# Database Systems
# CSE 414

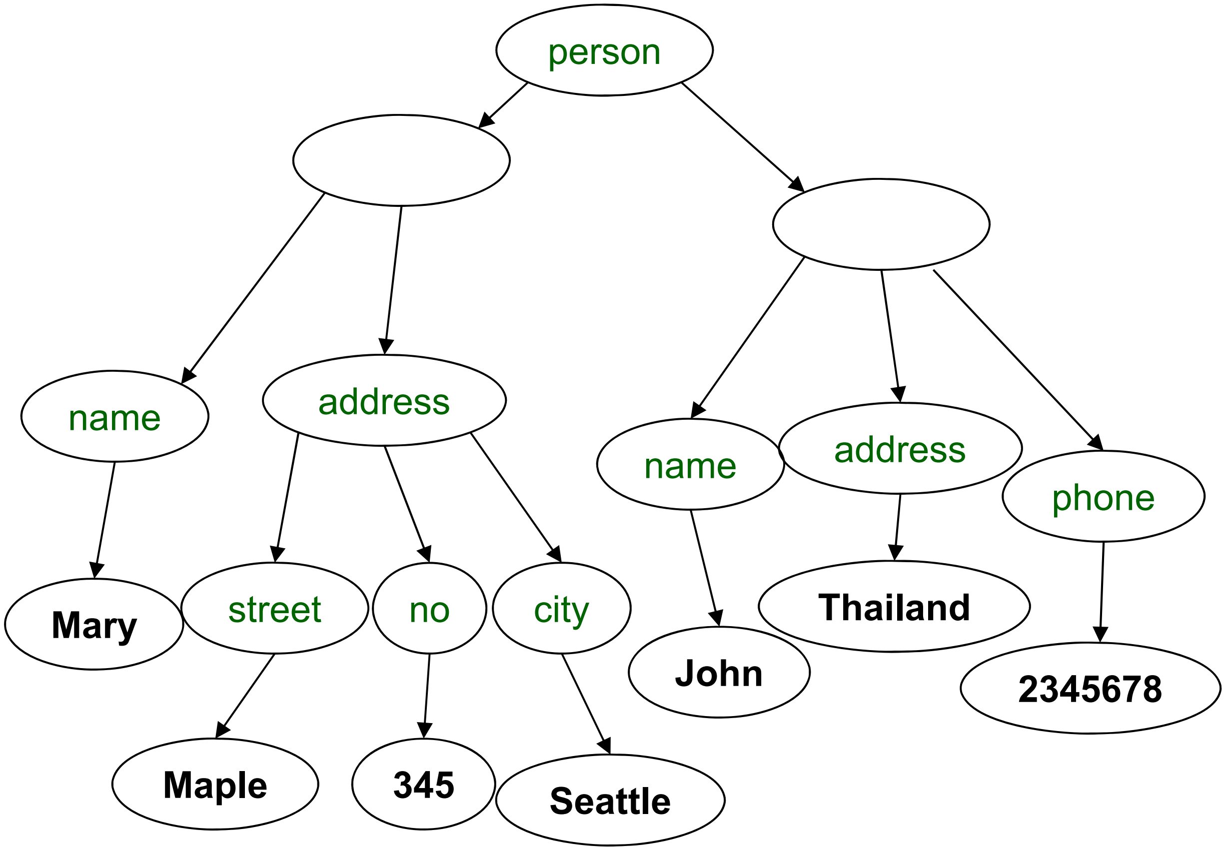
## Lecture 12-13: JSON and SQL++
(mostly not in textbook)

# NoSQL (cont)

# JSON (cont.)

# JSON Semantics: a Tree !

```
{“person”:
   [ {“name”: “Mary”,
       “address”:
           {“street”: “Maple”,
             “no”: 345,
             “city”: “Seattle”}},
     {“name”: “John”,
       “address”: “Thailand”,
       “phone”: 2345678}
     ]
}
```



