

CPSC 504 – Background

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

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January 10 and 15, 2024

Administrative notes

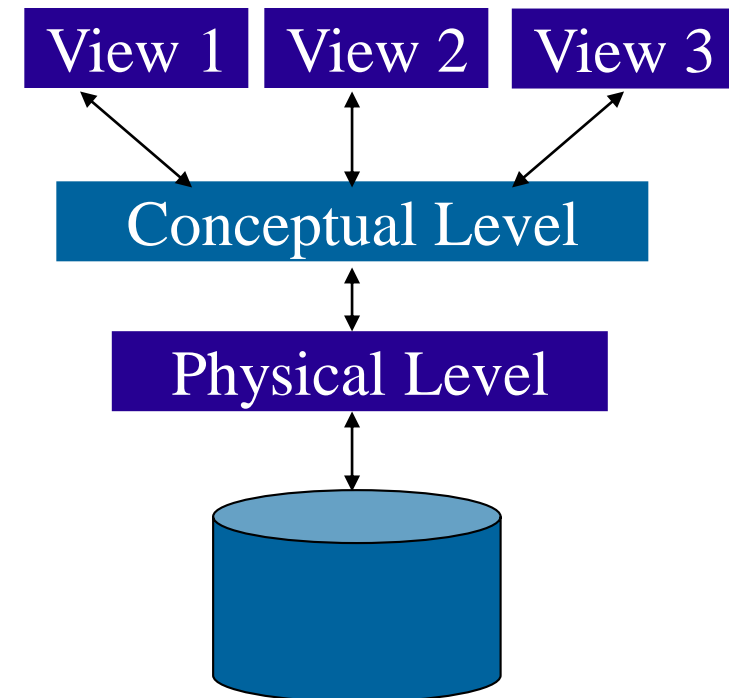
- Don't forget to sign up for a presentation and a discussion
- Anyone having topics they'd like for student request days should send those to me
- Please sign up for the mailing list (majordomo@cs – “subscribe cpsc504”)
- The homework is on the web, due beginning of class January 22
 - General theory – 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.



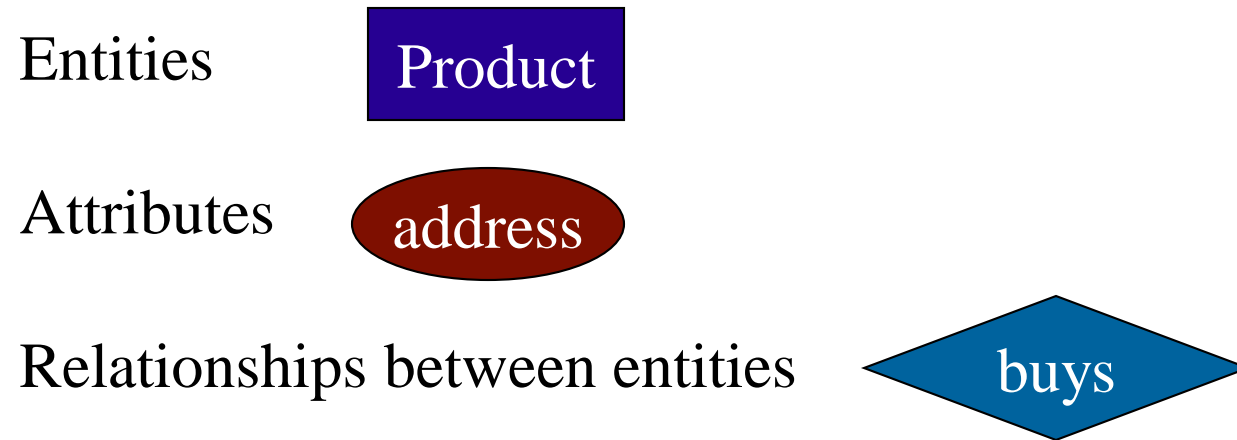
Schema and Instances

- 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

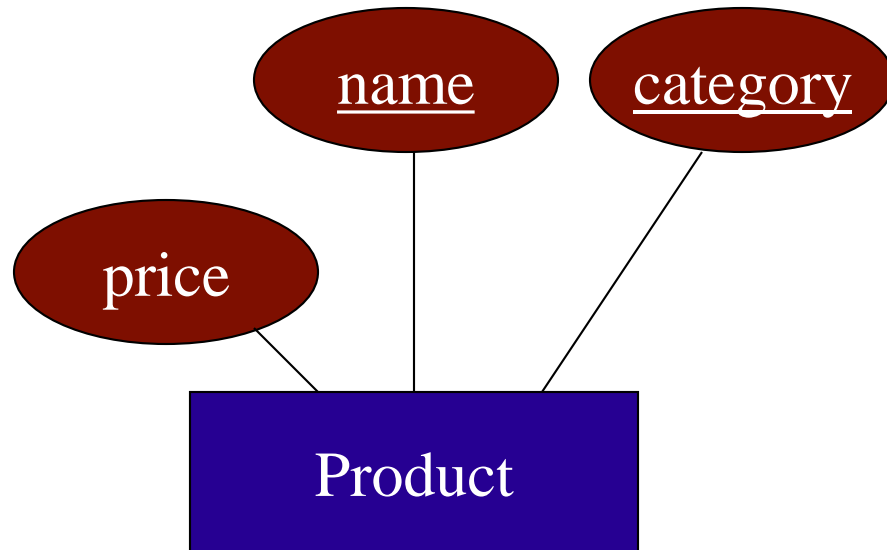
- What are the entities and relationships involved?
 - Entities are usually nouns, e.g., “course” “prof”
 - Relationships are statements about 2 or more objects. Often, verbs., e.g., “a prof teaches a course”
- What information about these entities and relationships should we store in the database?
-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

