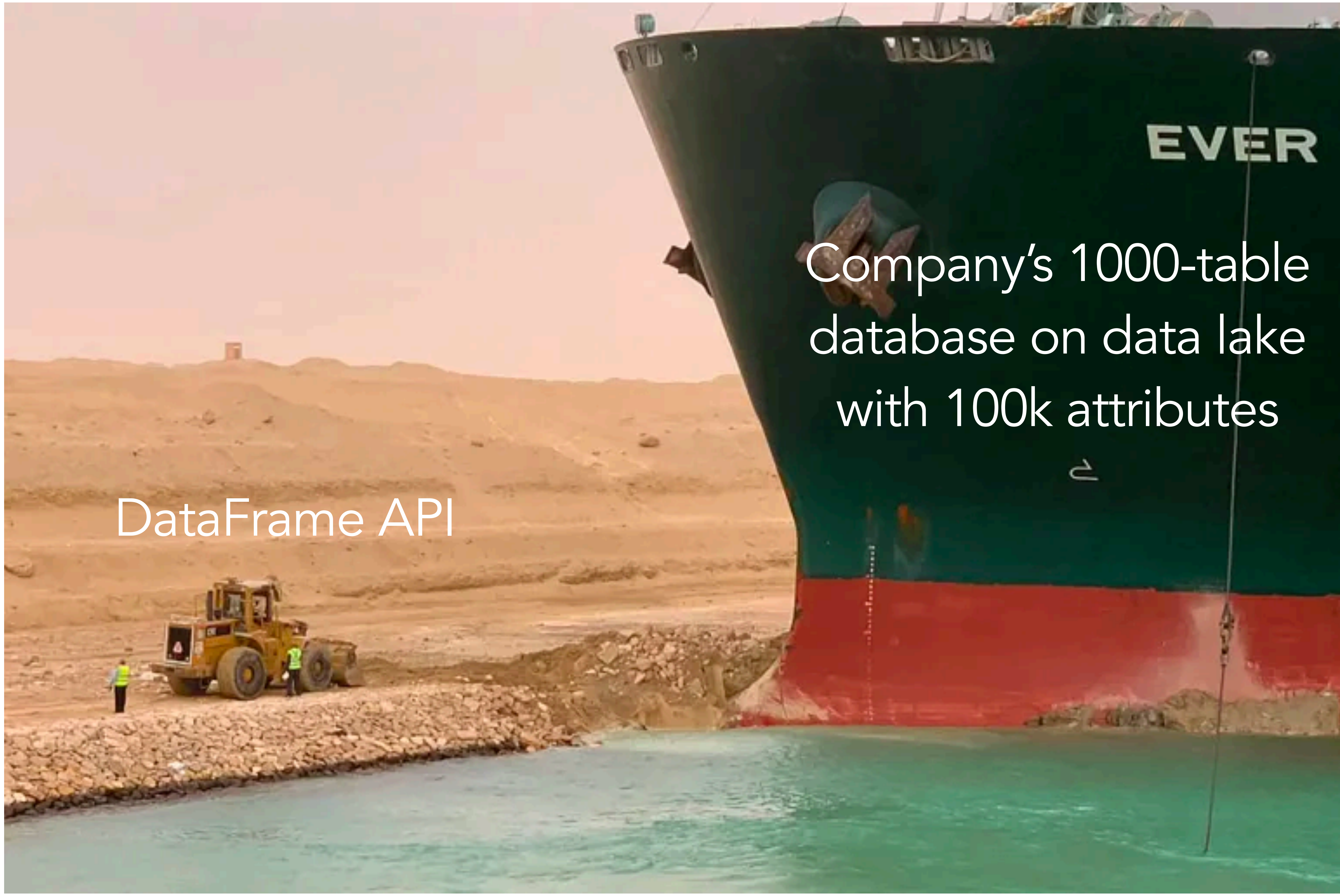
DSC 204a Scalable Data Systems

- Haojian Jin



Meme idea credit: https://datasystemsfun.tumblr.com/

Where are we in the class?

Foundations of Data Systems (2 weeks)

- Digital representation of Data → Computer Organization → Memory hierarchy → Process → Storage

Scaling Distributed Systems (3 weeks)

- Cloud → Network → Distributed storage → Parallelism → Partition and replication

Data Processing and Programming model (5 weeks)

- **Data Models evolution** → Data encoding evolution → IO & Unix Pipes → Batch processing (MapReduce) → Stream processing (Spark)

Today’s topic: Data Model Evolutions & Query language

- Overview
- PIA (Distributed systems review)

PA2

- Overview
    - PA.
        - PA0: Memory hierarchy (Dask).
        - PA1: Parallelism (Dask).
        - PA2: Data processing (Spark).
    - Lectures:
        - Foundations of DataSys (Data, Network, OS)
        - Scaling Distributed systems
        - Programming Interfaces

Plan in the next few weeks

- Data models & query language
  - relational model
  - document model
  - graph model
- Encoding & Evolution
  - Json, XML, Protobuf
- Data Flow
  - REST and RPC
  - Message-passing data flow

Plan in the next few weeks

- Batch processing
  - Unix pipes
  - MapReduce
- Stream processing
  - Spark
- Emerging topics

Today’s topic: Data Model Evolutions & Query language

- Object-relational mismatch
- ID v.s. Strings
- Many-to-many v.s. one-to-many
- Hierarchical/network/relational model
- Query languages

Overview

- Data models:
  - not only on how the **software is written**, but also on how **we (human)** think about the problem that we are solving.
- Most applications are built by layering one data model on top of another.
- For each layer, the key question is:
  - how is it represented in terms of the next-lower layer?
  - each layer hides the complexity of the layers below it by providing a clean data model.

Overview

- General-purpose data models for data storage and querying
    - Relational DB: IBM DB2, MS SQL Server, PostgreSQL
    - Document DB: MongoDB, RethinkDB, CouchDB, Espresso
    - Graph-based DB: Neo4j, Titan, InfiniteGraph

Relational Model

- Data is organized into relations (called tables in SQL), where each relation is an unordered collection of tuples (rows in SQL).
- The goal of the relational model was to hide that implementation detail behind a cleaner interface.
- Optimization opportunities => Better performance!

The Birth of NoSQL (Not Only SQL | Document Model)

- A need for **greater scalability** than relational databases can easily achieve, including very large datasets or very high write throughput
- A widespread preference for **free and open source** software over commercial database products
- **Specialized query operations** that are not well supported by the relational model
- Frustration with the restrictiveness of relational schemas, and a desire for a more **dynamic and expressive** data model

Relational Model Versus Document Model

Polyglot persistence: It therefore seems likely that in the foreseeable future, relational databases will continue to be used alongside a broad variety of nonrelational datastores

The Object-relational Mismatch

- If data is stored in relational tables, **an awkward translation layer** is required between the objects in the application code and the database model of tables, rows, and columns.
- The disconnect between the models is sometimes called an **impedance mismatch**.

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 reader. Avid traveler. Active blogger.

Experience

Co-chair • Bill & Melinda Gates Foundation
2000 – Present

Co-founder, Chairman • Microsoft
1975 – Present

Education

Harvard University
1973 – 1975

Lakeside School, Seattle

Contact Info

Blog: thegatesnotes.com
Twitter: @BillGates

users table

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

The Object-relational Mismatch

- Traditional SQL model (prior to SQL:1999): the most common normalized representation is to put positions, education, and contact information in separate tables, with a **foreign key reference** to the users table.
- Later versions of the SQL standard added support for **structured datatypes and XML data**; this allowed multi-valued data to be stored within a single row, with support for querying and indexing inside those documents.
- A third option is to encode jobs, education, and contact info as a **JSON or XML document**, store it on a text column in the database, and let the application interpret its structure and content.

```json
{
  "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"
  }
}
```

Locality

- The JSON representation has better locality than the multi-table schema.
- If you want to fetch a profile in the relational example, you need to either perform multiple queries or perform a messy multiway join between the users table and its subordinate tables.
- In the JSON representation, all the relevant information is in one place, and one query is sufficient.

Today’s topic: Data Model Evolutions & Query language

- Object-relational mismatch
- ID v.s. Strings
- Many-to-many v.s. one-to-many
- Hierarchical/network/relational model
- Query languages

plain-text vs standardized lists for region/industrial

```
{
  "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},
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  ],
  "contact_info": {
    "blog":    "http://thegatesnotes.com",
    "twitter": "http://twitter.com/BillGates"
  }
}
```

Standardized lists for region/industrial vs plain-text

+ Consistent style and spelling across profiles
+ Avoiding ambiguity (e.g., if there are several cities with the same name)
+ Ease of updating — the name is stored in only one place, so it is easy to update across the board if it ever needs to be changed (e.g., change of a city name due to political events)
+ Localization support — when the site is translated into other languages, the standardized lists can be localized, so the region and industry can be displayed in the viewer's language
+ Better search — e.g., a search for philanthropists in the state of Washington can match this profile, because the list of regions can encode the fact that Seattle is in Washington (which is not apparent from the string "Greater Seattle Area")

Standardized lists for region/industrial vs plain-text

+ When you store the text directly, you are duplicating the human-meaningful information in every record that uses it.
+ The advantage of using an ID is that because it has no meaning to humans, it never needs to change
+ Removing such duplication is the key idea behind **normalization** in databases.