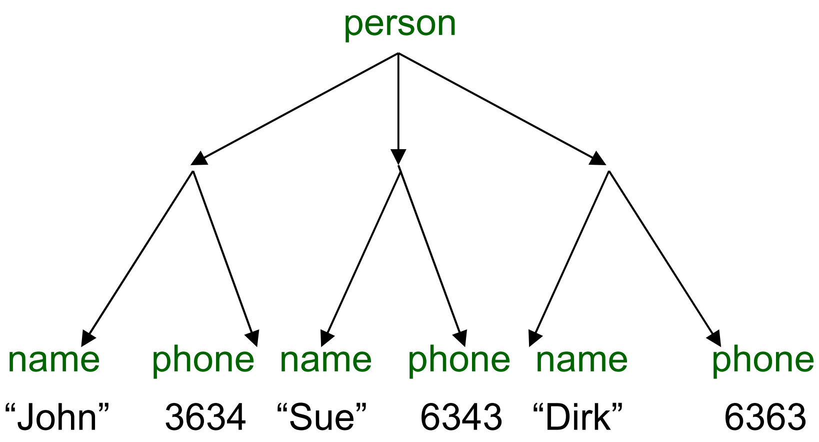
# JSON Data

- JSON is self-describing
- Schema elements become part of the data
  - Relational schema: person(name, phone)
  - In JSON “person”, “name”, “phone” are part of the data, and are repeated many times
- Consequence: JSON is much more flexible
- JSON = semi-structured data

# Mapping Relational Data to JSON

**Person**

| name | phone |
|---|---|
| John | 3634 |
| Sue | 6343 |
| Dirk | 6363 |



person

name “John”   phone 3634   name “Sue”   phone 6343   name “Dirk”   phone 6363

```
{“person”:
     [{“name”: “John”, “phone”: 3634},
       {“name”: “Sue”,  “phone”: 6343},
       {“name”: “Dirk”,  “phone”: 6383}
      ]
}
```

# Mapping Relational Data to JSON

May inline foreign keys

**Person**

| name | phone |
|---|---|
| John | 3634 |
| Sue | 6343 |

**Orders**

| personName | date | product |
|---|---|---|
| John | 2002 | Gizmo |
| John | 2004 | Gadget |
| Sue | 2002 | Gadget |

```
{“Person”:
     [{“name”: “John”,
       “phone”: 3646,
       “Orders”: [{“date”: 2002,
                   “product”: “Gizmo”},
                  {“date”: 2004,
                   “product”: “Gadget”}
                 ]
      },
      {“name”: “Sue”,
       “phone”: 6343,
       “Orders”: [{“date”: 2002,
                    “product”: “Gadget”}
                 ]
       }
     ]
}
```

# JSON = Semi-structured Data (1/3)

- Missing attributes:

```
{“person”:
    [{“name”: “John”, “phone”: 1234},
     {“name”: “Joe”}]
}
```

no phone !

- Could represent a table with nulls

| name | phone |
|---|---|
| John | 1234 |
| Joe | - |

# JSON = Semi-structured Data (2/3)

- Repeated attributes

```
{"person":
   [{"name": "John", "phone": 1234},
    {"name": "Mary", "phone": [1234, 5678]}]
}
```

Two phones !

- Impossible in one table:

| name | phone |  |
|---|---|---|
| Mary | 2345 | 3456 |
|  |  |  |

???

# JSON = Semi-structured Data (3/3)

- Attributes with different types in different objects

```
{“person”:
    [{“name”: “Sue”, “phone”: 3456},
     {“name”: {“first”: “John”, “last”: “Smith”}, “phone”: 2345}
    ]
}
```

Structured name !

- Nested collections
- Heterogeneous collections

# Discussion

- *Data exchange formats*
  - well suited for exchanging data between apps
  - XML, JSON, Protobuf
- Increasingly, some systems use them as a data model:
  - SQL Server: supports for XML-valued relations
  - CouchBase, Mongodb: JSON as data model
  - Dremel (BigQuery): Protobuf as data model

# Query Languages for Semi-Structured Data

- XML: XPath, XQuery (see end of lecture, textbook)
  - Supported inside many RDBMS (SQL Server, DB2, Oracle)
  - Several standalone XPath/XQuery engines
- Protobuf: used internally by Google, and externally in BigQuery. similar to compiled JSON
- JSON:
  - CouchBase: N1QL
  - MongoDB: has a pattern-based language
  - JSONiq http://www.jsoniq.org/
  - AsterixDB: AQL and SQL++

# AsterixDB

# AsterixDB

- NoSQL database system (document store)
- Developed at UC Irvine
  - Now an Apache project
- Designed to be installed on a cluster
  - multiple machines (nodes) together implement the DBMS
  - allows scale to much larger amounts of data
- Weak support for multi-node transactions
- Good support for multi-node **queries**

