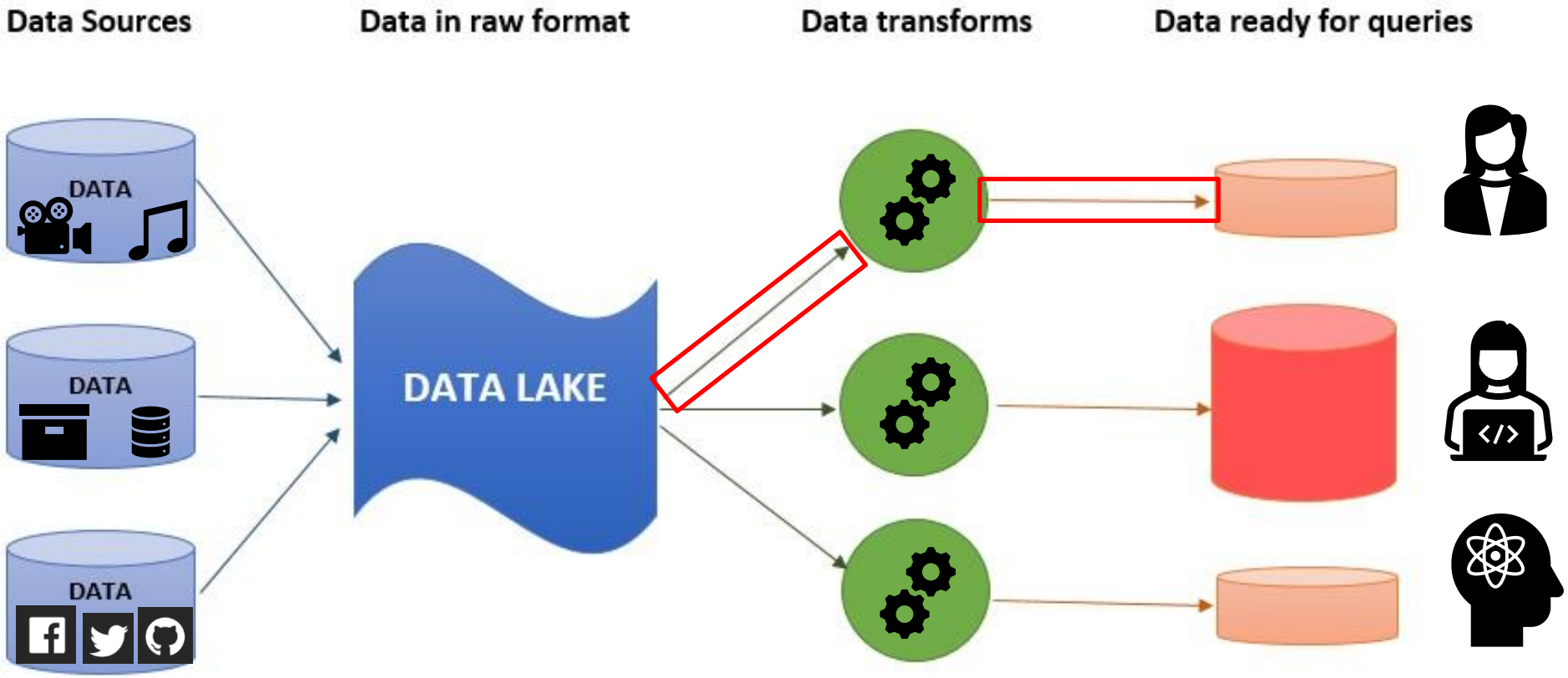
COMP9321 Data Services Engineering

Term 1, 2024

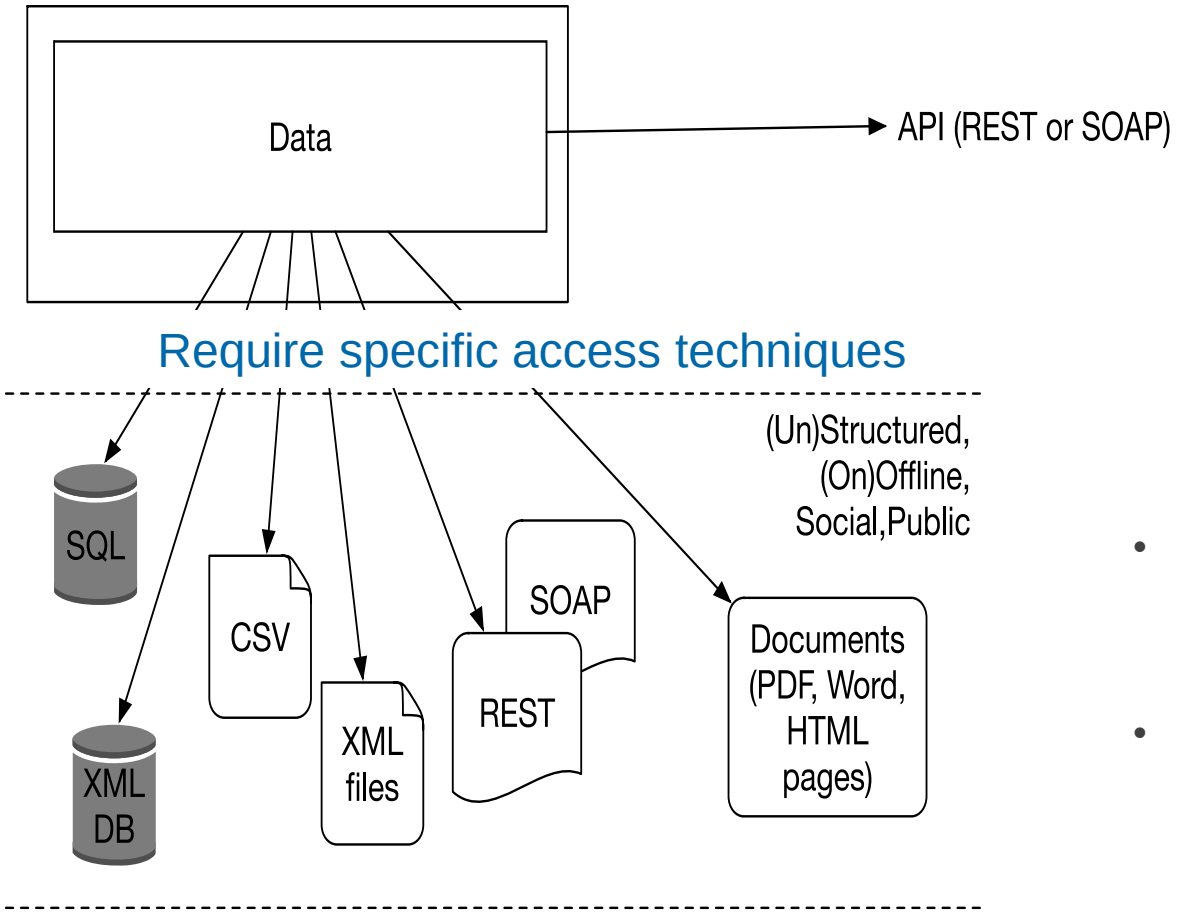
Week 1: Data Access

Data Lakes and Data Pipelines



Data Services – what is it about?

Two sides of a coin:



- Data integration/aggregation from multiple sources (data prep)
- Data publication for consumer access (API)

Challenges from implementation view point

Difficult to obtain a ”single view of X” for any X

- What data do I have about X?
- How do I stitch together the info I need (choose the right data model)?
- What else is X related to?

No uniformity (model or language)

- Data about X is stored in many different formats.
- Accessing or updating X involves many different APIs or access methods
- Manual coding of ”distributed query plans”

What’s data sources or existing APIs available and where?

What protocol do they use?

What format are they in?

Obtaining Data

Useful data can be found in many places

- on the Web, possibly via an API
- in documents in a file system
- in spreadsheets
- in videos
- etc. etc. etc.

and in a variety of formats

- Unformatted text (in files)
- PDF documents (in files)
- HTML documents (web pages)
- XML documents (via web APIs)
- JSON data (often via web APIs)
- CSV data files (spreadsheets)

Unformatted Text Data

Unformatted text is generally *unfriendly*

Hi James,

Here are some stats on in the **first term** of **2018** sales in **Australia**.

Up by **20%** on last year for our **end point solutions**

(**backup solutions** sales ranking **highest**).

And **corporate solutions** sales is **up** by **30%** !!

Vulnerability scanning solutions ranking **highest**.

Best regards,

Unformatted Text Data (Cont'd)

The same information can be conveyed in many ways

Hey James,

FYI

Sales in Australia for the end point solutions increased by 20% where backup solutions being most popular.

And corporate solutions' sales had a great jump by (40%) with an increase demand for vulnerability scanners

Regards,

Hmmmmmmmmm

Unformatted Text Data (Cont'd)

In order to mine useful data from text, sophisticated techniques are required like:

- Natural language processing (NLP) (syntax)
- Machine Learning (ML) (patterns)

Such techniques are, at best, approximate

Specific problems …

- Named entity recognition (who/what is end point solutions?)
- Training requirements (for ML)

PDF Documents

PDF documents have some structure

- which specifies content and layout commands
- including both text and (mainly) binary data (e.g. OCR)
- but structure is not necessarily helpful for extraction

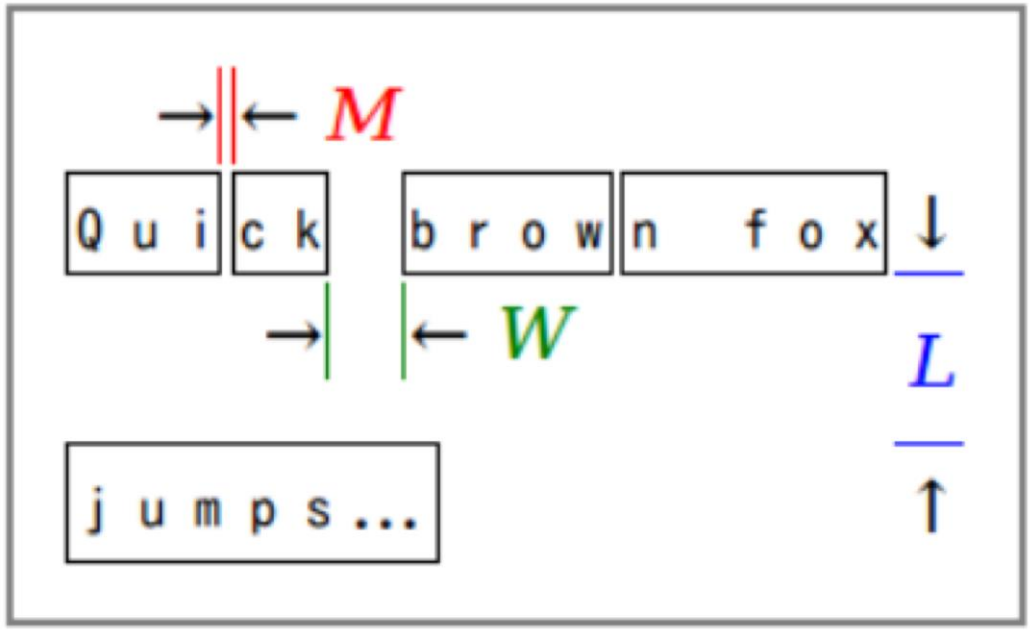
Python packages (e.g. pyPDF2) for dealing with PDF

- aim to extract the text from the document
- but don’t aim to keep the layout structure

PDF Documents (Cont'd)

Why even extracting text from PDFs is hard …

- text chunks don't necessarily correspond to words



PDF Documents (Cont'd)

More sophisticated extraction from PDF

PDFminer (including pdf2txt.py and dumppdf.py)

- toolset implemented in Python (v2)
- parses PDF documents, both text & images
- can convert PDFs to other formats (e.g. HTML)
- can output text + layout information

But still requires significant work to extract *data*

- requires NLP/ML, but aided by layout information

PDF Documents (Cont'd)

Tables are often sources of useful data, but require …

- finding table boundaries
- finding rows and columns
- finding cell boundaries
- extracting text from cells
- etc. etc.

Above is easy in HTML

Much harder in PDF

But e.g. pdftables.com

State	City	Town	POP
New York	Rensselaer	Troy	1
		Brunswick	2
	St. Lawrence	Potsdam	3
		Canton	4
California	San Diego	Coronado	5
		Del Mar	6
	Los Angeles	Malibu	7
		Compton	8

HTML Documents

HTML documents include explicit markup

- which is more *semantic* than PDF layout data
- making it easier to recognise document components
- but content is still semi-structured (“at creator’s whim”)

However, much HTML these days is generated

- giving a regular structure which is parseable

HTML Documents (Cont'd)

Example HTML (2)

<h1>Sales</h1>

 Anti-virus solution 50000

 Backup solutions 150000

Easy to find structure; recognising columns harder.

HTML Documents (Cont'd)

Example HTML (2)

```
<h1>Sales</h1>
<table>
<tr> <th>Solution</th> <th>Quantity</th> </tr>
<tr> <td>Anti-virus</td> <td>50000</td> </tr>
<tr> <td>Backup</td> <td>150000</td> </tr>
</table>
```

Easy to find columns; headings assist with semantics.

HTML Documents (Cont'd)

The Python BeautifulSoup library allows analysis of HTML

Example:

```
<!doctype html>
<html>
    <head><title> A simple page </title></head>
    <body>
            <p> Some simple content.</p>
    </body>
</html>
```

Assume above is in http://sec.com/p.html

HTML Documents (Cont’d)

```
import requests
from bs4 import BeautifulSoup
URL = 'https://www.monster.com/jobs/search/?q=Data-Scientist&where=Australia'
page = requests.get(URL, verify = False)
soup = BeautifulSoup(page.content, 'html.parser’)
job_elems = results.find_all('section', class_='card-content')
for job_elem in job_elems:
    title_elem = job_elem.find('h2', class_='title')
    company_elem = job_elem.find('div', class_='company')
    location_elem = job_elem.find('div', class_='location')
    print(title_elem)
    print(company_elem)
    print(location_elem)
```

Can use text and structure to explore document

HTML Documents (Cont'd)

Combined with other Python modules e.g. regexps

- BeautifulSoup provides powerful tools to extract text
- can also place text in context within page structure
- can allow extraction of structured data

– from within known page structures

– or using specific patterns of tags/text

– which is often the case nowadays

– when HTML is mostly generated by scripts

HTML Documents (Cont'd)

Example: UNSW Handbook

Easy to navigate and scrape because ...

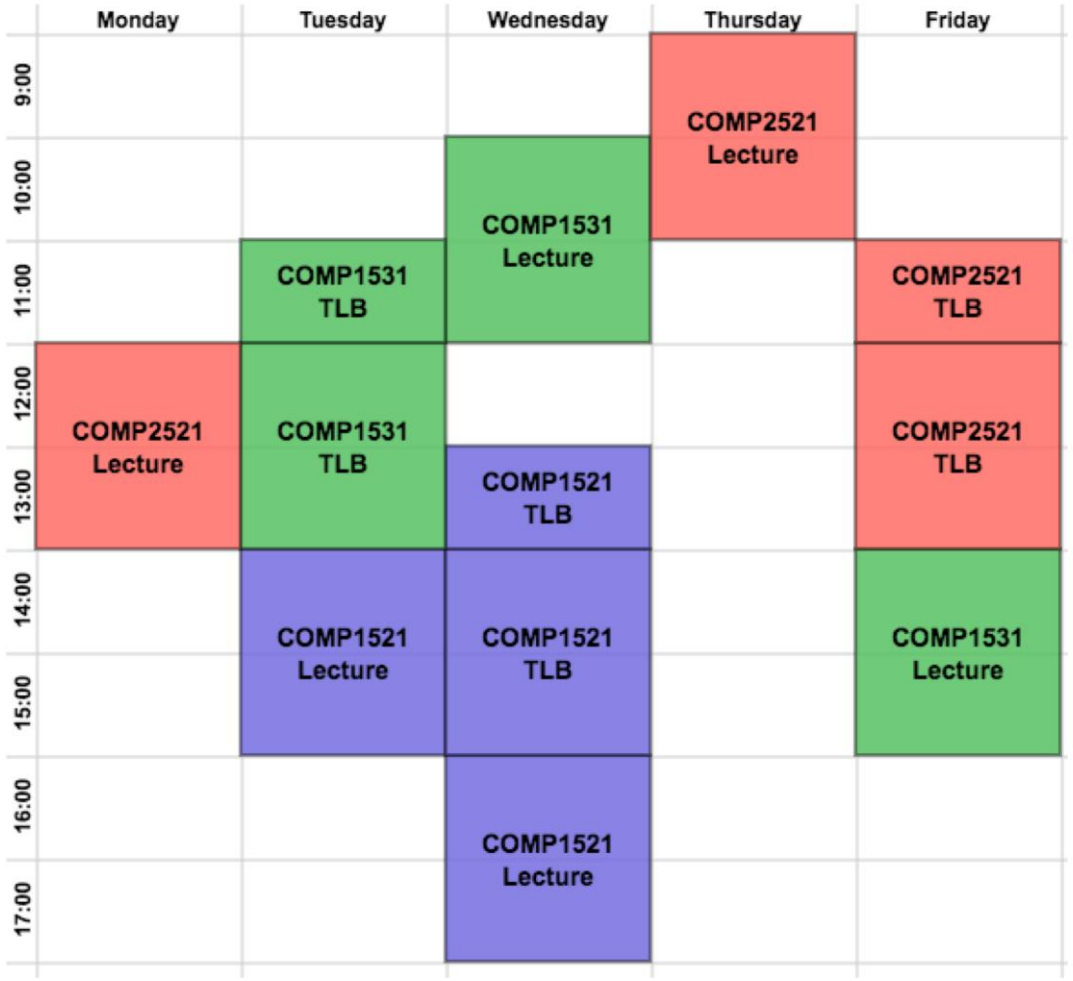
- all program/stream/course pages have same structure
- significant amount of cross-linkage among pages
- index pages give links to all pages of given type

https://www.handbook.unsw.edu.au/

HTML Documents (Cont'd)