- More complex data model
- Hard to debug
  - A small project?
  - Normalization v.s. Denormalization?

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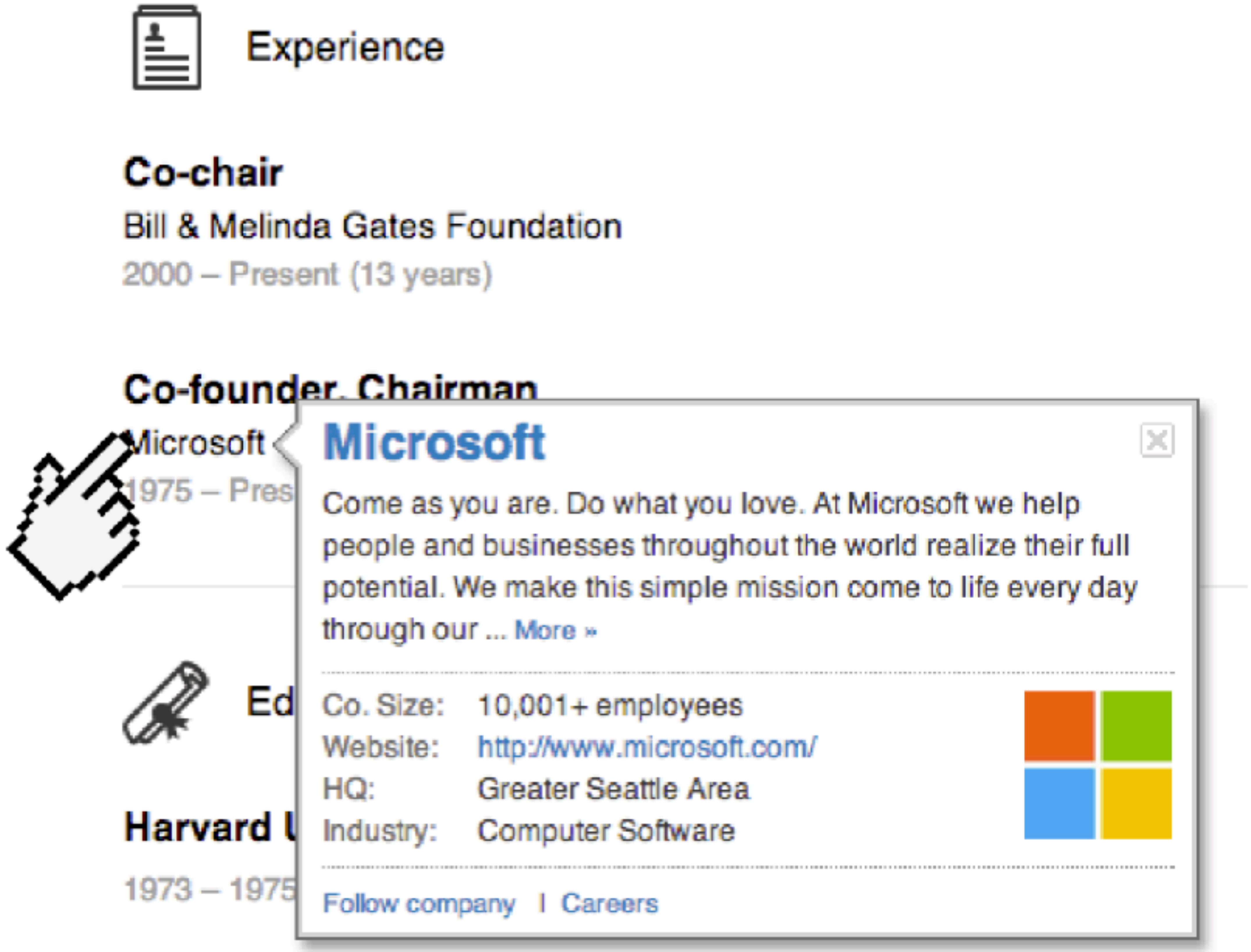
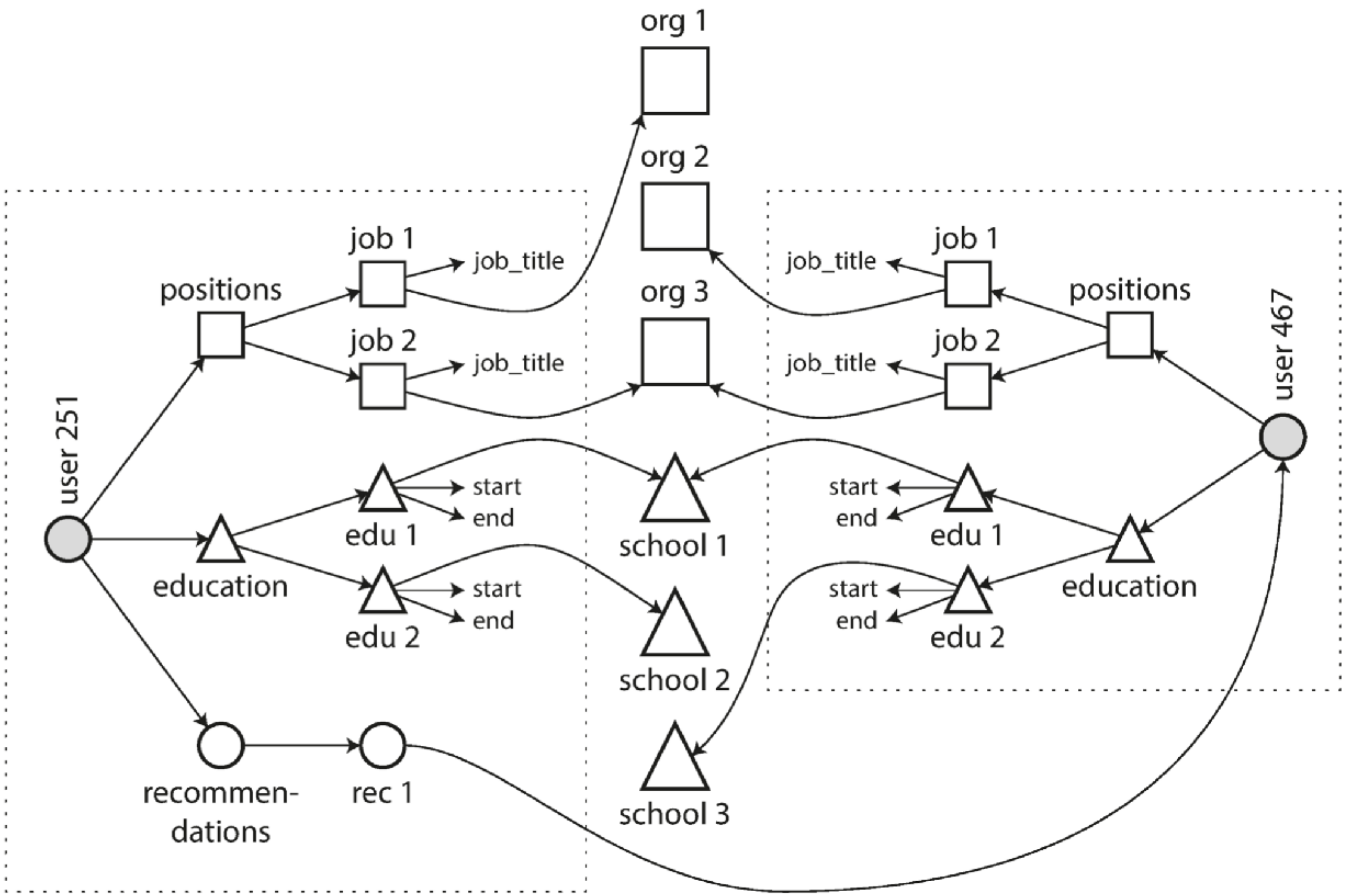
- Query languages

Many-to-one and Many-to-Many Relationships





The data within each dotted rectangle can be grouped into one document, but the references to organizations, schools, and other users need to be represented as references, and require joins when queried.

Many-to-one and Many-to-Many Relationships

- Normalizing this data requires many-to-one relationships, which don't fit nicely into the document model.
- Organizations and schools as entities: In the previous description, organization (the company where the user worked) and school_name (where they studied) are just strings. Perhaps they should be references to entities instead?
- Recommendations: one user can write a recommendation for another user. The recommendation is shown on the résumé of the user who was recommended, together with the name and photo of the user making the recommendation. If the recommender updates their photo, any recommendations they have written need to reflect the new photo.

