Fundamentals of Database Systems CMPSC 174A

Unit 3: NoSQL, JSON, Semistructured Data

(3 lectures*)

*Slides may change: refresh each lecture

Introduction to Data Management
CMPSC 174A

Lecture 11: NoSQL

Class Overview

- Unit 1: Intro
- Unit 2: Relational Data Models and Query Languages
- Unit 3: Non-relational data
  - NoSQL
  - JSON
- Unit 4: RDMBS internals and query optimization
- Unit 5: Parallel query processing
- Unit 6: DBMS usability, conceptual design
- Unit 7: Transactions
- Unit 8: Advanced topics (time permitting)

Two Classes of Database Applications

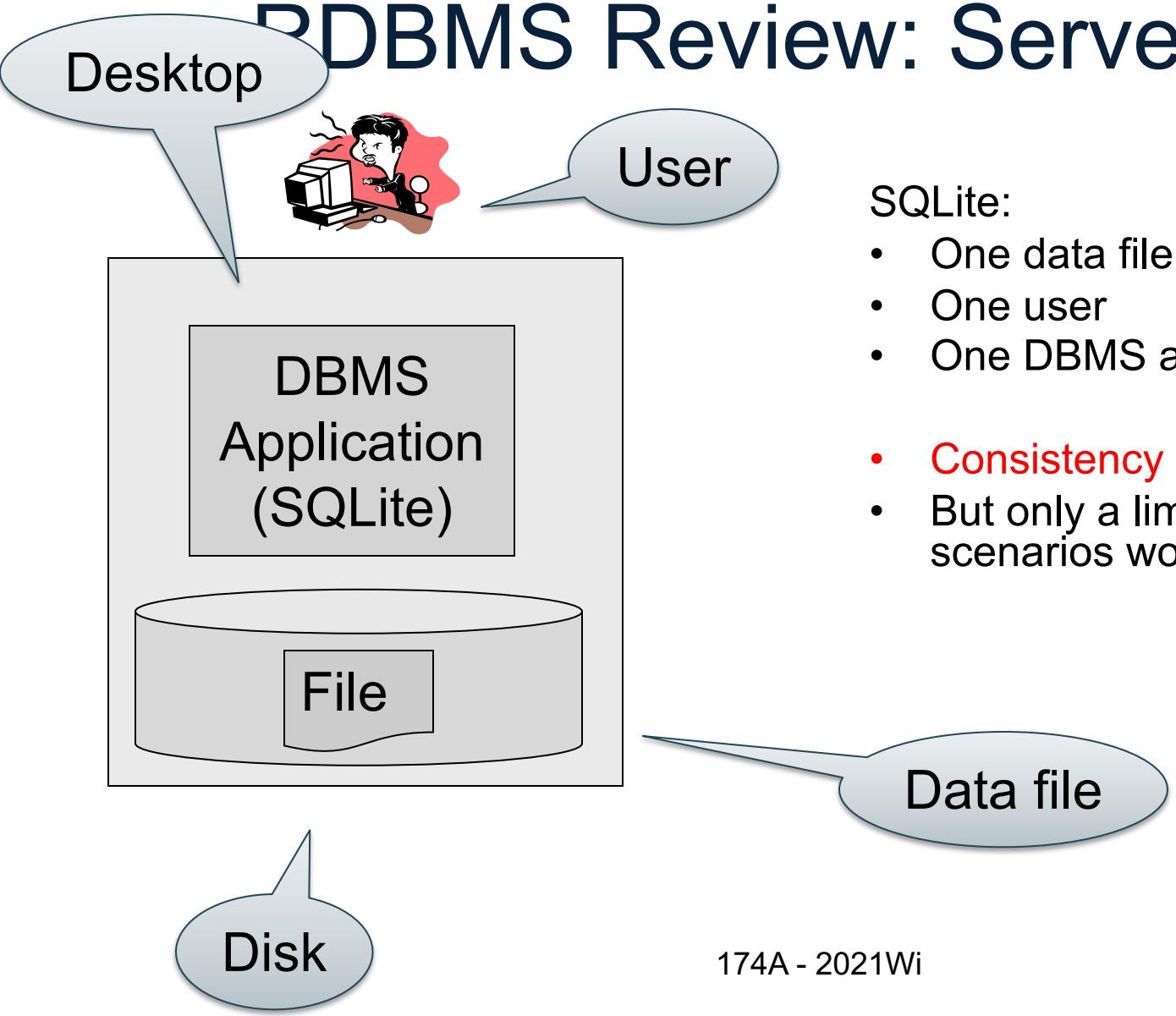
- OLTP (Online Transaction Processing)
  - Queries are simple lookups: 0 or 1 join
    E.g., find customer by ID and their orders
  - Many updates. E.g., insert order, update payment
  - Consistency is critical: transactions (more later)
- OLAP (Online Analytical Processing)
  - aka “Decision Support”
  - Queries have many joins, and group-by’s
    E.g., sum revenues by store, product, clerk, date
  - No updates

