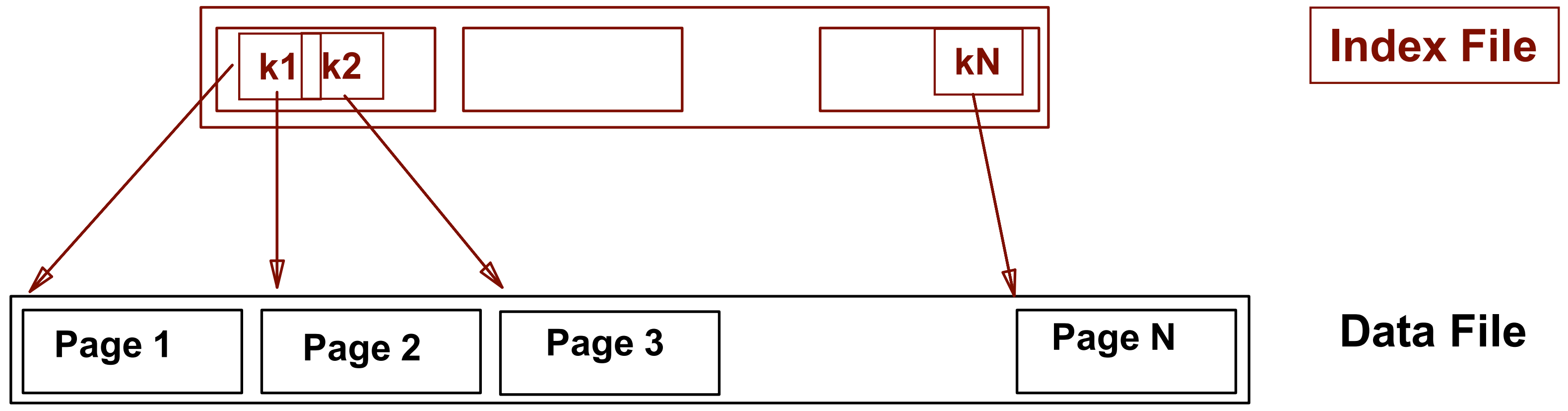
Query optimization also specifies the algorithms for each operator; then queries can be executed

Overview of Query Optimization

- Plan: *Tree of ordered Relational Algebra operators and choice of algorithm for each operator*
- Two main issues:
  - For a given query, what plans are considered?
    - Algorithm to search plan space for cheapest (estimated) plan.
  - How is the cost of a plan estimated?
- Ideally: Want to find best plan.
  Practically: Avoid worst plans.
- Some tactics
  - Do selections early
  - Use materialized views
  - Use Indexes

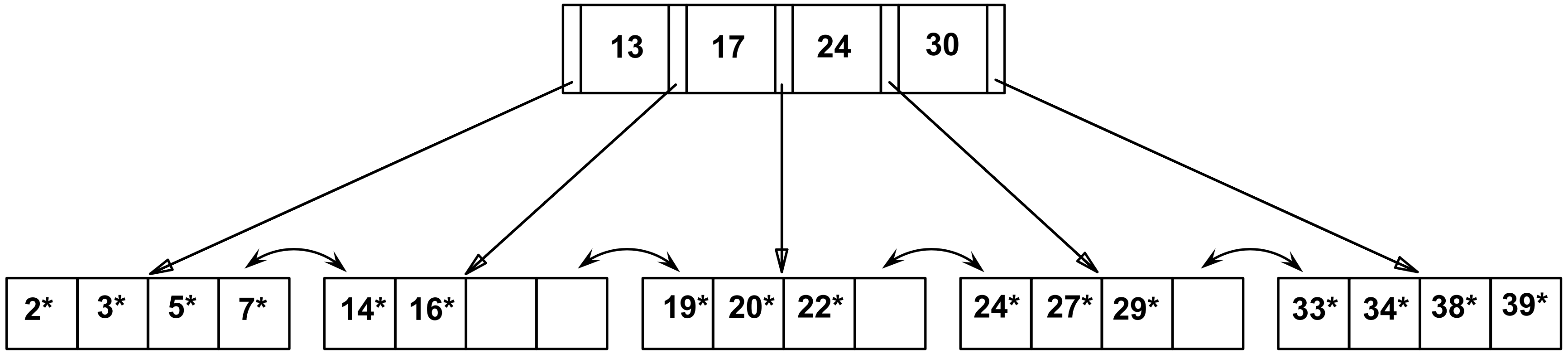
Tree-Based Indexes

- *``Find all students with gpa > 3.0''*
  - If data is sorted, do binary search to find first such student, then scan to find others.
  - Cost of binary search can be quite high.
- Simple idea: Create an `index' file.



Example B+ Tree

- Search begins at root, and key comparisons direct it to a leaf.
- Search for 5*, 15*, all data entries >= 24* ...