Example: Bojangles (retires and replaced with Crossangles)

Timetable generator implemented by CSE student using data scraped from classutil



Source: https://tdransfield.net/projects/bojangles/

XML and JSON Data

XML and JSON are already structured data

- good for representing hierarchical structure
- have tags to indicate type of data (metadata)
- have much software to traverse their content

Tags help to massage into target structure

XML and JSON Data (Cont’d)

Example XML

```
<?xml version="1.0"?>
<countries>
   <country name="Liechtenstein">
         <rank>2</rank> <year>2008</year>
         <neighbour name="Austria" direction="E"/>
         <neighbour name="Switzerland" direction="W"/>
   </country>
   <country name="Singapore">...</country>
   <country name=“Australia”>...</country>
</countries>
```

XML and JSON Data (Cont'd)

Example XML: xml.etree.ElementTree

```
import xml.etree.ElementTree as ET
tree = ET.parse('country_data.xml')
root = tree.getroot()
root.tag # displays 'countries'
    for c in root:
            print c.tag c.attrib
# displays ...
# country {'name': 'Liechtenstein'}
# country {'name': 'Singapore'}
# country {'name': 'Australia'}
```

XML and JSON Data (Cont'd)

Much useful data is available in JSON format

- typically from web service API's

Python provides JSON library module (json)

- dump() serializes Python objects as JSON data
- load() converts JSON data into Python objects
- apply standard Python methods to load'ed objects

Example: https://hackerone.com/reports/328486.json

CSV Data

Most CSV data is effectively a (relational) table

• however may not be normalised (in RDB sense)

Much CSV data is produced from spreadsheets

• column headings provide metadata (if available)

Example:

“ZID”,“Name”,”Degree”,”WAM”

“8787878”,”Al-Banna, Morty”,”1678”,”80.5”

“9601234”,“Paik, Helen”,”8543”,”95.1”

CSV Data (Cont'd)

Python has several CSV modules

csv provides basic reading/writing of CSV data

- each row becomes a Python list
- collection of rows is a list of lists

pandas provides reading/writing CSV data

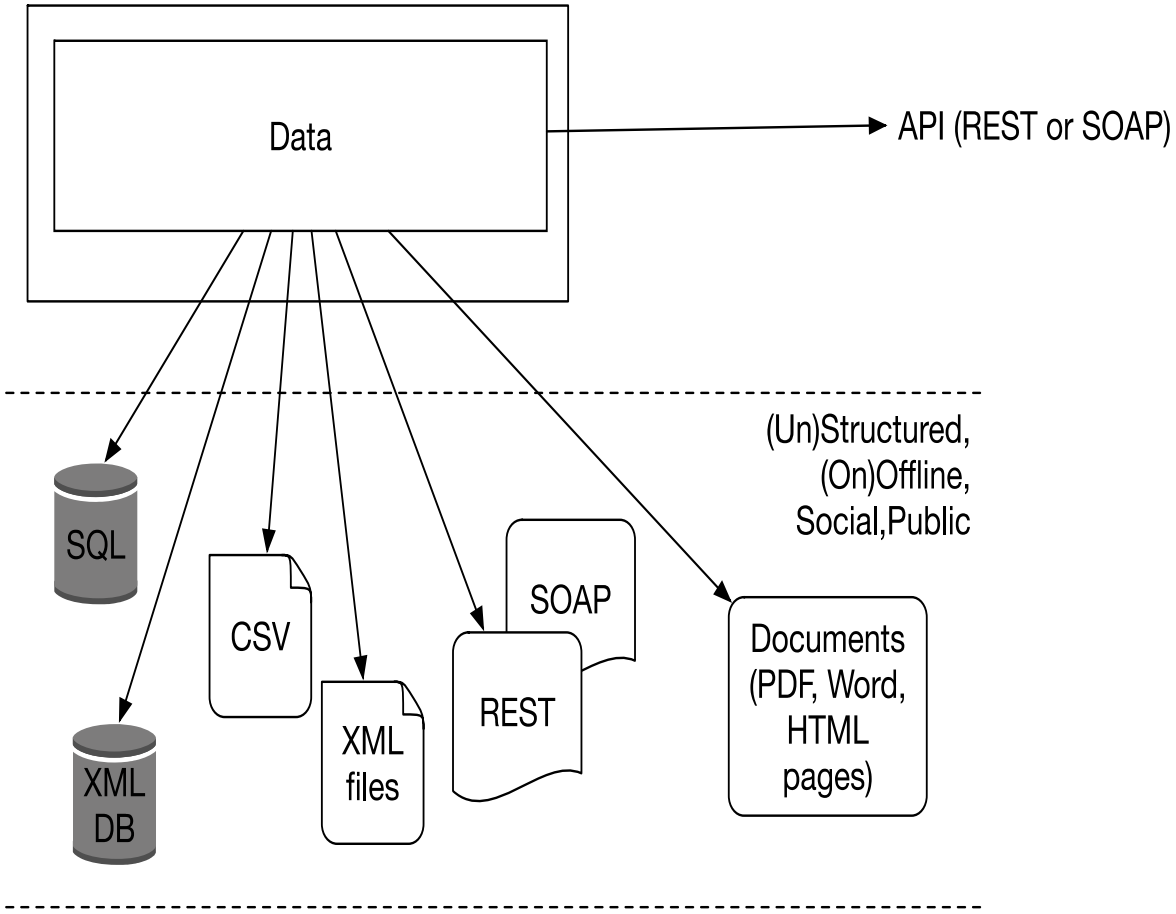
- also, an abstraction of the data (DataFrame)
- plus a range of operators for filtering/calculating

Example: http://www.abs.gov.au/browse?opendocument&ref=topBar

FYI, Before We continue, What is Kaggle?

- **What**? Data Science Community
- **Why**?
  - ❖ Find and publish data sets
  - ❖ Explore and build models in a web-based data-science environment
  - ❖ Work with other data scientists and machine learning engineers
  - ❖ Enter competitions to solve data science challenges.
- **How**? Just join for free and contribute to get more visibility

Back to Data Services

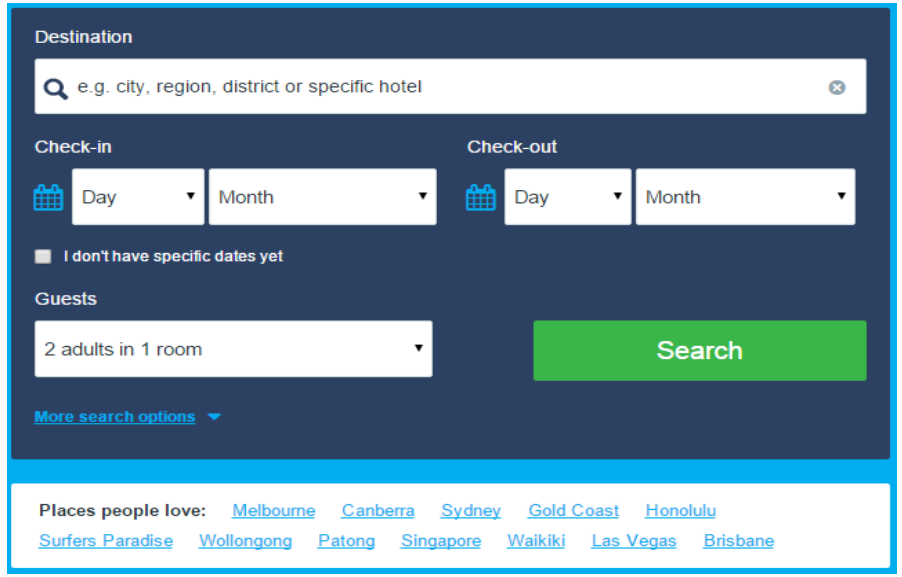


Challenge

How do we store and access this data ?

E-Commerce website

- Data operations are mainly transactions (Reads and “Writes”)
- Operations are mostly on-line
- Response time should be quick but important to maintain **security** and **reliability** of the *transactions.*
- ACID properties are important



Challenge

How do we store and access this data ?

Image serving website (many social network sites in general)

- Data operations are mainly fetching information (Reads)
  - also the “fan-out” effect is challenge
- Operations are mainly on-line
- High bandwidth requirement
- ACID requirements can be relaxed

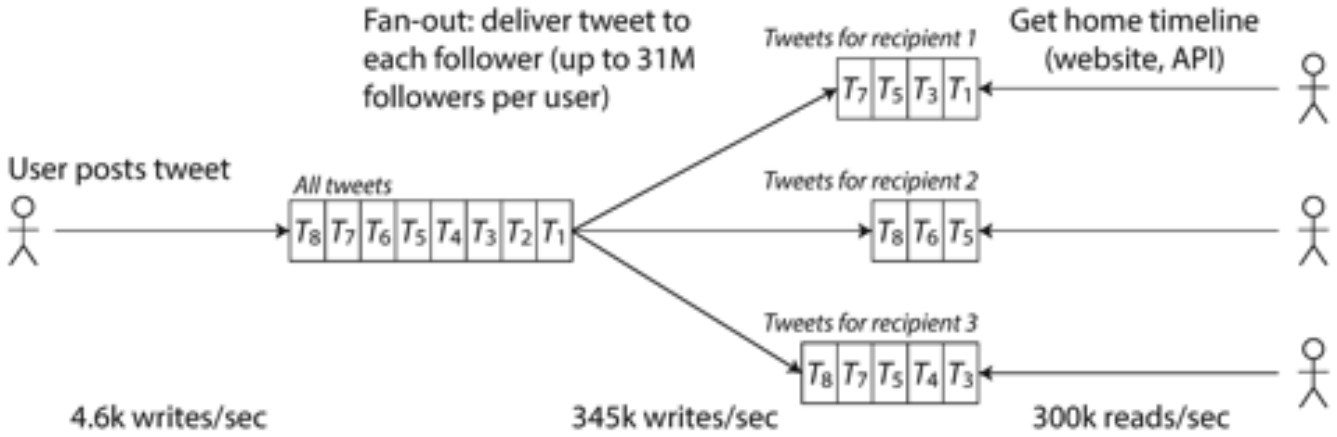


Figure 1-3. Twitter's data pipeline for delivering tweets to followers, with load parameters as of November 2012 [16].

A user can see tweets posted by the people they follow …

- A new post –> look up the followers and 'write' to each follower's timeline ahead of time -> makes reading easy
- But this also creates a lot of 'writing' work
  - On average 75 followers, but can vary widely (some users have 30 million followers)
  - May need to consider the distribution of the followers per user (and how often each user tweets)

Challenge

- How do we store and access this data ?

Search Website

- Data operations are mainly reading index files for answering queries (Reads)
- Index compilation is performed off-line due to the large size of source data (the entire Web)
- ACID requirements can be relaxed
- Response times must be as fast as possible.

Challenge for API …

How do we store and access this data over the web ?

- Consumption of Data (for you to take data in …)
- Publication of Data (for you to make data available for others …)

Important question: What is your data model behind the API?

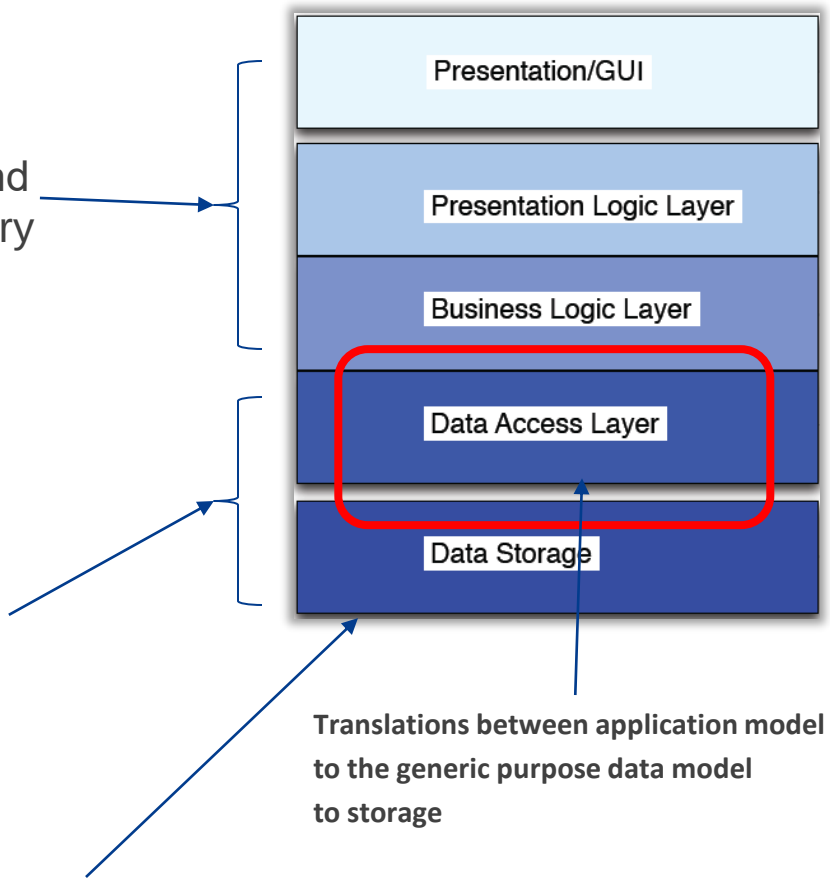
Data models can change how we think about the problem you are solving

What is in a data model …

An application developer “thinks” in terms of the real world (people, organisations, actions, goods, etc.) … and model it as objects/data structures and APIs that manipulate them – these models are very specific to each application

When you want to store the objects, you express them in generic-purpose data model such as JSON, XML documents or tables.

The “storage” also allows the representation to be queried, searched or manipulated.



The engineers of the ‘storage solution’ software decide on how JSON/XML/tables are represented in terms of bytes in memory, disk or on a network.

Relational Model vs. “NoSQL” Models

Relational Model (more or so synonymous with SQL)

- The best known, probably the most successful data model which has proven itself in many aspects to be the data model of choice in many applications
- Data is organised into relations (table) where each relation holds an unordered collection of tuples (rows)

Based on solid theory and well engineered implementation -> many competing models have been proposed, but never managed to take over SQL

Built for business data processing

- Typical business transactions (airline reservations, stock keeping, etc.)
- Batch processing (invoicing, payroll, reporting, etc.)

Turned out it was still generically applicable to many modern Web applications too

Hypothetical Relational Database Model

PubID	Publisher	PubAddress
03-4472822	Random House	123 4th Stree, New York
04-7733903	Wiley and Sons	45 Lincoln Blvd, Chicago
03-4859223	O'Reilly Press	77 Boston Ave, Cambridge
03-3920886	City Lights Books	99 Market, San Francisco

AuthorID	AuthorName	AuthorBDay
345-28-2938	Haile Selassie	14-Aug-92
392-48-9965	Joe Blow	14-Mar-15
454-22-4012	Sally Hemmings	12-Sep-70
663-59-1254	Hannah Arendt	12-Mar-06

ISBN	AuthorID	PubID	Date	Title
1-34532-482-1	345-28-2938	03-4472822	1990	Cold Fusion for Dummies
1-38482-995-1	392-48-9965	04-7733903	1985	Macrame and Straw Tying
2-35921-499-4	454-22-4012	03-4859223	1852	Fluid Dynamics of Aquaducts
1-38278-293-4	663-59-1254	03-3920886	1967	Beads, Baskets & Revolution

Image: http://gnosis.cx/publish/programming/xml_matters_8.html

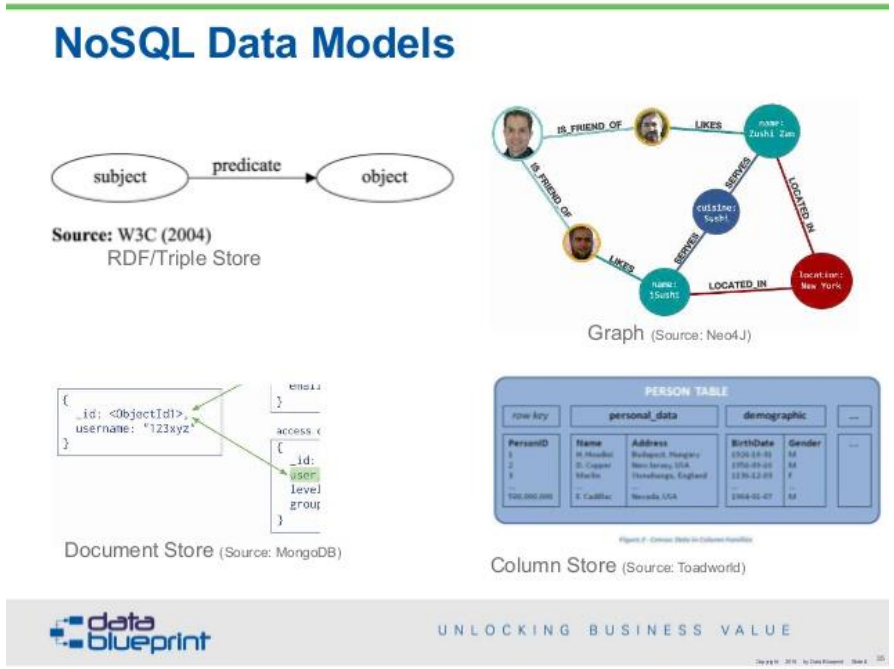
Relational Model vs. “NoSQL” Models

The rise of NoSQL … (since 2010 or so)

- Refers to a host of technologies that implement distributed, “non-relational” databases

Why NoSQL?