NoSQL Motivation

- Originally motivated by Web 2.0 applications
  - E.g. Facebook, Amazon, Instagram, etc
  - Startups need to scaleup from 10 to 10^7 quickly

- Needed: very large scale OLTP workloads
- Give up on consistency, give up OLAP
- NoSQL: reduce functionality
  - Simpler data model
  - Very restricted updates

RDBMS Review: Serverless

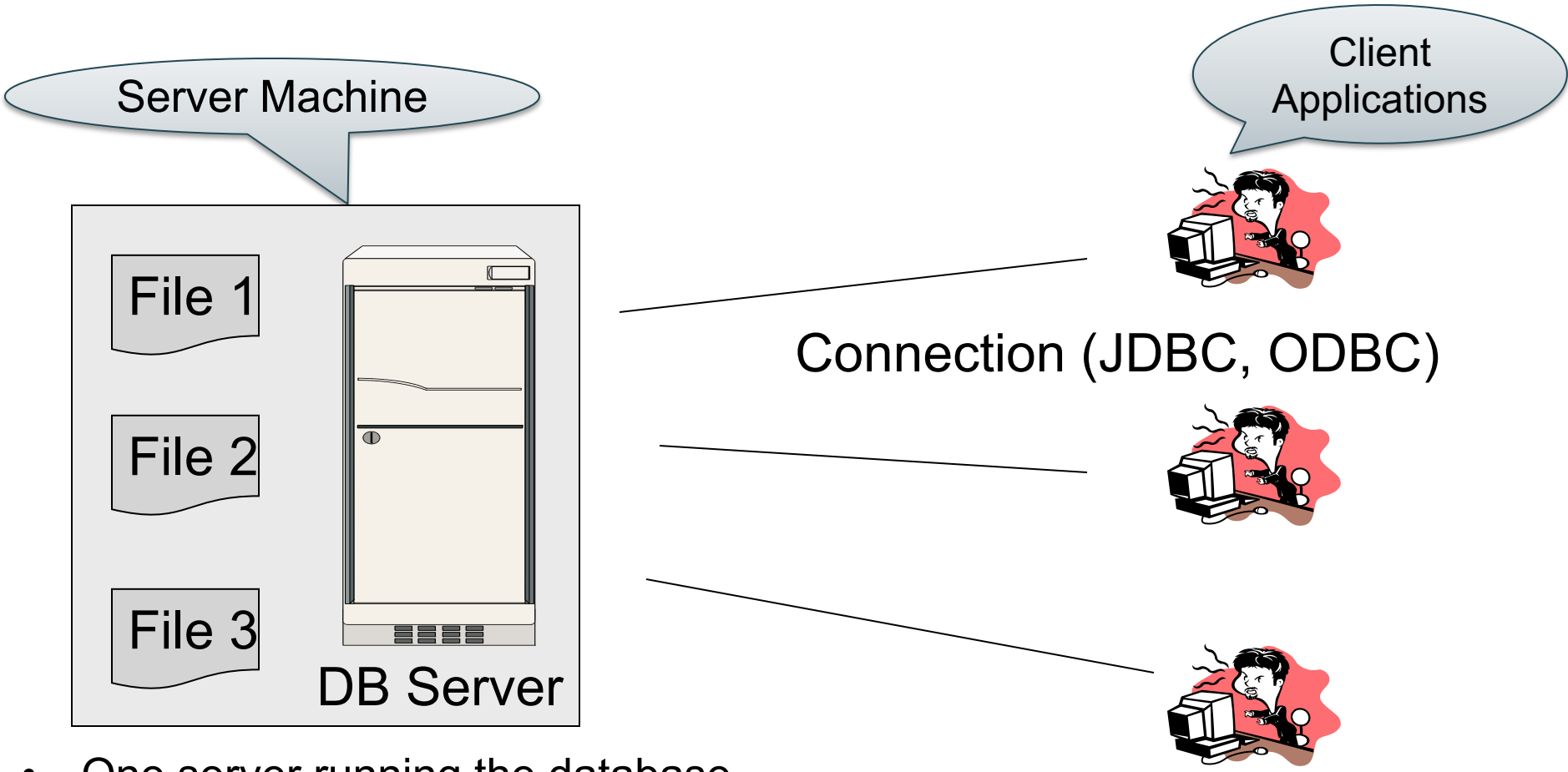


SQLite:

- One data file
- One user
- One DBMS application

- Consistency is easy
- But only a limited number of scenarios work with such model