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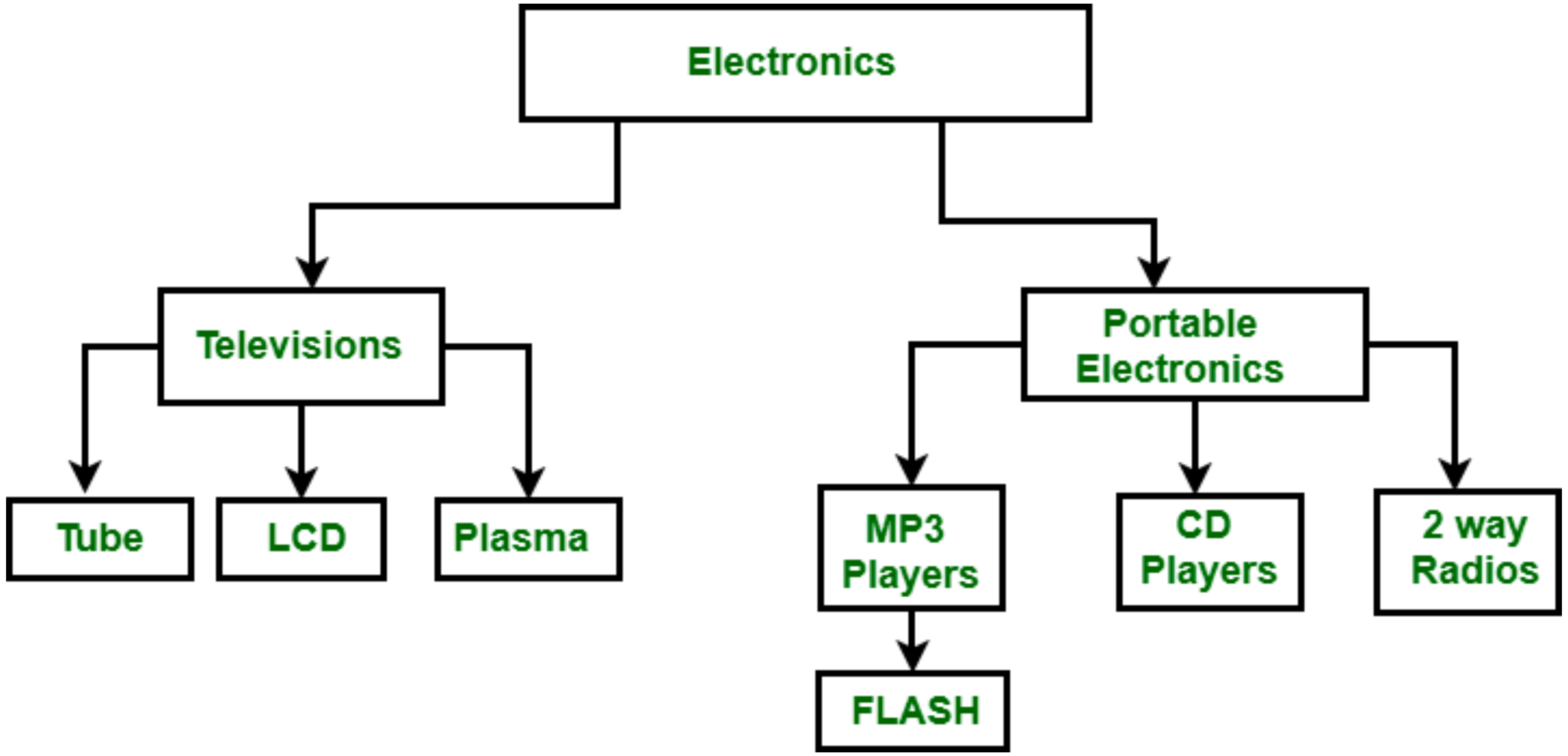
- Hierarchical/network/relational data model
- Declarative | imperative query languages

Are Document Databases Repeating History?

While **many-to-many relationships** and **joins** are routinely used in relational databases, document databases and NoSQL reopened the debate on how best to represent such relationships in a database.

Hierarchical data model



- every record has exactly one parent
- Worked well for one-to-many relationships
- Hard for many-to-many relationships
- Not support join.

Network Model

- A record could have multiple parents.
- The links between records in the network model were not foreign keys, but more like pointers in a programming language.
- The only way of accessing a record was to follow a path from a root record along these chains of links. This was called an **access path**.
- Good for limited hardware capabilities in the 1970.
- Querying and updating are complicated and inflexible.
  - A side effect to too much freedom.

The Relational Model

- Lay out all the data in the open: a relation (table) is simply a collection of tuples (rows).
- The query optimizer automatically decides which parts of the query to execute in which order, and which indexes to use.
- If you want to query your data in new ways, you can just declare a new index, and queries will automatically use whichever indexes are most appropriate.
- The relational model thus made it much easier to add new features to applications.
- You only need to build a query optimizer once, and then all applications that use the database can benefit from it.

Relationships

- **One to many: e.g., Positions, education, contact_info.**
  - Document databases ~ the hierarchical model: storing nested records.
- **Many to many: e.g., Organizations**
- **Many to one: e.g., five students are finishing one project.**
  - The related item is referenced by a unique identifier, which is called **a foreign key** in the relational model and **a document reference** in the document model. That identifier is resolved at read time by using **a join** or **follow-up queries**.

Which data model leads to simpler application code?

- If the data in your application has a document-like structure -> good idea to use a document model.
    - A tree of one-to-many relationships.
    - Entire tree needs to read at once.
    - Partitioning (shredding) has a cost => can lead to cumbersome schemas.
- Limitation:
    - Cannot refer directly to a nested item (However, as long as documents are not too deeply nested, that is not usually a problem.)
    - The poor support for joins in document databases (depending on the application)
    - many-to-many relationships

Schema flexibility in the document model

Most document databases, and the JSON support in relational databases, do not enforce any schema on the data in documents.

Schema-on-read (Document) is similar to dynamic (runtime) type checking in programming languages.

```
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];
}
```

Schema flexibility in the document model

Schema-on-write (Relational) is similar to static (compile-time) type checking.

Schema changes have a bad reputation of being slow and requiring downtime. => Not that bad.

Set to its default of NULL and fill it in at read time, like it would with a document database.

```sql
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
```

Data locality for queries

- If your application often needs to access the entire document, there is a performance advantage to this **storage locality**. The idea of grouping related data together for locality is not limited to the document model.

Convergence of document and relational databases

- It seems that relational and document databases are becoming more similar over time, and that is a good thing: the data models complement each other.
- A hybrid of the relational and document models is a good route for databases to take in the future.

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- Declarative | imperative query languages

Query Languages for Data

- An **imperative** language tells the computer to perform certain operations in a certain order.
- In a **declarative** query language, like SQL or relational algebra, you just specify the pattern of the data you want—what conditions the results must meet, and how you want the data to be transformed —but not **how** to achieve that goal.
- SQL is a **declarative** query language, whereas IMS and CODASYL queried the database using **imperative** code.

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;
}
```

- declarative

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

- imperative

More examples