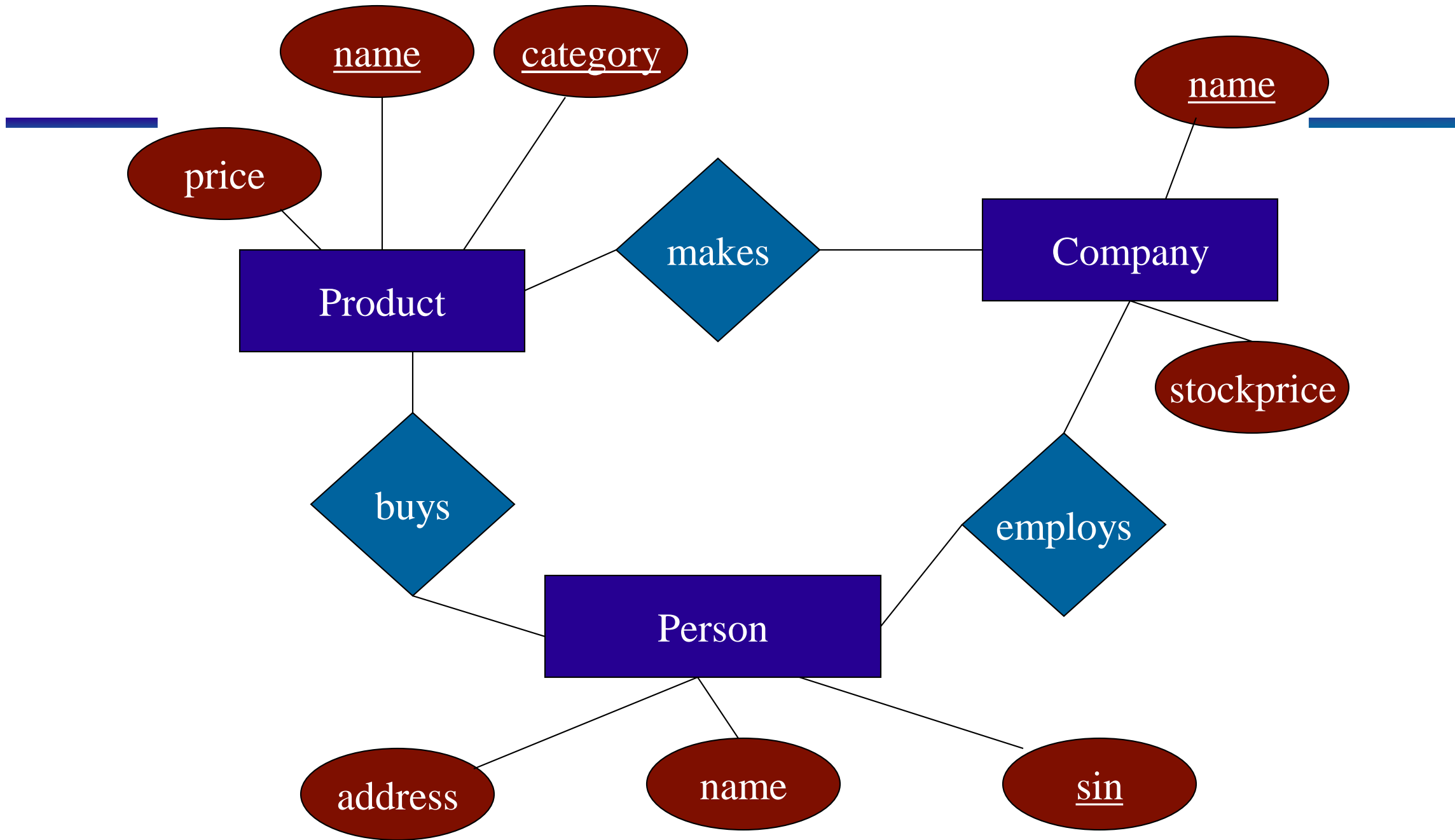
Entity / Relationship Diagrams



Keys in E/R Diagrams

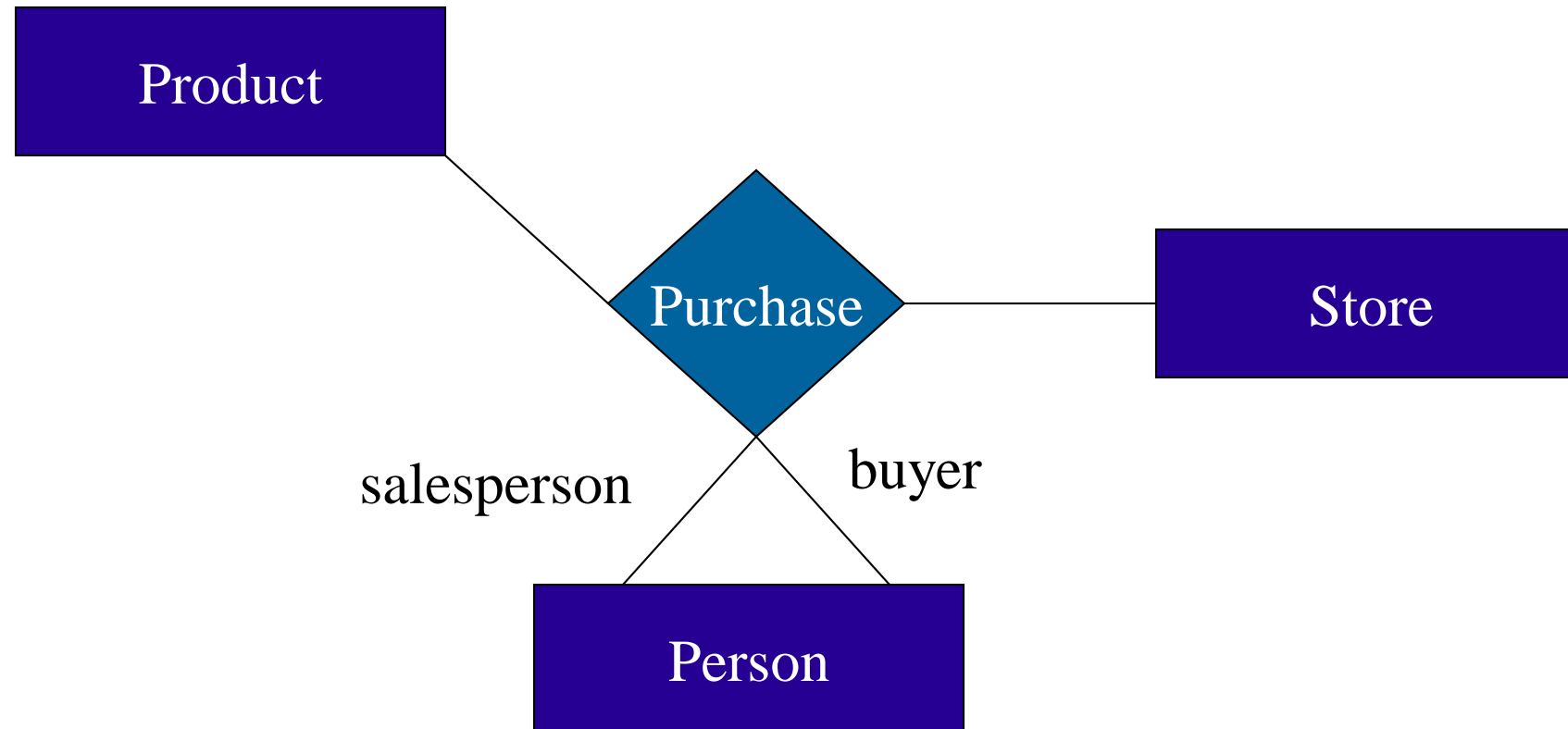
Every entity set must have a key which is identified by an underline