RDBMS Review: Client-Server



- One server running the database
- Many clients, connecting via the ODBC or JDBC (Java Database Connectivity) protocol

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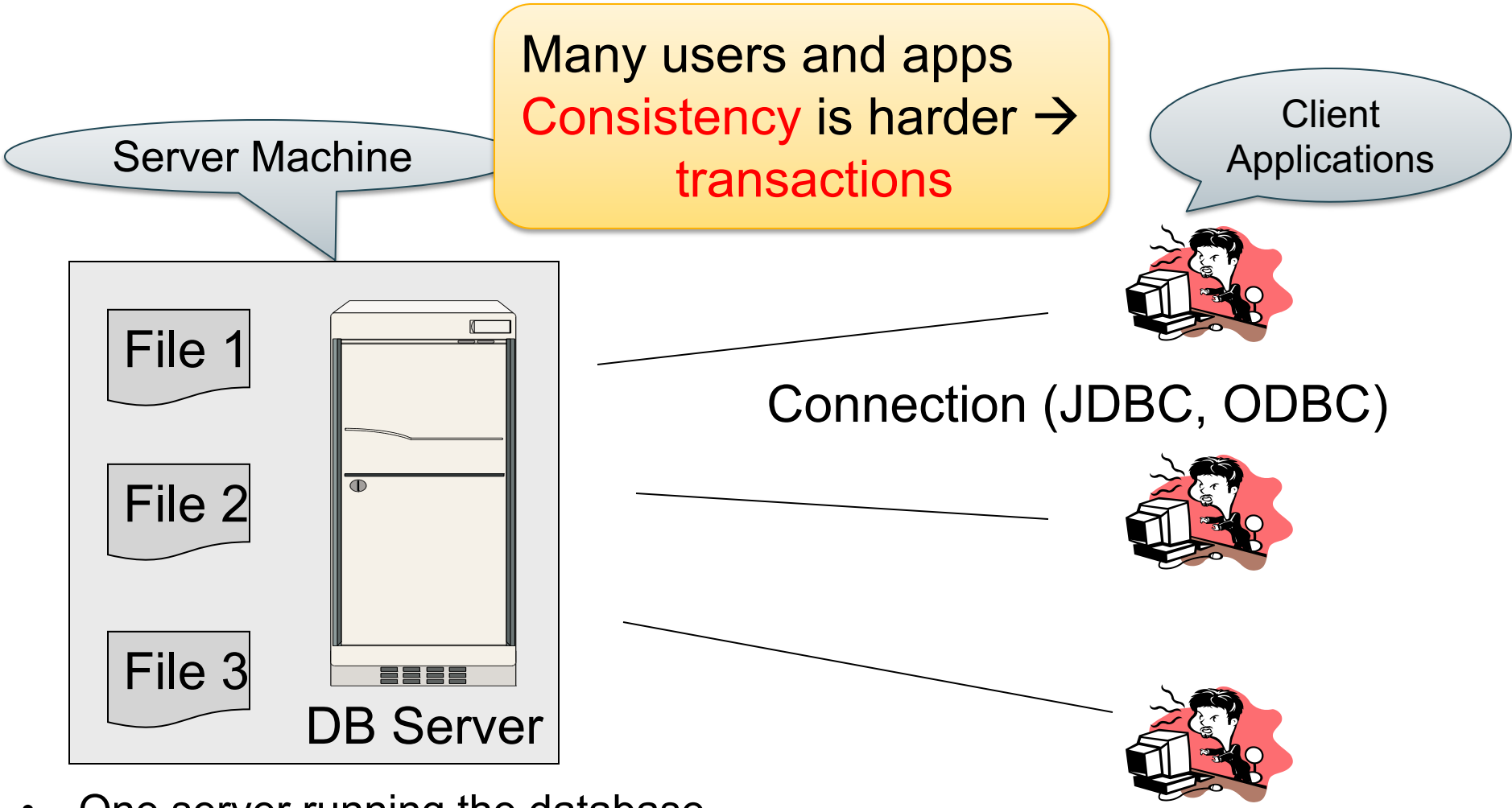

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Client-Server

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  - Microsoft's Management Studio (for SQL Server), or
  - psql (for postgres)
  - Some Java program (HW8) or some C++ program