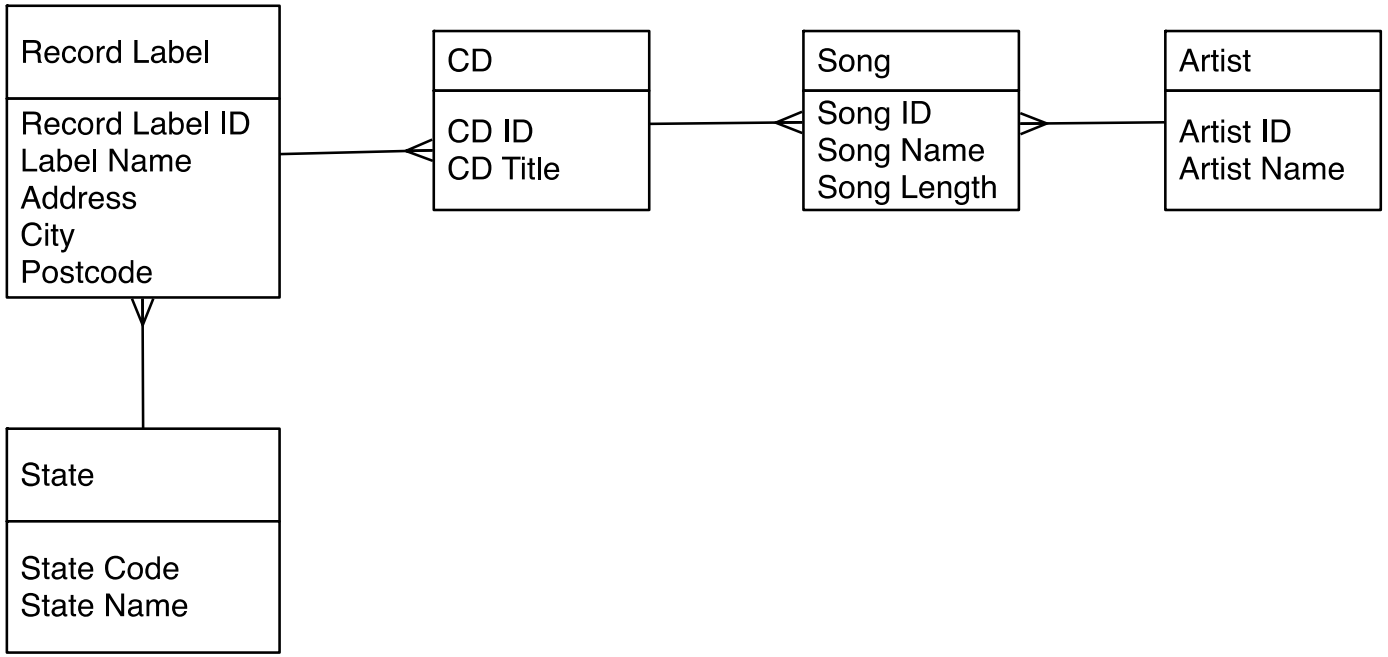
- A need for greater scalability – very large datasets or very high ‘write’ throughput
- A need for more expressive and dynamic data model
- Usually do not require a fixed table schema nor do they use the concept of joins
- All NoSQL offerings relax one or more of the ACID properties



Designing Data-Intensive Applications, by Martin Kleppmann

Image: https://www.slideshare.net/Dataversity/trends-in-data-modeling

Problems with Relational Models



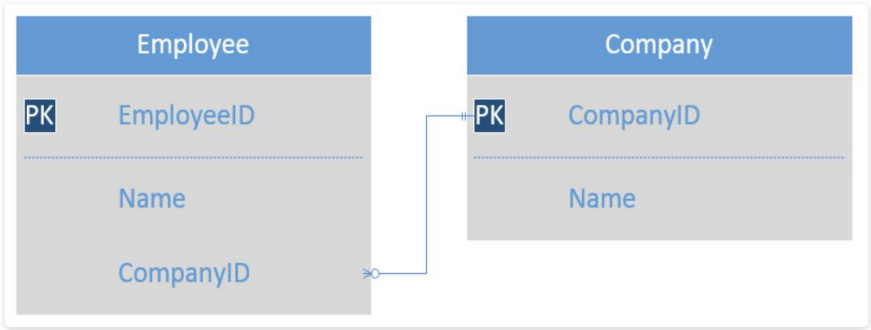
Normalisation … 3NF

* many fragments -> leading to many joins -> scalability ?

Problems with Relational Models

The Object-Relational Mismatch (Impedance Mismatch)

- Refers to the problem of a mismatch between application data model (your business objects) and data model for storage (in relational tables)
- This mismatch creates a need for an awkward translation layer between the objects in the application code and the database model of tables/row/columns.



Employee and Company

```
public class Employee
{
    public string Name { get; private set; }
    public Company Company { get; private set; }
}

public class Company
{
    public string Name { get; private set; }
    public List<Employee> Employees { get; private set; }
}
```


Designing Data-Intensive Applications, by Martin Kleppmann

http://enterprisecraftsmanship.com/2016/11/03/oop-fp-and-object-relational-impedance-mismatch/

Alternative Data Models?

Relational Modelling
of a resume (e.g., LinkedIn Profile)

Typical normalised form would put multi-values in separate tables with user_id as foreign key

Fragmented tables -> join

users table

user_id	first_name	last_name	summary
251	Bill	Gates	Co-chair of … blogger.

region_id	industry_id	photo_id
us:91	131	57817532

regions table

id	region_name
us:7	Greater Boston Area
us:91	Greater Seattle Area

industries table

id	industry_name
43	Financial Services
48	Construction
131	Philanthropy

positions table

id	user_id	job_title	organization
458	251	Co-chair	Bill & Melinda Gates F…
457	251	Co-founder, Chairman	Microsoft

education table

id	user_id	school_name	start	end
807	251	Harvard University	1973	1975
806	251	Lakeside School, Seattle	NULL	NULL

contact_info table

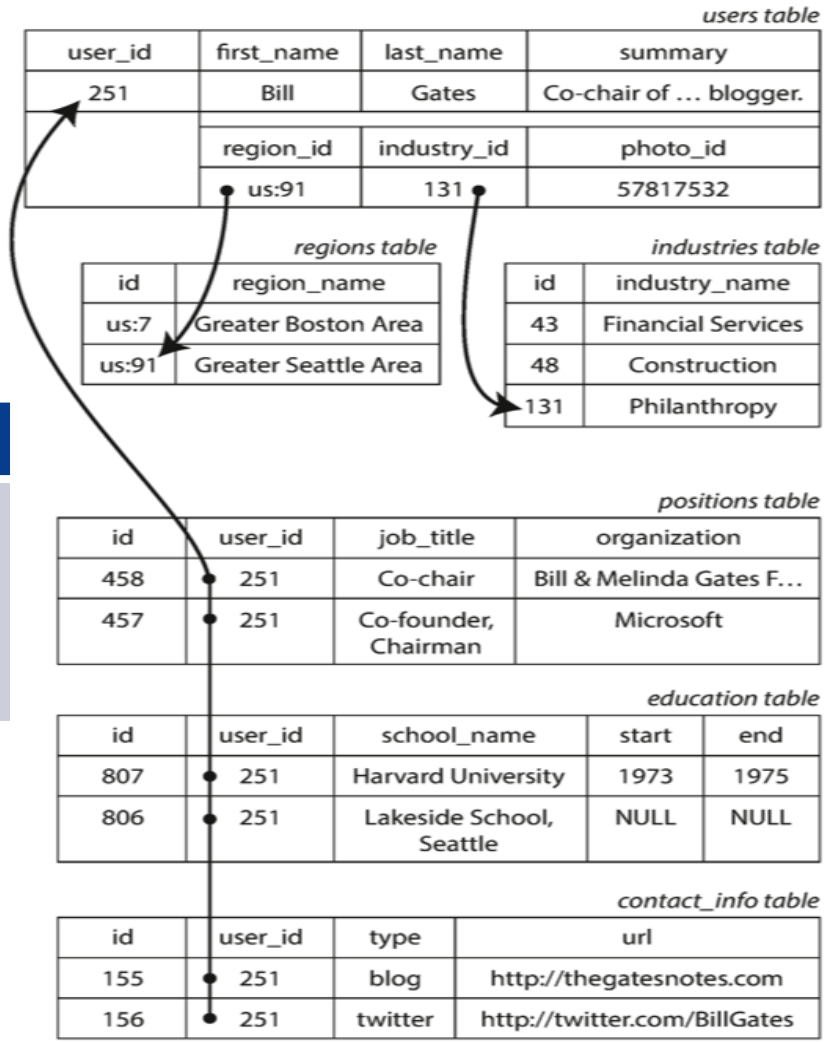
id	user_id	type	url
155	251	blog	http://thegatesnotes.com
156	251	twitter	http://twitter.com/BillGates

Added features in SQL …

Some databases support an idea similar to ‘Arrays’:

- an store multi values in a single row
- can be queried and indexed

User_id	…	Job_title	School_name
251		{co-chair, Bill & Melinda Gates ..}, {Chairman, Microsoft)	{Havard University, 1973,1975},{Lakeside School, Null, Null}



Alternative Data Models?

Example 2-1. Representing a LinkedIn profile as a JSON document

```
{
  "user_id":     251,
  "first_name":  "Bill",
  "last_name":   "Gates",
  "summary":     "Co-chair of the Bill & Melinda Gates...
Active blogger.",
  "region_id":   "us:91",
  "industry_id": 131,
  "photo_url":   "/p/7/000/253/05b/308dd6e.jpg",
  "positions": [
    {"job_title": "Co-chair", "organization": "Bill &
Melinda Gates Foundation"},
    {"job_title": "Co-founder, Chairman", "organization":
"Microsoft"}
  ],
  "education": [
    {"school_name": "Harvard University",       "start":
1973, "end": 1975},
    {"school_name": "Lakeside School, Seattle", "start":
null, "end": null}
  ],
  "contact_info": {
    "blog":    "http://thegatesnotes.com",
    "twitter": "http://twitter.com/BillGates"
  }
}
```

Another option:

- Encodes jobs, education, contact info as a JSON (or XML) document
- Stores the whole document in a text column in the database
- Application code accessing this info will have to deal with the structure as a whole
- You cannot use the database to query for values inside the column

Document-based databases support this idea naturally (e.g., MongoDB – insert/query JSON objects)

Document-based databases

MongoDB (the most well-known example)

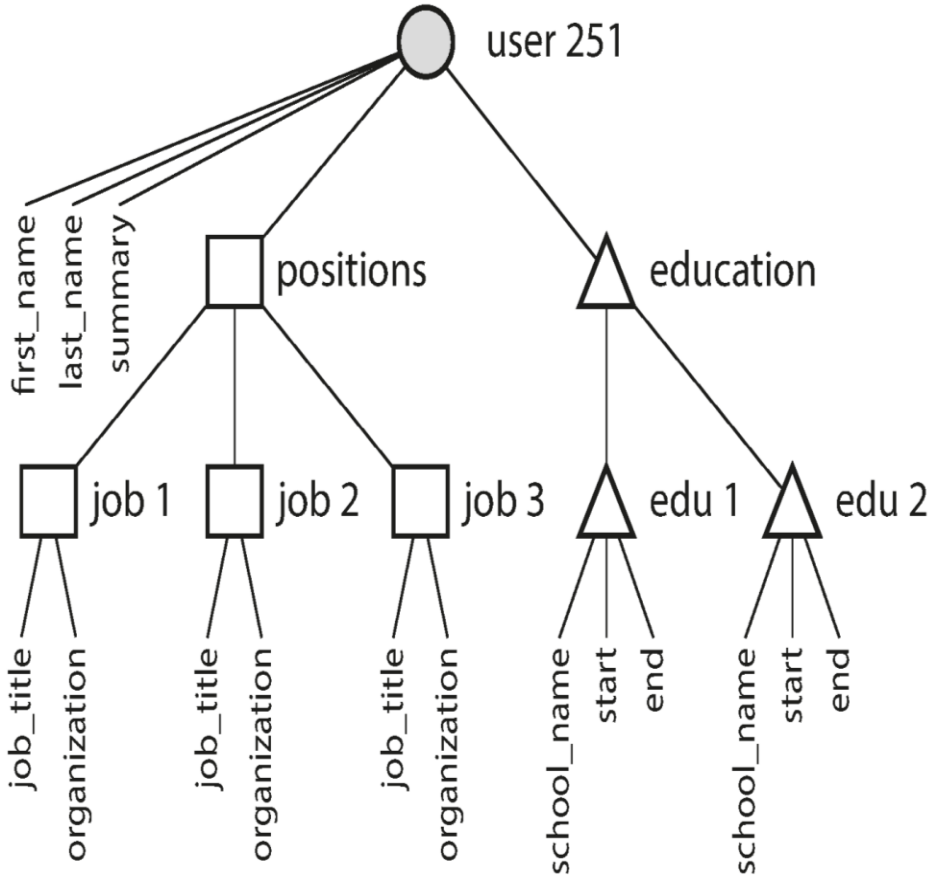
RDBMS	MongoDB
Database	Database
Table	Collection
Tuple/Row	Document
column	Field
Table Join	Embedded Documents
Primary Key	Primary Key (Default key _id provided by mongodb itself)

Notable points:

- Collections do not enforce a schema. Documents within a collection can have different fields. Typically, all documents in a collection are of similar or related purpose
- No joins (everything embedded in a single object)

https://www.tutorialspoint.com/mongodb/mongodb_overview.htm

Document-based databases



Embedded objects normally are the result of One-to-Many relationships

Improved “locality”

- a single retrieval request is enough to get all necessary info on “User”

The mismatch between application data model and storage-purpose data model is significantly reduced

- “Create a User” (JSON) in app code and “Insert a User” (JSON) into Document Collections

Document model is not good with …

http://www.linkedin.com/in/williamhgates

Bill Gates

Greater Seattle Area | Philanthropy

Summary

Co-chair of the Bill & Melinda Gates Foundation.
Chairman, Microsoft Corporation, Voracious

What about Many-to-One or Many-to-Many?

users table

user_id	first_name	last_name	summary
251	Bill	Gates	Co-chair of … blogger.

region_id	industry_id	photo_id
us:91	131	57817532

regions table

id	region_name
us:7	Greater Boston Area
us:91	Greater Seattle Area

industries table

id	industry_name
43	Financial Services
48	Construction
131	Philanthropy

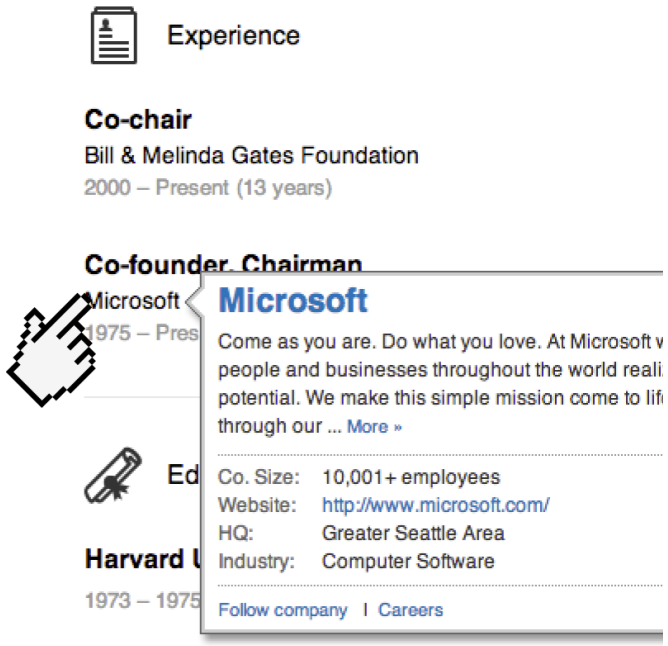
The relational model based solution of these “look-up tables” are useful:

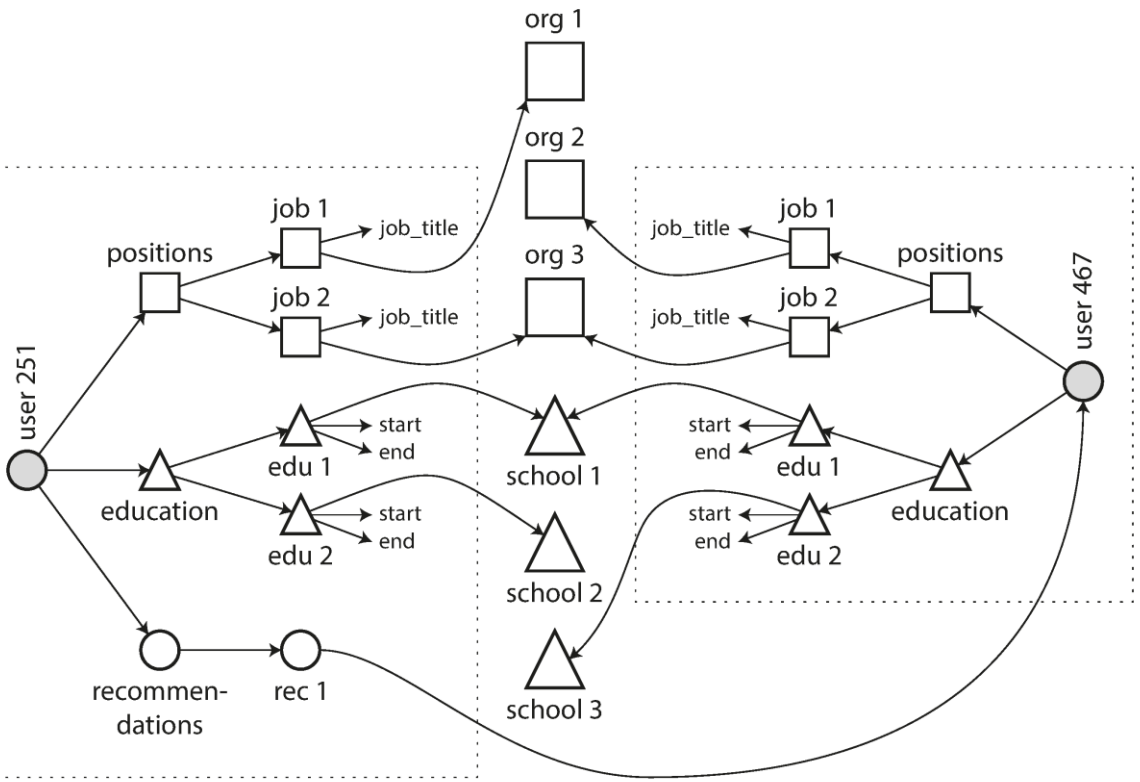
- Consistent style and spelling across Users
- Avoiding ambiguity (e.g., if several cities with the same name)
- Ease of updating (the name is stored in only one place)
- Better search – a search for philanthropists in the state of Washington can match this User 251 (via another table)

Storing ID vs Text -> NOT duplicating text is more flexible and keeps data consistent – reason for normalising in RDB

Document model is not good with …

The single “documents” tend to become more interconnected as more features are added





The company – linking it as a full entity by itself
(Many-to-One Relationship)

The recommendations – linking it to other Users
(Many-to-Many Relationships)

Relational vs. Document

When it comes to representing many-to-one and many-to-many relationships, both are not that different …

- Foreign keys (ID references) in relational
- Document references (Doc ID) in document-based

The IDs are resolved at retrieval time by using a join or follow-up queries.