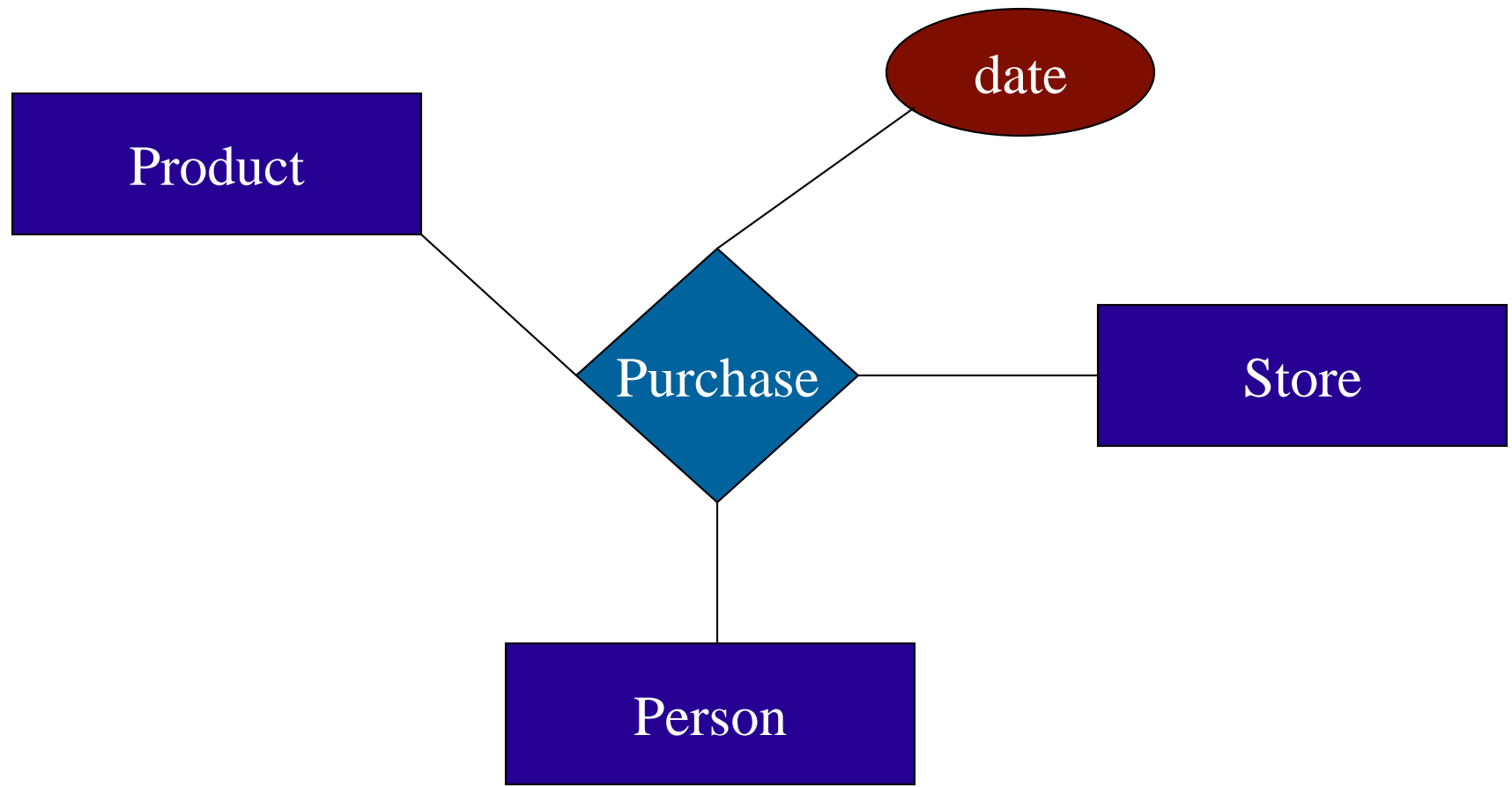


Roles in Relationships

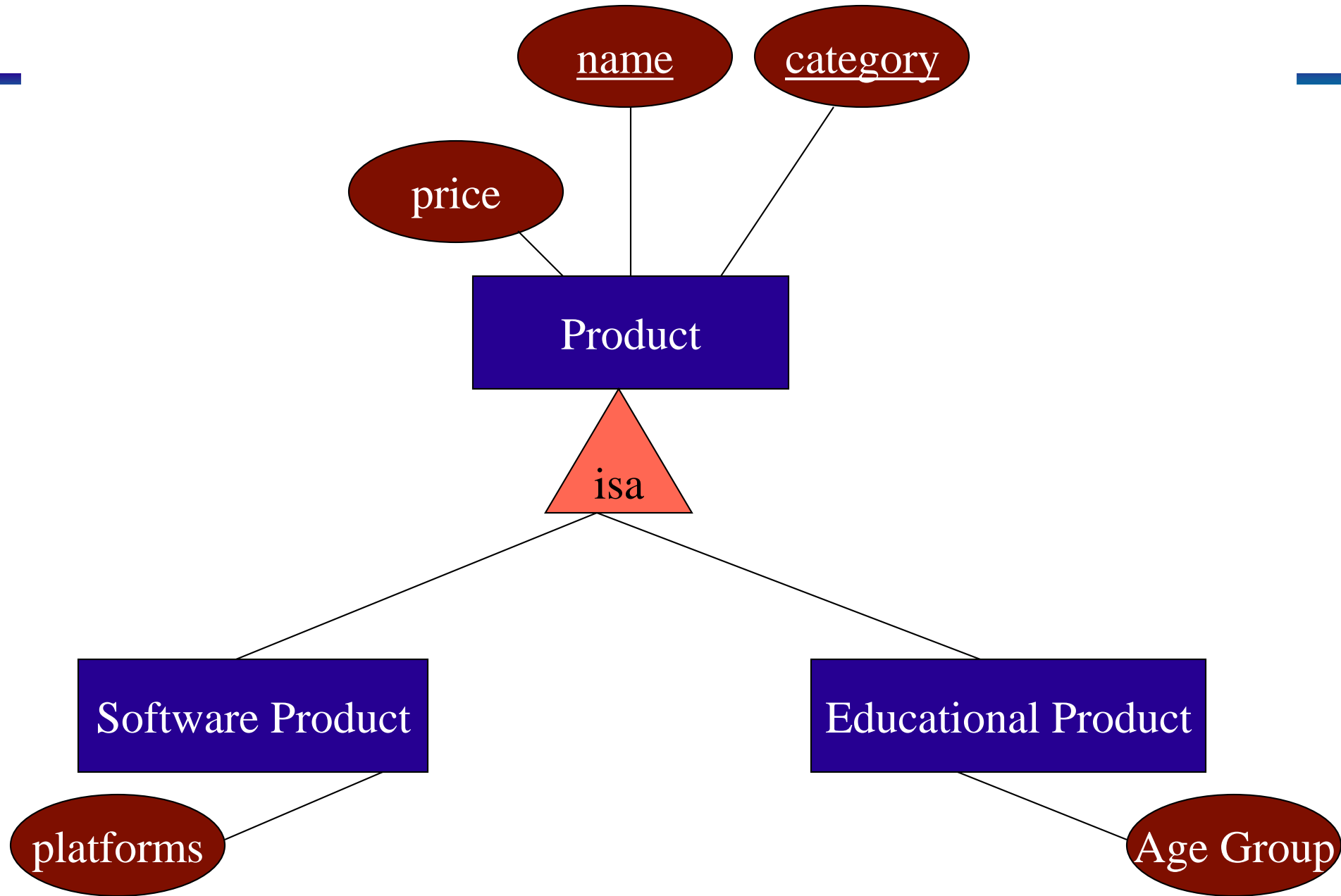
What if we need an entity set twice in one relationship?



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?

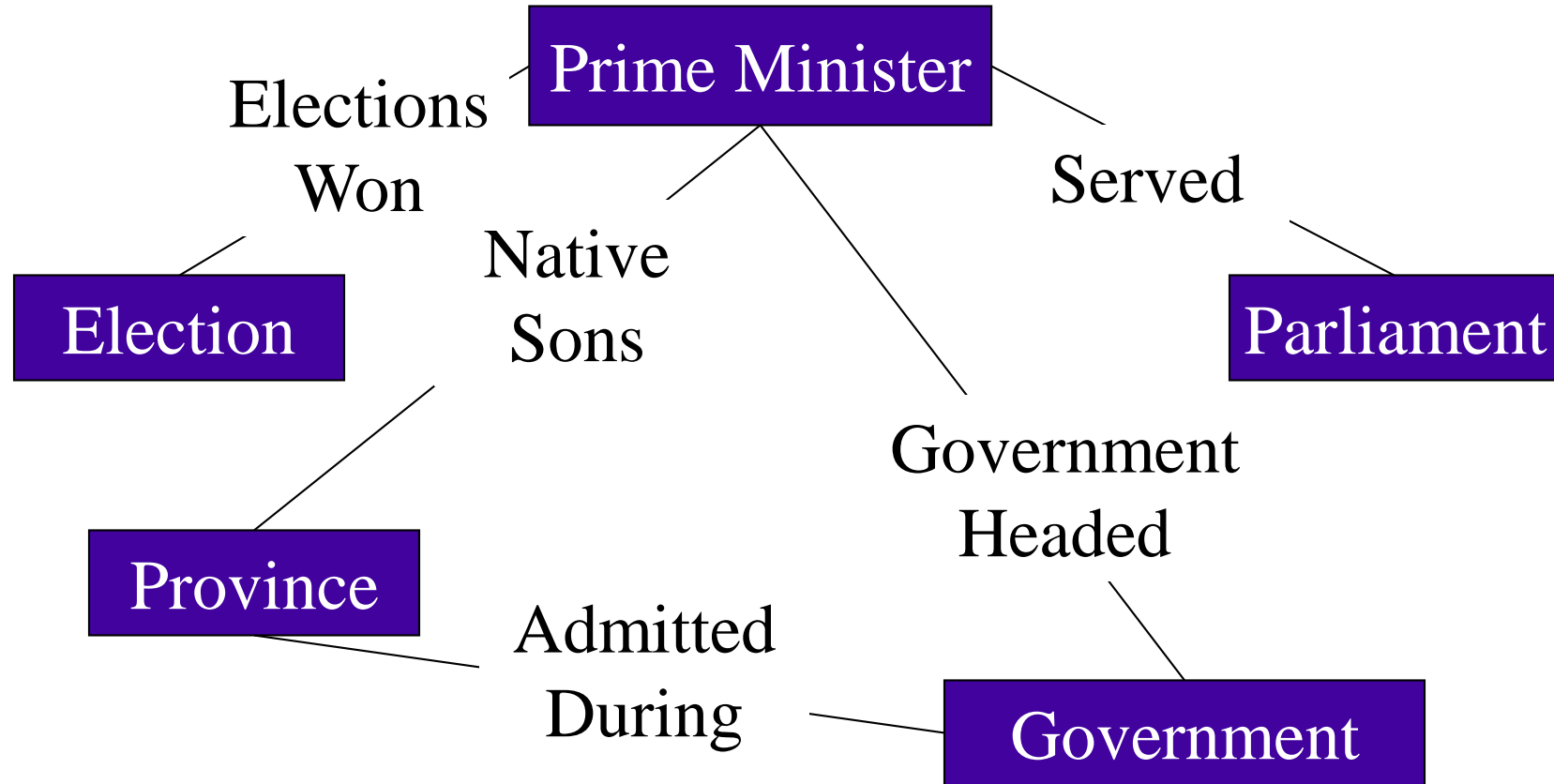
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- Entity Relationship (ER) diagrams
- **Relational databases**
 - How did we get here?
 - What's in a relational schema?
 - From ER to relational
 - Query Languages
- Object Oriented Databases (OODBs)
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-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