# AsterixDB (cont.)

- Data is **partitioned** over nodes by primary key
  - queries involve not only disk, but also network I/O
- Supports advanced queries
  - joins
  - nested queries
  - grouping and aggregation
- No statistics maintained yet (per docs)
  - may need more hints to get good performance
  - expect this to improve

# AQL and SQL++

- Asterix's own query language is AQL
  - based on XQuery (for XML)

- SQL++
  - SQL-like syntax for AQL
  - more familiar to database users

# Asterix Data Model (ADM)

- ADM is an extension of JSON
- Objects:
  - {“Name”: “Alice”, “age”: 40}
  - Fields must be distinct:
    {“Name”: “Alice”, “age”: 40, ~~“age”:50~~}

Can’t have repeated fields

- Arrays:
  - [1, 3, “Fred”, 2, 9]
  - Note: can be heterogeneous
- Bags:
  - {{1, 3, “Fred”, “Fred”, 2, 9}}

# Examples

Try these queries yourself:

```
SELECT age FROM [ {'name': 'Alice', 'age': ['30', '50']} ] x;
```

```
SELECT age FROM {{ {'name': 'Alice', 'age': ['30', '50']} }} x;
```

```
-- error
SELECT age FROM {'name': 'Alice', 'age': ['30', '50']} x;
```

# Data Types

- Supports SQL / JSON data type:
  - boolean, integer, float (various precisions), null
- Some SQL types not in JSON:
  - date, time, interval
- Some new types:
  - geometry (point, line, …)
  - UUID = universally unique identifier
    (systems generated, globally unique key)

# Null vs. Missing

- {“age”: null} = the value NULL (like in SQL)
- {“age”: missing} = { } = really missing

```
SELECT x.b FROM [{'a': 1, 'b': 2}, {'a': 3}] x;
```

```
{ "b": 2 }
{  }
```

```
SELECT x.b FROM [{'a': 1, 'b': 2}, {'a': 3, 'b': missing}] x;
```

```
{ "b": 2 }
{  }
```

# SQL++ Overview

- Data definition language:
  - Dataverse (= database)
  - Dataset (= table)
    - each row uses a declared Type
  - Types
    - declares the required parts
    - can allow for extra data (open vs. closed types)
  - Indexes
- Query language: select-from-where

# Dataverse

A Dataverse is a Database

- CREATE DATAVERSE lec16
- CREATE DATAVERSE lec16 IF NOT EXISTS

- DROP DATAVERSE lec16
- DROP DATAVERSE lec16 IF EXISTS

- USE lec16

# Type

- Defines the schema of a collection
- It lists all *required* fields
- Fields followed by ? are *optional*
- CLOSED type = no other fields allowed
- OPEN type = other fields allowed

# Closed Types

```
USE lec16;
DROP TYPE PersonType IF EXISTS;
CREATE TYPE PersonType AS CLOSED {
   Name: string,
   age: int,
   email: string?
}
```

{"Name": "Alice", "age": 30, "email": "a@alice.com"}

{"Name": "Bob", "age": 40}

-- not OK:
{"Name": "Carol", “age”: 35, ~~"phone": "123456789"~~}

# Open Types

```
USE lec16;
DROP TYPE PersonType IF EXISTS;
CREATE TYPE PersonType AS OPEN {
   Name : string,
   age: int,
   email: string?
}
```

```
{"Name": "Alice", "age": 30, "email": "a@alice.com"}

{"Name": "Bob", "age": 40}

-- Now it’s OK:
{"Name": "Carol", “age”: 35, "phone": "123456789"}
```

# Types with Nested Collections

```
USE lec16;
DROP TYPE PersonType IF EXISTS;
CREATE TYPE PersonType AS CLOSED {
   Name: string,
   phone: [string]
}
```

```
{"Name": "Carol", "phone": ["1234”]}
{"Name": "David", "phone": [“2345”, “6789”]}
{"Name": "Evan",  "phone": []}
```

# Datasets

- Dataset = relation
- Must have a type
  - can be a trivial OPEN type
- Must have a key
  - can be declared “autogenerated” if UUID
  - (SQL systems usually support auto-incremented unique integer IDs)

