CMSC724: Data Models

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Outline

Databases: A Brief History

- 1960's: Computers finally become attractive, and enterprises start using it. Most applications initially used their own data stores.
- Data base: coined in military information systems to denote "shared data banks" by multiple applications
- Why ?
  - Each application had its own format
  - Although the data was there, basically unavailable to other programs
    - Often original object code was lost
- Instead, define a data format, store it as a "data dictionary", and allow general-purpose "data-base management" software to access it
- Issues:
  - How to write data dictionaries? How to access data?
  - Disadvantages of integration: integrity, security, privacy concerns
  - Who controls the data?

Databases: A Brief History

- 1960's
  - Birth of "hierarchical model" and "network model"
    - Both allowed "connecting" records of different types (e.g., connect "accounts" with "customers")
    - Network model attempted to be very general and flexible —- Charlie Bachman received Turing Award
  - IBM designed its IMS hierarchical database in 1966 for the Apollo space program; still around today
    - ".. more than 95 percent of the top Fortune 1000 companies use IMS to process more than 50 billion transactions a day and manage 15 million gigabytes of critical business data" (from IBM Website on IMS)
    - Predates "hard disks"
  - However, both models exposed too much of the internal data structures/pointers etc to the users

Databases: A Brief History

- 1970's: Relational Model
  - Origins in Set Theory
  - Some early work by D.L.Childs (somewhat forgotten)
  - Edgar F. "Ted" Codd: Developed the relational model
    - Elegant, formal model that provided almost complete "data independence"
    - Users didn't need to worry about how the data was stored, processed etc.
    - High level query language (relational algebra)
    - Notion of *normal forms* —- Allowed one to reason about and remove redundancies

Databases: A Brief History

- 1970's: Relational Model
  - Led to two influential projects: INGRES (UC Berkeley), System R (IBM)
  - Also paved the way for a 1977 startup called "Software Development Laboratories"
    - Didn't care about IMS/IDMS compatibility (as IBM had to)
- 1976: Peter Chen proposed "Entity-Relationship Model"
  - Allowed higher-level, conceptual modeling; easier for humans to think about
- 1980: Commercialization/wide-spread acceptance
  - SQL emerged as a standard, in large part because of IBM's backing
  - People still sometimes complain about its limitations
- Late 80's: Object-oriented, object-relational databases
  - Enriching the expressive power of relational model
  - Other proposals for semantic data models

Databases: A Brief History

- Late 80's, early 90's
  - Many database companies, but starting to consolidate
  - Parallel databases beginning to emerge
  - Data mining/OLAP (online analytical processing)
  - Focus on client tools for application development: PowerBuilder (Sybase), Oracle Developer etc.
  - Client-server model becomes popular
- Mid/late 90's
  - Web arrives: Growth of *middleware* that connects web apps to databases
    - Active server pages, Enterprise Java Beans, ColdFusion
  - OLAP matures and becomes mainstream

Databases: A Brief History

- Early 00's to mid 00's
  - A sudden boom in data warehousing/analytics
    - Companies like: Aster Data, Greenplum, Vertica, Kickfire, and probably 10 others
    - Some consolidation recently
  - Column-stores, analytics, streaming data, become important
- Late 00's
  - *map-reduce*: framework for large-scale data analysis
  - *key-value stores:* framework for "scale-first" data management
  - Databases late to react, but have adopted
    - Exploring different design points in integration of databases and map-reduce
    - Transactions and consistency in distributed key-value stores
- Next?

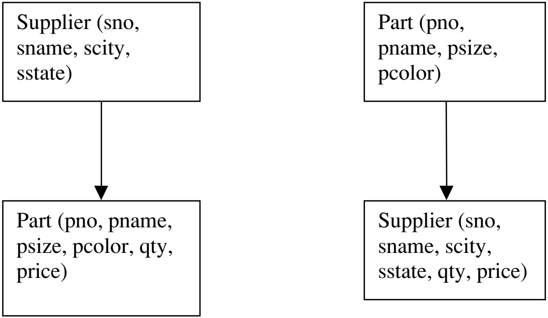
Outline

Data Modeling

- A data model theory typically involves
  - "structural part" – collection of concepts/constructs to *represent* data
  - "integrity part" – constraints to *ensure data integrity*
  - "manipulation part" – constructs for *manipulating* the data
- We would like it to be:
  - Sufficiently expressive – can capture real-world data well
  - Easy to use
  - Lends itself to good performance

Data Models

- Hierarchical/IMS
  - Constructs: Hierarchy, keys, record types, DL/1 lang.