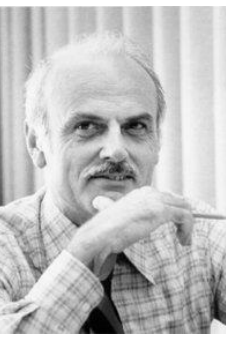
Example IMS (Hierarchical) query: Print the names of all the provinces admitted during a Liberal Government

```
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 BINARY(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 SADMIO_AREA CHAR(20),
  1 province_ADMITTED DEFINED SADMIO_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('SADMIO ');
/* 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,SADMIO_AREA,province_ADMITTED_SSA);
  DO WHILE(PCB.STATUS_CODE=SUCCESSFUL);
    PUT EDIT(province_NAME)(A);
    CALL PLITDLI(FOUR,GNP,QUERY_PCB,SADMIO_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,PRESIDENT_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.
- Old Competitor: object-oriented model
 - **ObjectStore**, Versant, Ontos
 - A synthesis emerged: *object-relational model*
 - Informix Universal Server, UniSQL, O2, Oracle, DB2
- Medium-old competitor: **XML** data model
- New competitor: No-SQL

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)

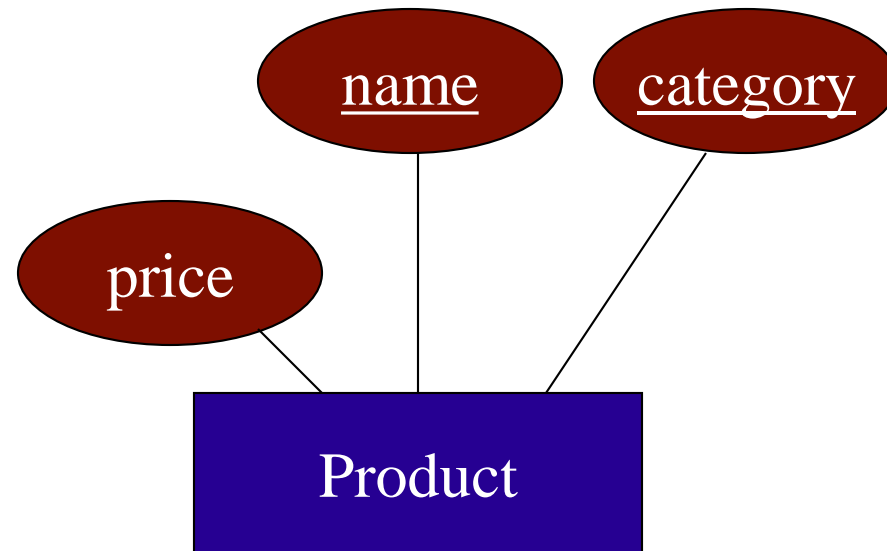
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From E/R Diagrams to Relational Schema

- Entity set \rightarrow relation
- Relationship \rightarrow relation

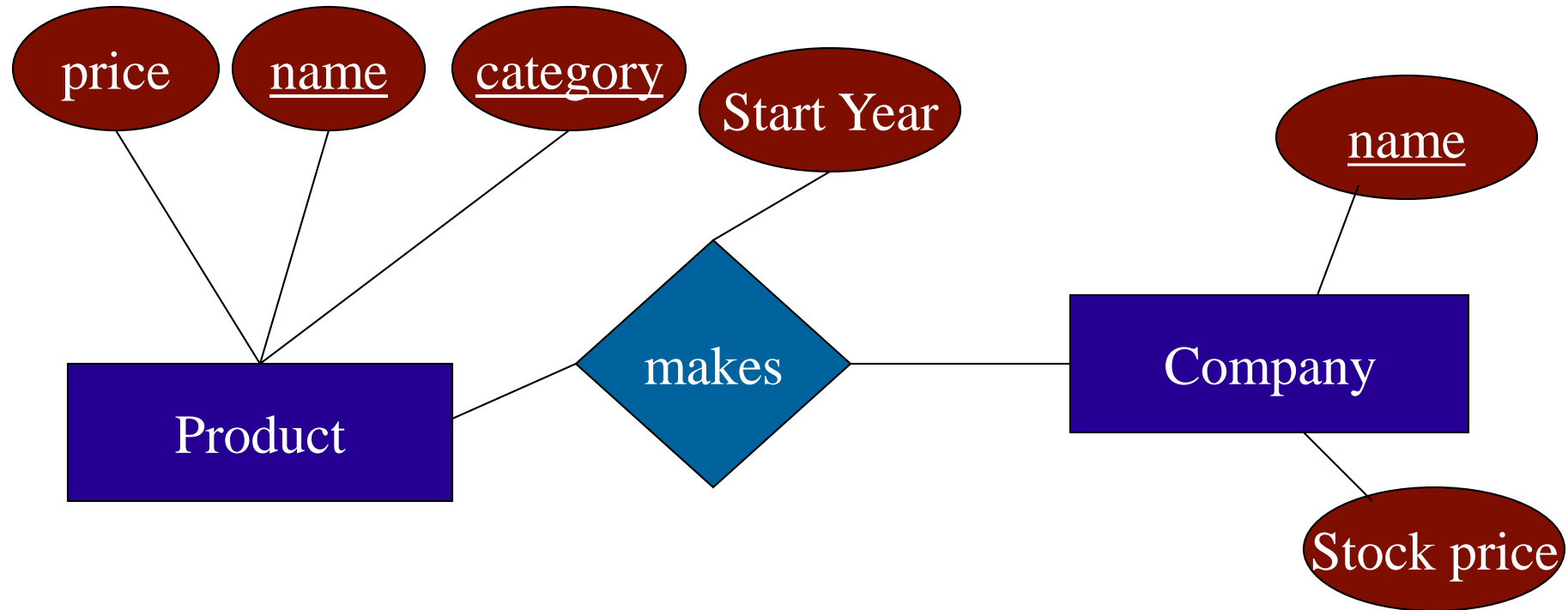
Entity Set to Relation



Product(name, category, price)

name	category	price
gizmo	gadgets	\$19.99

Relationships to Relations



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

<u>Product-name</u>	<u>Product-Category</u>	<u>Company-name</u>	<u>Starting-year</u>
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(Name, Price, Category, Manufacturer)
 - 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

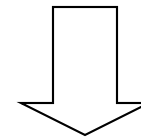
- *Select* (σ)- chose tuples from a relation
- *Project* (π)- chose attributes from relation
- *Join* (\bowtie) - allows combining of 2 relations
- *Set-difference* ($-$) Tuples in relation 1, but not in relation 2.
- *Union* (\cup)
- *Cartesian Product* (\times) Each tuple of R1 with each tuple in R2

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

?



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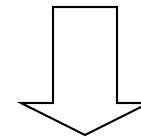
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Product

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Selection:

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



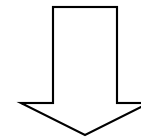
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Find name of all the products

Product

Name	Price	Category	Manufacturer
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?



Name
Gizmo
Powergizmo
SingleTouch
MultiTouch

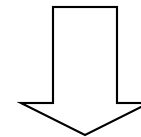
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Projection:

π_{Name} Product



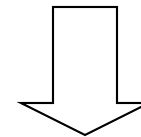
Name
Gizmo
Powergizmo
SingleTouch
MultiTouch

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

Product

Name	Price	Category	Manufacturer
Gizmo	\$19.99	Gadgets	GizmoWorks
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SingleTouch	\$149.99	Photography	Canon
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?



Name	Price	Manufacturer
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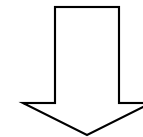
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Selection + Projection:

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



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

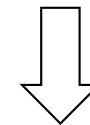
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Company

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

?



Name	Price
SingleTouch	\$149.99

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

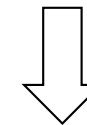
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Company

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

Exercise: using this schema or any other, write two queries in 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)
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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)

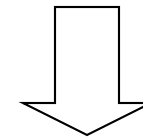
Person(name, phone number, city)

Selection:

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

Product

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What's the SQL?

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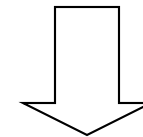
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SELECT *
FROM Product
WHERE Manufacturer = 'GizmoWorks'



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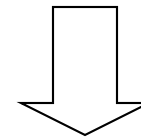
Selection + Projection:

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

Product

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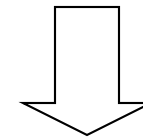
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```
SELECT Name, Price,  
Manufacturer  
FROM Product  
WHERE Price > 100
```

Name	Price	Manufacturer
SingleTouch	\$149.99	Canon
MultiTouch	\$203.99	Hitachi

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

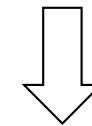
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Company

Cname	StockPrice	Country
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Canon	65	Japan
Hitachi	15	Japan

What's the SQL?