# Dataset with Existing Key

```
USE lec16;
DROP TYPE PersonType IF EXISTS;
CREATE TYPE PersonType AS CLOSED {
   Name: string,
   email: string?
}
```

```
{"Name": "Alice"}
{"Name": "Bob"}
…
```

```
USE lec16;
DROP DATASET Person IF EXISTS;
CREATE DATASET Person(PersonType) PRIMARY KEY Name;
```

# Dataset with Auto Generated Key

```
USE lec16;
DROP TYPE PersonType IF EXISTS;
CREATE TYPE PersonType AS CLOSED {
   myKey: uuid,
   Name: string,
   email: string?
}
```

```
{"Name": "Alice"}
{"Name": "Bob"}
…
```

Note: no myKey since it will be auto-generated

```
USE lec16;
DROP DATASET Person IF EXISTS;
CREATE DATASET Person(PersonType)
    PRIMARY KEY myKey AUTOGENERATED;
```

# Discussion of NFNF

- NFNF = Non First Normal Form
  - one or more attributes contain a collection
- One extreme: a single row with a huge, nested collection
- Better: multiple rows, reduced number of nested collections

# Example from HWS

mondial.adm is totally semi-structured:
{“mondial”: {“country”: [...], “continent”: [...], ..., “desert”: [...]}}

| **country** | **continent** | **organization** | **sea** | **...** | **mountain** | **desert** |
|---|---|---|---|---|---|---|
| [{“name”: “Albania”, ...},<br>{“name”: “Greece”, ...},<br>...] | ... | ... | ... | | ... | ... |

country.adm, sea.adm, mountain.adm are more structured

Country:

| **-car_code** | **name** | **...** | **ethnicgroups** | **religions** | **...** | **city** |
|---|---|---|---|---|---|---|
| AL | Albania | ... | [ ... ] | [ ... ] | ... | [ ... ] |
| GR | Greece | ... | [ ... ] | [ ... ] | ... | [ ... ] |
| ... | ... | ... | ... | | | |

# Indexes

- Can declare an index on an attribute of a top-most collection
- Available:
  - BTREE: good for equality and range queries
    E.g. name="Greece"; 20 < age and age < 40
  - RTREE: good for 2-dimensional range queries
    E.g. 20 < x and x < 40 and 10 < y and y < 50
  - KEYWORD: good for substring search

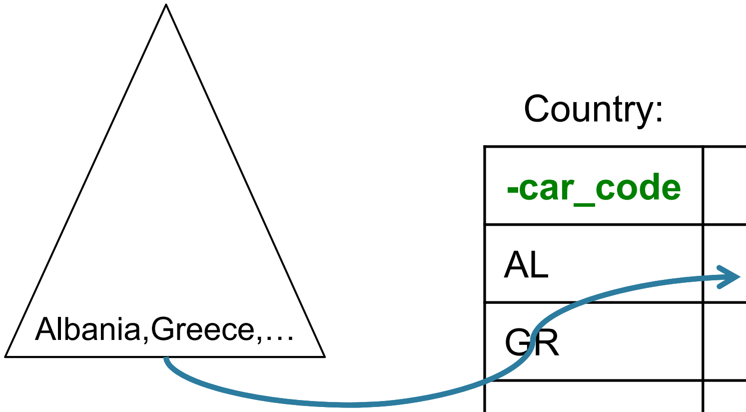
as you already know…

# Indexes

Cannot index inside a nested collection

```
USE lec16;
CREATE INDEX countryID
    ON country(name)
    TYPE BTREE;
```

~~USE lec16;~~
~~CREATE INDEX cityname~~
~~ON country(city.name)~~
~~TYPE BTREE;~~



Country:

| -car_code | name | ... | ethnicgroups | religions | ... | city |
|---|---|---|---|---|---|---|
| AL | Albania | ... | [ ... ] | [ ... ] | ... | [ ... ] |
| GR | Greece | ... | [ ... ] | [ ... ] | ... | [ ... ] |
| ... | ... | ... | ... | | | |
| BG | Belgium | ... | | | | |
| ... | | | | | | |

# Asterix Data Model (ADM)

- ADM is an extension of JSON
- Objects:
  - {"Name": "Alice", "age": 40}
  - Fields must be distinct:
    {"Name": "Alice", "age": 40, ~~"age":50~~}