```html
<ul>
    <li class="selected"> ❶
        <p>Sharks</p> ❷
        <ul>
            <li>Great White Shark</li>
            <li>Tiger Shark</li>
            <li>Hammerhead Shark</li>
        </ul>
    </li>
    <li>
        <p>Whales</p>
        <ul>
            <li>Blue Whale</li>
            <li>Humpback Whale</li>
            <li>Fin Whale</li>
        </ul>
    </li>
</ul>
```

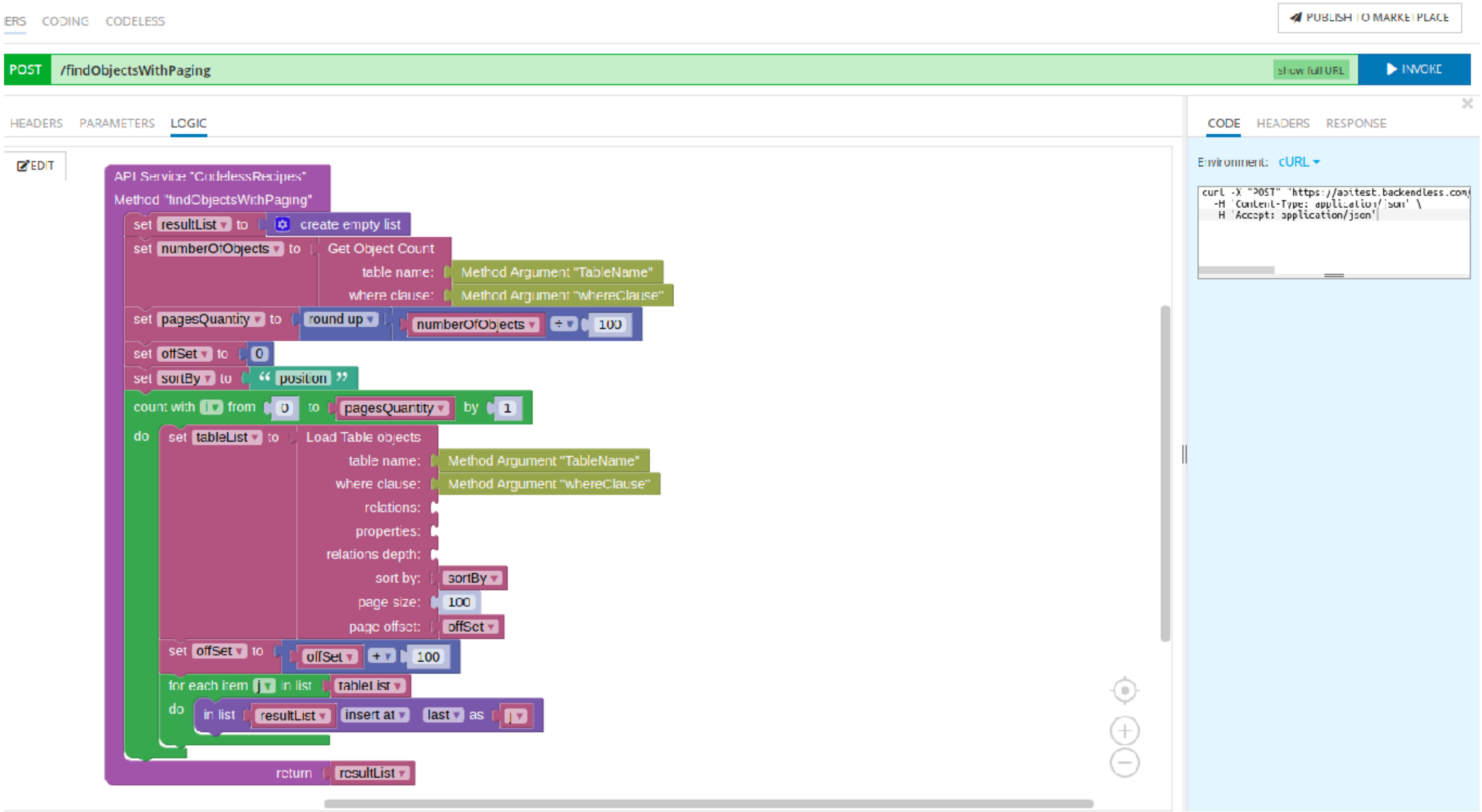
```css
li.selected > p {
    background-color: blue;
}
```

```javascript
var liElements = document.getElementsByTagName("li");
for (var i = 0; i < liElements.length; i++) {
    if (liElements[i].className === "selected") {
        var children = liElements[i].childNodes;
        for (var j = 0; j < children.length; j++) {
            var child = children[j];
            if (child.nodeType === Node.ELEMENT_NODE && child.tagName === "P") {
                child.setAttribute("style", "background-color: blue");
            }
        }
    }
}
```

Tradeoffs

- Declarative
  - More concise, easier to maintain
  - Performance optimization, parallel execution
  - Simple APIs, Hide low-level details
  - Hard to debug, limited degree of freedom
- Imperative
  - Easier to debug
  - More degree of freedom
  - Require more expertises

Future directions: Codeless



Future directions: ChatGPT

DA

Generate an sql query to exact the sum of sales in a standard employee table

Sure! To extract the sum of sales from a standard employee table, you would need to know the specific structure of your table, including the column names. However, I can provide you with a generic example based on common column names. Let's assume you have an "employees" table with columns such as "employee_id" and "sales_amount". You can use the following SQL query to calculate the sum of sales:

sql Copy code

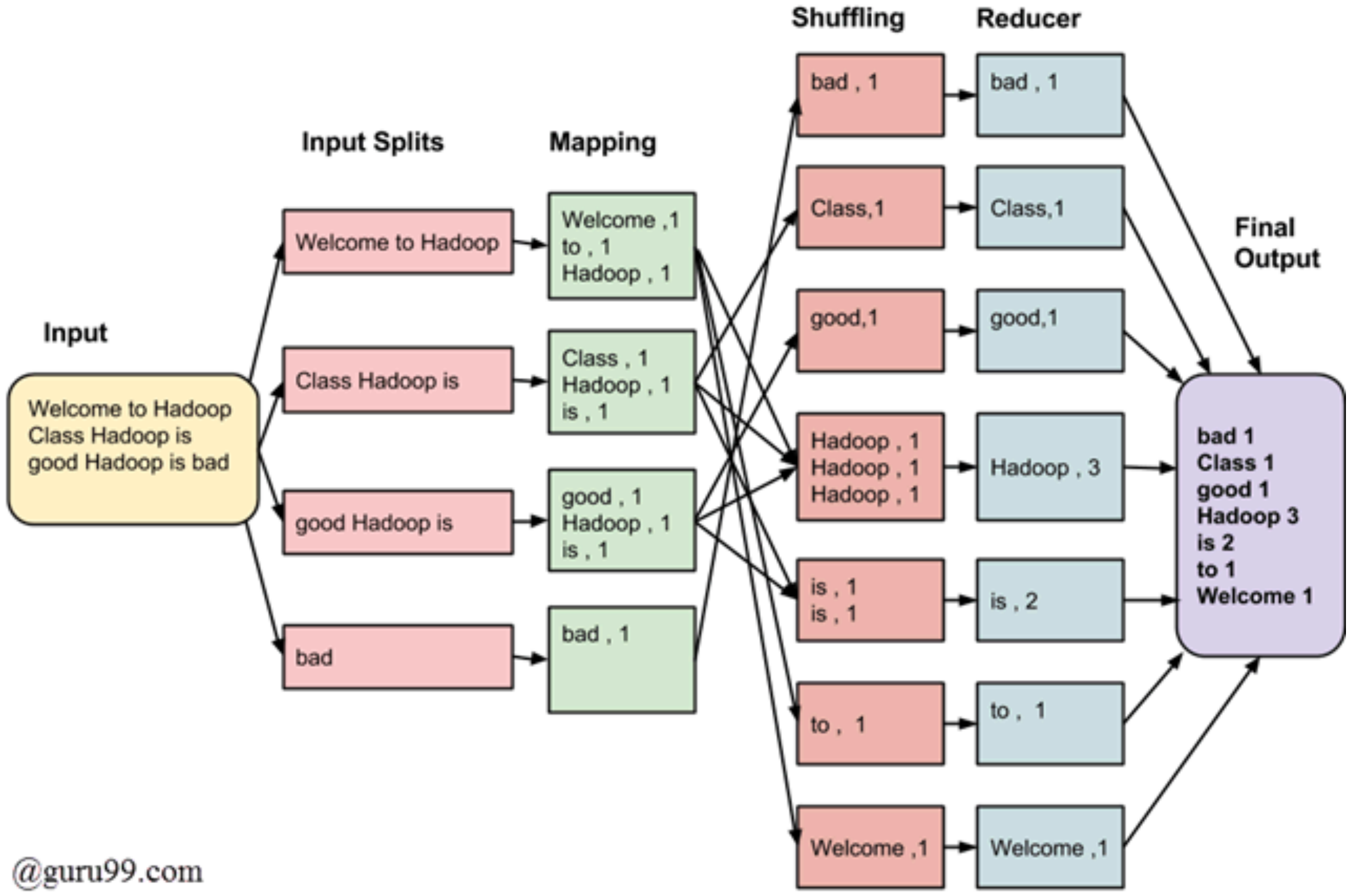
```sql
SELECT SUM(sales_amount) AS total_sales
FROM employees;
```

In this query, the `SUM()` function is used to add up the values in the "sales_amount" column for all rows in the "employees" table. The result will be returned as "total_sales" in the query output.

Remember to replace "employees" with the actual name of your table, and "sales_amount" with the correct column name in your table that holds the sales data.

Query Languages for Data: MapReduce Querying