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

Name	Price
SingleTouch	\$149.99

π Name, Price $((\sigma_{\text{Price}} \leq 200 \text{ Product}) \bowtie \text{Manufacturer} = \text{Cname} (\sigma_{\text{Country}} = \text{'Japan' Company}))$

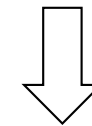
Product

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

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)

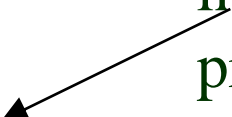
Datalog Rules and Queries

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)&
NOT Company(M, SP, "Canada")

Negated subgoal

(sometimes you'll see &'s between atoms and sometimes &; both mean "and")

Relations:

Product (name, price, category, manufacturer)

Purchase (buyer, seller, store, product)

Company (name, stock price, country)

Person (name, phone number, city)

Conjunctive Queries

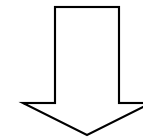
- A subset of Datalog
- Only relations appear in the right hand side of rules
- No negation
- Functionally equivalent to Select, Project, Join queries
- Very popular in modeling relationships between databases

Selection:

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

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?

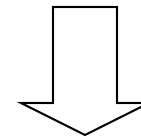
Name	Price	Category	Manufacturer
Gizmo	\$19.99	Gadgets	GizmoWorks
Powergizmo	\$29.99	Gadgets	GizmoWorks

Selection:

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

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



$Q(n,p,c, \text{'GizmoWorks'}) :- \text{Product}(n,p,c, \text{'GizmoWorks'})$

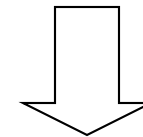
Name	Price	Category	Manufacturer
Gizmo	\$19.99	Gadgets	GizmoWorks
Powergizmo	\$29.99	Gadgets	GizmoWorks

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
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MultiTouch	\$203.99	Household	Hitachi



What's the Datalog?

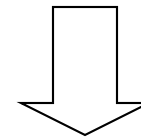
Name	Price	Manufacturer
SingleTouch	\$149.99	Canon
MultiTouch	\$203.99	Hitachi

Selection + Projection:

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

Product

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SingleTouch	\$149.99	Photography	Canon
MultiTouch	\$203.99	Household	Hitachi



$Q(n,p,m) :- \text{Product}(n,p,c,m), p > 100$

Name	Price	Manufacturer
SingleTouch	\$149.99	Canon
MultiTouch	\$203.99	Hitachi

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

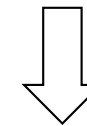
Product

Name	Price	Category	Manufacturer
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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 Datalog?



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

Name	Price
SingleTouch	\$149.99

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

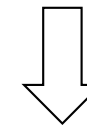
Product

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,'Japan'), 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

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

IntlProd(N) :- Product(N,P,C,M) & Company (M2, SP, C2) &
NOT Company(M, SP, "Canada")

Negated subgoal

(sometimes you'll see &'s between atoms and sometimes &; both mean "and")

Relations:

Product (name, price, category, manufacturer)

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
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- XML
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- Database internals (Briefly)
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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*

