Relational Data Model: Part 2

“Bad” Relational Schema

- Suppliers(name, address, item, price)
- Issues
  - redundancy - address is repeated for every item
    - wasted space - is that still a concern?
    - wasted resources (time, compute) to maintain it
  - potential inconsistency (update anomalies) - may update address in one place but not another
  - insertion anomalies - can’t have a supplier without having at least one item
    - NULLs an option but create their own problems
      - what if a real item gets added, do we delete NULL valued row
      - (Item, Name) is a key and having NULL values in key is “not-good”
  - deletion anomalies - reverse (if all items deleted we lose address info)

Anomalies

- update anomalies - may update address in one place but not another
- insertion anomalies - can't have a supplier without having at least one item
  - NULLs an option but create their own problems
    - what if a real item gets added, do we delete NULL valued row
    - (Item, Name) is a key and having NULL values in key is "not-good"
- deletion anomalies - reverse (if all items deleted we lose address info)

name	addr	item	price
S1	123 Any	P1	10
S1	123 Any	P2	20
S2	1 Main	P1	11
S2	1 Main	P3	100
S4	11 State	P1	9
S3	10 State	P4	1000

Update Anomaly

- update *s* set addr = '100 Any' where item = 'P1' and name = 'S1'

name	addr	item	price
S1	123 Any	P1	10
S1	123 Any	P2	20
S2	1 Main	P1	11
S2	1 Main	P3	100
S4	11 State	P1	9
S3	10 State	P4	1000

name	addr	item	price
S1	100 Any	P1	10
S1	123 Any	P2	20
S2	1 Main	P1	11
S2	1 Main	P3	100
S4	11 State	P1	9
S3	10 State	P4	1000

Insertion Anomaly

- insertion anomalies - can't have a supplier without having at least one item
  - NULLs an option but create their own problems
    - what if a real item gets added, do we delete NULL valued row
    - (Item, Name) is a key and having NULL values in key is "not-good"
- want to add 'S5'
- add a "real" entry for S5
- add a part with no supplier

name	addr	item	price
S1	123 Any	P1	10
S1	123 Any	P2	20
S2	1 Main	P1	11
S2	1 Main	P3	100
S4	11 State	P1	9
S3	10 State	P4	1000

name	addr	item	price
S1	100 Any	P1	10
S1	123 Any	P2	20
S2	1 Main	P1	11
S2	1 Main	P3	100
S4	11 State	P1	9
S3	10 State	P4	1000
S5	100 Main	null	null
S5	100 Main	P2	22
null	null	P5	null

Deletion Anomaly

- deletion anomalies - can't have a supplier without having at least one item
  - NULLs an option but create their own problems
    - what if a real item gets deleted, do we delete NULL valued row
    - (Item, Name) is a key and having NULL values in key is "not-good"
- delete 'P4' but lose 'S3'
- could make it null
- same issue deleting say 'S2'

name	addr	item	price
S1	123 Any	P1	10
S1	123 Any	P2	20
S2	1 Main	P1	11
S2	1 Main	P3	100
S4	11 State	P1	9
S3	10 State	P4	1000

name	addr	item	price
S1	100 Any	P1	10
S1	123 Any	P2	20
S2	1 Main	P1	11
S2	1 Main	P3	100
S4	11 State	P1	9
S3	10 State	P4	1000

Better Way

- Break it up as:
  - SuppAddr(name, address)
  - SuppItemPrice(name, item, price)
- Now we'll need a join to discover address for an item
- But problems go away

name	addr
S1	123 Any
S3	10 State
S2	1 Main
S4	11 State

name	item	price
S2	P3	100
S1	P2	20
S1	P1	10
S3	P4	1000
S2	P1	11
S4	P1	9

Update Anomaly?

name	addr
S1	100 Any
S3	10 State
S2	1 Main
S4	11 State

- update *s* set addr = ‘100 Any’ where name = ‘S1’

name	item	price
S2	P3	100
S1	P2	20
S1	P1	10
S3	P4	1000
S2	P1	11
S4	P1	9

Insertion Anomaly?