```
db.observations.mapReduce(
    function map() { ❷
        var year  = this.observationTimestamp.getFullYear();
        var month = this.observationTimestamp.getMonth() + 1;
        emit(year + "-" + month, this.numAnimals); ❸
    },
    function reduce(key, values) { ❹
        return Array.sum(values); ❺
    },
    {
        query: { family: "Sharks" }, ❶
        out: "monthlySharkReport" ❻
    }
);
```



Query Languages for Data: MapReduce Querying

- **MapReduce** is a programming model for processing large amounts of data in bulk across many machines, popularized by Google.
- MapReduce is neither a declarative query language nor a fully imperative query API, but somewhere in between

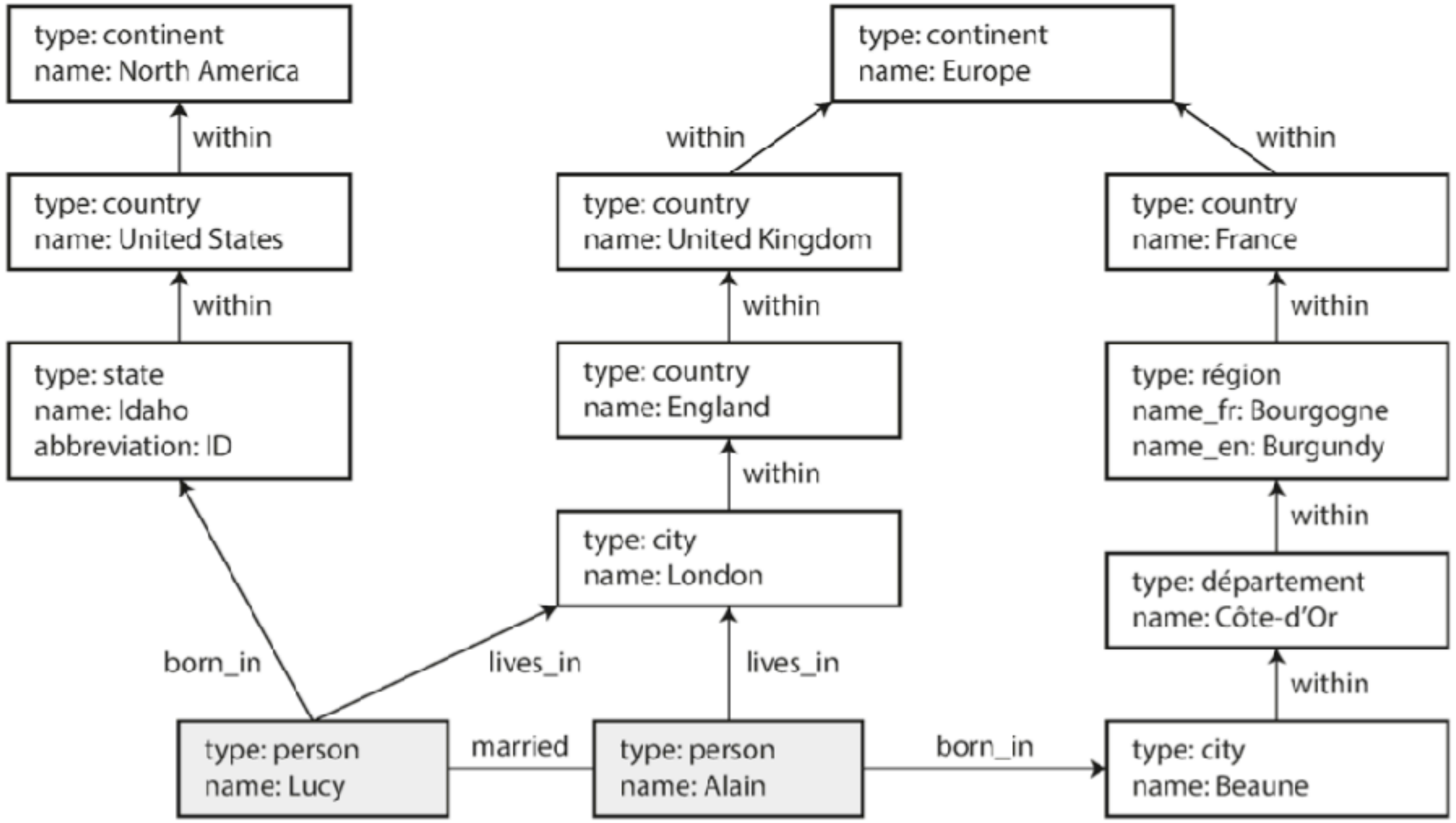
```
db.observations.mapReduce(
    function map() { ❷
        var year  = this.observationTimestamp.getFullYear();
        var month = this.observationTimestamp.getMonth() + 1;
        emit(year + "-" + month, this.numAnimals); ❸
    },
    function reduce(key, values) { ❹
        return Array.sum(values); ❺
    },
    {
        query: { family: "Sharks" }, ❶
        out: "monthlySharkReport" ❻
    }
);
```

Graph-Like Data Models

- If your application has mostly one-to-many relationships or no relationships between records, the document model is appropriate.
- A graph consists of two kinds of objects: **vertices** and **edges**.
- Social graphs: Vertices are people, and 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 or railway lines between them.

Graph-structured data

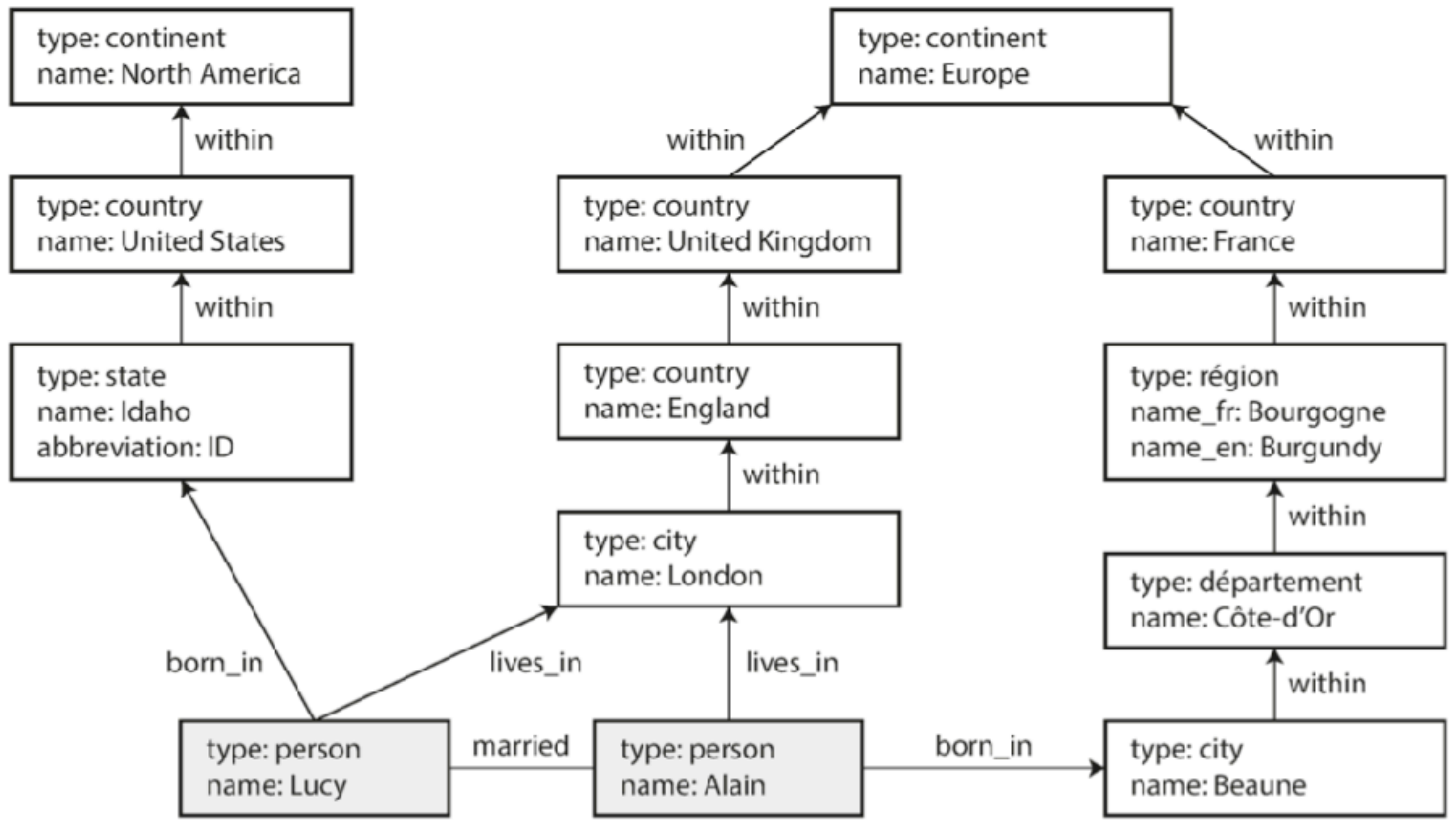
- Many graph-like algorithms
- Different types of query languages
- Imperative and declarative
- Will discuss more later.



Graph-Like Data Models: Property Graphs

Each vertex consists of:

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



Each edge consists of:

- A unique identifier
- The vertex at which the edge starts (the tail vertex)
- The vertex at which the edge ends (the head vertex)
- A label to describe the kind of relationship between the two vertices
- A collection of properties (key-value pairs)

Property Graphs

- Think of it as two tables: one for vertices and one for edges.
- Any vertex can have an edge connecting it with any other vertex. There is **no schema** that restricts which kinds of things can or cannot be associated.
- Given any vertex, you can efficiently find both its incoming and its outgoing edges, and thus **traverse** the graph—i.e., follow a path through a chain of vertices —both forward and backward.
- By using **different labels** for different kinds of relationships, you can store several different kinds of information in a single graph, while still maintaining a clean data model.

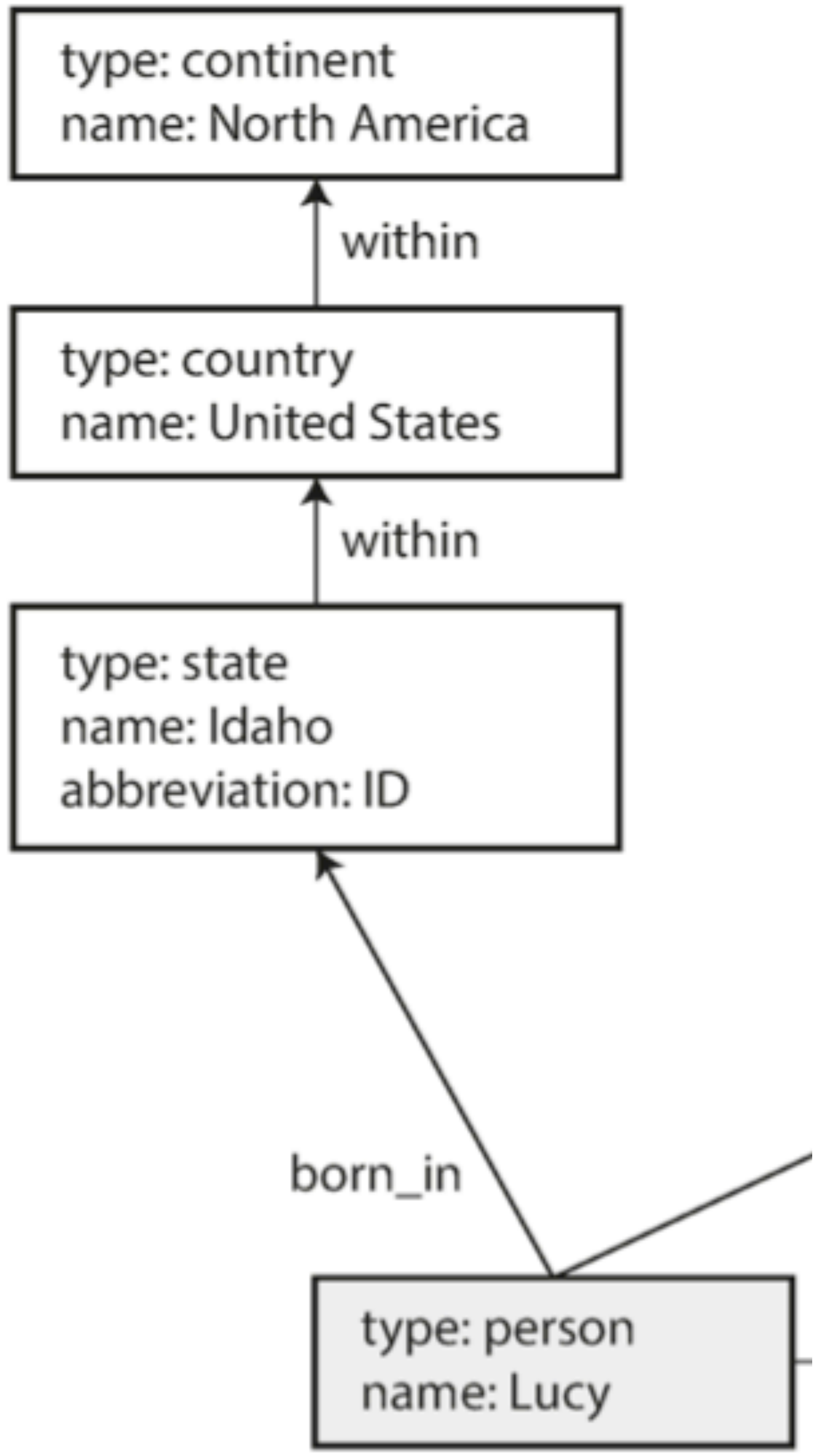
Property Graphs

- Flexibility for data modeling
  - US (Counties, States), France (departments, regions), .. (Province)
  - Compare it with the document model and relational model?
- Extensibility
  - Add new properties
  - Add new types of facts

The Cypher Query Language (Neo4j)

Cypher is a declarative query language for property graphs, created for the graph database.