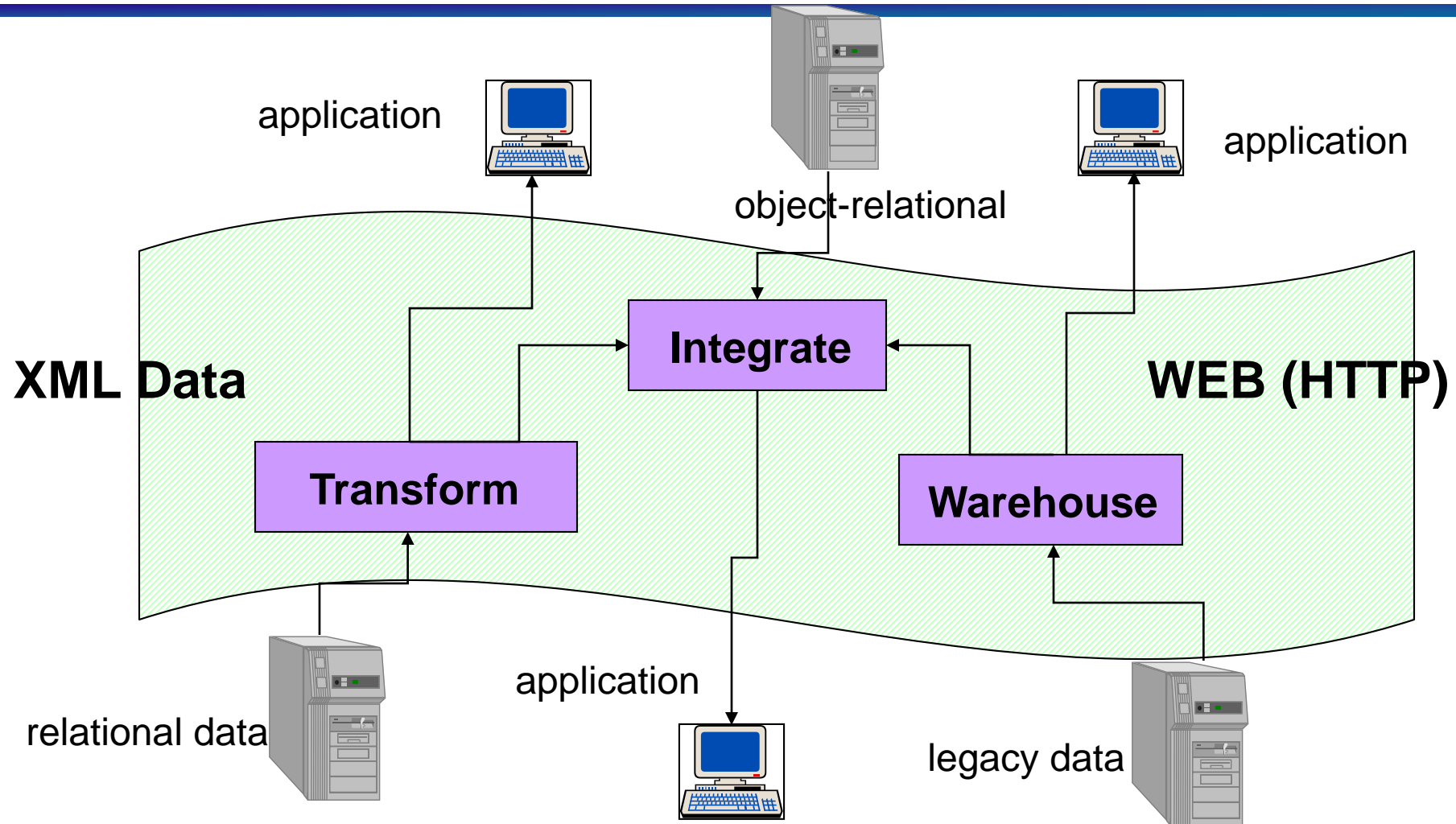
XML is self-describing

- 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

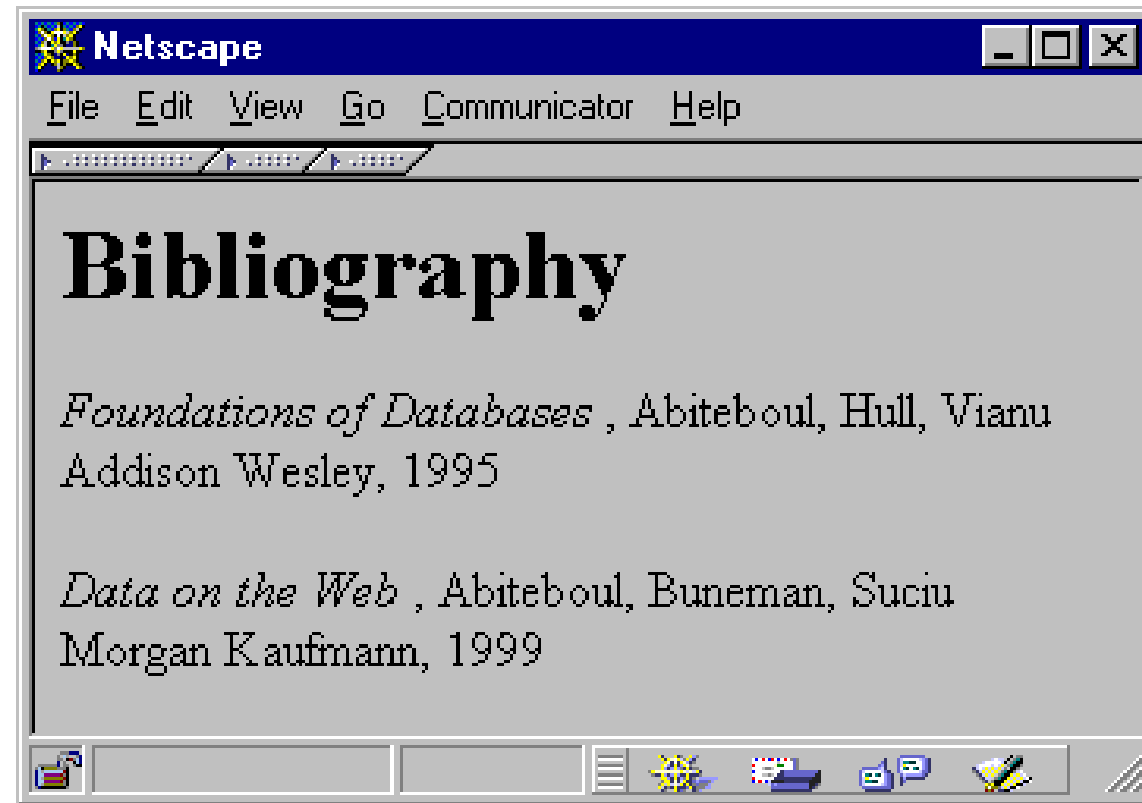
Why XML is of Interest to Us

- 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



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, Suci
```

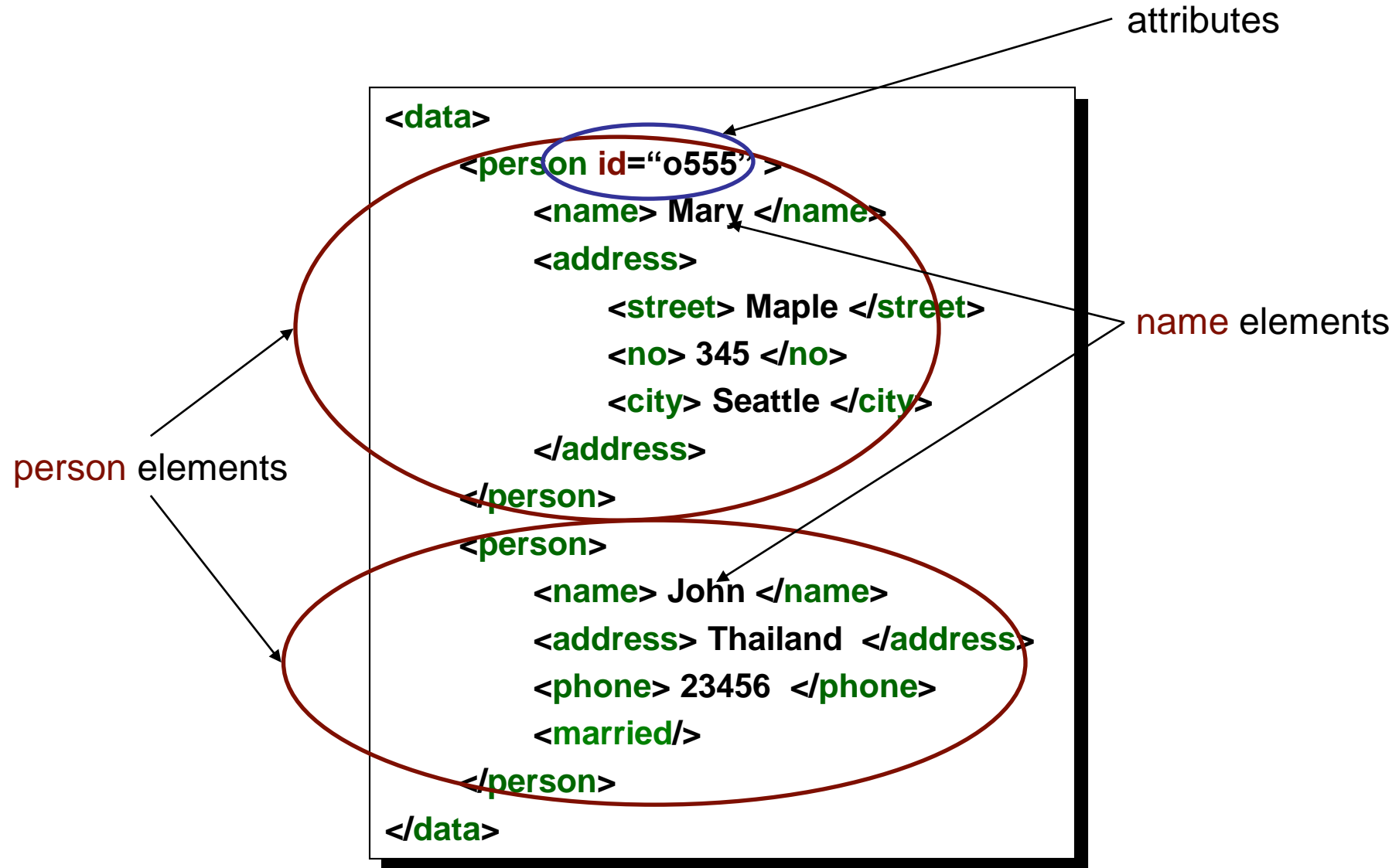
```
  <br> Morgan Kaufmann, 1999
```

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



XML Terminology

- Elements

- enclosed within tags:

- `<person> ... </person>`

- nested within other elements:

- `<person> <address> ... </address> </person>`

- can be empty

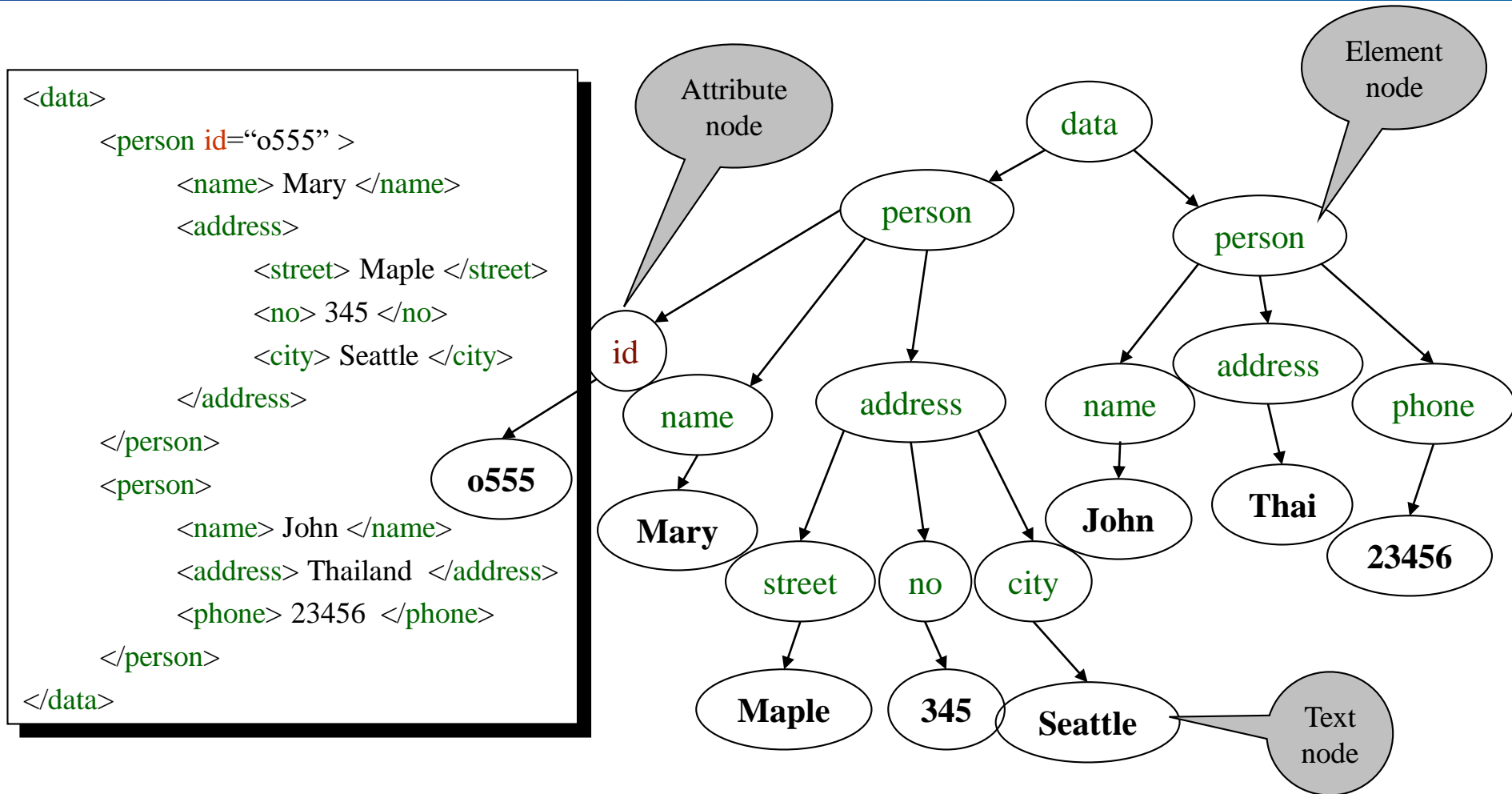
- `<married></married>` abbreviated as `<married/>`

- can have **Attributes**

- `<person id="0005"> ... </person>`

- XML document has as single ROOT element

XML as a Tree !!



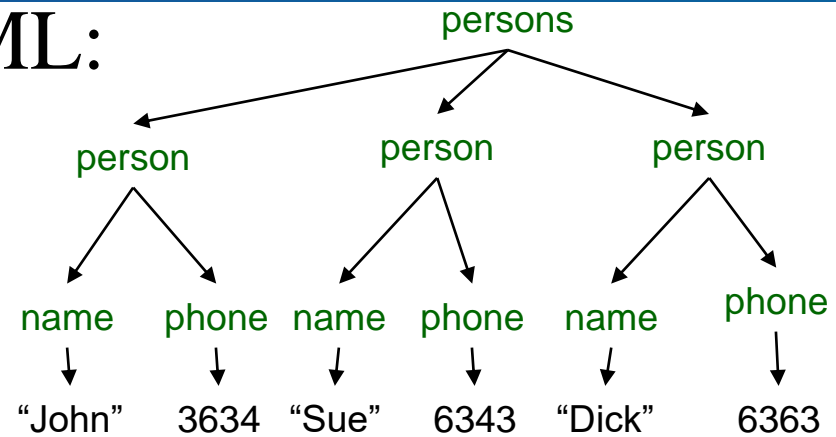
Minor Detail: Order matters !!!