- want to add 'S5'
- add a "real" entry for S5
- add a part with no supplier
  - use null
  - have separate table, if part can be an independent entity

name	addr
S1	100 Any
S3	10 State
S2	1 Main
S4	11 State
S5	100 Main

name	item	price
S2	P3	100
S1	P2	20
S1	P1	10
S3	P4	1000
S2	P1	11
S4	P1	9
S5	P2	22
null	P5	null

Dependency

- Functional dependency says that if we know value of a set of columns uniquely determines the value of another set of columns.
  - Thus it's a statement (constraint) saying what relation instances are allowed
- Cause and cure of redundancy go hand-in-hand: we use the functional dependency to eliminate/reduce redundancy

Constraints Revisted

- Domain constraints (depends on semantics of domain),e.g. age between 0 and 150
- Restrictions depending only on relationship between values (functional dependencies)
- FD's arise naturally, e.g. for an entity set, an entity uniquely determines its attributes: so key -> attributes
- Note that we can't deduce FD's from an instance, they are "statements" about what instances are legal/allowed

Suppliers

- Suppliers(name, address, item, price)
  - name -> address
  - name, item -> price
- What other dependencies can we conclude
  - trivial ones: name -> name; name, item -> item
  - nontrivial: name, item -> address, price

closure of F = F^+

- Let F be a set of FD's
- F^+ is the set of FD's logically implied by F
- set of rules called "Armstrong's Axioms"
  - If $Y \subseteq X$ then, X->Y (reflexivity)
  - If X->Y, then XZ -> YZ (augmentation)
  - If X->Y and Y->Z then X->Z (transitivity)

Example

- R(City, State, Zip)
  - FD1: City, State -> Zip
  - FD2: Zip -> City
- Does State, Zip -> City, State, Zip ?
  1. Zip -> City (given)
  2. State, Zip -> City, State (from augmentation of above with State)
  3. City, State -> Zip (given)
  4. City, State -> City, State, Zip (from augmentation)
  5. State, Zip -> City, State, Zip (transitivity with 2 and 4)

Attribute Closure X^+

- Computing and comparing F^+ is expensive
- Closure of Attributes, X, X^+ is set of all attributes A such that X->A is implied by the set of FD's
- So we can tell if X->Y is in F^+ by computing X^+ and checking if Y is in X^+

Computing Attribute Closure

- Illustrated by Example: Let X=BD, want to compute X^+
- FDs: AB->C; C->A; BC->D; ACD->B; D->EG; BE->C; CG->BD; CE->AG;
- X(0) = BD; X(1) {B,D,BD in lhs} = BDEG; X(2) = BDEGC; X(3) = BDEGCA (all attributes)

Equivalence of two FD sets

- F covers G (or G covers F) if $F^+ = G^+$
- minimal cover is when all FD's are of following nature
  - RHS has only one attribute
  - No FD X->A is unnecessary i.e. $(F - \{X->A\})^+ <> F^+$
  - No attribute in LHS is unnecessary, i.e. for X->A, if Z is a proper subset of X then:

    $(F - \{X->A\} \cup \{Z->A\})^+ <> F^+$

Computing Minimal Cover

- Put FD's in standard form (i.e. one attribute in RHS)
- Minimize LHS of each FD (see if it can be removed while maintaining equivalence)
- Delete redundant FD's

Example: minimal cover of F

- F = {AB->C, C->A, BC->D, ACD->B, D->EG, BE->C, CG-> BD, CE->AG}
- Step 1 results in: AB->C, C->A, BC->D, ACD->B, D->E, D->G, BE->C, CG->B, CG->D, CE->A, CE->G
- Step 2: ACD->B simplifies to CD->B as C->A
- Step 3: CE->A is redundant (C->A), CG->B is redundant (CG->D, CD->B)
- Other results possible

Decomposition

- Lossless Join Decomposition of R into R1 and R2 if for every relation r of schema R the following is true
  - $r = \pi_{R1}(r) \bowtie \pi_{R2}(r)$
    - satisfied if R1∩R2 -> R1; or R1∩R2 -> R2
    - The original R = R1 ⋈ R2 (natural join of R1, R2)
- Dependency Preserving decomposition = when all FD's can evaluated in the decomposed relations

Supplier Decomposition

- name -> address
- name, item -> price
- Decompose as:
  - SuppAddr(name, address)
  - SuppItemPrice(name, item, price)
- R1∩R2 = name -> name, address
- lossless decomposition

name	addr
S1	123 Any
S3	10 State
S2	1 Main
S4	11 State

name	item	price
S2	P3	100
S1	P2	20
S1	P1	10
S3	P4	1000
S2	P1	11
S4	P1	9

Examples

- Consider R(City, State, Zip), R(C,S,Z) for short
- We have the FD's CS->Z and Z->C
- We can decompose R(C,S,Z) into R1(C,Z) and R2(S,Z) as CZ∩SZ -> C or Z -> C (R1)
- FD Z->C can be evaluated in R1 but FD CS->Z can't be evaluated without a join
- Note that a decomposition can preserve dependencies but not be loss-less think R(A,B,C,D) where A->B and C->D decomposed into R1(A,B) and R2(C,D)

BCNF = Boyce-Codd NF

- Only non trivial FD's are where key->attributes
- R(C,S,Z) is not in BCNF because of FD: Z->C as Z is not a key of R
- A typical ER model is likely to be in BCNF, unless there are unexpected relationships between attributes
  - Are such FD's irrelevant? Do they tell us something that is not of much use? Is Z->C info of any use?