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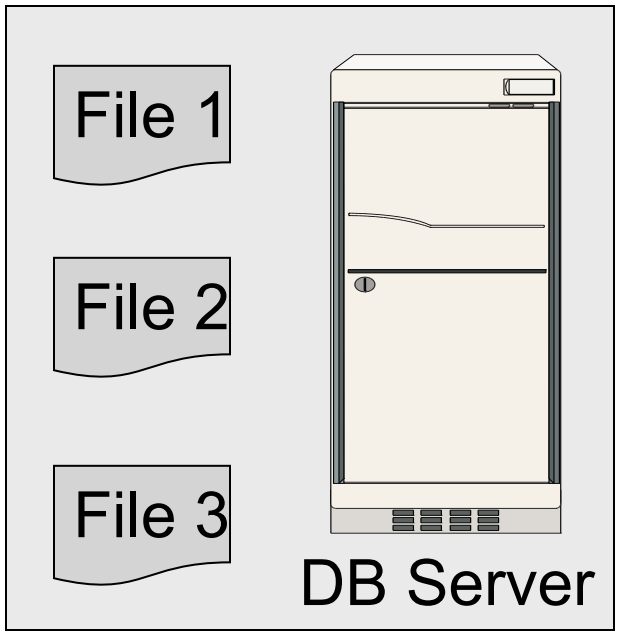
- Clients "talk" to server using JDBC/ODBC protocol