Two Hierarchical Organizations
Figure 2

Data Models

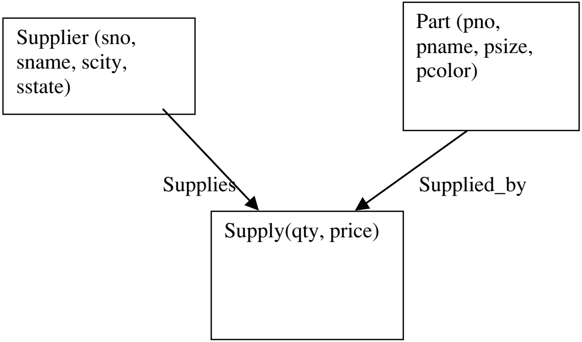
- Hierarchical/IMS
- Root records can either be:
    - Stored sequentially
    - Indexed in a B-tree using the key of the record
    - Hashed using the key of the record
- Dependent records are found from the root using either
    - Physical sequentially
    - Various forms of pointers.
- Leads to heavy physical data dependence

Data Models

- Hierarchical/IMS
  - Issues:
    - Navigational interaction
    - No physical data independence
    - Repetition of information (m-to-n relationships)
    - Inability to represent information
    - Last two solved by a latter extension
  - Some logical data independence

Data Models

- Network/CODASYL
  - Constructs: “set” type, network structure

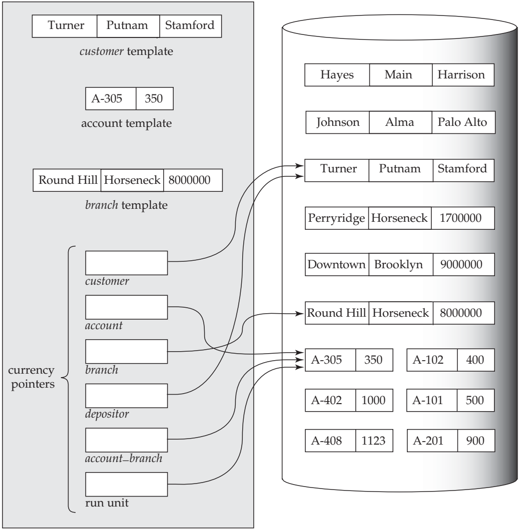


A CODASYL Network
Figure 5

Data Models

- Network/CODASYL
  - Constructs: "set" type, network structure
  - "programmer as a navigator"
  - Cons:
    - No physical or logical data independence
    - Bulk loading
    - 3-way relationships
    - Very complex programming constructs

Data Models: Network/CODASYL




```
customer.customer_city := "Harrison";
find any customer using customer_city;
while DB-status = 0 do
    begin
        get customer;
        print (customer.customer_name);
        find duplicate customer using customer_c
    end;
```

Figure A.20 Program work area.

Data Models

- Relational
    - Constructs: Relations, relational algebra/calculus, functional dependencies
    - Physical and logical data independence
    - Cons:
        - Transitive closure
        - (initially) performance
        - (initially) too complex and mathematical languages

Data Models

- Many debates in 1970's
- Relational Model Advocates
  - Nothing as complex as CODASYL can possibly be a good idea
  - CODASYL does not provide acceptable data independence
  - Record-at-a-time programming is too hard to optimize
  - CODASYL and IMS are not flexible enough to easily represent common situations (such as marriage ceremonies)
- CODASYL Advocates
  - COBOL programmers cannot possibly understand the new-fangled relational languages
  - It is impossible to implement the relational model efficiently
  - CODASYL can represent tables, so what's the big deal?
- Both camps changed positions to move towards each other
- (According to Authors) Effectively settled by mini-computer revolution, and by IBM who announced new relational products

Data Models

- Don Chamberlin of IBM was an early CODASYL advocate (later co-invented SQL)

"He (Codd) gave a seminar and a lot of us went to listen to him. This was as I say a revelation for me because Codd had a bunch of queries that were fairly complicated queries and since I'd been studying CODASYL, I could imagine how those queries would have been represented in CODASYL by programs that were five pages long that would navigate through this labyrinth of pointers and stuff. Codd would sort of write them down as one-liners. These would be queries like, "Find the employees who earn more than their managers." [laughter] He just whacked them out and you could sort of read them, and they weren't complicated at all, and I said, "Wow." This was kind of a conversion experience for me, that I understood what the relational thing was about after that."