Can't have repeated fields

- Arrays:
  - [1, 3, "Fred", 2, 9]
  - Note: can be heterogeneous
- Bags:
  - {{1, 3, "Fred", "Fred", 2, 9}}

# Examples

Try these queries yourself:

```
SELECT age FROM [ {'name': 'Alice', 'age': ['30', '50']} ] x;
```

```
~> {”age": [“30”, “50”]}
```

```
SELECT age FROM {{ {'name': 'Alice', 'age': ['30', '50']} }} x;
```

```
~> {”age": [“30”, “50”]}
```

```
-- error
SELECT age FROM {'name': 'Alice', 'age': ['30', '50']} x;
```

# SQL++ Overview

```
SELECT ... FROM ... WHERE ... [GROUP BY ...]
```

# Retrieve Everything

```
[{“mondial”:
    {“country”: [ country1, country2, …],
     “continent”: […],
      “organization”: […],
      ...
      ...
}]
```

```
SELECT x.mondial FROM world x;
```

Answer

```
{“mondial”:
      {“country”: [ country1, country2, …],
      “continent”: […],
      “organization”: […],
      ...
      ...
}
```

```
[{“mondial”:
   {“country”: [ country1, country2, …],
    “continent”: […],
     “organization”: […],
     …
     …
}]
```

# Retrieve countries

```
SELECT x.mondial.country FROM world x;
```

Answer

```
{“country”: [ country1, country2, …]}
```

```
[{"mondial":
   {"country": [ country1, country2, …],
    "continent": […],
     "organization": […],
     …
     …
}]
```

# Retrieve countries, one by one

```
SELECT y as country FROM world x, x.mondial.country y;
```

Answer

```
{"country": country1}
{"country": country2}
…
```

# Escape characters

```
[{“mondial”:
   {“country”: [ country1, country2, …],
    “continent”: […],
     “organization”: […],
     ...
     ...
}]
```

“-car_code” illegal field
Use ` ... `

```
SELECT y.`-car_code` as code, y.name as name
FROM world x, x.mondial.country y order by y.name;
```

Answer

```
{“code”: “AFG”, “name”: “Afganistan”}
{“code”: “AL”, “name”: “Albania”}
...
```

# Nested Collections

- If the value of attribute B is some other collection, then we can simply iterate over it

```
SELECT x.A, y.C, y.D
FROM mydata x, x.B y;
```

x.B is a collection

```
{“A”: “a1”, “B”: [{“C”: “c1”, “D”: “d1”}, {“C”: “c2”, “D”: “d2”}]}
{“A”: “a2”, “B”: [{“C”: “c3”, “D”: “d3”}]}
{“A”: “a3”, “B”: [{“C”: “c4”, “D”: “d4”}, {“C”: “c5”, “D”: “d5”}]}
```

```
{“A”: “a1”, “C”: “c1”, “D”: “d1”}
{“A”: “a1”, “C”: “c2”, “D”: “d2”}
{“A”: “a2”, “C”: “c3”, “D”: “d3”}
{“A”: “a3”, “C”: “c4”, “D”: “d4”}
{“A”: “a3”, “C”: “c5”, “D”: “d5”}
```

# Heterogeneous Collections

```
[{“mondial”:
   {“country”: [ country1, country2, …],
    “continent”: […],
     “organization”: […],
     ...
     ...
}]
```

Runtime error

```
SELECT z.name as province_name, u.name as city_name
FROM world x, x.mondial.country y, y.province z, z.city u
WHERE  y.name='Greece';
```

The problem:

```
...
“province”: [ ...
   {“name”: "Attiki”,
    “city” : [ {“name”: “Athens”...}, {“name”: “Pireus”...}, ..]
     ...},
    {“name”: “Ipiros”,
    “city” : {“name”: “Ioannia”...}
     ...},
```

city is an array

city is an object

```
[{“mondial”:
   {“country”: [ country1, country2, …],
    “continent”: […],
     “organization”: […],
      …
      …
}]
```

# Heterogeneous Collections

```
SELECT z.name as province_name, u.name as city_name
FROM world x, x.mondial.country y, y.province z, z.city u
WHERE  y.name='Greece' and is_array(z.city);
```

Just the arrays

The problem:

```
...
“province”: [ ...
   {“name”: "Attiki”,
    “city” : [ {“name”: “Athens”...}, {“name”: “Pireus”...}, ..]
     ...},
    {“name”: ”Ipiros”,
    “city” : {“name”: “Ioannia”...}
     ...},
```