Query Execution

- Now that we have the plan, what do we do with it?
  - How do joins work?
  - How do deal with paging in data, etc.
- New research covers new paradigms where interleaved with optimization

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Transactions

Address two issues:

- Access by multiple users
- Protection against crashes

Transactions

Transaction = group of statements that must be executed atomically

- Transaction properties: ACID
  - ***Atomicity***: either all or none of the operations are completed
  - ***Consistency***: preserves database integrity
  - ***Isolation***: concurrent transactions must not interfere with each other
  - ***Durability***: changes from successful transactions must persist through failures

Transaction Example

- Consider two transactions:

```
T1:     READ(A)
        A=A+100
        WRITE(A)
        READ(B)
        B=B-100
        WRITE(B)

T2:     READ(A)
        A=1.1*A
        WRITE(A)
        READ(B)
        B=1.1*B
        WRITE(B)
```

- Intuitively, T1 transfers $100 to A's account from B's account. T2 credits both accounts with a 10% interest payment.
- No guarantee that T1 executes before T2 or vice-versa. However, the end effect must be equivalent to these two transactions running serially in some order:

  T1, T2 or T2, T1

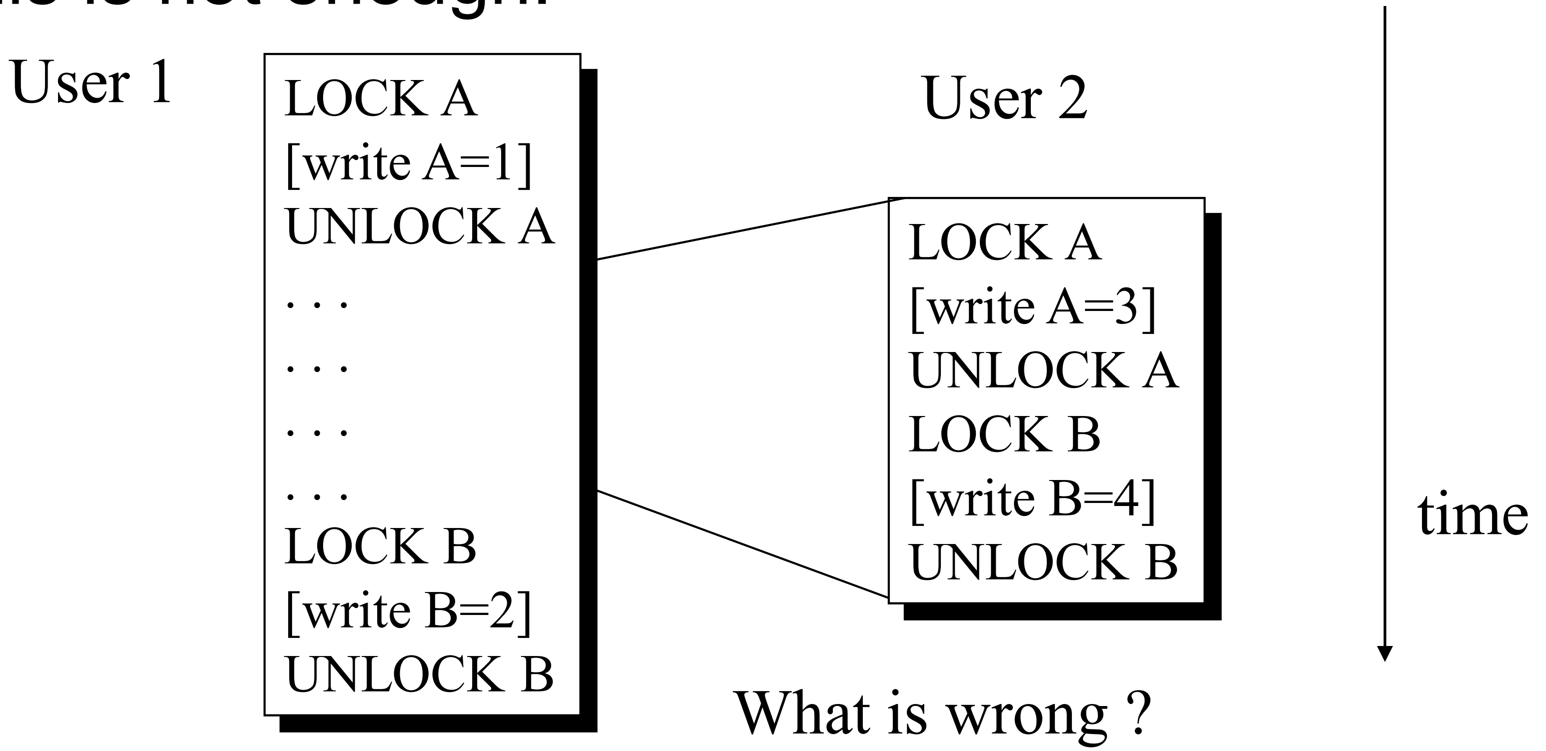
Transactions: Serializability

Serializability = the technical term for isolation

- An execution is ***serial*** if it is completely before or completely after any other function’s execution
- An execution is ***serializable*** if it equivalent to one that is serial
- DBMS can offer serializability guarantees

Serializability Example

- Enforced with locks, like in Operating Systems !
- But this is not enough:



What is wrong ?