```
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)
```



The Cypher Query Language

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
```

- Multiple ways to execute the query.
  - Person first.
  - Location first.
  - Edge first.

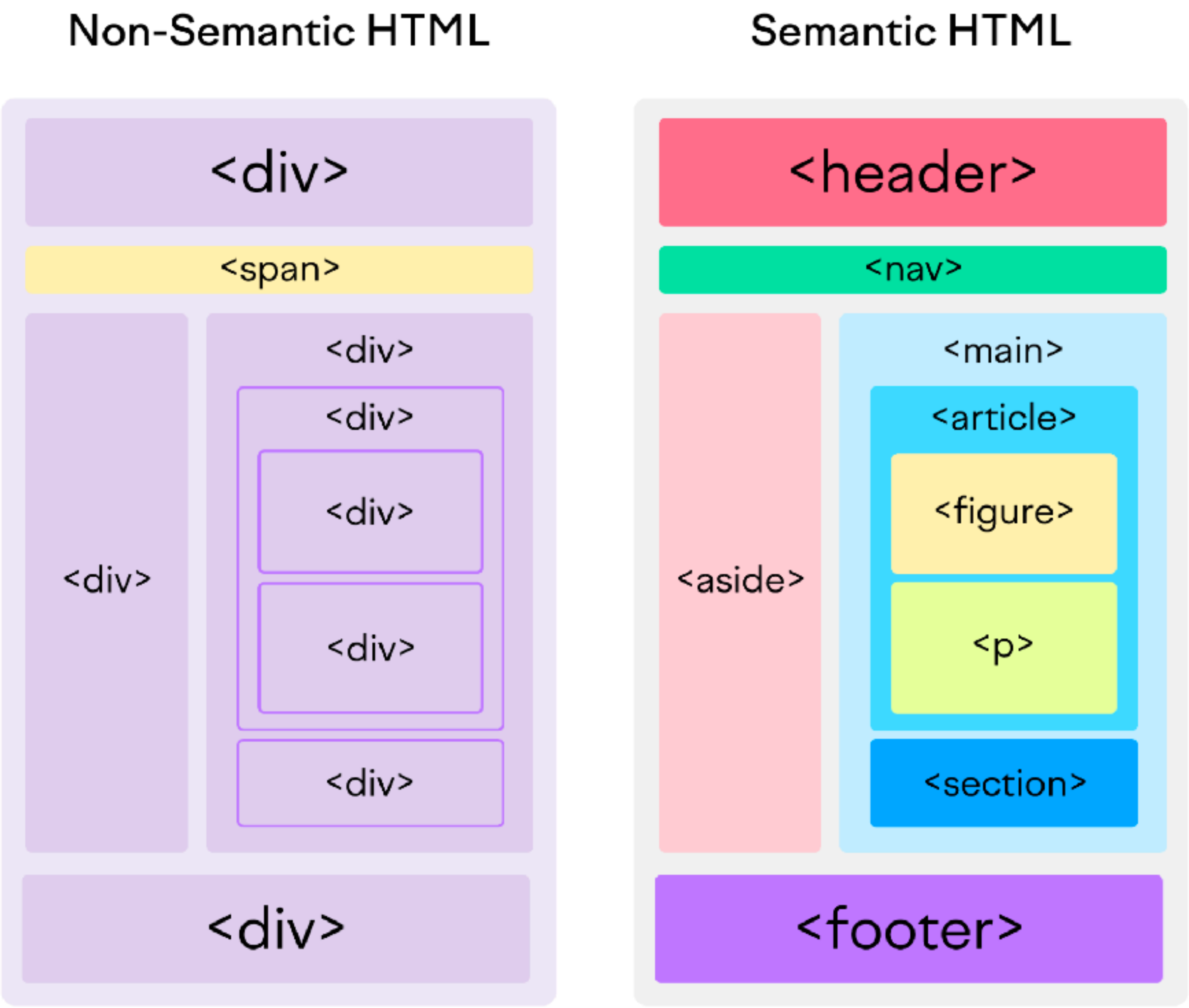
Triple-Stores and SPARQL

- triple-store model = property graph model
- In a triple-store, all information is stored in the form of very simple three-part statements: (**subject**, **predicate**, **object**). The subject of a triple is equivalent to a vertex in a graph.

```
@prefix : <urn:example:>.
_:lucy     a       :Person.
_:lucy     :name   "Lucy".
_:lucy     :bornIn _:idaho.
_:idaho    a       :Location.
_:idaho    :name   "Idaho".
_:idaho    :type   "state".
_:idaho    :within _:usa.
_:usa      a       :Location.
_:usa      :name   "United States".
_:usa      :type   "country".
_:usa      :within _:namerica.
_:namerica a       :Location.
_:namerica :name   "North America".
_:namerica :type   "continent".
```