3NF

- Also allows that for FD: X->A, A is part of a key
- So in R(C,S,Z) which has keys CS and ZS, Z->C doesn't violate 3NF as C is part of key CS.

3NF violated

- If X->A violates 3NF, then either X is a proper subset of a key, i.e. part of a key determines an attribute (also called partial dependency)
- Or X is not a proper subset of any key; in that case X->A would be a transitive dependency when FD: key->X is considered (this is 2NF…)

Decomposing R into 3NF

- If we compute minimum cover then for each dependency X->A in minimum cover, we add the relation XA in the schema.
- Of course if dependencies are X->A, X->B, etc. then we combine them into a single relation, XAB
- This set of relations ∪ {key of R} would give a 3NF decomposition of R

Normalization as discovering ERs

- One way to think of schema refinement is to discover entities and relationships from the data
  - A good/detailed ER model should end up directly as a 3NF or BCNF
- The functional dependencies guide us to determine entities and their relationships
- What if we already have a bunch of data, say in a universal relation?

Universal Relation

- A relation that captures all the information in schema
- Decomposable into smaller relations, but how?

dept	cid	course_name	sid	last_name	first_name	status	semester	year
CS	300	Programming II	2012144	Bush	George	4	2	2015
CS	300	Programming II	2014101	Obama	Barack	3	2	2015
CS	300	Programming II	2015001	Lincoln	Abraham	1	2	2015
CS	564	DBMS	2012144	Bush	George	4	1	2016
CS	564	DBMS	2014101	Obama	Barack	3	1	2016
CS	564	DBMS	2016001	Clinton	Bill	5	1	2016
Math	234	Calculus III	2012144	Bush	George	4	1	2013
PolSci	104	US Govt	2012144	Bush	George	4	1	2016
PolSci	104	US Govt	2012144	Bush	George	4	2	2015
PolSci	104	US Govt	2014101	Obama	Barack	3	1	2016
PolSci	104	US Govt	2015001	Lincoln	Abraham	1	1	2016

Discovering FD's

- could come from requirement of the data/application, i.e., constraint
- sometimes be inferred from data, but need validation
  - dept, cid -> course_name
    - CS,300 -> 'Programming II', etc.
  - sid -> last_name, first_name
  - sid -> status? or sid, semester, year -> status