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

← structured name !

- 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 types
- Database internals (Briefly)
- Potpourri

Other data formats

- Key-value pairs (e.g., No SQL)
- Makefiles
- Forms
- Application code

What format is your data in?

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 - Transaction Processing
- Potpourri

How SQL Gets Executed: Query Execution Plans

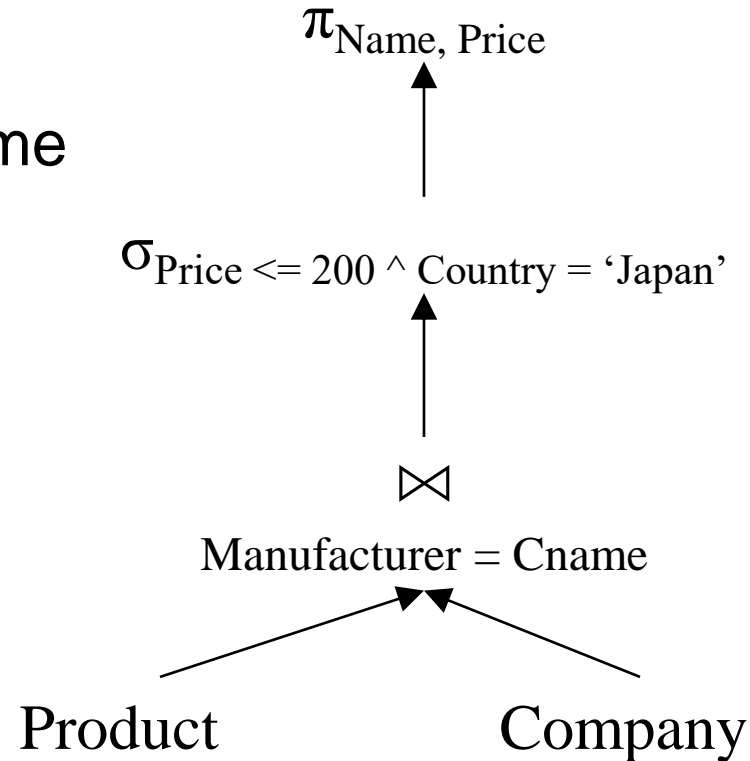
Select Name, Price

From Product, Company

Where Manufacturer = Cname

AND Price <= 200

AND Country = 'Japan'



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

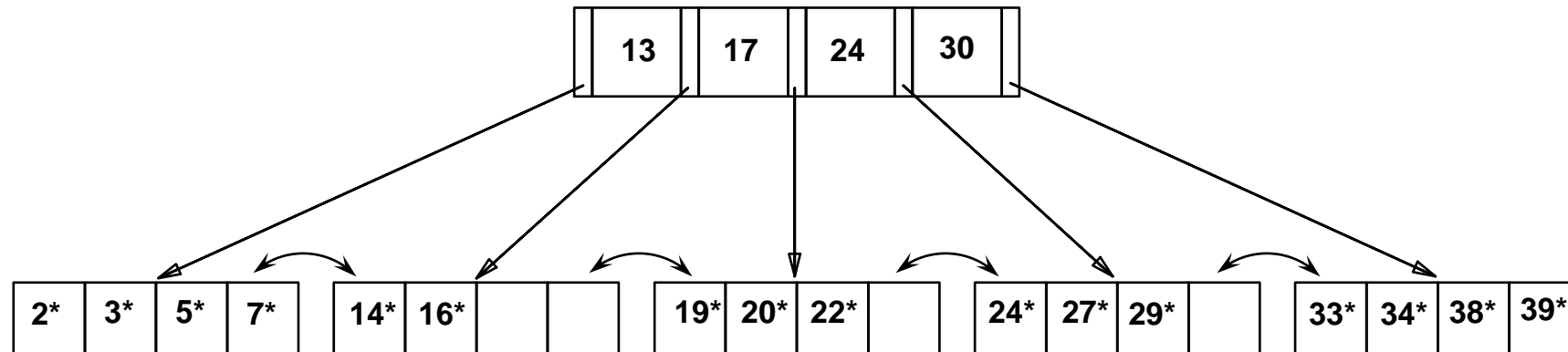
Tree-Based Indexes

- “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 $\geq 24^*$...



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:
 - Intuitively, T1 transfers \$100 to A's account from B's account. T2 credits both accounts with a 10% interest payment.