# Heterogeneous Collections

```
[{"mondial":
    {"country": [ country1, country2, …],
     "continent": […],
      "organization": […],
      …
      …
}]
```

Note: get name directly from z

```
SELECT z.name as province_name, z.city.name as city_name
FROM world x, x.mondial.country y, y.province z
WHERE  y.name='Greece' and not is_array(z.city);
```

Just the objects

The problem:

```
…
"province": [ …
    {"name": "Attiki",
     "city" : [ {"name": "Athens"...}, {"name": "Pireus"...}, ..]
      ...},
     {"name": "Ipiros",
     "city" : {"name": "Ioannia"...}
      ...},
```

# Heterogeneous Collections

```
[{“mondial”:
   {“country”: [ country1, country2, …],
    “continent”: […],
     “organization”: […],
     ...
     ...
}]
```

```
SELECT z.name as province_name, u.name as city_name
FROM world x, x.mondial.country y, y.province z,
          (CASE WHEN is_array(z.city) THEN z.city
                         ELSE [z.city] END) u
WHEREy.name='Greece';
```

Get both!

The problem:

```
...
“province”: [ ...
   {“name”: "Attiki”,
    “city” : [ {“name”: “Athens”...}, {“name”: “Pireus”...}, ..]
     ...},
    {“name”: “Ipiros”,
    “city” : {“name”: “Ioannia”...}
     ...},
```

# Heterogeneous Collections

```
{“mondial”:
   {“country”: [ country1, country2, …],
    “continent”: […],
     “organization”: […],
     ...
     ...
}
```

```
SELECT z.name as province_name, u.name as city_name
FROM world x, x.mondial.country y, y.province z,
        (CASE WHEN z.city is missing THEN []
                      WHEN is_array(z.city) THEN z.city
                      ELSE [z.city] END) u
WHERE  y.name='Greece';
```

Even better

The problem:

```
...
“province”: [ ...
   {“name”: "Attiki”,
    “city” : [ {“name”: “Athens”...}, {“name”: “Pireus”...}, ..]
     ...},
    {“name”: “Ipiros”,
    “city” : {“name”: “Ioannia”...}
     ...},
```

# Useful Functions

- is_array
- is_boolean
- is_number
- is_object
- is_string
- is_null
- is_missing
- is_unknown = is_null or is_missing

# Useful Paradigms

- Unnesting
- Nesting
- Group-by / aggregate
- Join
- Multi-value join

# Basic Unnesting

- An array: [a, b, c]
- A nested array: arr = [[a, b], [], [b, c, d]]
- Unnest(arr) = [a, b, b, c, d]

```
SELECT y
FROM arr x, x y
```

# Unnesting Specific Field

A nested collection

coll =
[{A:a1, F:[{B:b1}, {B:b2}], G:[{C:c1}]},
{A:a2, F:[{B:b3}, {B:b4}, {B:b5}], G:[ ]},
{A:a3, F:[{B:b6}], G:[{C:c2}, {C:c3}]}]

$\text{Unnest}_F$(coll) =
[{A:a1, B:b1, G:[{C:c1}]},
{A:a1, B:b2, G:[{C:c1}]},
{A:a2, B:b3, G:[]},
{A:a2, B:b4, G:[]},
{A:a2, B:b5, G:[]},
{A:a3, B:b6, G:[{C:c2}, {C:c3}]}]

$\text{Unnest}_G$(coll) =
[{A:a1, F:[{B:b1}, {B:b2}], C:c1},
{A:a3, F:[{B:b6}], C:c2},
{A:a3, F:[{B:b6}], C:c3]}

New RA expression

```
SELECT x.A, y.B, x.G
FROM coll x, x.F y
```

SQL++

```
SELECT x.A, x.F, z.C
FROM coll x, x.G z
```

# Nesting (like group-by)

A flat collection

coll =
[{A:a1, B:b1}, {A:a1, B:b2}, {A:a2, B:b1}]

new RA expression

$\text{Nest}_A$(coll) =
[{A:a1, GRP:[{B:b1}, {B:b2}]},
{A:a2, GRP:[{B:b1}]}]