Web Apps: 3 Tier



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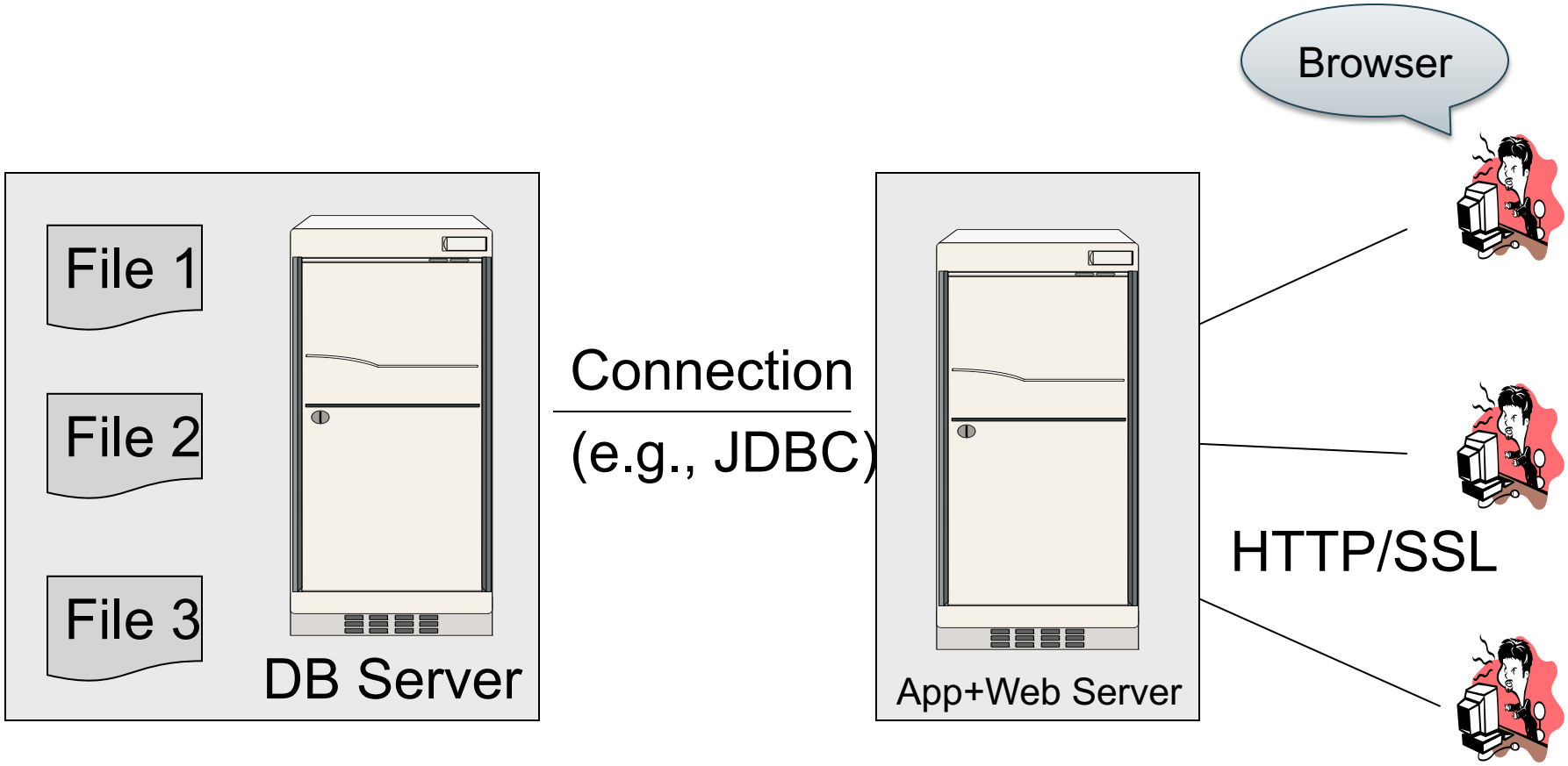
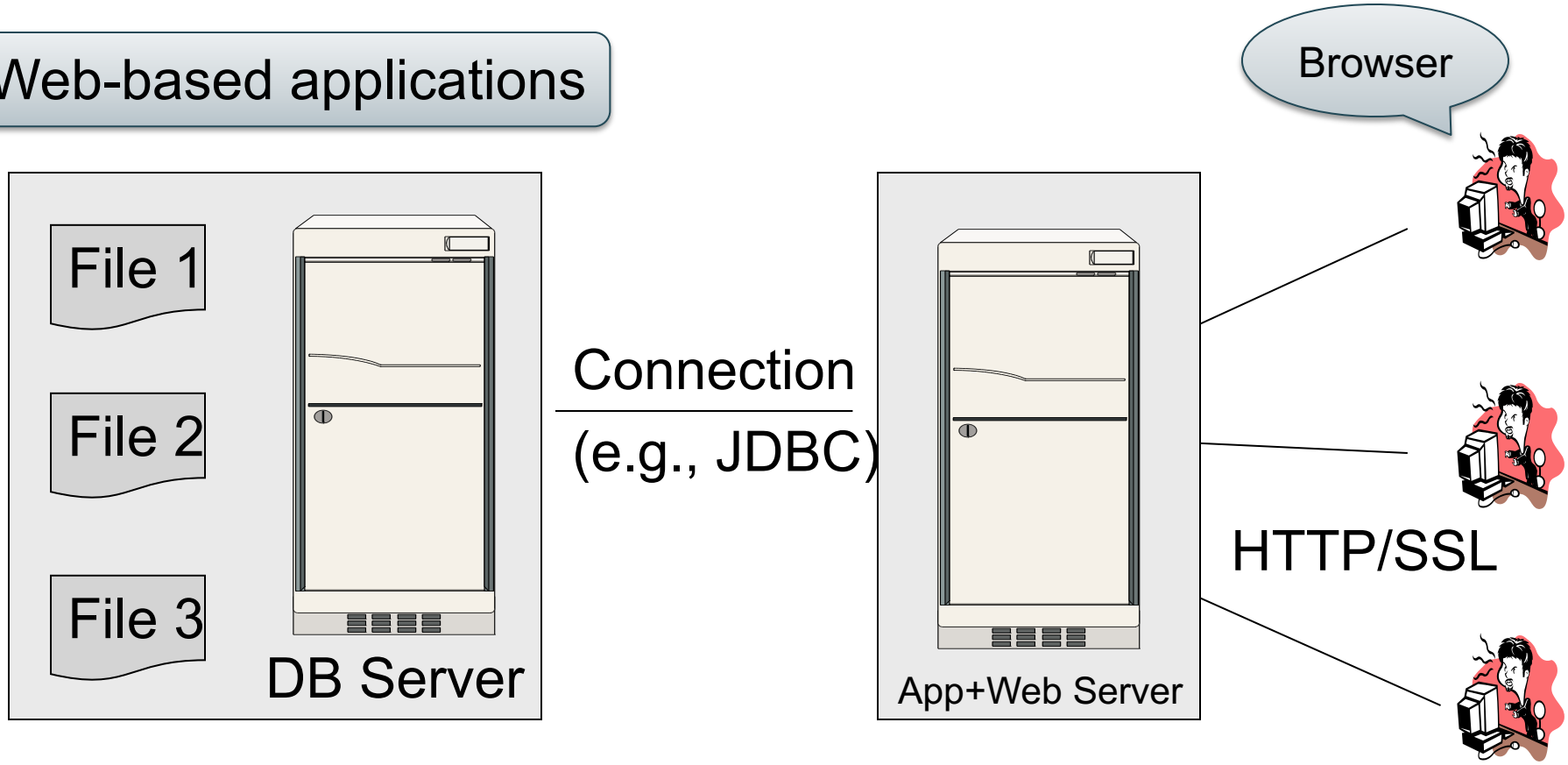


Web Apps: 3 Tier

Web-based applications



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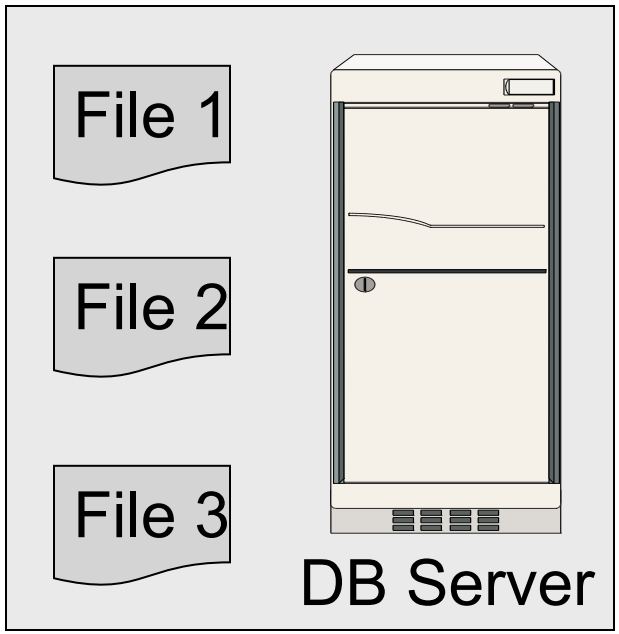