Data Models

- Entity-relational
  - Constructs: entity, relationship
  - Limitations: Lack of query language, ease of mapping into relational
  - The conceptual model of choice to design the schema

An E-R Diagram
Figure 8

Data Models

- Relational++
  - Constructs: set-valued attributes, aggregation, generalization etc
  - Gem [Zaniolo 83]
    - Add to relational model: —- Set-valued attributes —- Tuple-reference as a data type and cascaded dot notation —- Inheritance hierarchies
  - Limitations: Didn't prove terribly useful either functionally or performance-wise
- Semantic data models
  - Constructs: class, class variable, multiple inheritance etc
  - Similar limitations

Data Models

- Object-oriented
  - Designed to get around the impedance mismatch
  - Essentially became persistent PLs
  - Interesting technical challenge: Pointer "swizzling"
  - Weak support for transaction, queries etc.
    - Largely single-user systems
    - DBMS must run in the same address space as the application
  - Several reasons didn't succeed
    - No major additional functionality for most applications
    - No standards
    - Too tied to a single programming language

Data Models

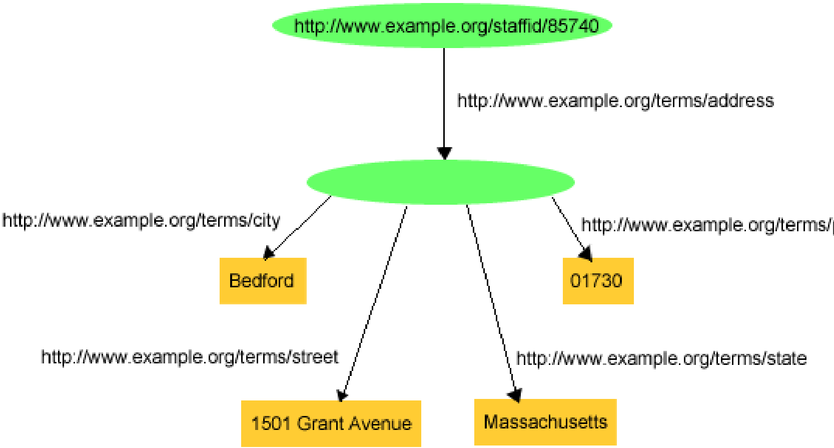
- OR
  - Constructs: User-defined functions, types, access methods
- Semi-structured
  - "Schema last"
  - Constructs: DTD, XMLSchema, union types etc
  - Issues: Limited applicability ??, doesn't really solve semantic heterogeneity
  - Standard for wire format
- Javascript Object Notation (JSON)
  - Very similar to XML, and seems to be increasingly replacing it

Data Models

- RDF: Resource Description Framework
  - Originally intended as a "metadata data model"
  - Key construct: a "subject-predicate-object" triple
    - E.g., subject=sky - predicate=has-the-color - object=blue
  - Direct mapping to a labeled, directed multi-graph
  - Typically stored in relational databases, or what are called "triple-stores"
  - But some graph database products out there as well (e.g., DEX)

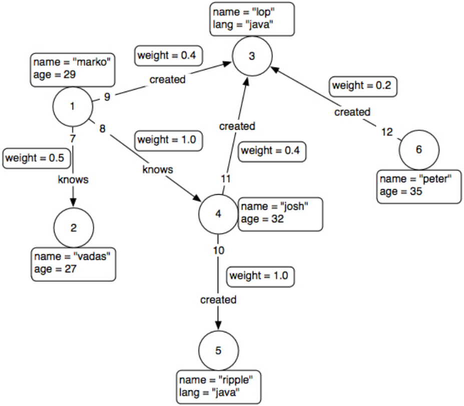
Data Models

- RDF: Resource Description Framework



Data Models

- Graph Data Models
  - Increasing interest in graph databases
  - Property Graph Model (used by many open source tools)



  - Throwback to Network??
    - Applications on top are quite different though

Data Models

- Array Data Models
  - Proposed recently for “Scientific Data Management”
  - Stonebraker one of the key proponents
  - Key abstract: an “array”
  - Key operations include slicing, subsetting, Filtering etc.
  - Presumably a better fit for scientific applications

Some lessons

- Physical/logical data independence desirable
- Record-at-a-time, navigational interfaces force manual query optimization and won't scale
- Technical debates settled by the marketplace in many cases
- KISS
- OO: Packages will not sell to users without "major pain"
- User-defined functions and access method effective
- Schema-last is probably a niche market
- Semantic heterogeneity not solved by XML