CSE544

Monday
April 26, 2004

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Announcements

- Project Milestone
  - Due today
- Next paper: *On the Unusual Effectiveness of Logic in Computer Science*
  - Need to read only up to section 3
  - Review due on Wednesday
  - It's very short; review should be similar :)

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XML Storage

Shanmugasundaram's paper:

- Shred XML data à relations
  - Easy: use the DTD
- Translate XML queries à SQL queries
  - Largely ignored in the paper
- Tagging
  - SQL tuple streams à XML
  - How do we do that ?

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XML Storage

Other ways:

- Schema independent shredding
- BLOBs
- Use an object storage system

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OO Databases

- Started late 80's
  - The OO Manifesto
- Main idea:
  - Toss the relational model !
  - Use the OO model – e.g. C++ classes

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OO Databases

Two interpretations:

- Make a programming language persistent (ObjectStore)
  - No query language
  - Niche market
  - ObjectStore is still around, renamed to Exelon, stores XML objects now
- Build a new database from scratch (O_2)
  - Elegant extension of SQL
  - Later adopted by ODMG in the OQL language

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ODL / OQL

```
interface Person
  (extent People key ssn)
{  attribute string  ssn;
   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;}
```

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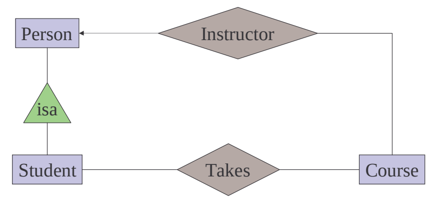
Same in E/R



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ODL / OQL

```
select C.name
from  Crs C
where C.instructor.dept = 'EE'
```

Follow pointers instead of joins

```
select S.name
from  Students S, S.takes C
where C.instructor.dept = 'EE'
```

Is this more efficient than joins?

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Object-Relational (OR) Databases

- Take an incremental approach
- Keep the relational model, but allow attributes of complex types
  - Inheritance
  - Pointers
  - Methods (a security nightmare)
- All major commercial databases today are OR
- Trend: XML datatype

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Theory

- Recall: relational databases invented by a theoretician (Codd)
- Fundamental principle: separate the WHAT from the HOW - *data independence*
- WHAT: First Order Logic (FO)
- HOW: Relational algebra (RA)

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FO Syntax

Given:

- A vocabulary: $R_1, \ldots, R_k$
- An arity, $ar(R_i)$, for each $i=1,\ldots,k$
- An infinite supply of variables $x_1, x_2, x_3, \ldots$
- Constants: $c_1, c_2, c_3, \ldots$

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FO Syntax

- Terms (t) and FO formulas (φ) are:

$$t ::= x \mid c$$

$$\varphi ::= R(t_1, ..., t_{ar(R)}) \mid t_i = t_j \mid \varphi \wedge \varphi' \mid \varphi \vee \varphi' \mid \neg\varphi' \mid \forall x.\varphi \mid \exists x.\varphi$$

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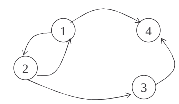
FO Examples

Most interesting case:

Vocabulary = one binary relation R (encodes a graph)



R=

1	2
2	1
2	3
1	4
3	4

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FO Sentences

- Does there exists a loop in the graph ?

$\varphi \equiv \exists x.R(x,x)$

- Are there paths of length >2 ?

$\varphi \equiv \exists x.\exists y.\exists z.\exists u.(R(x,y) \wedge R(y,z) \wedge R(z,u))$

- Is there a "sink" node ?

$\varphi \equiv \exists x.\forall y.R(x,y)$

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FO Queries

- Find all nodes connected by a path of length 2:

$\varphi(x,y) \equiv \exists u.(R(x,u) \wedge R(u,y))$

- Find all nodes without outgoing edges:

$\varphi(x) \equiv \exists u.(R(u,x) \wedge \forall y.\neg R(x,y))$

These are *open formulas*

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In Class

- Retrieve all nodes with at least two children
- A node x is more important than y if every child of y is also a child of x. Retrieve all 'most important nodes' in the graph

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FO in Databases

FO	**Databases**
Vocabulary: $R_1, ..., R_n$	Database schema: $R_1, ..., R_n$
Model: $\mathbf{D} = (D, R_1^D, \ldots, R_k^D)$	Database instance: $\mathbf{D} = (D, R_1^D, \ldots, R_k^D)$
Sentences are *true* or *false*	Formulas compute *queries*