Semantic web

- Human-readable v.s. machine-readable



Semantic web

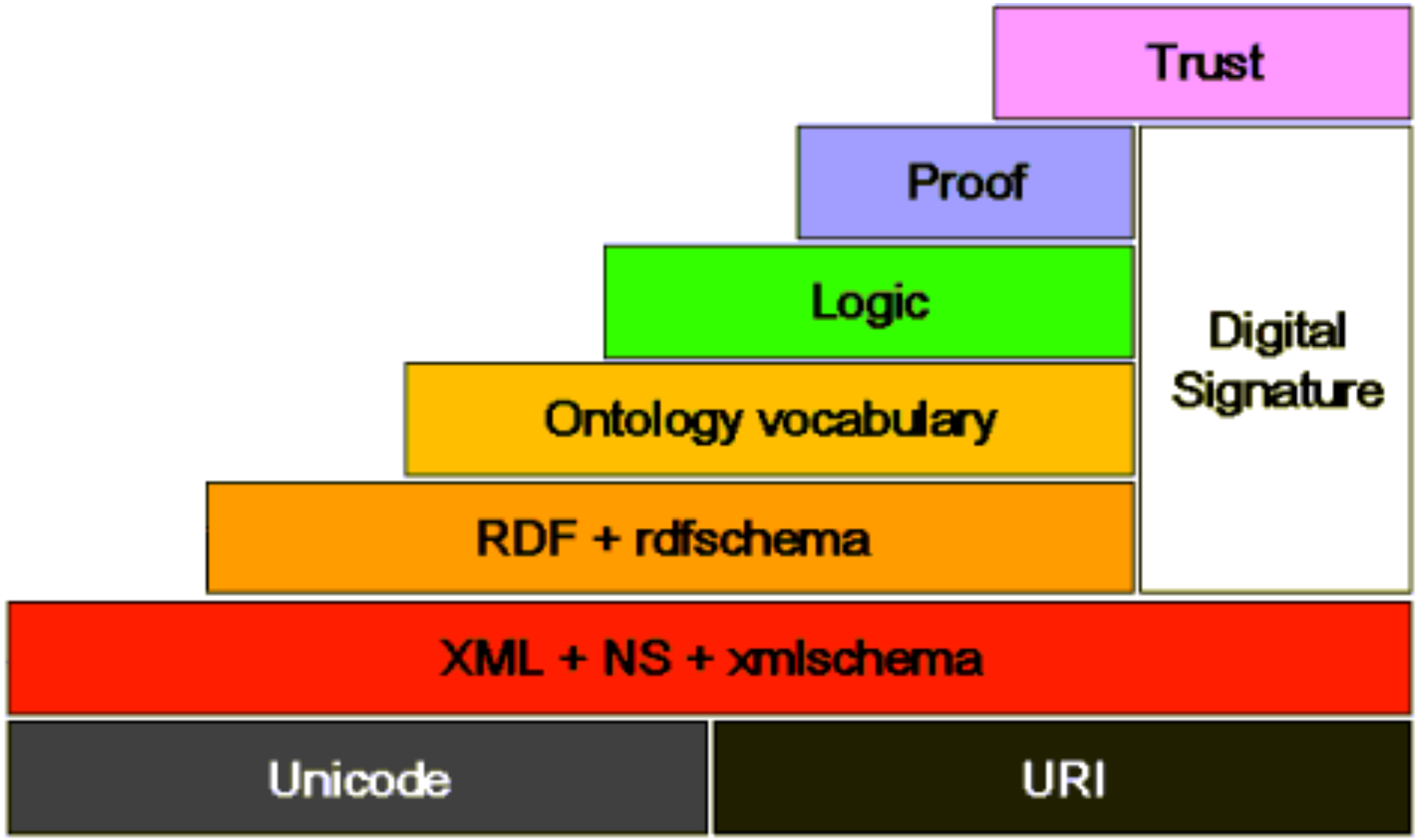
```
<?xml version="1.0"?>
<books>
   <book>
     <author> H.M. Deitel and P.J.Deitel </author>
     <title>  C++ How To Program </title>
     <publisher> Prentice Hall Publishing Co. </ publisher>
   </book>
   <book>
      <author>Jack Herrington</author>
      <title>PHP Hacks</title>
      <publisher>O'Reilly</publisher>
   </book>
</books>
```

(a)

```
<xsd:schema
xmlns:xsd="http://www.w3.org/1999/XMLSchema">
<xsd:element name="BOOK" type="BOOKTYPE"/>
<xsd:complexType name="BOOK_TYPE" >
<xsd:element name="AUTHOR" type="xsd:string"
      minOccurs="1" maxOccurs="unbounded"/>
<xsd:element name="TITLE" type="xsd:string"/>
. . .
<xsd:attribute name="isbn" type="xsd:string"/>
</xsd:complexType>
</xsd:schema>
```

(b)

Figure 1. (a) An XML instance, and (b) An example of XML Schema.



RDF data model

```
@prefix : <urn:example:>.
_:lucy     a :Person;   :name "Lucy";          :bornIn _:idaho.
_:idaho    a :Location; :name "Idaho";         :type "state";   :within _:usa.
_:usa      a :Location; :name "United States"; :type "country"; :within _:namerica.
_:namerica a :Location; :name "North America"; :type "continent".
```

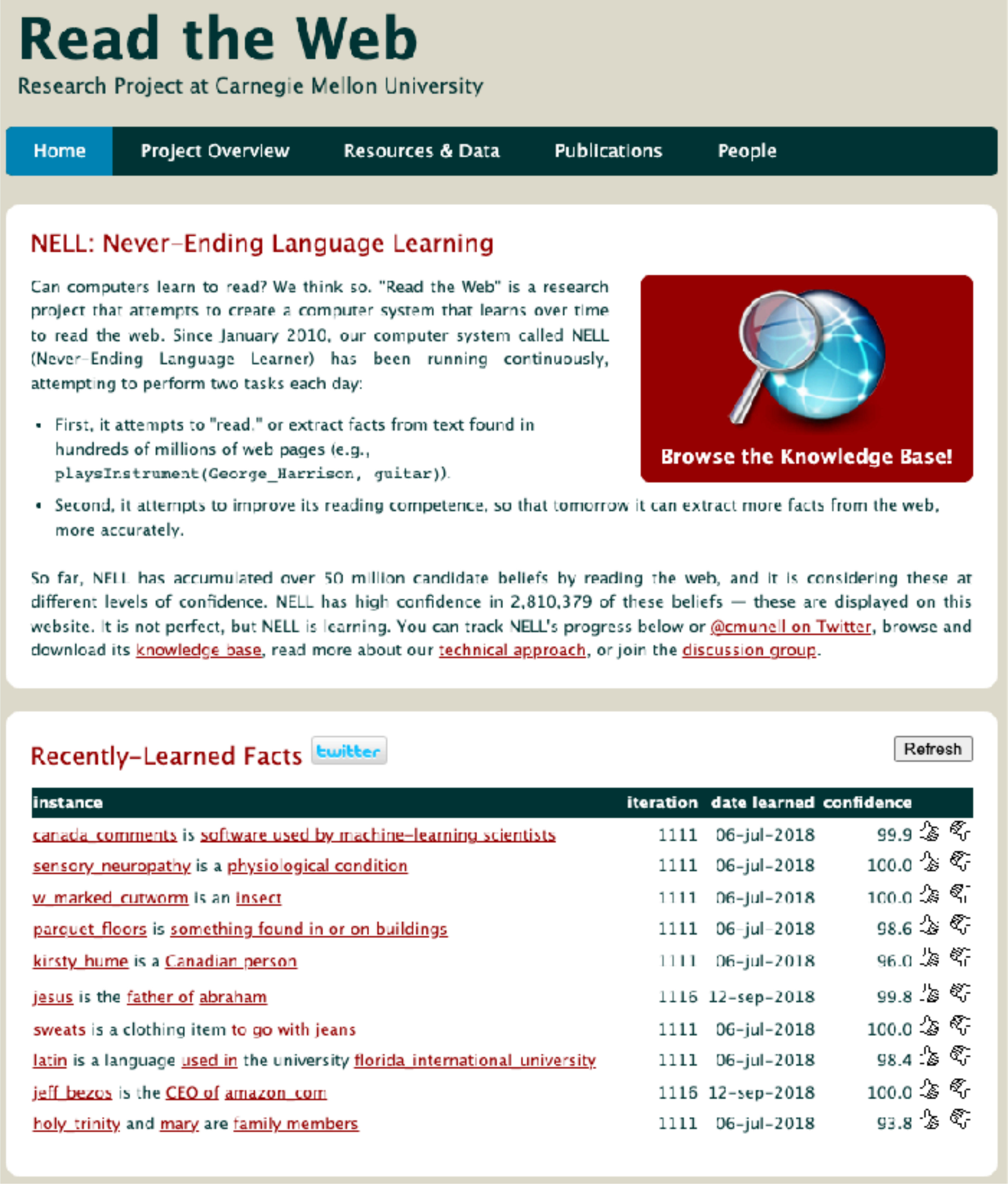
- The Resource Description Framework (RDF) was intended as a mechanism for different websites to publish data in a consistent format, allowing data from different websites to be automatically combined into a web of data—a kind of internet-wide **"database of everything."**

```
<rdf:RDF xmlns="urn:example:"
    xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#">

  <Location rdf:nodeID="idaho">
    <name>Idaho</name>
    <type>state</type>
    <within>
      <Location rdf:nodeID="usa">
        <name>United States</name>
        <type>country</type>
        <within>
          <Location rdf:nodeID="namerica">
            <name>North America</name>
            <type>continent</type>
          </Location>
        </within>
      </Location>
    </within>
  </Location>

  <Person rdf:nodeID="lucy">
    <name>Lucy</name>
    <bornIn rdf:nodeID="idaho"/>
  </Person>
</rdf:RDF>
```