- But joins on M-M or M-1 relationship are a routine – highly optimised at the database level
- Document models – join support could be weak, application code might have to resolve the relationships as needed

Relational vs. Document

Which data model leads to simpler application code?

- If the application data model looks like a tree (document-like) -> it can be loaded at once using document-based model
- If M-M relationships are central to the application data model -> relational model is efficient in joins. If document model is used, some of the ‘join’ logic will have to move to application code

Consider the kinds of relationships between data items. If they are highly interconnected data (e.g., social network)

- document model is not so good,
- relational model is OK …
- graph models would be natural (to be seen later)

Relational vs. Document

Schema flexibility, always a good thing?

- Most document-based databases do not enforce any schema in documents (schema-less databases)
  - Arbitrary keys and values can be added to a document and when reading clients have no guarantees as to what fields the documents may contain
- Schema-on-read
  - The structure of the data is implicit, only interpreted when the data is read by application code
  - ≈ dynamic (runtime) type checking
- Schema-on-write
  - The traditional approach of RDB - explicit schema and the database ensures all written data conforms to it
  - ≈ static (compile-time) type checking

Relational vs. Document

Schema flexibility, always a good thing?

- When does this ‘schema-on-read/write’ matter? -> when application wants to change the format of its data.
- E.g., User name in one field -> User name in two fields.

(Document Based)

```
if (user && user.name && !user.first_name) {
    // Documents written before Dec 8, 2013 don't have
first_name
    user.first_name = user.name.split(" ")[0];
}
```

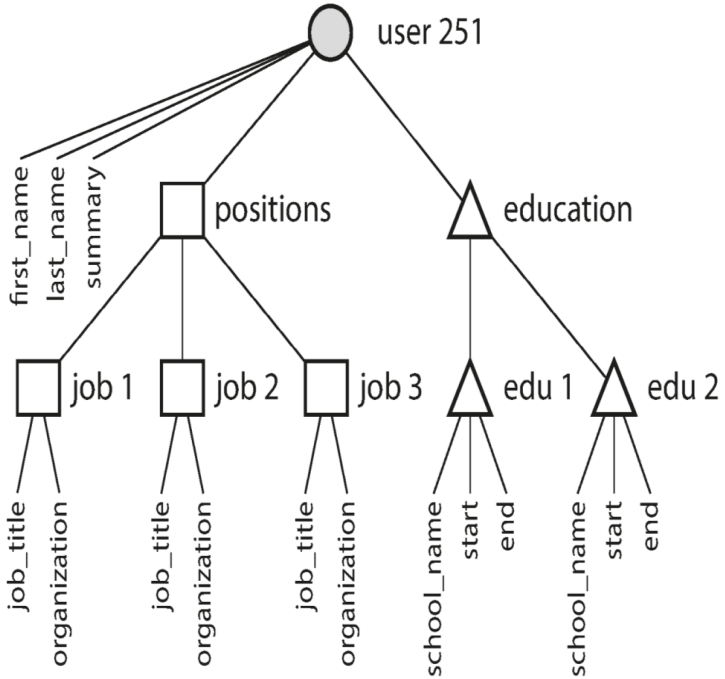
(Relational DB)

```
ALTER TABLE users ADD COLUMN first_name text;
UPDATE users SET first_name = split_part(name, ' ', 1);
-- PostgreSQL
UPDATE users SET first_name = substring_index(name, ' ',
1);      -- MySQL
```

DOC model is considered advantageous if the docs in the collection tend to have different structures (e.g., different types of related objects)

Relational vs. Document

Data locality for queries - doc-based systems store a document as a single continuous string as JSON or XML (or a binary variant)



users table

user_id	first_name	last_name	summary
251	Bill	Gates	Co-chair of … blogger.

region_id	industry_id	photo_id
us:91	131	57817532

regions table

id	region_name
us:7	Greater Boston Area
us:91	Greater Seattle Area

industries table

id	industry_name
43	Financial Services
48	Construction
131	Philanthropy

positions table

id	user_id	job_title	organization
458	251	Co-chair	Bill & Melinda Gates F…
457	251	Co-founder, Chairman	Microsoft

education table

id	user_id	school_name	start	end
807	251	Harvard University	1973	1975
806	251	Lakeside School, Seattle	NULL	NULL

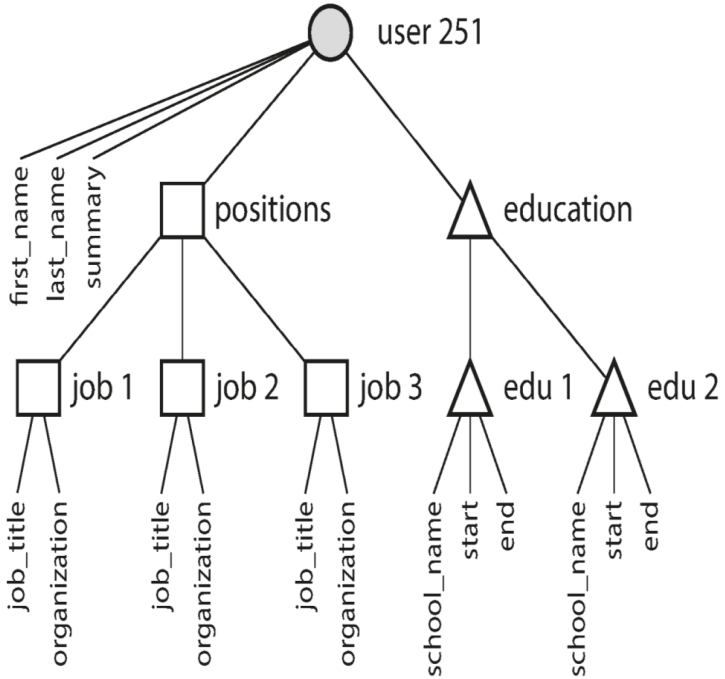
contact_info table

id	user_id	type	url
155	251	blog	http://thegatesnotes.com
156	251	twitter	http://twitter.com/BillGates

If your application requires the entire document (e.g., to render it on a Web page as a whole), there is a performance advantage over split tables

Relational vs. Document

The locality of Doc-based systems

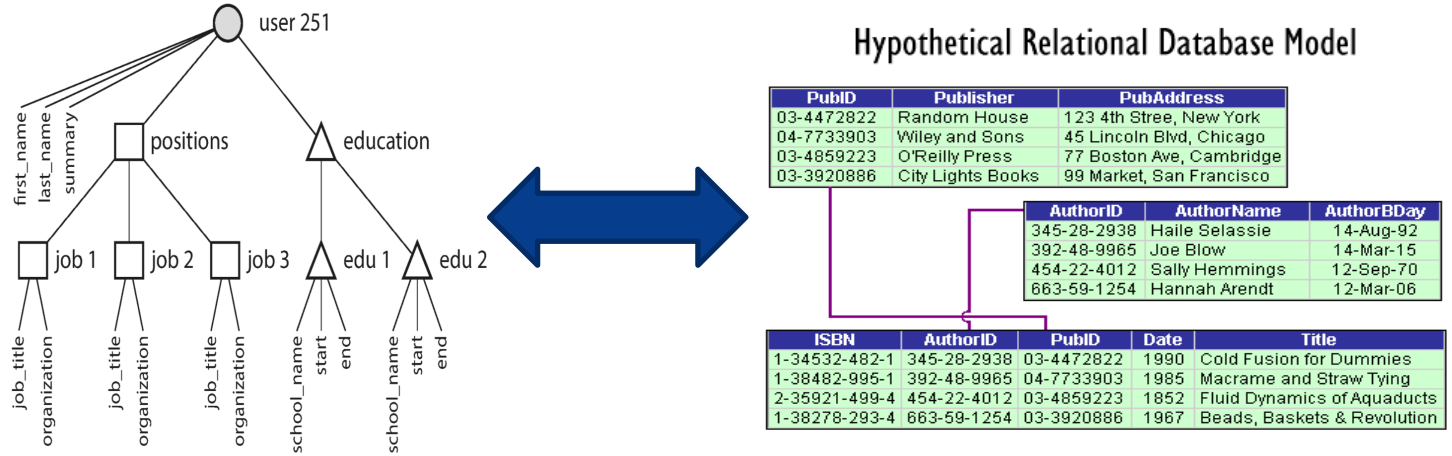


Data locality advantage only applies if you need large parts of the document at a time (often the whole document needs to be loaded only if you need to access a small portion of it)

On Updates, normally the whole document needs to be rewritten (except tiny changes that do not change the overall encoded size of the document)

Relational vs. Document

Convergence of document and relational databases



PostgreSQL (since v.9.3), MySQL (since v.5.7). IBM DB2 (since v.10) support JSON documents.

RethinkDB, MongoDB (document-based) support relational-like joins in its query language

The two models can complement each other -> A hybrid model seems like a trend in these two systems

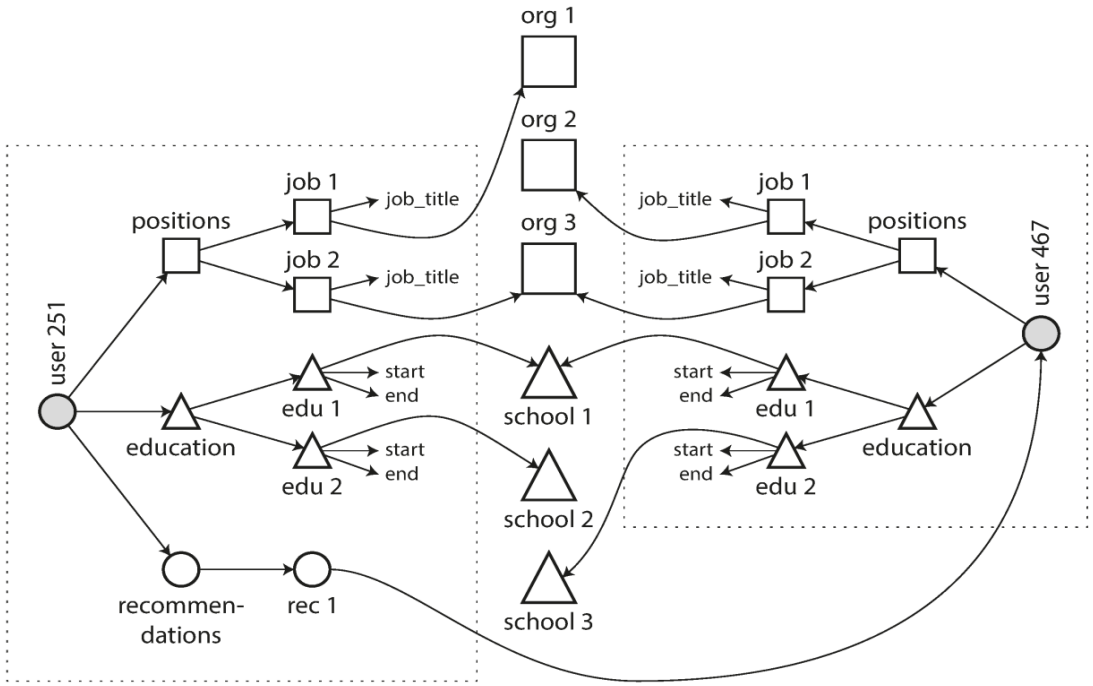
Graph-like Models

M-M relationships are an important factor in deciding which data model to go with

1-M (tree/doc), self-contained -> Document model

M-M -> either relational or graph

Highly M-M, complicated connections -> graph …



Graph:

- Vertices/nodes: represent entities
- Edges/arcs: represent relationships

The recommendations – linking it to other Users **(Many-to-Many Relationships)**

Graph-like Models

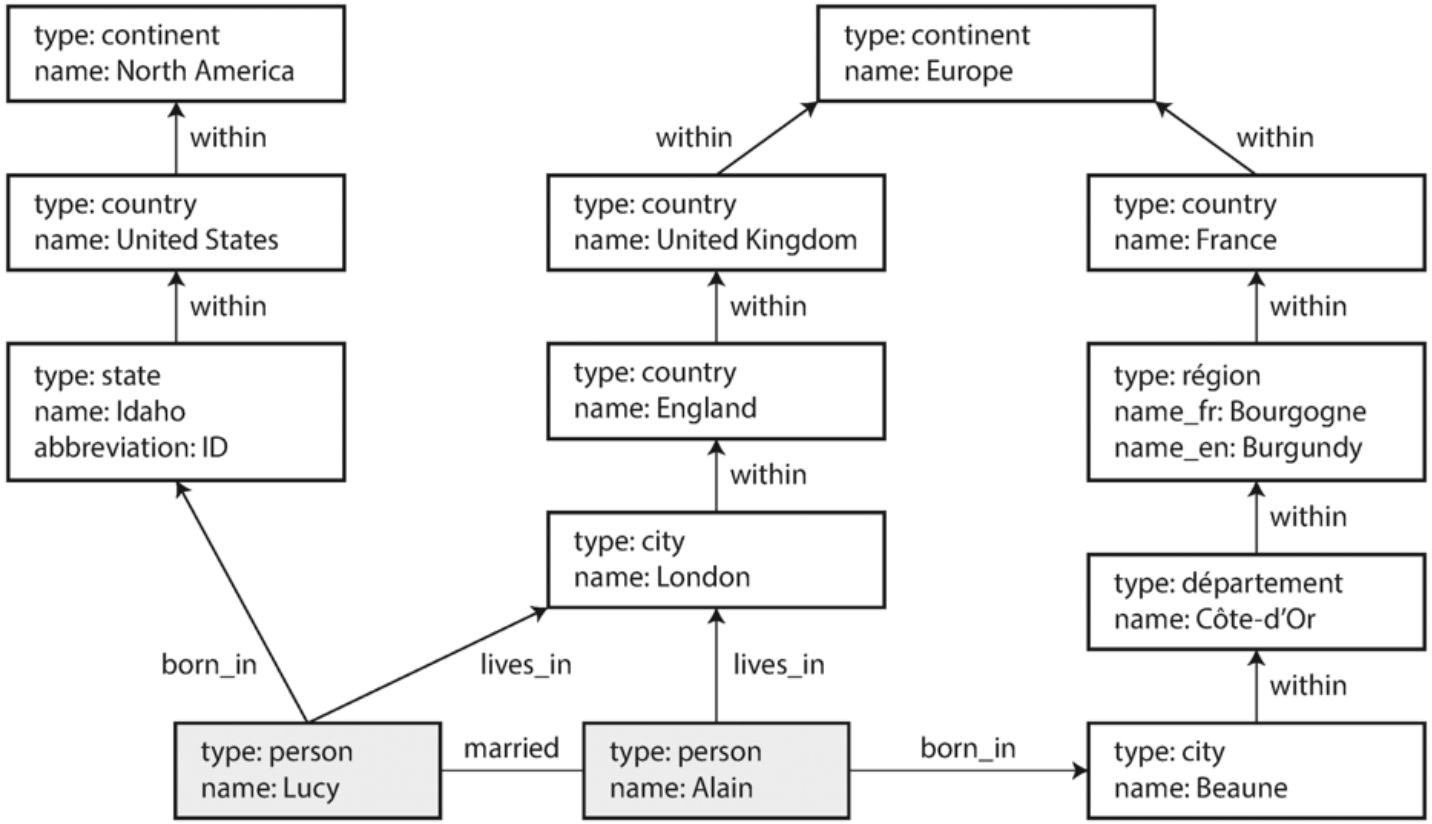
Many kinds of data can be modelled as a graph

- Social Graph – vertices are people, edges indicate which people know each other
- The Web Graph – vertices are web pages and edges indicate HTML links to other pages
- Road or Rail networks – vertices are junctions and edges represent the roads/railways between them

Well-known algorithms on the model

http://www.supplychain247.com/article/why_supply_chains_should_be_more_socially_engaged
http://canacopegdl.com/single.php?id=http://www-inst.eecs.berkeley.edu/~cs61bl/r//cur/graphs/web.graph.png
https://visualign.wordpress.com/2012/07/11/london-tube-map-and-graph-visualizations/

Graph-like Models



Vertices are not limited to the same type of data.