In Practice

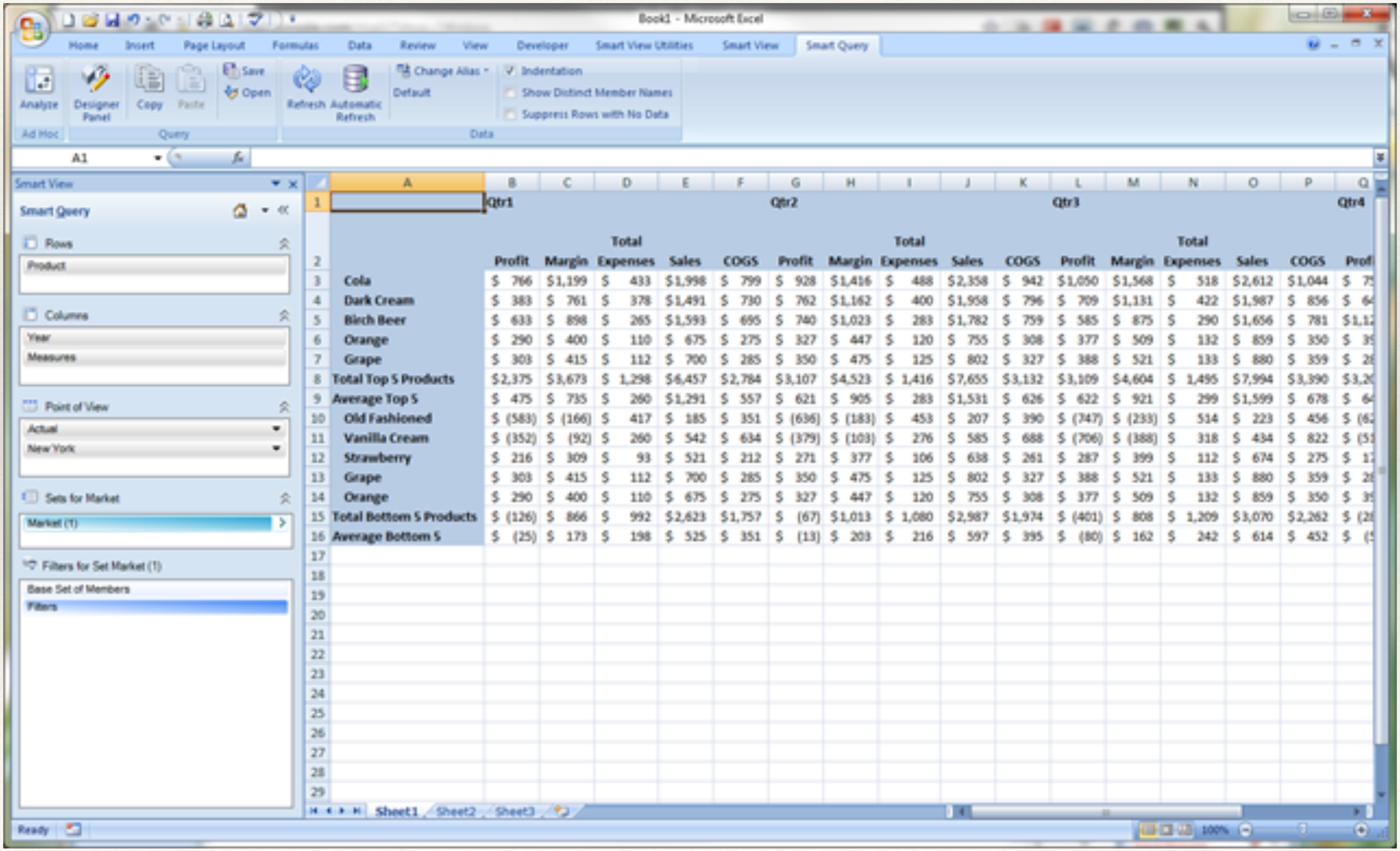
- Good to identify the functional dependencies in the data
- Use that to guide the logical schema (table definitions)
- 3NF is mostly good enough, and preserves FD's
- Surrogate keys can help with redundancy (with tradeoffs)
- Generally verify that there is not much redundancy
- Sometimes we may want to denormalize or not normalize it all the way to save on join costs