NELL (the data model remains)



Read the Web

Research Project at Carnegie Mellon University

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NELL: Never-Ending Language Learning

Can computers learn to read? We think so. "Read the Web" is a research project that attempts to create a computer system that learns over time to read the web. Since January 2010, our computer system called NELL (Never-Ending Language Learner) has been running continuously, attempting to perform two tasks each day:

- First, it attempts to "read," or extract facts from text found in hundreds of millions of web pages (e.g., playsInstrument(George_Harrison, guitar)).
- Second, it attempts to improve its reading competence, so that tomorrow it can extract more facts from the web, more accurately.

Browse the Knowledge Base!

So far, NELL has accumulated over 50 million candidate beliefs by reading the web, and it is considering these at different levels of confidence. NELL has high confidence in 2,810,379 of these beliefs — these are displayed on this website. It is not perfect, but NELL is learning. You can track NELL's progress below or @cmunell on Twitter, browse and download its knowledge base, read more about our technical approach, or join the discussion group.

Recently-Learned Facts

twitter

Refresh

instance	iteration	date learned	confidence
canada_comments is software used by machine-learning scientists	1111	06-jul-2018	99.9
sensory_neuropathy is a physiological condition	1111	06-jul-2018	100.0
w_marked_cutworm is an insect	1111	06-jul-2018	100.0
parquet_floors is something found in or on buildings	1111	06-jul-2018	98.6
kirsty_hume is a Canadian person	1111	06-jul-2018	96.0
jesus is the father of abraham	1116	12-sep-2018	99.8
sweats is a clothing item to go with jeans	1111	06-jul-2018	100.0
latin is a language used in the university florida_international_university	1111	06-jul-2018	98.4
jeff_bezos is the CEO of amazon_com	1116	12-sep-2018	100.0
holy_trinity and mary are family members	1111	06-jul-2018	93.8

SPARQL

- SPARQL is a query language for triple-stores using the RDF data model. SPARQL is a nice query language.

Cypher

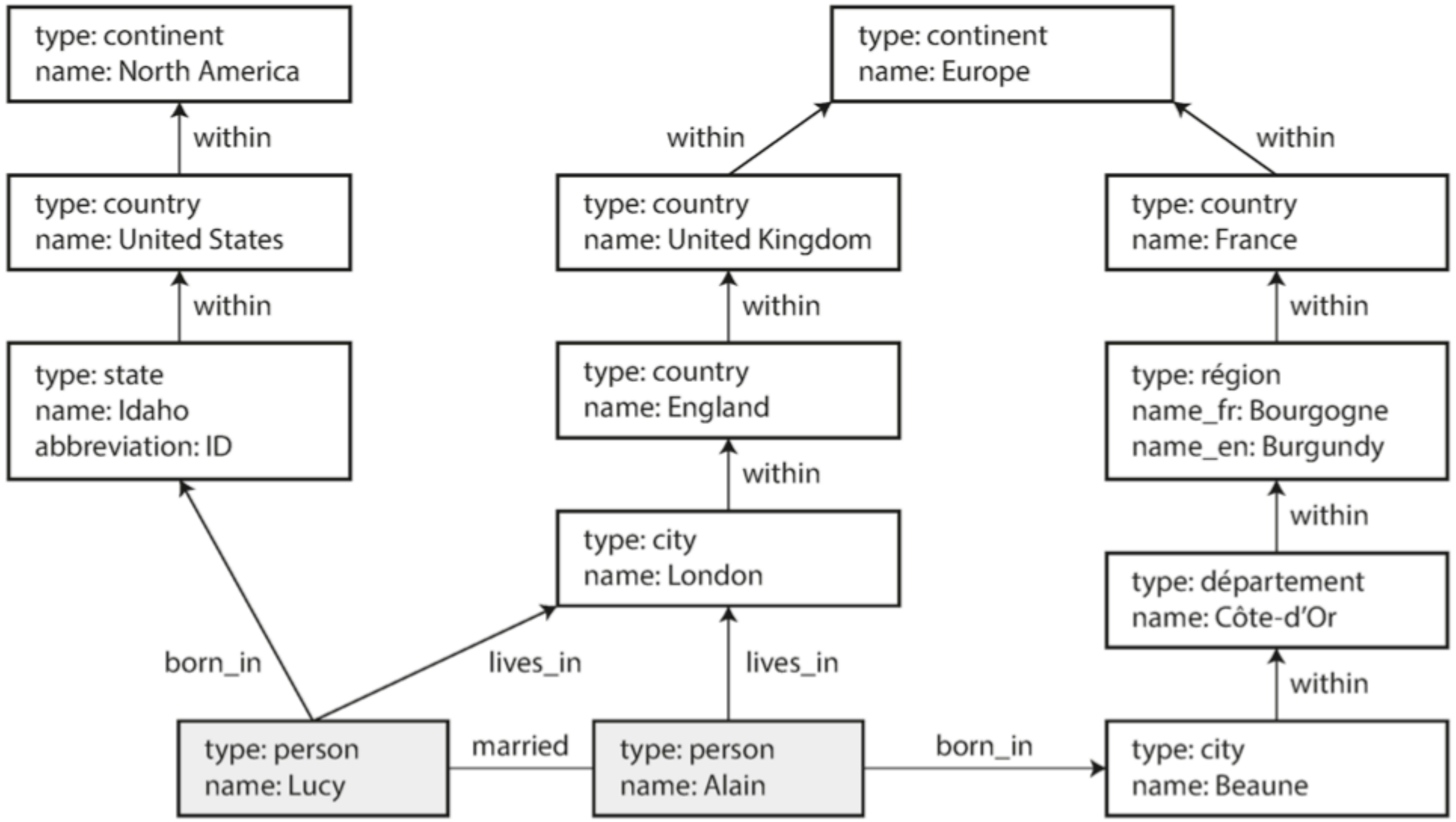
```
MATCH
  (person) -[:BORN_IN]->  () -[:WITHIN*0..]-> (us:Location {name:'United States'}),
  (person) -[:LIVES_IN]-> () -[:WITHIN*0..]-> (eu:Location {name:'Europe'})
RETURN person.name
```

SPARQL

```
PREFIX : <urn:example:>

SELECT ?personName WHERE {
  ?person :name ?personName.
  ?person :bornIn  / :within* / :name "United States".
  ?person :livesIn / :within* / :name "Europe".
}
```

Property graph v.s. RDF




```
@prefix : <urn:example:>.
_:lucy     a       :Person.
_:lucy     :name   "Lucy".
_:lucy     :bornIn _:idaho.
_:idaho    a       :Location.
_:idaho    :name   "Idaho".
_:idaho    :type   "state".
_:idaho    :within _:usa.
_:usa      a       :Location.
_:usa      :name   "United States".
_:usa      :type   "country".
_:usa      :within _:namerica.
_:namerica a       :Location.
_:namerica :name   "North America".
_:namerica :type   "continent".
```

Datalog

```
name(namerica, 'North America').
type(namerica, continent).

name(usa, 'United States').
type(usa, country).
within(usa, namerica).

name(idaho, 'Idaho').
type(idaho, state).
within(idaho, usa).

name(lucy, 'Lucy').
born_in(lucy, idaho).
```

```
within_recursive(Location, Name) :- name(Location, Name).     /* Rule 1 */

within_recursive(Location, Name) :- within(Location, Via),     /* Rule 2 */
                                    within_recursive(Via, Name).

migrated(Name, BornIn, LivingIn) :- name(Person, Name),        /* Rule 3 */
                                    born_in(Person, BornLoc),
                                    within_recursive(BornLoc, BornIn),
                                    lives_in(Person, LivingLoc),
                                    within_recursive(LivingLoc, LivingIn).

?- migrated(Who, 'United States', 'Europe').
/* Who = 'Lucy'. */
```

Data model

Query language

Evolution

- Datalog => SPARQL => Cypher
- Triple | RDF => Property Graphs => Document
  - More reuse.
  - More concise.
  - More flexibility.

Today's topic: Data Model Evolutions & Query language

- Object-relational mismatch
- ID v.s. Strings
- Many-to-many v.s. one-to-many
- Hierarchical/network/relational model
- Imperative & declarative Query languages