Graph-like Models

Facebook, TAO system (2013)

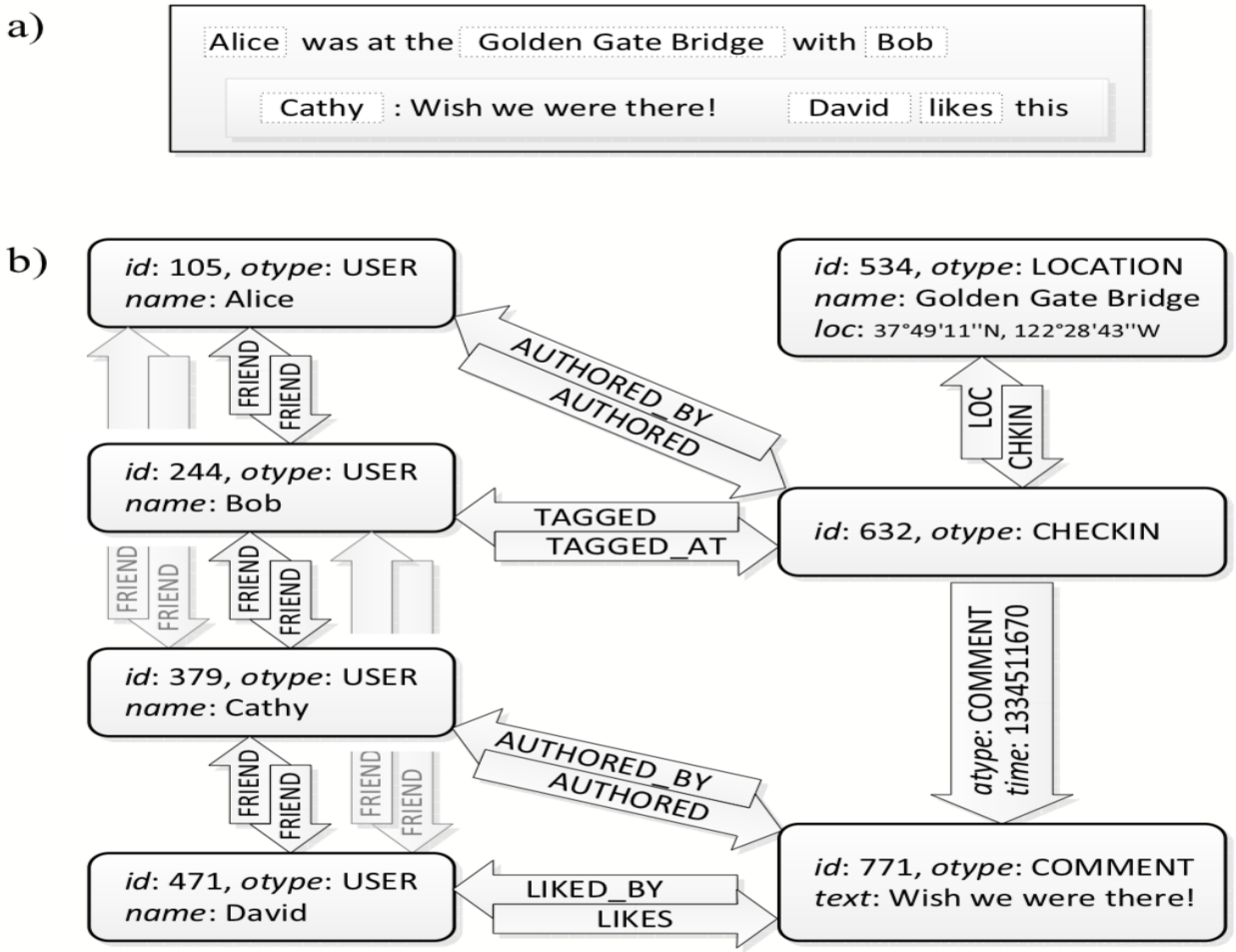


Figure 1: A running example of how a user's checkin might be mapped to objects and associations.

Storing and Querying Graph-like Models

Property Graph model:

Each vertex:

- Identifier
- A set of outgoing edges
- A set of incoming edges
- A collection of properties (key-value pairs)

Each edge:

- Identifier
- The vertex at which the edge starts (tail)
- The vertex at which the edge ends (head)
- A label for the relationship
- A collection of properties

(e.g., PostgreSQL, using json type)

Example 2-2. Representing a property graph using a relational schema

```
CREATE TABLE vertices (
    vertex_id   integer PRIMARY KEY,
    properties  json
);

CREATE TABLE edges (
    edge_id     integer PRIMARY KEY,
    tail_vertex integer REFERENCES vertices (vertex_id),
    head_vertex integer REFERENCES vertices (vertex_id),
    label       text,
    properties  json
);

CREATE INDEX edges_tails ON edges (tail_vertex);
CREATE INDEX edges_heads ON edges (head_vertex);
```

Storing and Querying Graph-like Models

Property Graph model:

Any vertex can have edges (no schema-based restriction on what kinds of 'things' can be connected)

Given any vertex, you can efficiently find both incoming and outcoming edges – traversing the graph

By using different labels for different types of relationships, you can store several different kinds of information in a single graph

These features give graphs a great flexibility for data modelling

(e.g., PostgreSQL, using json type)

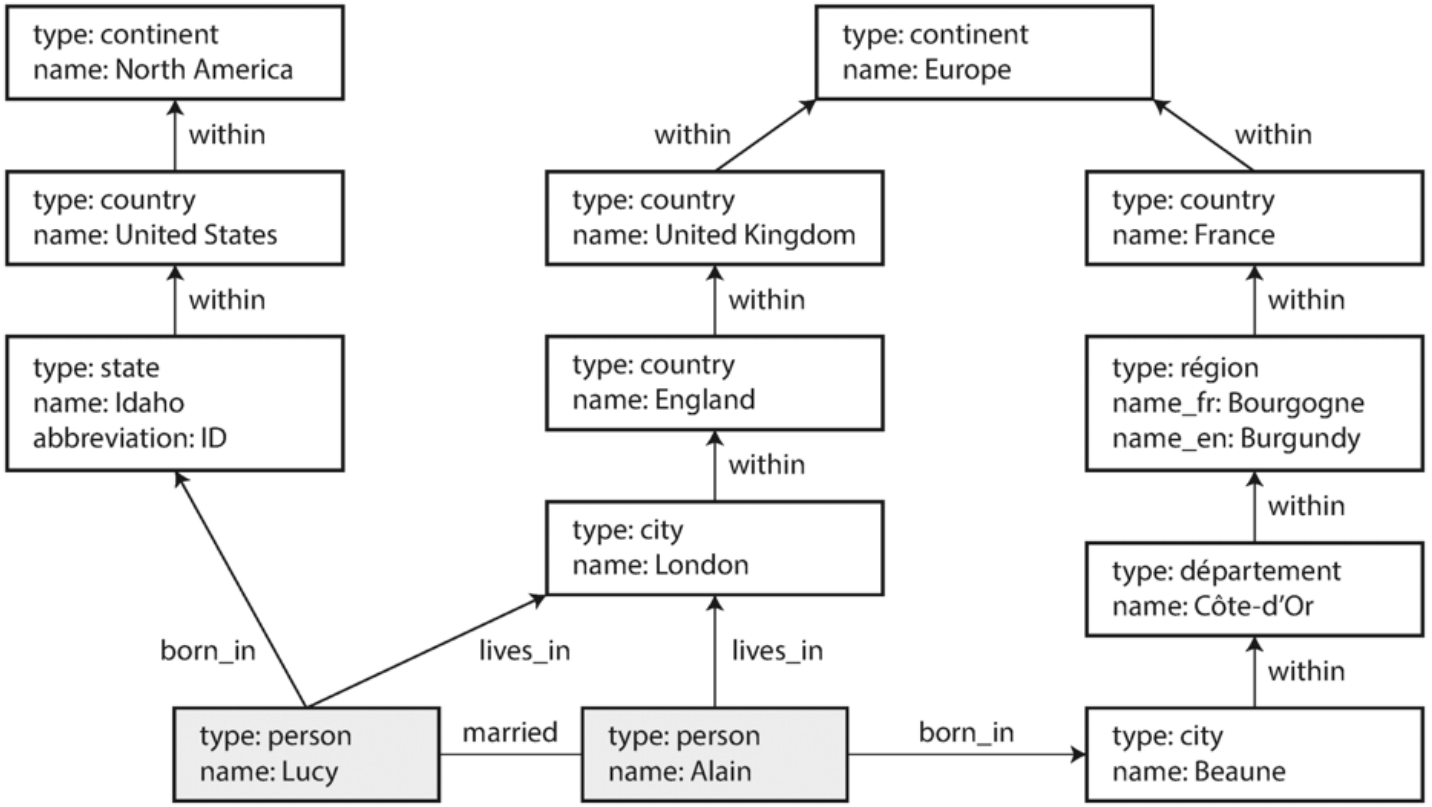
Example 2-2. Representing a property graph using a relational schema

```
CREATE TABLE vertices (
    vertex_id   integer PRIMARY KEY,
    properties  json
);

CREATE TABLE edges (
    edge_id     integer PRIMARY KEY,
    tail_vertex integer REFERENCES vertices (vertex_id),
    head_vertex integer REFERENCES vertices (vertex_id),
    label       text,
    properties  json
);

CREATE INDEX edges_tails ON edges (tail_vertex);
CREATE INDEX edges_heads ON edges (head_vertex);
```

So graphs are “very” flexible … (cf. RDB)



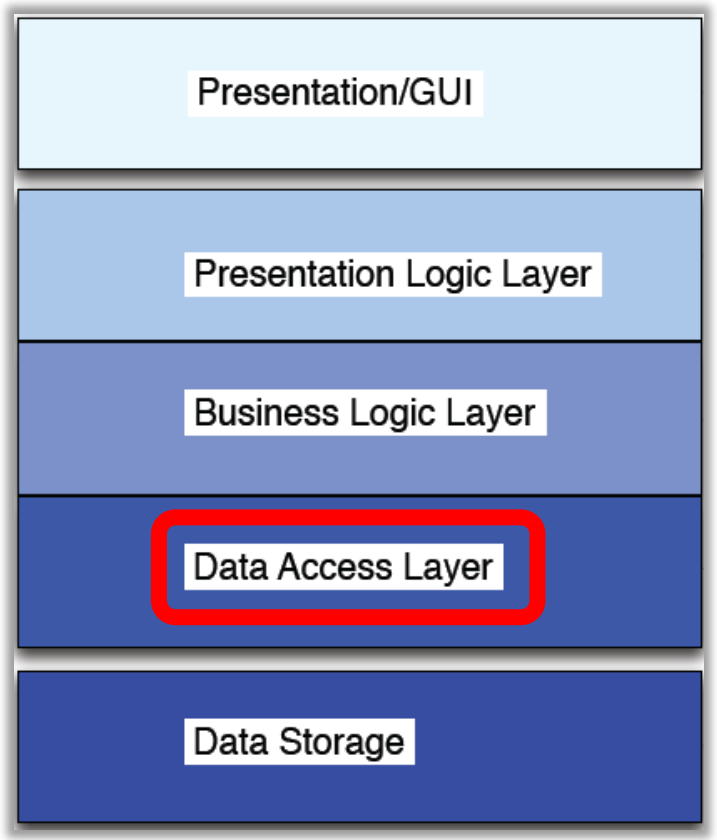
- Different kinds of regional structures in different countries
- Type country “within” a type country
- Varying granularity (e.g., born_in “type:state”, lives_in type:city)

Accessing DB from an application …

When you work with a database system (regardless of its storage model) in an application, the code issues a query statements to the database via some form of “data-connectivity API”

The application code blocks relating to using this library form “Data Access Layer” in the stack.

- For objects to persists, we need to convert the object values into the values that can be stored in the storage and convert them back upon retrieval.
- This should be done while preserving the properties of the objects and their relationships



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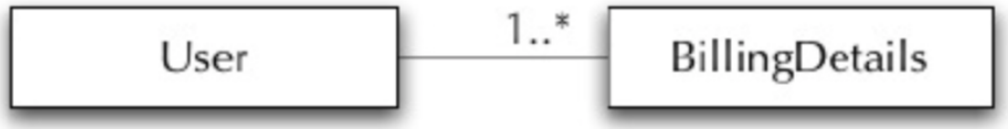
Impedance (or Paradigm) Mismatch Problem




```
public class User  {
   private String userName;
   private String name;
   private String address;
   private Set billingDetails;
   // accessor methods
}
```

```
public class BillingDetails  {
   private String accountNumber;
   private String accountName;
   private String accountType;
   private User user;
   // accessor methods
}
```

```
create table User (
   username varchar(15)
        not null primary key,
   name varchar(50) not null,
   address varchar(100)
)
```

```
create table Billing_Details (
   account_number varchar(10)
                not null primary key,
   account_name varchar(50) not null,
   account_type varchar(2) not null,
   username varchar(15)
        foreign key references user
)
```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Impedance Mismatch Problem

Granularity Problem

We want to create a separate `Address` class as other classes in the system may also carry address information.

How should this be represented in relational tables?

- Should we add an Address table?
- Should we add an Address column to the User table instead?
- Should the Address be a string? Or multi-columns?
  - ***Coarse Granularity***, as a single field
  - ***Fine Granularity,*** as multiple fields

address = 200 2nd Ave. South #358, St. Petersburg, FL 33701-4313 USA

street address = 200 2nd Ave. South #358
city = St. Petersburg
postal code = FL 33701-4313
country = USA

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Impedance Mismatch Problem

In application code:

Identity Concept Mismatch

Objects can be either equal or identical:

identical = same object (address)

equal = same values

In RDB, these two separate concepts do not exists. There is only one concept of identify = primary key. (i.e., same primary key -> same objects)

Potentially problematic, if duplicate objects are considered the same object (or vice versa) in database

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Impedance (or Paradigm) Mismatch Problem

Association Problem

- User, Address and BillingDetails classes are associated (different kind of associations - represented differently in tables)
- Association mapping and the management of the entity associations are central concept of any object persistence solution.
- OO languages represent associations using *object references* and collections of object references

Object references are directional; the association is from one object to another. To be able to navigate 'between' objects, one needs to define the association *twice*.

```
public class User {
  private Set billingDetails; ...
}
```

```
public class BillingDetails {
  private User user; ...
}
```

Impedance Mismatch Problem

Object Graph Navigation

In OO, method chaining like:

User.getBillingDetails().getAccountNumber() is commonly done …

From a user, you access the billing information, from that, you access the account number …

However, this is not an efficient way to retrieve data from relational tables (i.e., instead of accessing single objects, you'd do joins …)

```
select * from USER u where u.USER_ID = 123
```

if we need to retrieve the same User and then subsequently visit each of the associated BillingDetails instances, we use a different query:

```
select *
from USER u, BILLING_DETAILS bd
where u.USER_ID = bd.USER_ID
and u.USER_ID = 123
```


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Query languages for data

```
function getSharks() {
    var sharks = [];
    for (var i = 0; i < animals.length; i++) {
        if (animals[i].family === "Sharks") {
            sharks.push(animals[i]);
        }
    }
    return sharks;
}
```

Most programming languages are imperative:

- step-by-step instructions on how the data should be returned …

```
SELECT * FROM animals WHERE family = 'Sharks';
```

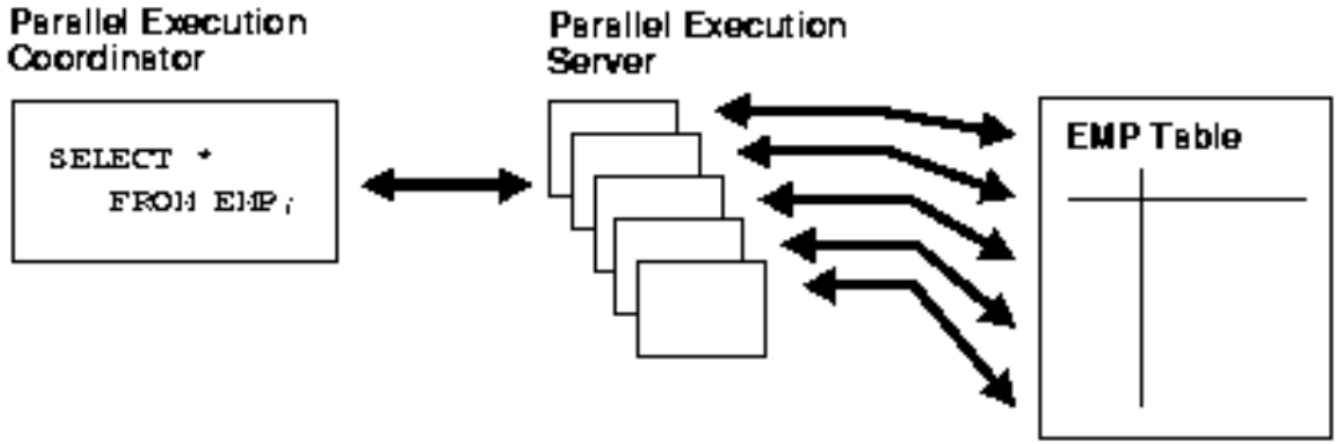
Most query languages are Declarative:

- Specify the pattern of data to be returned, not how it is returned
- The database is optimised on how to do this

This declarative query paradigm is the same in Relational or Document-based systems

Query languages for data

```
SELECT * FROM animals WHERE
```



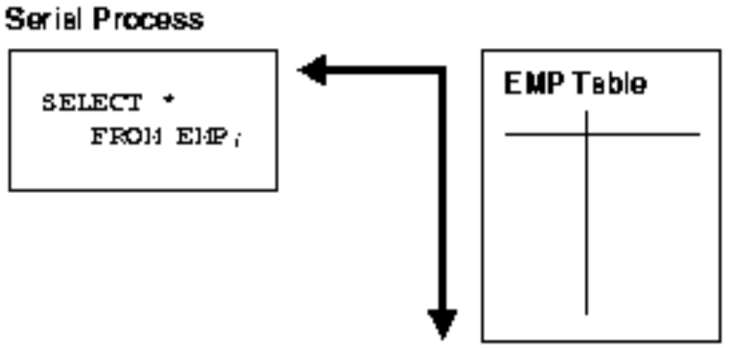
Declarative query paradigm is good for many reasons:

It is up to the database to decide which index tables to consult, which joins should be performed, in which order the various parts of the query are executed

The query language can remain concise

Any further optimisation/performance improvement of the database system can happen without affecting the query interface (e.g., re-arranging disk space)

Suitable for parallel execution strategy …



Query Languages for Data

Accessing DB from an Application:

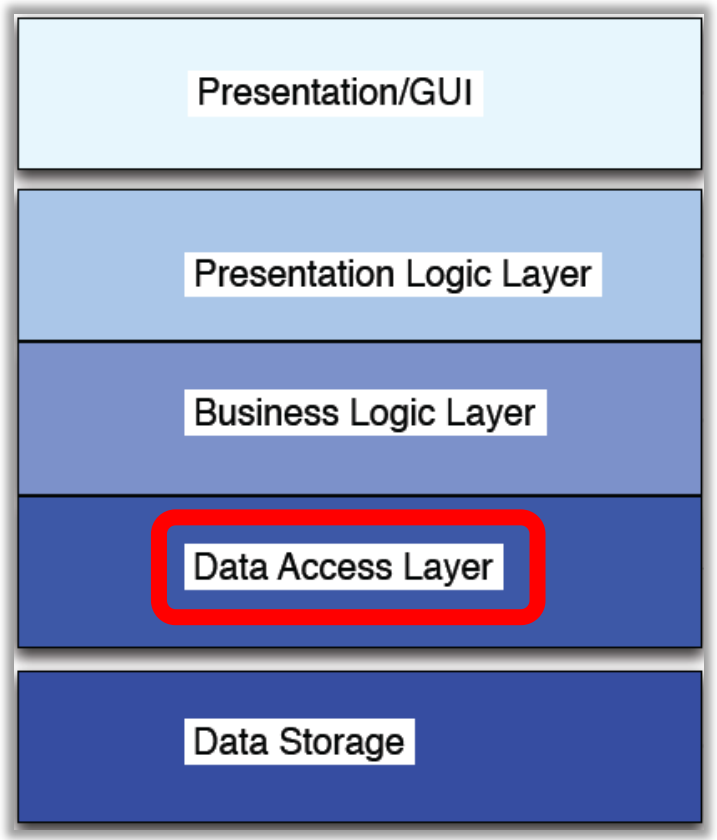
When you work with a database system (regardless of its storage model) in an application, the code issues a query statements to the database via some form of “data-connectivity API”

Database connectivity API specifications

- Java has JDBC API, Python has DB-API, Microsoft variety has ODBC API, etc.

Each specification is then implemented by the database system provider as a library for the developers (e.g., DB-API library for PostgreSQL, or JDBC library for Oracle)

The application code blocks relating to using this library form “Data Access Layer” in the stack.



Directly Executing SQL

DBAPI – e.g., psycopg2

```
import psycopg2
connection = psycopg2.connect("scott", "tiger", "test")

cursor = connection.cursor()
cursor.execute(
          "select emp_id, emp_name from employee "
          "where emp_id=%(emp_id)s",
          {'emp_id':5})
emp_name = cursor.fetchone()[1]
cursor.close()

cursor = connection.cursor()
cursor.execute(
          "insert into employee_of_month "
          "(emp_name) values (%(emp_name)s)",
          {"emp_name":emp_name})
cursor.close()

connection.commit()
```

Connect
(network/or file handle)

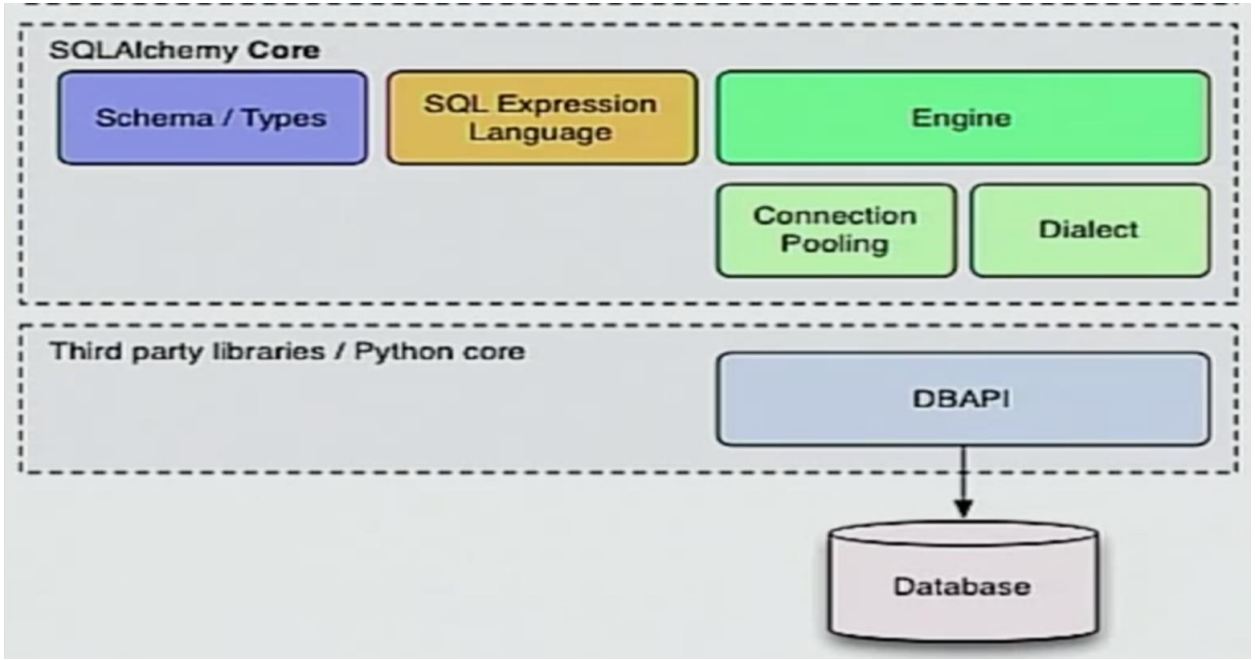
"An object for
Table rows and loops
within them"

Bound parameter

Directly Executing SQL

DBAPI

- Many different implementations of the spec …
- Inconsistency between different implementations (e.g., bound parameter formats, exception hierarchy)
- No explicit transaction markers (no begin() transaction)



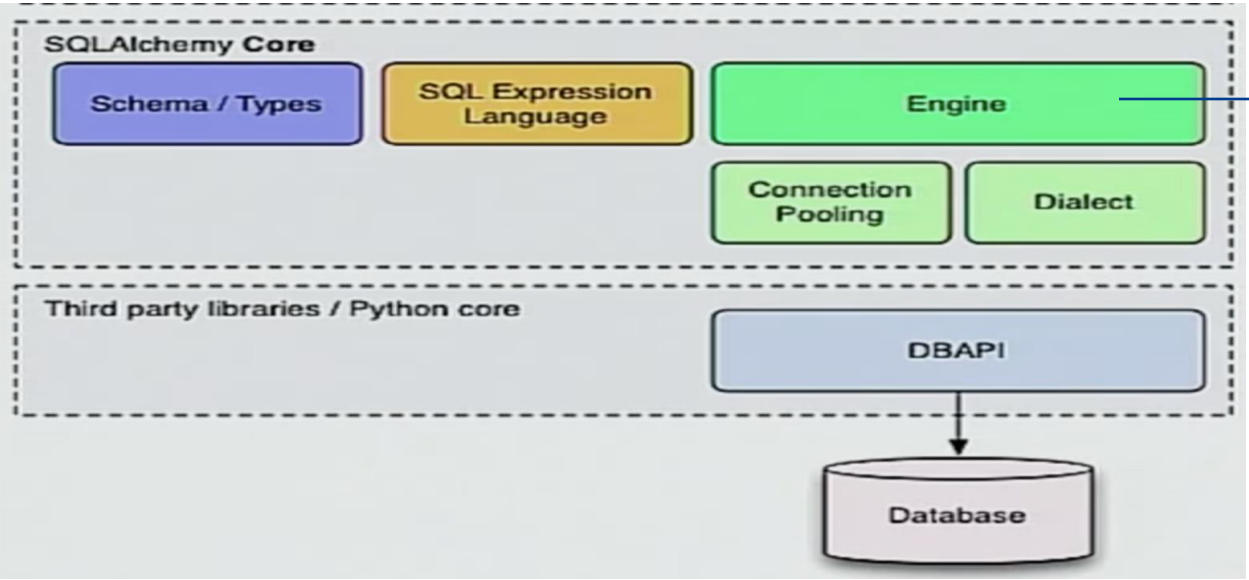
A range of services built on top of DBAPI

Directly Executing SQL

SQLAlchemy

- “Uniform” SQL access to relational databases (in SQLAlchemy way)
- i.e., SQL access library built on top of the DBAPI connectivity

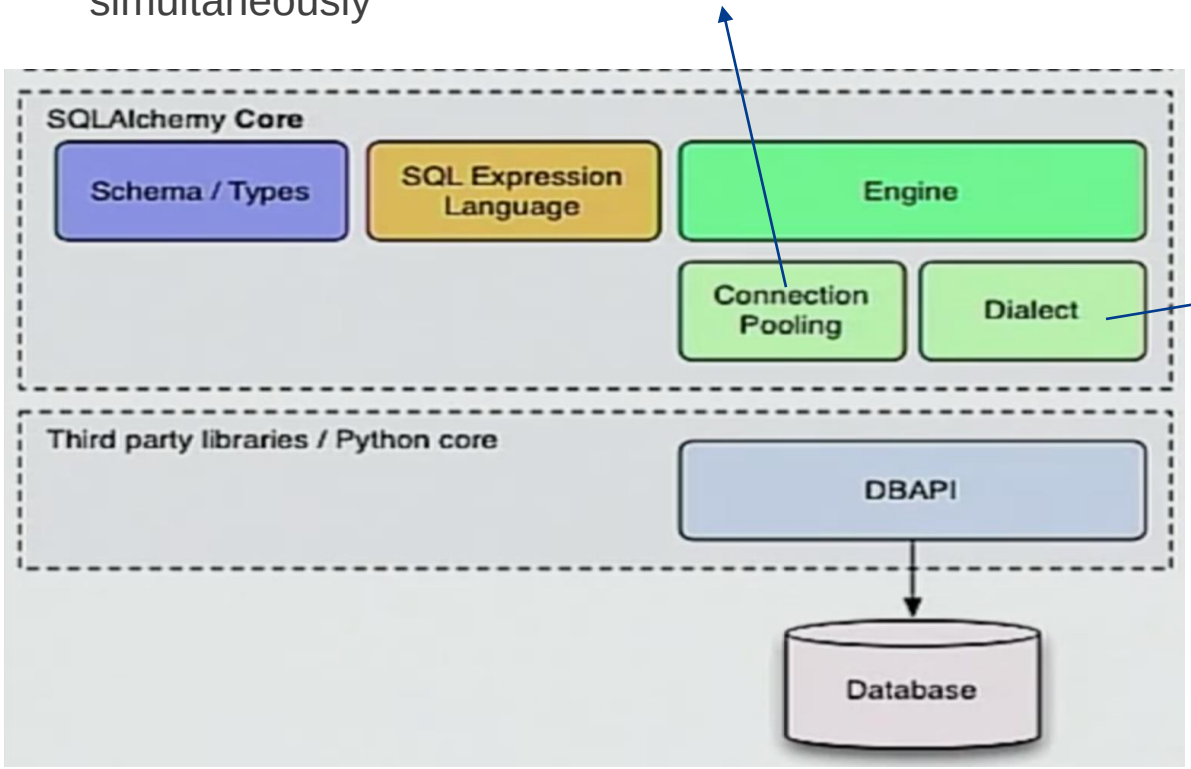
```
from sqlalchemy import create_engine
engine = create_engine('postgresql://usr:pass@localhost:5432/sqlalchemy')
…
engine = create_engine('sqlite:///some.db')
```



Object that maintains
The classical DBAPI interactions
With the database

Directly Executing SQL

- Connection Pooling (≈ connection sharing)
  - Creating DB connections are expensive
  - With pooling, program fetches an existing connection, use and put it back into pool
  - easier management of the number of connections that an application might use simultaneously



SELECT TOP 10 * FROM people;

Or

SELECT * FROM people LIMIT 10;

Directly Executing SQL (SQLAlchemy Core)

```
users = Table('users', metadata,
   Column('id', Integer, Sequence('user_id_seq'), primary_key=True),
   Column('name', String(50)),
   Column('fullname', String(50)),
   Column('password', String(12))
)
```

SQL Expression Language

```
>>> ins = users.insert()
>>> conn.execute(ins, id=2, name='wendy', fullname='Wendy Williams')
```

```
INSERT INTO users (id, name, fullname) VALUES (?, ?, ?)
(2, 'wendy', 'Wendy Williams')
COMMIT
```

```
>>> from sqlalchemy.sql import select
>>> s = select([users])
>>> result = conn.execute(s)
```

```
SELECT users.id, users.name, users.fullname
FROM users
()
```

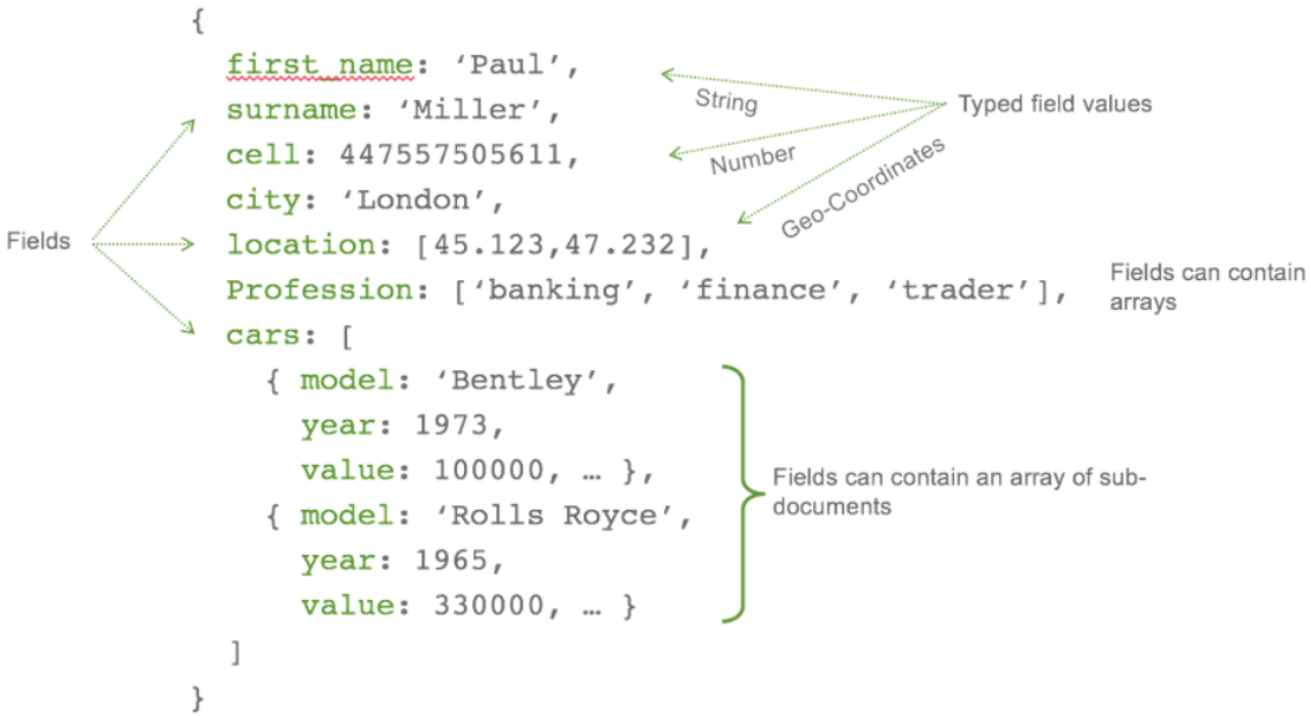
MongoDB Query

The basic idea of databased connectivity API applies with MongoDB too …

Many implementations

- Direct: PyMongo, Motor
- ORM-like: PyMODM, MongoEngine, etc.