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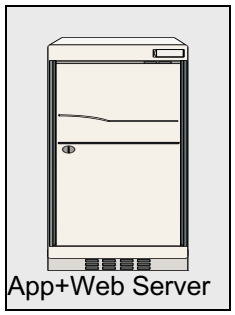
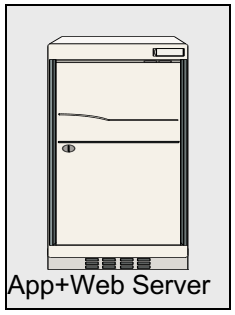
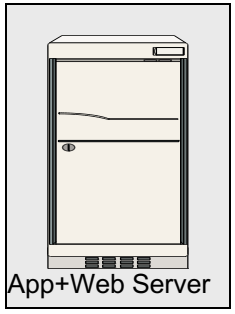
(e.g., JDBC)





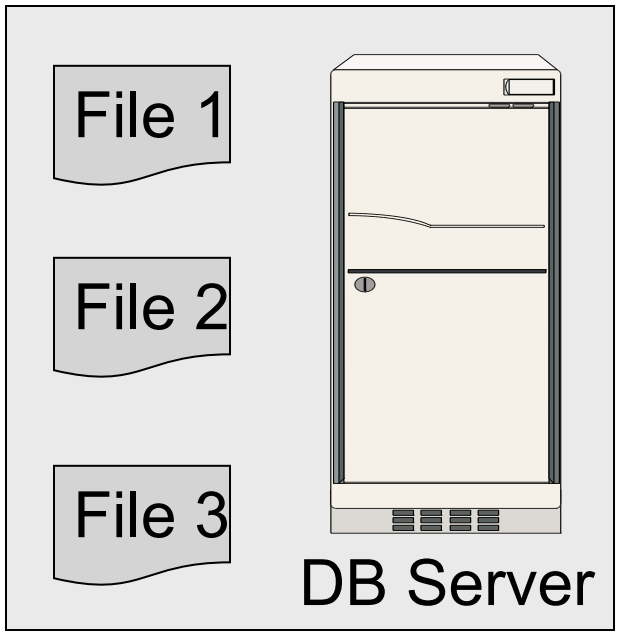


HTTP/SSL

os: 3 Tier

Replicate App server for scaleup

Web-based applications



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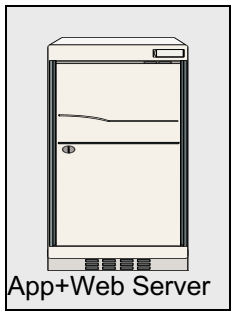

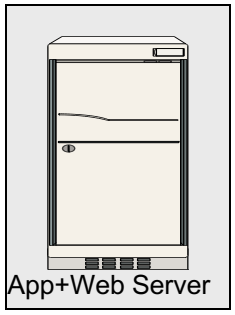

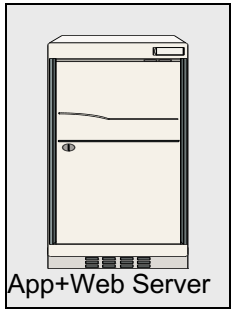

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Why not replicate DB server?

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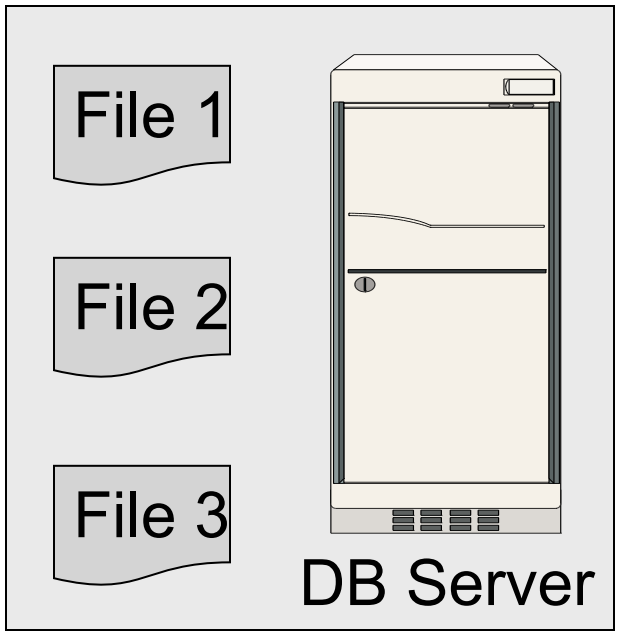