$\text{Nest}_B$(coll) =
[{B:b1, GRP:[{A:a1}, {A:a2}]},
{B:b2, GRP:[{A:a1}]}]

```
SELECT DISTINCT x.A,
    (SELECT y.B FROM coll y WHERE x.A = y.A) as GRP
FROM coll x
```

```
SELECT DISTINCT x.A, g as GRP
FROM coll x
LET g = (SELECT y.B FROM coll y WHERE x.A = y.A)
```

# Group-by / Aggregate

A nested collection

```
coll =
[{A:a1, F:[{B:b1}, {B:b2}], G:[{C:c1}]},
 {A:a2, F:[{B:b3}, {B:b4}, {B:b5}], G:[ ]},
 {A:a3, F:[{B:b6}], G:[{C:c2}, {C:c3}]}]
```

Count the number of elements in the F collection

coll_count = collection count

```
SELECT x.A, coll_count(x.F) as cnt
FROM coll x
```

```
SELECT x.A, count(*) as cnt
FROM coll x, x.F y
GROUP BY x.A
```

These are NOT equivalent!
(Why?)

# Group-by / Aggregate

A flat collection

```
coll =
[{A:a1, B:b1}, {A:a1, B:b2}, {A:a2, B:b1}]
```

```
SELECT DISTINCT x.A, coll_count(g) as cnt
FROM coll x
LET g = (SELECT y.B FROM coll y WHERE x.A = y.A)
```

```
SELECT x.A, count(*) as cnt
FROM coll x
GROUP BY x.A
```

Are these equivalent?

# Join

Two flat collection

```
coll1 = [{A:a1, B:b1}, {A:a1, B:b2}, {A:a2, B:b1}]
coll2 = [{B:b1, C:c1}, {B:b1, C:c2}, {B:b3, C:c3}]
```

```
SELECT x.A, x.B, y.C
FROM coll1 x, coll2 y
WHERE x.B = y.B
```

# Multi-Value Join

- A many-to-one relationship should have one foreign key, from “many” to “one”
  - each of the “many” points to the same “one”
- Sometimes, people represent it in the opposite direction, from “one” to “many”:
  - Ex: list of employees of a manager
  - reference could be space-separated string of keys
  - need to use split(string, separator) to split it into a collection of foreign keys

# Multi-Value Join

```
river =
[{"name": ”Danube”, "-country": "SRB A D H HR SK BG RO MD UA”},
 {"name": "Colorado”, "-country": "MEX USA”},
  ... ]
```

```
SELECT ...
FROM country x, river y,
          split(y.`-country`, “ ”) z
WHERE x.`-car_code` = z
```

String

Separator

split(“MEX USA”, “ ”) =
 [“MEX”, “USA”]

# Behind the Scenes

Query Processing on NFNF data:

- Option 1: give up on query plans
- Option 2: represent the data as a collection of flat tables, convert SQL++ to a standard relational query plan

You can apply the second approach yourself, to work with semi-structured data using a familiar RDBMS

- for data analysis, this may be more efficient until semi-structured DBMSs catch up to RDBMSs

# Flattening SQL++ Queries

## A nested collection

```
coll =
[{A:a1, F:[{B:b1}, {B:b2}], G:[{C:c1}]},
 {A:a2, F:[{B:b3}, {B:b4}, {B:b5}], G:[ ]},
 {A:a1, F:[{B:b6}], G:[{C:c2}, {C:c3}]}]
```

## Flat Representation

coll:

| id | A |
|---|---|
| 1 | a1 |
| 2 | a2 |
| 3 | a1 |

F

| parent | B |
|---|---|
| 1 | b1 |
| 1 | b2 |
| 2 | b3 |
| 2 | b4 |
| 2 | b5 |
| 3 | b6 |

G

| parent | C |
|---|---|
| 1 | c1 |
| 3 | c2 |
| 3 | c3 |

SQL++

```
SELECT x.A, y.B
FROM coll x, x.F y
WHERE x.A = ‘a1’
```

SQL

```
SELECT x.A, y.B
FROM coll x, F y
WHERE x.id = y.parent and x.A = ‘a1’
```

```
SELECT x.A, y.B
FROM coll x, x.F y, x.G z
WHERE y.B = z.C
```

```
SELECT x.A, y.B
FROM coll x, F y, G z
WHERE x.id = y.parent and x.id = z.parent
           and y.B = z.C
```