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FO Semantics

- In FO we express WHAT we want
- Sometimes it's even unclear HOW to get it
- See accompanying slides on FO semantics
  - They explain HOW to get it, but it's impractical

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Relational Algebra

- An algebra over relations
- Five operators:
  $\cup$, -, $\times$, σ, Π
- Meaning:

$R_1 \cup R_2$ = set union
$R_1 - R_2$ = set difference
$R_1 \times R_2$ = cartesian product
$\sigma_c(R)$ = subset of tuples satisfying condition c
$\Pi_a(R)$ = projection on the attributes in a

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FO $\rightarrow$ RA

$\varphi(x) \equiv R(x,x) \quad \rightarrow \quad \Pi_1(\sigma_{1=2}(R))$

$\varphi(x,y) \equiv \exists z.\exists u.(R(x,z) \wedge R(z,u) \wedge R(u,y)) \quad \rightarrow \quad \Pi_{16}(\sigma_{2=3 \wedge 4=5}(R \times R \times R))$

$\Pi_{16}((R \text{ join}_{2=1} R) \text{ join}_{4=1} R))$

$\varphi(x) \equiv \forall y.R(x,y) \quad \rightarrow \quad ?$

WHAT $\rightarrow$ HOW

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FO v.s. RA

Theorem. Every query in RA can be expressed in FO

Proof

This shows how to go from HOW to WHAT
not very interesting

What about the converse ?

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The Drinkers/Beers Example

- Vocabulary:

Likes(drinker,beer), Serves(bar,beer), Frequents(drinker,bar)

- Find all drinkers that frequent some bar that serve some beer that they like:

$\varphi(d) \equiv \exists ba. \exists be.(F(d,ba) \wedge L(d,be))$

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Lots of Fun Examples (in class)

- Find drinkers that frequent some bar that serves only beer they like
- Find drinkers that frequent only bars that serve some beer they like
- Find drinkers that frequent only bars that serve only beer they like

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Unsafe FO Queries

- Find all nodes that are not in the graph:

$$q(x) = \neg\exists y.R(x, y) \wedge \neg\exists z.R(z, x)$$

what's wrong ?

Unsafe FO Queries

- Find all nodes that are connected to "everything":

$$q(x) = \forall y.R(x, y)$$

what's wrong ?

Unsafe FO Queries

- Find all pairs of employees or offices:

$$q(x, y) = Emp(x) \vee Office(y)$$

what's wrong ?

- We don't want such queries !

Safe Queries

A model **D** = (D, R_1^D, …, R_k^D)

- In FO:
  - both D and R_1^D, …, R_k^D may be infinite
- In databases:
  - D may infinite (**int**, **string,** etc)
  - R_1^D, …, R_k^D are always finite
  - We call this a *finite model*

Safe Queries

- φ is a *finite* query if for every finite model **D**, φ(**D**) is finite
- φ is *safe*, or *domain independent*, if for every two models **D**, **D'** having the same relations:

  D = (D, R_1^D, …, R_k^D), **D'** = (D', R_1^D, …, R_k^D)

  we have φ(**D**) = φ(**D'**)
- If φ is safe then it is also finite (why ?)
- Note: book has different but equivalent definition

Safe Queries

- **Definition**. Given **D** = (D, R_1^D, …, R_k^D), the *active domain* is D_a = the set of all constants in R_1^D, …, R_k^D
- **Example**. Given a graph **D** = (D, R)
  $D_a = \{ x \mid \exists y.R(x,y) \vee \exists z.R(z,x)\}$
- **Property**. If a query is safe, it suffices to range quantifiers only over the active domain (why ?)
- Hence we can *compute* safe queries

Safe Queries

- The **safe relational calculus** consists only of safe queries. However:
- **Theorem** It is undecidable if a given a FO query is safe.
- Need to write only safe queries, but how do we know how which queries are safe ?
- Work around: write them in an obviously safe way
  - Range restricted queries - formally defined in [AHU]

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FO v.s. RA

Theorem. Every safe query in FO can be expressed in RA

Proof

From WHAT to HOW
this is really interesting and motivated the relational model

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Limited Expressive Power

- Vocabulary: binary relation R
- The following queries cannot be expressed in FO:
- Transitive closure:
  - $\forall x.\forall y.$ there exists $x_1, ..., x_n$ s.t. $R(x,x_1) \wedge R(x_1,x_2) \wedge ... \wedge R(x_{n-1},x_n) \wedge R(x_n,y)$
- Parity: the number of edges in R is even

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