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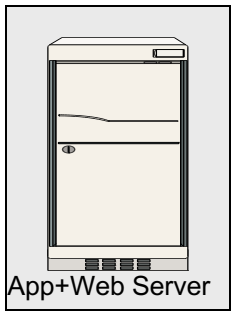
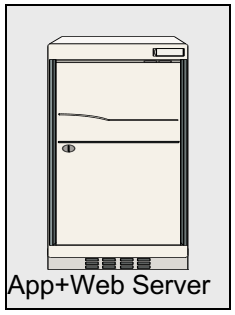
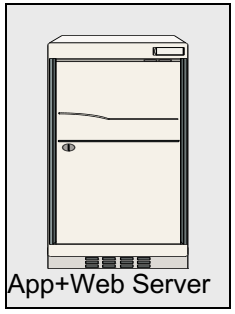






HTTP/SSL

Why not replicate DB server?

Consistency!

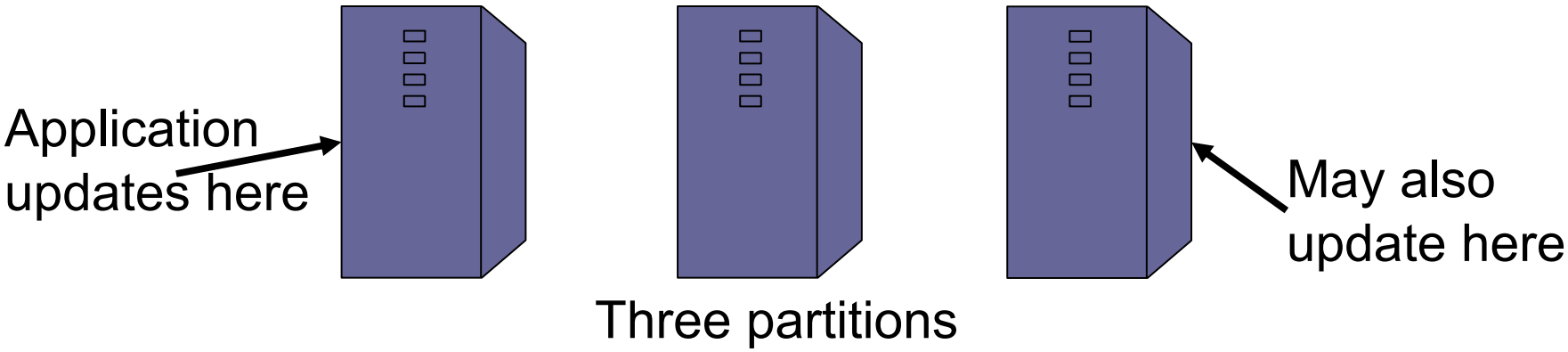
Replicating the Database

- Two basic approaches:
  - Scale up through partitioning – “sharding”
  - Scale up through replication

- Consistency is much harder to enforce

Scale Through Partitioning

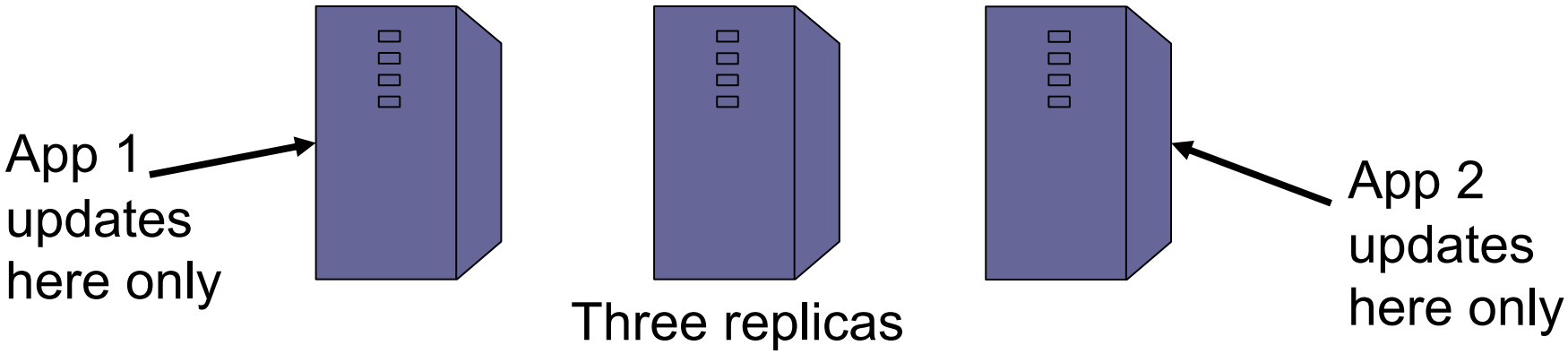
- Partition the database across many machines in a cluster
  - Database now fits in main memory
  - Queries spread across these machines
- Can increase throughput
- Easy for writes but reads become expensive!