JSON Documents
as the first class citizens



https://www.mongodb.com/blog/post/getting-started-with-python-and-mongodb

MongoDB Query

MongoDB Server (download, install, run …) and MongoDB Client (connect, create db, …)

```
db.users.insertOne(
   {
      name: "sue",
      age: 26,
      status: "pending"
   }
)
```

collection

Create one if the collection doesn't exist

field: value

field: value

field: value

document

```
db.users.find(
   { age: { $gt: 18 } },
   { name: 1, address: 1 }
).limit(5)
```

collection

query criteria

projection

cursor modifier

```
db.users.updateMany(
   { age: { $lt: 18 } },
   { $set: { status: "reject" } }
)
```

collection

update filter

update action

```
db.users.deleteMany(
   { status: "reject" }
)
```

collection

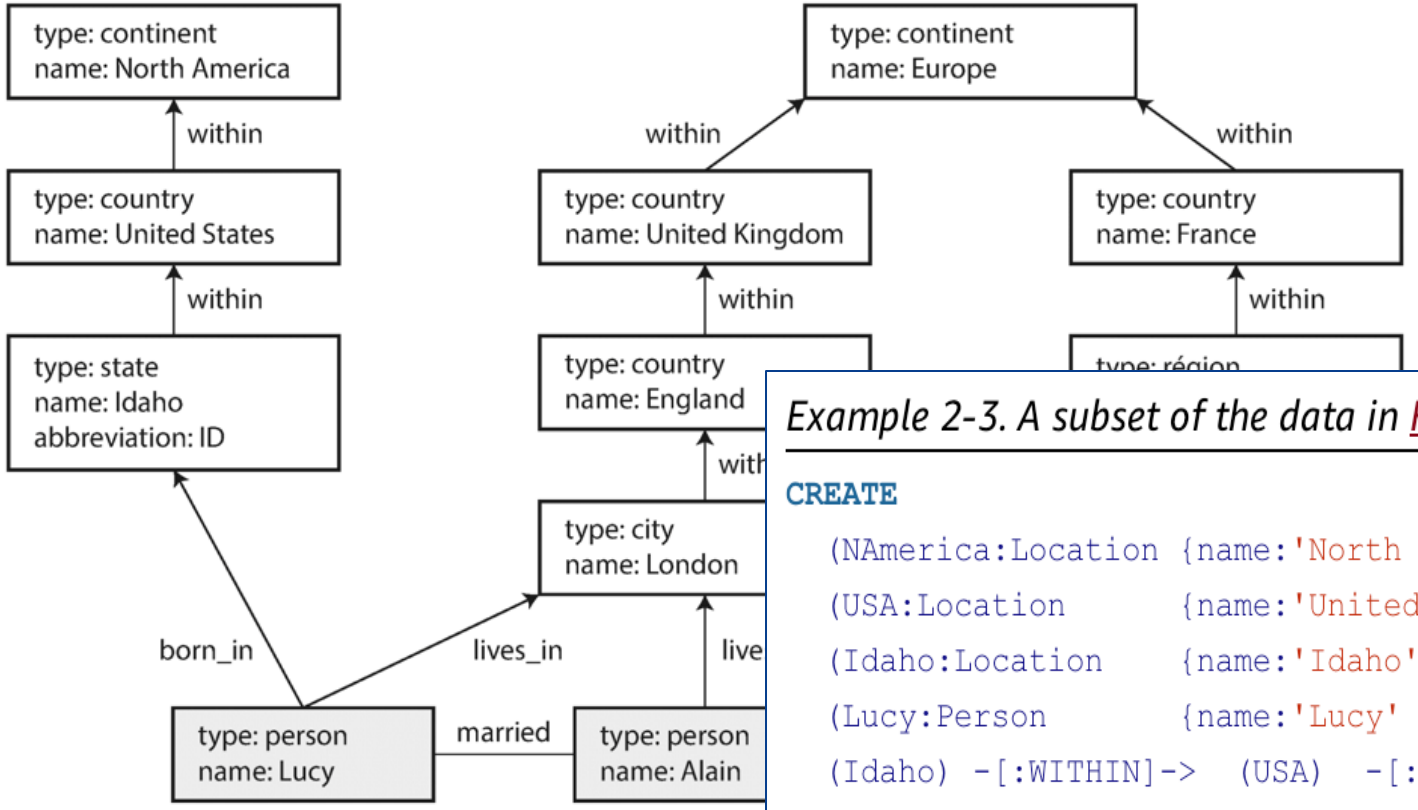
delete filter

https://docs.mongodb.com/manual/crud/

Querying Graph-like Models

Cypher Query - declarative query language for graphs

https://neo4j.com/developer/example-project/

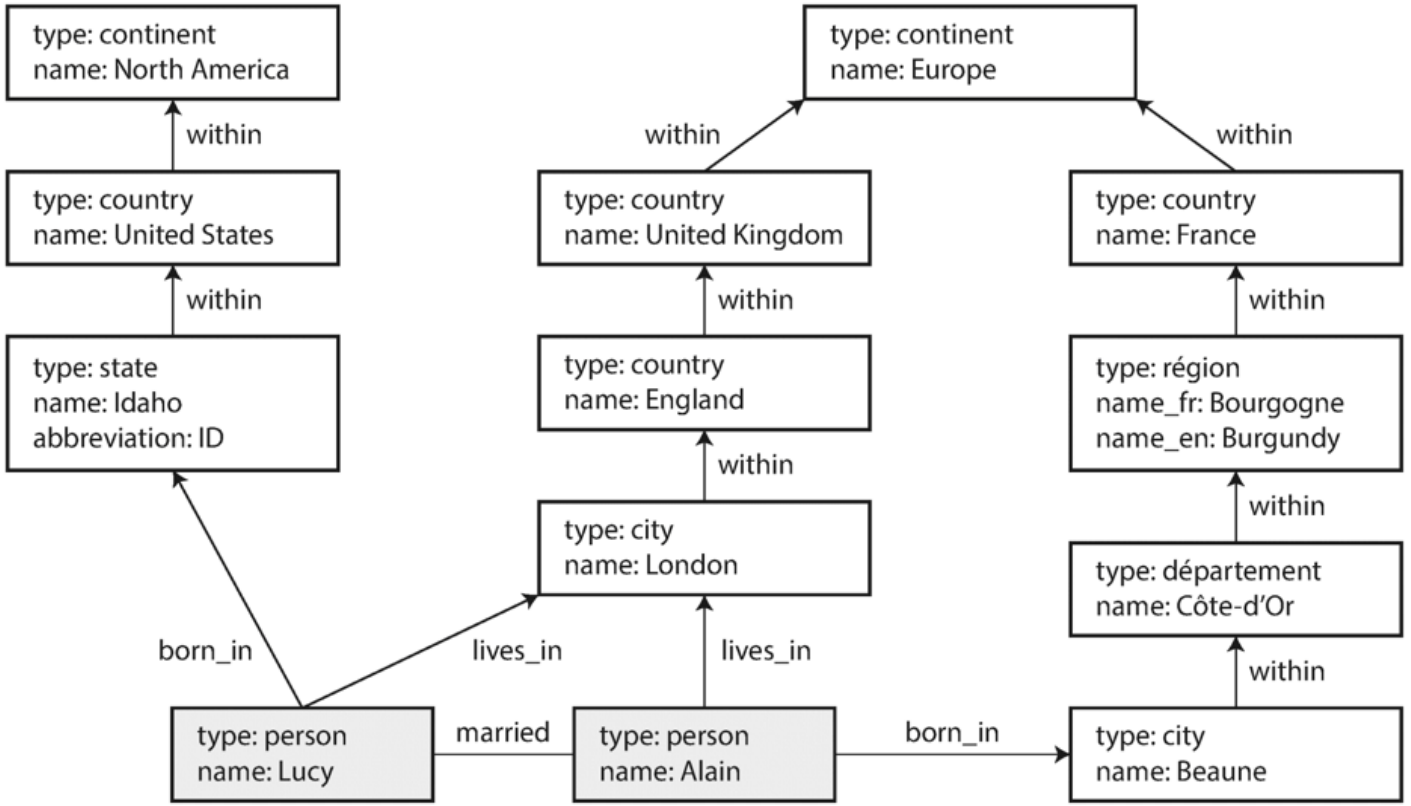


Example 2-3. A subset of the data in Figure 2-5, represented as a Cypher query

```
CREATE
  (NAmerica:Location {name:'North America', type:'continent'}),
  (USA:Location      {name:'United States', type:'country'  }),
  (Idaho:Location    {name:'Idaho',         type:'state'    }),
  (Lucy:Person       {name:'Lucy' }),
  (Idaho) -[:WITHIN]->  (USA)  -[:WITHIN]-> (NAmerica),
  (Lucy)  -[:BORN_IN]-> (Idaho)
```

Example 2-4. Cypher query to find people who emigrated from the US to Europe

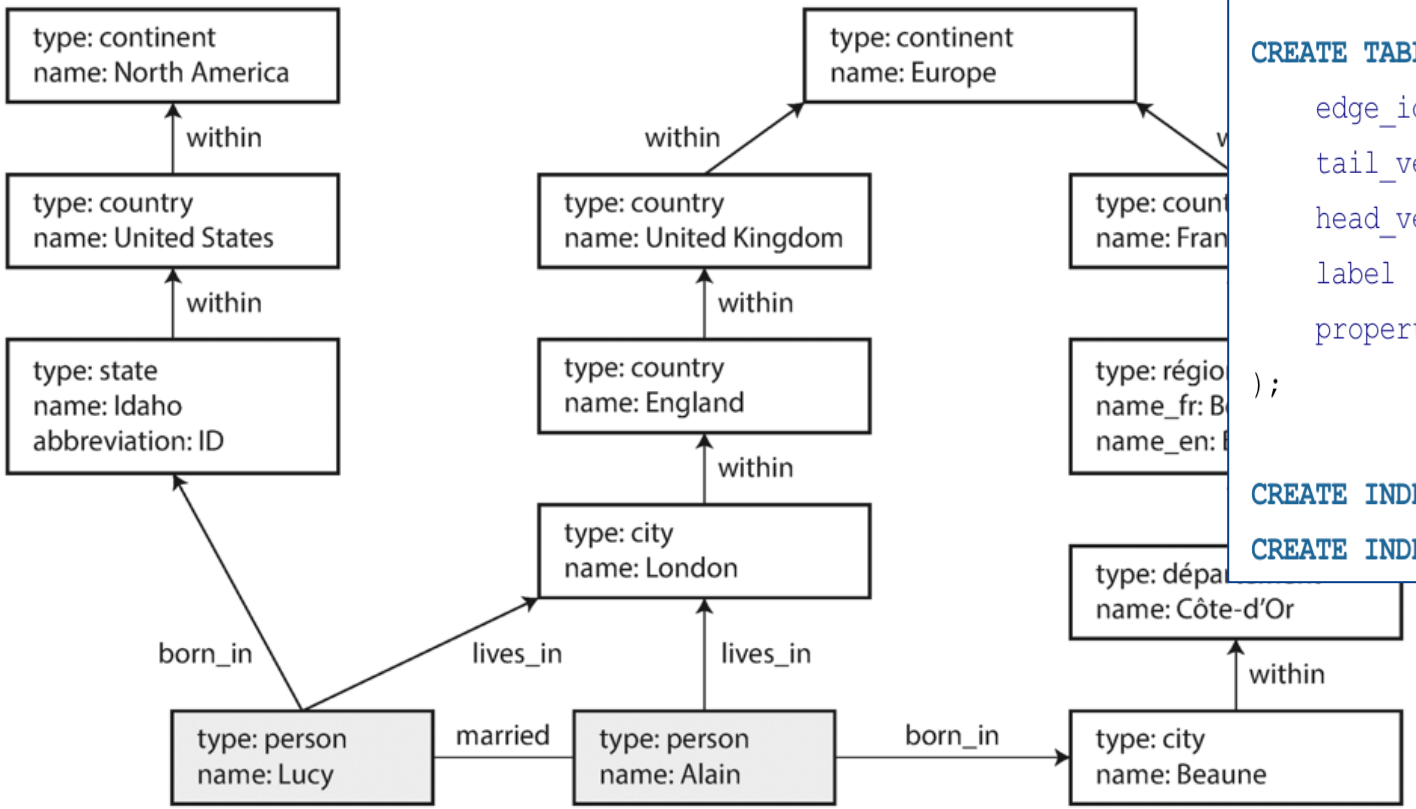
```
MATCH
  (person) -[:BORN_IN]->  () -[:WITHIN*0..]-> (us:Location {name:'United
States'}),
  (person) -[:LIVES_IN]-> () -[:WITHIN*0..]-> (eu:Location
{name:'Europe'})
RETURN person.name
```



"Find the names of all the people who emigrated from the United States to Europe"

"Declarative" language -> the execution details hidden

Doing the same in relational tables and SQL … ??



Example 2-2. Representing a property graph using a relational schema

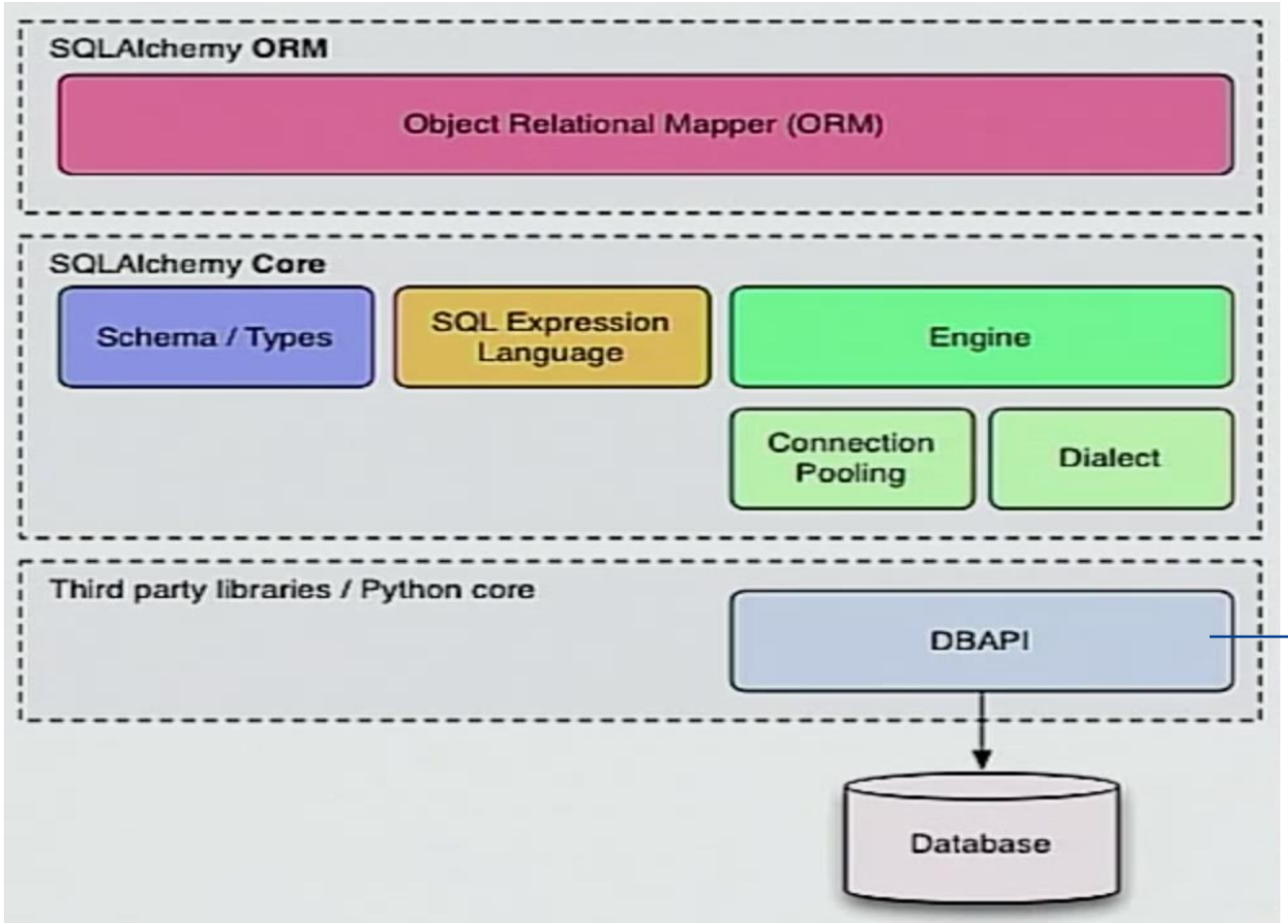
```
CREATE TABLE vertices (
    vertex_id   integer PRIMARY KEY,
    properties  json
);

CREATE TABLE edges (
    edge_id     integer PRIMARY KEY,
    tail_vertex integer REFERENCES vertices (vertex_id),
    head_vertex integer REFERENCES vertices (vertex_id),
    label       text,
    properties  json
);

CREATE INDEX edges_tails ON edges (tail_vertex);
CREATE INDEX edges_heads ON edges (head_vertex);
```

```
WITH RECURSIVE

  -- in_usa is the set of vertex IDs of all locations within
the United States
  in_usa(vertex_id) AS (
      SELECT vertex_id FROM vertices WHERE properties->>'name'
= 'United States' ❶
    UNION
      SELECT edges.tail_vertex FROM edges ❷
        JOIN in_usa ON edges.head_vertex = in_usa.vertex_id
        WHERE edges.label = 'within'
  ),

  -- in_europe is the set of vertex IDs of all locations within
Europe
  in_europe(vertex_id) AS (
      SELECT vertex_id FROM vertices WHERE properties->>'name'
= 'Europe' ❸
    UNION
      SELECT edges.tail_vertex FROM edges
        JOIN in_europe ON edges.head_vertex =
in_europe.vertex_id
        WHERE edges.label = 'within'
  ),

  -- born_in_usa is the set of vertex IDs of all people born in
the US
  born_in_usa(vertex_id) AS ( ❹
    SELECT edges.tail_vertex FROM edges
      JOIN in_usa ON edges.head_vertex = in_usa.vertex_id
      WHERE edges.label = 'born_in'
  ),

  -- lives_in_europe is the set of vertex IDs of all people
living in Europe
  lives_in_europe(vertex_id) AS ( ❺
    SELECT edges.tail_vertex FROM edges
      JOIN in_europe ON edges.head_vertex = in_europe.vertex_id
      WHERE edges.label = 'lives_in'
  )

SELECT vertices.properties->>'name'
FROM vertices
-- join to find those people who were both born in the US *and*
live in Europe
JOIN born_in_usa     ON vertices.vertex_id =
born_in_usa.vertex_id ❻
JOIN lives_in_europe ON vertices.vertex_id =
lives_in_europe.vertex_id;
```