```
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)
```

- 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

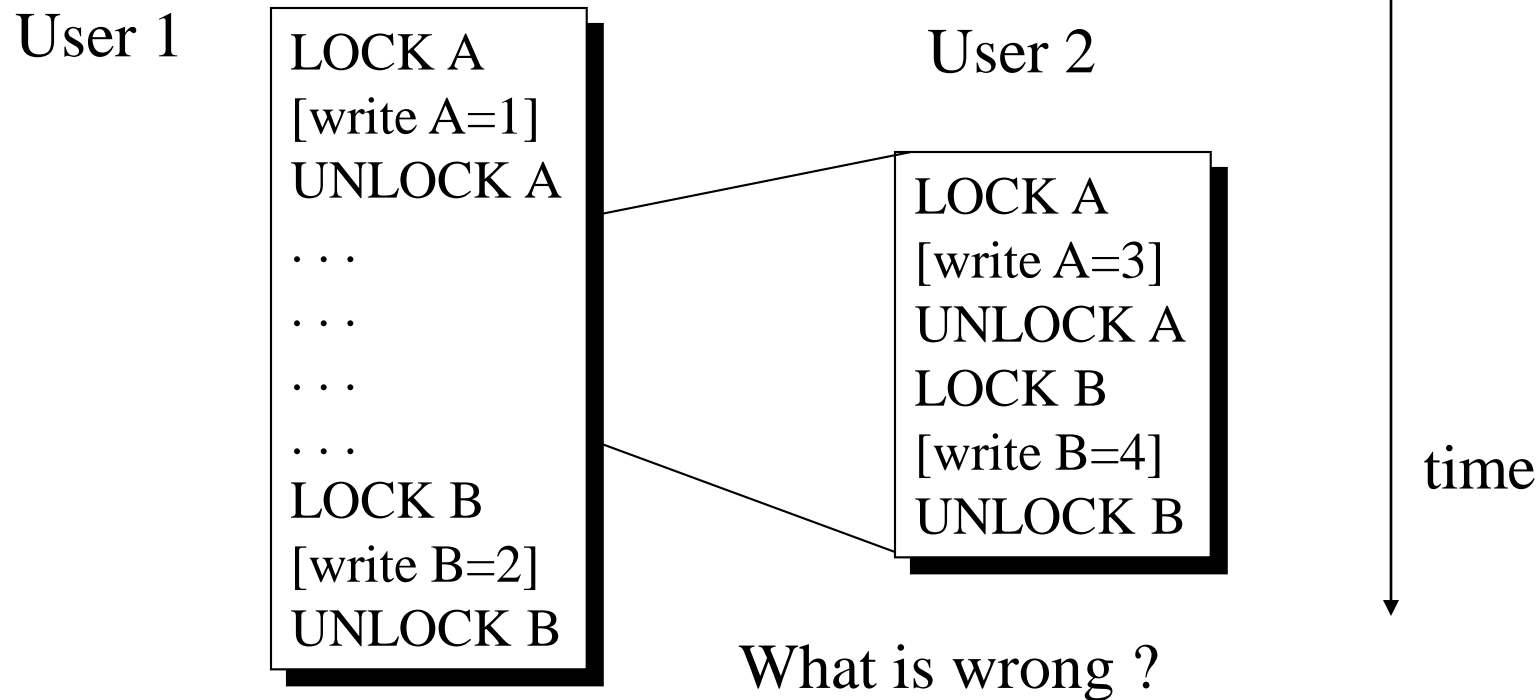
Transactions: Serializability

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 is 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:



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

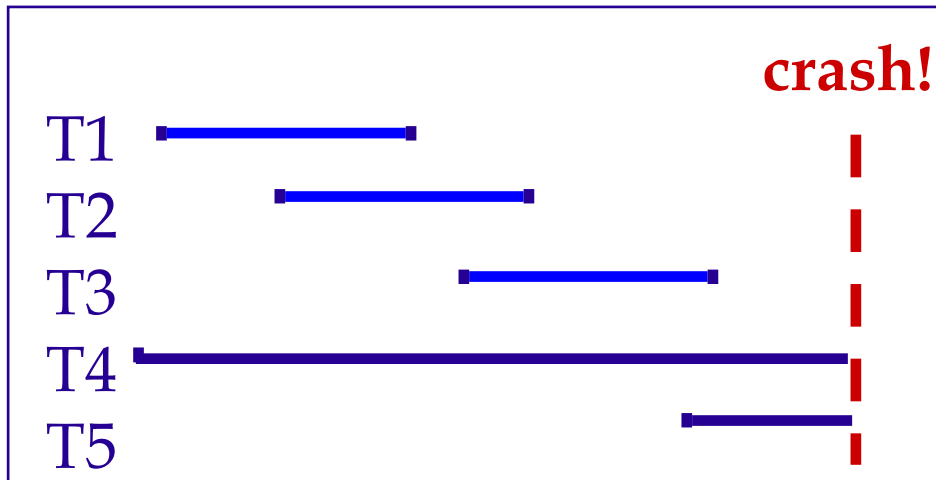
Enforcing Atomicity & Durability

- 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?



Force

No Force

	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

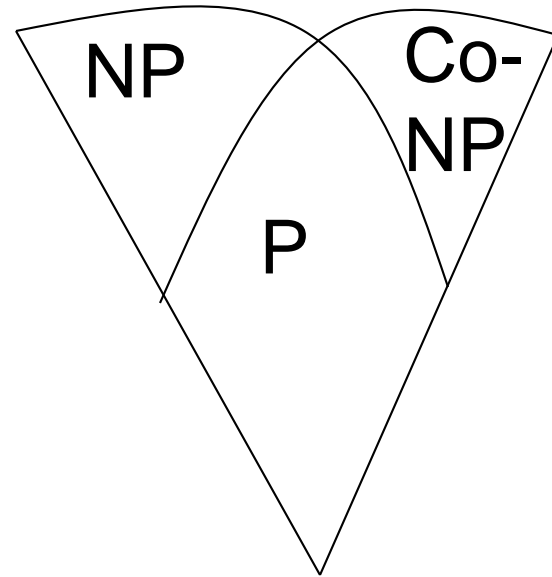
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 - Complexity
 - Memory hierarchy

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 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

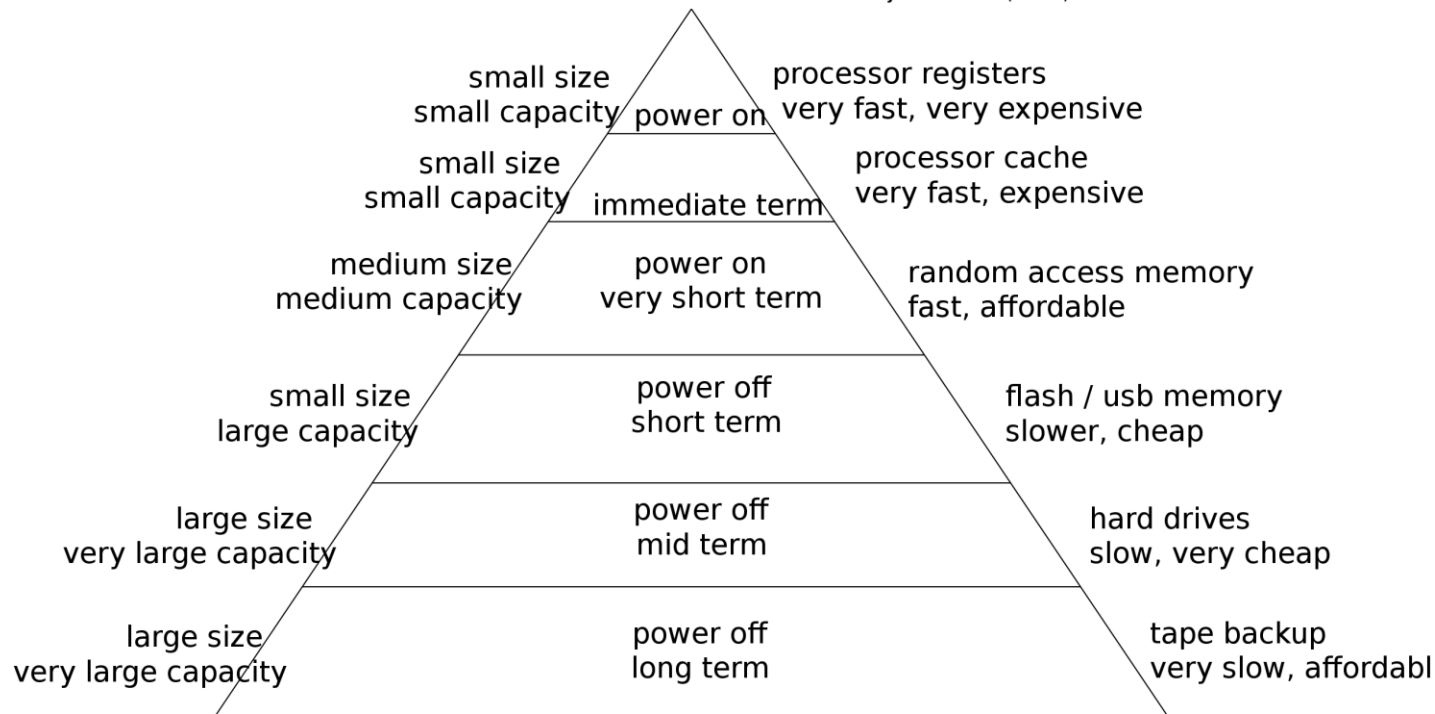
Complexity Ice Cream Cone



Memory hierarchy

Computer Memory Hierarchy

by Dan Lash (.com)



Note: Moore's law is over; multi-cores/processors much more common in last 20 years

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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!
- Projects! Looking for a group? Stick around!