Multi-dimensional Data Model

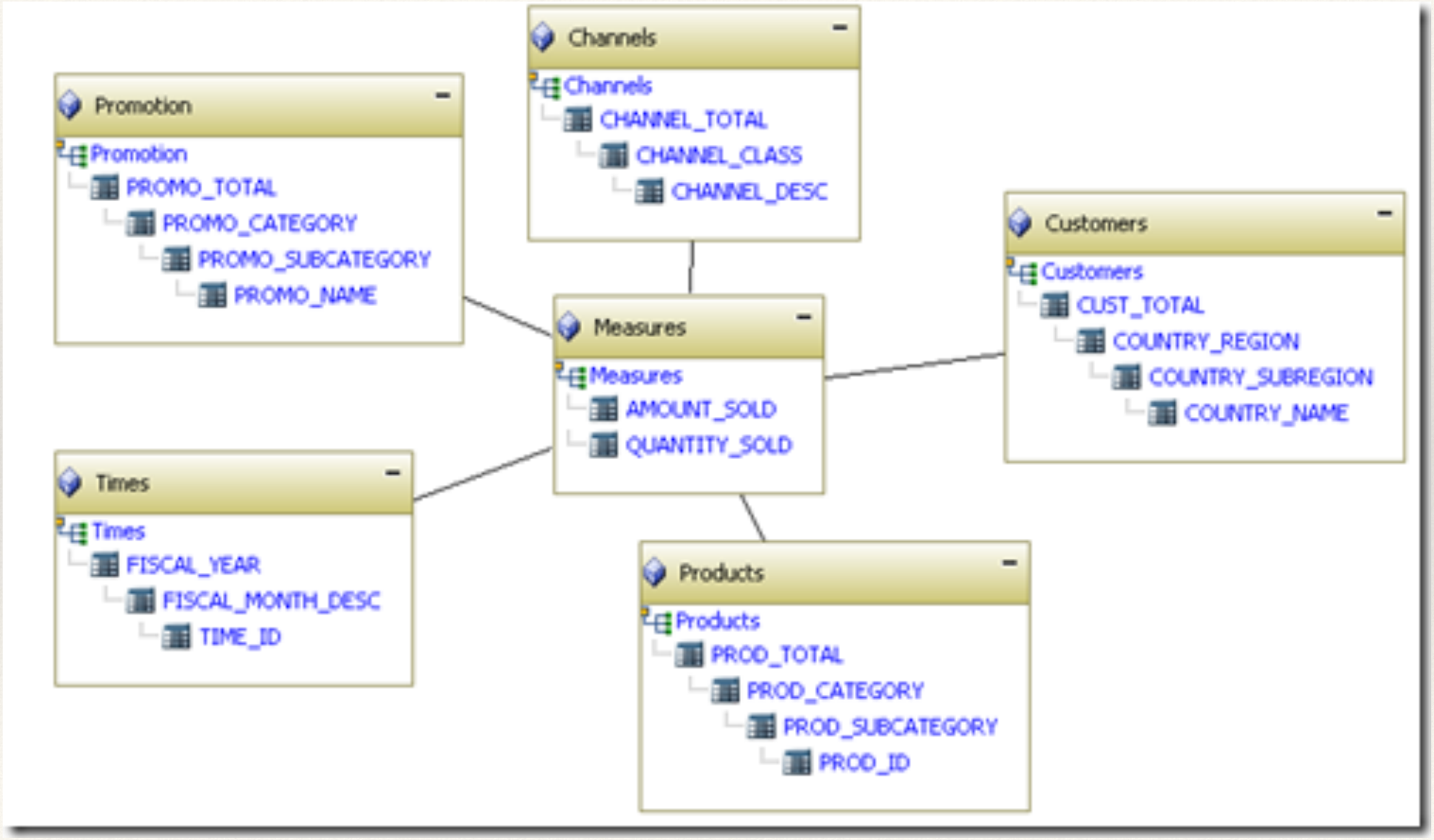
Multi-Dimensional Data Model

- Think spreadsheets and reporting but generalized
- Metrics of interest vary across several dimensions
  - sales varying across product, stores, time
- The dimensions are arranged in hierarchies
  - store, city, region, country
  - date, week, month, quarter, year

A MDDB "Query" View



A MDDB Schema



MDDB & Relational: aka Star Schema

- MD Schema can be modeled as a Relational Schema
- Relational is flexible and powerful
- Fact table captures the measures
- Dimension tables capture the dimensions, the hierarchies being implicit in the column names and rollup dependencies

A Star Schema

- Fact
  - measures(channel_id, country_id, prod_id, time_id, promo_id, amount_sold, quantity_sold)
- Dimensions
  - channels(channel_id, channel_desc, channel_class, channel_total)
  - customers(country_id, country_name, country_subregion, country_region, cust_total)
  - products(prod_id, prod_subcategory, prod_category, prod_total)
  - times(time_id, fiscal_month_desc, fiscal_year)
  - promotion(promo_id, promo_name, promo_subcategory, promo_category, promo_total)

Levels of Abstraction in DBMS 1.5.2

- Physical Schema is the way the relations are actually stored in SSD/HDD. It also defines indexes, statistics etc. defined on the table. (Indexes are defined using DDL.)
- Logical (Conceptual) Schema is the DDL for creating the table. (It can sometimes specify the physical schema.)
- External Schema is the DDL that define's the external user's view of the database. Though some "base" tables are directly visible, most of it is protected through views.

Views

- Views look like tables to user but can be defined by pretty much any SQL query
- Only the definition stored in the database
- Simple views on a single table can be used for insert/delete/update operations as the operation is reflected on the underlying base table.

Views

```
create view Hourly as
  select ssn, name, lot, wages, hours
  from Employees
  where type = ‘H’;


create view Contract as
  select ssn, name, lot, contracted
  from Employees
  where type = ‘C’;


create view Regular as
  select ssn, name, lot
  from Employees
  where type = ‘R’;
```

Class Hierarchies using Views

Contract

ssn	name	lot	contractid
301	Bill	1	1001

Regular

ssn	name	lot
101	Abe	1

Hourly

ssn	name	lot	wages	hours
201	George	2	15	2
202	James	2	20	40

Employees

ssn	name	lot	type	wages	hours	contractid
201	George	2	H	15	2	null
202	James	2	H	20	40	null
301	Bill	1	C	null	null	1001
101	Abe	1	R	null	null	null

Views

- Hide complexity
- Limited Access/Security
- External Schema can be independent of Conceptual Schema (definitions of base tables)
  - logical data independence
  - can change conceptual schema without affecting users

Steps in Database Modeling

- Both data that's there and queries that may be asked
- ER may be useful for high level
- Concrete: Tables, Attributes
- Refine: Establishing relationships between attributes and tables
- Data Definition and Index structures
- Additional index structures