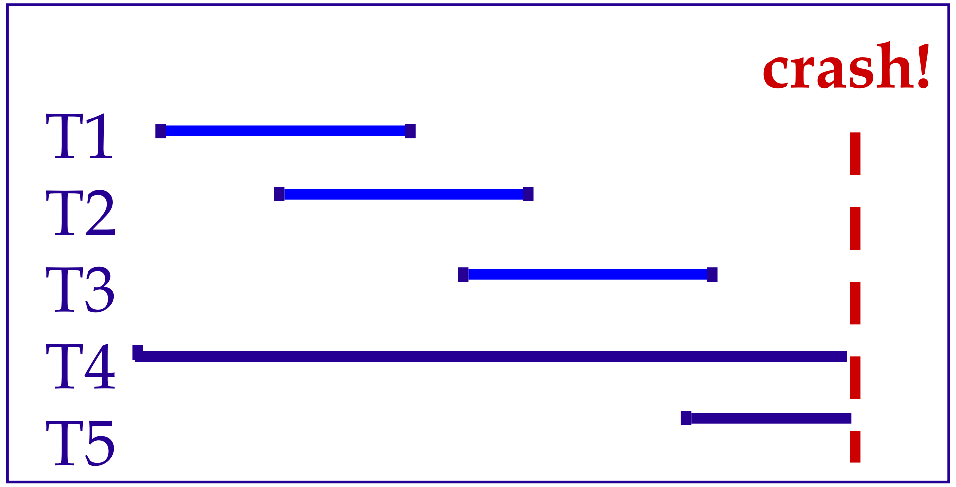
Okay, but what if it crashes?

Transaction States

- A transaction can be in one of the following states:
  - ***active***:
    - makes progress or waits for resources; the initial state
  - ***committed***:
    - after successful completing a “commit” command
    - to undo its effects we need to run a compensating transaction
  - A few others we won’t go into

Enforcing Atomicity & Durability

- Atomicity:
  - Transactions may abort ; Need to rollback changes
- Durability:
  - What if DBMS stops running? Need to "remember" committed changes.



- Desired behaviour after system restarts:
  - T1, T2, & T3 should be durable.
  - T4 & T5 should be aborted (effects not seen)

Handling the Buffer Pool

- Transactions modify pages in memory buffers
- Writing to disk is more permanent
- When should updated pages be written to disk?
- Force every write to disk?
  - Poor response time.
  - But provides durability.
- Steal buffer-pool frames from uncommitted Xacts? (resulting in write to disk)
  - If not, poor throughput.
  - If so, how can we ensure atomicity?

	No Steal	Steal
Force	Trivial	
No Force		Desired

What to do?

- Basic idea: use steal and no-force
- Keep a log that tracks what’s happened
- Make checkpoints where write down everything that’s actually happened
- After a crash: assure Atomicity and Durability by keeping all committed transactions and getting rid of actions of uncommitted transactions

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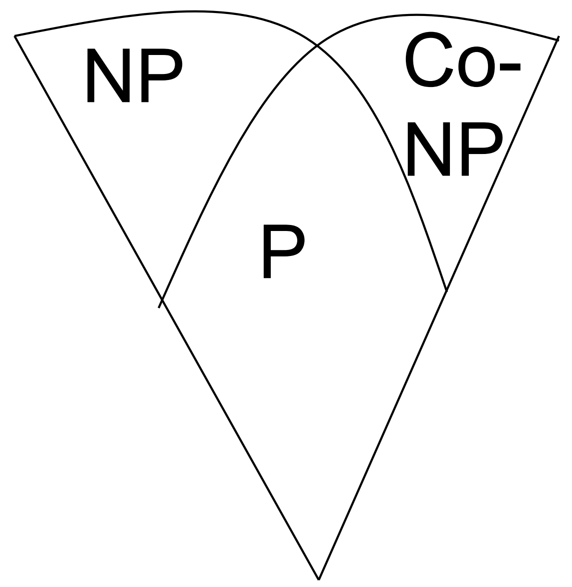
  - Complexity

Complexity

- Characterize algorithms by how much time they take
- The first major distinction: Polynomial (P) vs. Non-deterministic Polynomial (NP)
- Algorithms in P can be solved in P. time in size of input
  - E.g., merge sort is O(n log n) (where n = # of items)
- NP algorithms can be solved in NP time; equivalently, they can be *verified* in in polynomial time
- NP-complete = a set of algorithms that is as hard as possible but still in NP
  - E.g., Traveling Salesperson Problem
- Co-NP refers to algorithms whose converses are NP complete

Complexity Ice Cream Cone



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Now what?

- Time to read papers
- Prepare paper responses – it'll help you focus on the paper, and allow for the discussion leader to prepare better discussion
- You all have different backgrounds, interests, and insights. Bring them into class!

- If you're not yet enrolled in the class but are interested, stay for a minute or two