TL;DR

Object Relational Mapping (ORM)

e.g., Python SQLAlchemy ORM



(Optional)

SQL access management libraries"

Python standard/core Low-level database communication layer (many implementations)

- psycopg2 (PostgreSQL)
- cx_oracle (Oracle)
- pyodbc (ODBC)

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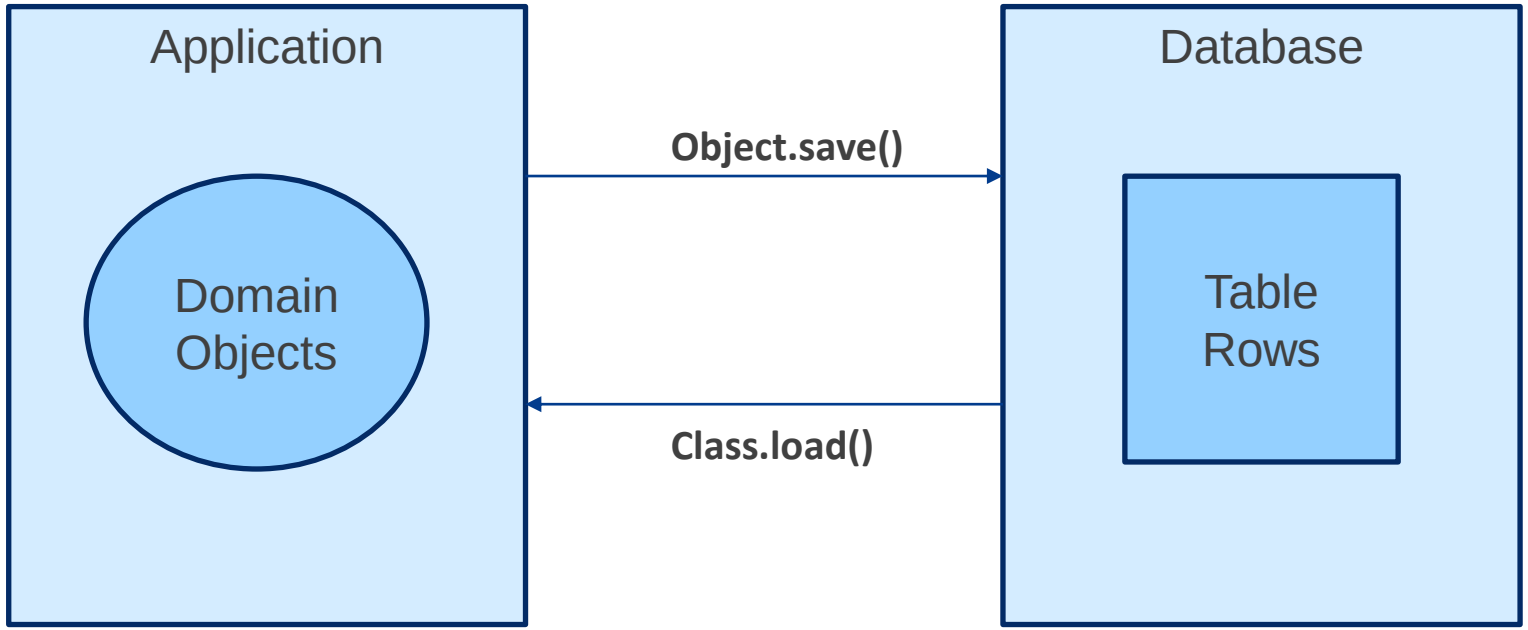
ORM

ORM is the process of associating object oriented classes (your application domain model) with database tables



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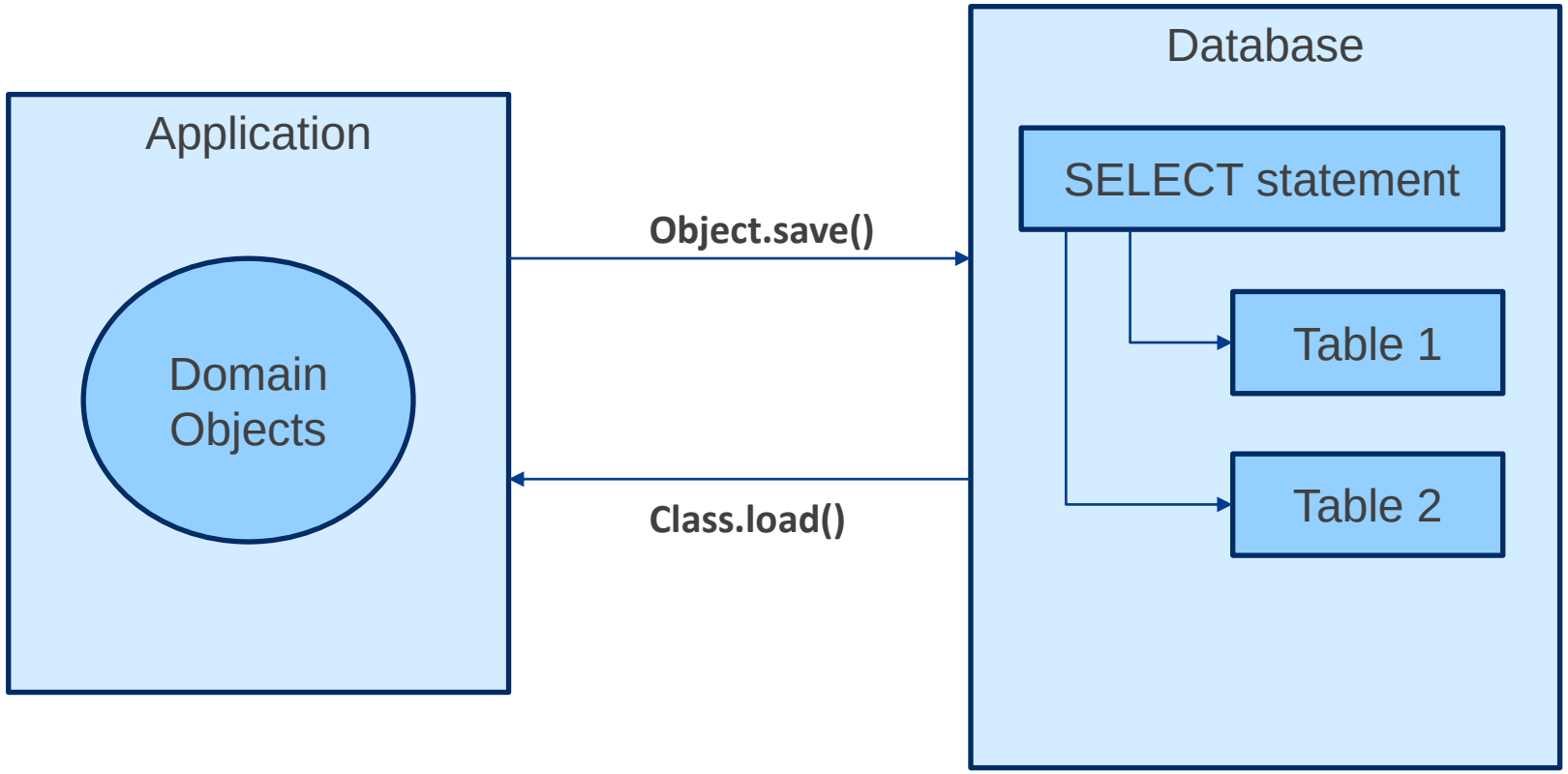
http://techspot.zzzeek.org/category/sqlalchemy/

ORM

Some ORM can represent arbitrary rows as domain objects – e.g., rows derived from SELECT statement joining multiple tables



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http://techspot.zzzeek.org/category/sqlalchemy/

SQLAlchemy ORM

ORM builds on SQLAlchemy Core

In contrast to the SQL Expression Language which presents schema-centric view of the data, ORM provides domain-model centric view of the data

```
>>> from salalchemy import Column, Integer, String

>>> class User(Base):
...     __tablename__ = 'user'

...     id = Column(Integer, primary_key=True)
...     name = Column(String)
...     fullname = Column(String)

...     def __repr__(self):
...         return "<User(%r, %r)>" % (
...                     self.name, self.fullname
...                 )

>>>
```

After this, User class now has an associated Table called ‘user’

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Managing and Publishing Metadata

Metadata, what is it?

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Managing and Publishing Metadata

Nearly every device we use relies on metadata or generates it …

Edward Snowden – a contractor at United States National Security Agency exposed how the agency collected metadata on telephone calls directly from telecommunications companies (note: only metadata, not the actual conversations)

But how much information could be inferred about individuals from only metadata ?

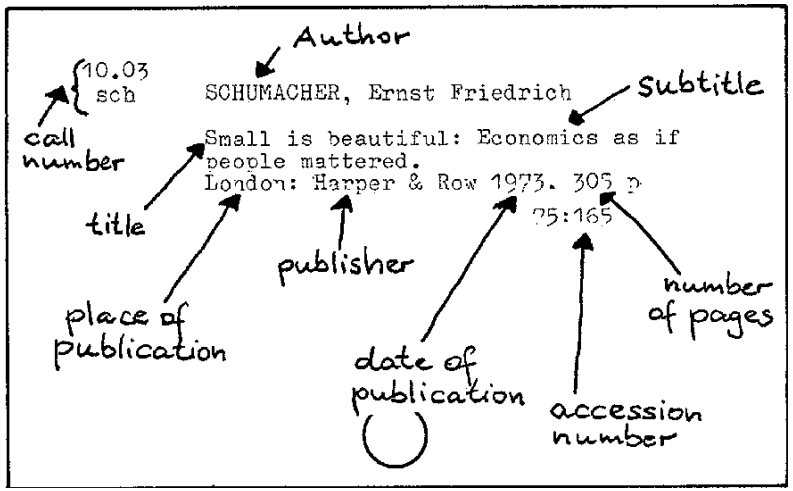
Possible metadata collected about a phone call:

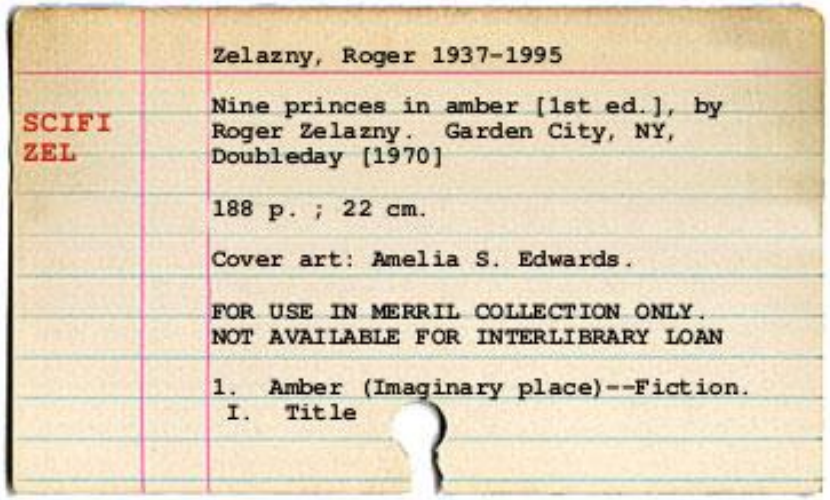
- Phone numbers (caller, recipient)
- Time and duration of the call
- Mobile phone locations (caller, recipient)
  - If mobile phone is in connection with local cell towers, a record of your location at any given moment …

Metadata is becoming as important as the data itself. Naturally, data services APIs should be aware of metadata and know how to publish and consume metadata along with the data.

Managing and Publishing Metadata

Librarians have been working with metadata for centuries …





In the end, they are data – which can be modelled, stored and managed now …

Title	Author	Date of publication	Subject	Call number	Pages
Intellectual Pro-	Palfrey,	2012	Intellectual proper-	HD53 .P35	172

Managing and Publishing Metadata

Why do we need metadata when we have data object itself?

- Metadata is a “map”, is a means by which the complexity of an object is represented in a simpler form
  - A roomful of books is not called a library, books + catalog is. The catalog provides a simplified representation of the materials in the library collection.
  - Primarily, metadata helps with ‘resource discovery’ – the process by which information resources that might be relevant to your need is identified.

Descriptive metadata: description of an object

Administrative metadata: information about the origin and maintenance of an object

e.g., a photograph digitized using a specific type of scanner at a particular resolution, with some restrictions on copyright, etc.

Structural metadata: information about how an object is organised (e.g., ToC)

Provenance metadata: traces/processes involved in producing the object.

Describing Description …

Metadata is a statement about a potentially informative “thing” (resource).

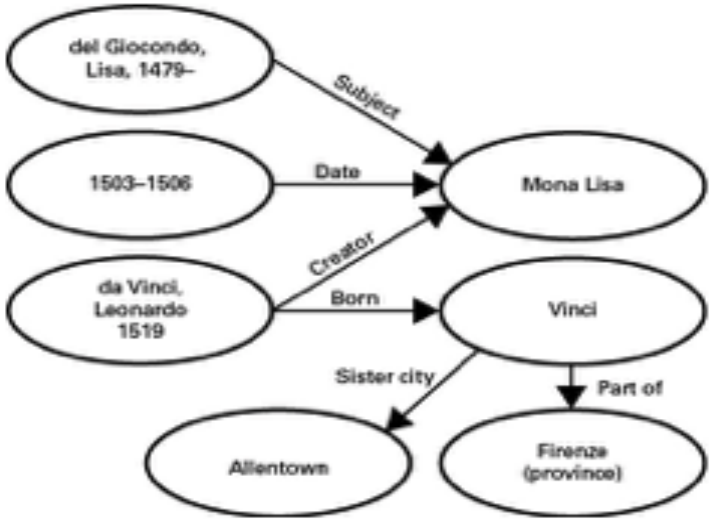
A well adopted metadata description language is RDF (resource description framework)

Subject: Mona Lisa **Predicate: Creator** **Object: Da Vinci**

Subject refers to the ‘entity’ being described

Object refers to another entity being used to describe the subject …

RDF Triples – could be a useful data model just by itself … (graphs -> network analysis -> gets interesting …!!)



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https://www.w3.org/TR/rdf11-primer/

Descriptive Metadata

Element	Definition
Contributor	An entity responsible for making contributions to the resource.
Coverage	The spatial or temporal topic of the resource, the spatial applicability of the resource, or the jurisdiction under which the resource is relevant.
Creator	An entity primarily responsible for making the resource.
Date	A point or period of time associated with an event in the lifecycle of the resource.
Description	An account of the resource.
Format	The file format, physical medium, or dimensions of the resource.
Identifier	An unambiguous reference to the resource within a given context.
Language	A language of the resource.
Publisher	An entity responsible for making the resource available.
Relation	A related resource.
Rights	Information about rights held in and over the resource.
Source	A related resource from which the described resource is derived.
Subject	The topic of the resource.
Title	A name given to the resource.
Type	The nature or genre of the resource.

Standard, the simplest form of metadata: **Dublin Core**

Originally developed to help improve the search engine and indexing the web documents

Title: Mona Lisa

Title: La Gioconda

Creator: Leonardo da Vinci

Subject: Lisa Gherardini

Date: 1503–1506

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Pomerantz, Jeffrey. Metadata (The MIT Press Essential Knowledge series)

RDF Example (with Dublin Core)

https://www.w3schools.com/xml/xml_rdf.asp

Useful Resources

- Video By Martin Fowler about NoSQL Databases (https://www.youtube.com/watch?v=8kotnF6hfd8#t26m)
- Comparison between MongoDB and Postgres (https://www.mongodb.com/compare/mongodb-postgresql)

Questions?