Scale Through Replication

Advantage of Replication:1. fault tole

- Create multiple copies of each database partition
- Spread queries across these replicas
- Can increase throughput and lower latency
- Can also improve fault-tolerance
- Easy for reads but writes become expensive!



Relational Model → NoSQL

SQL has the advantage of being stable:1. intege

- Relational DB: difficult to replicate/partition.Eg `Supplier(sno,…),Part(pno,…),Supply(sno,pno)`
  - Partition: we may be forced to join across servers
  - Replication: local copy has inconsistent versions
  - Consistency is hard in both cases (why?)

Replication brings Query execubtion problems. Replication brings Query consistency invariance.

- NoSQL: simplified data model
  - Given up on functionality
  - Application must now handle joins and consistency

We might have some comprimises on consistency to achieve dramatically bette

Data Models

Taxonomy: the subject of classification.

Taxonomy based on data models:

- Key-value stores
  - e.g., Project Voldemort, Memcached
- Document stores
  - e.g., SimpleDB, CouchDB, MongoDB
- Extensible Record Stores
  - e.g., HBase, Cassandra, PNUTS

Key-Value Stores Features

- **Data model**: (key,value) pairs
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  - No replication: key k is stored at server h(k)
  - 3-way replication: key k stored at h1(k),h2(k),h3(k)

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How does get(k) work? How does put(k,v) work?

Flights(fid, date, carrier, flight_num, origin, dest, ...)
Carriers(cid, name)

Example

- How would you represent the Flights data as key, value pairs?

How does query processing work?

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- Option 1: key=fid, value=entire flight record

How does query processing work?

Flights(fid, date, carrier, flight_num, origin, dest, ...)
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Example

- How would you represent the Flights data as key, value pairs?
- Option 1: key=fid, value=entire flight record
- Option 2: key=date, value=all flights that day

How does query processing work?

Flights(fid, date, carrier, flight_num, origin, dest, ...)
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Example

- How would you represent the Flights data as key, value pairs?
- Option 1: key=fid, value=entire flight record
- Option 2: key=date, value=all flights that day
- Option 3: key=(origin,dest), value=all flights between

How does query processing work?

Key-Value Stores Internals

- Partitioning:
  - Use a hash function h
  - Store every (key,value) pair on server h(key)
- Replication:
  - Store each key on (say) three servers
  - On update, propagate change to the other servers; *eventual consistency*
  - Issue: when an app reads one replica, it may be stale
- Usually: combine partitioning+replication

Data Models

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Motivation

- In Key, Value stores, the Value is often a very complex object
  - Key = '2010/7/1', Value = [all flights that date]

- Better: *value* to be structured data
  - JSON or Protobuf or XML
  - Called a "document" but it's just data

We will discuss JSON

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Extensible Record Stores

- Based on Google's BigTable
- HBase is an open source implementation of BigTable

- Data model:
  - Variant 1: key = rowID, value = record
  - Variant 2: key = (rowID, columnID), value = field

- Will not discuss in class

Fundamentals of Database Systems CMPSC 174A

Lecture 12: JSON, Semi-structured Data

Announcements

- Midterm: Feb 16, in class
- Material: up to NoSQL (Units 1, 2 and 3)
- Email me if you have special need

Where We Are

- So far we have studied the *relational data model*
  - Data is stored in tables(=relations)
  - Queries are expressions in SQL, relational algebra, or Datalog

- Today: Semistructured data model
  - Popular formats today: XML, JSON, protobuf

JSON - Overview

- JavaScript Object Notation = lightweight text-based open standard designed for human-readable data interchange. Interfaces in C, C++, Java, Python, Perl, etc.

- The filename extension is .json.

We will emphasize JSON as semi-structured data

JSON Syntax

```
{  "book": [
      {"id":"01",
       "language": "Java",
       "author": "H. Javeson",
       "year": 2015
      },
      {"id":"07",
       "language": "C++",
       "edition": "second"
       "author": "E. Sepp",
       "price": 22.25
      }
   ]
}
```

JSON vs Relational

- Relational data model
  - Rigid flat structure (tables)
  - Schema must be fixed in advanced
  - Binary representation: good for performance, bad for exchange
  - Query language based on Relational Calculus

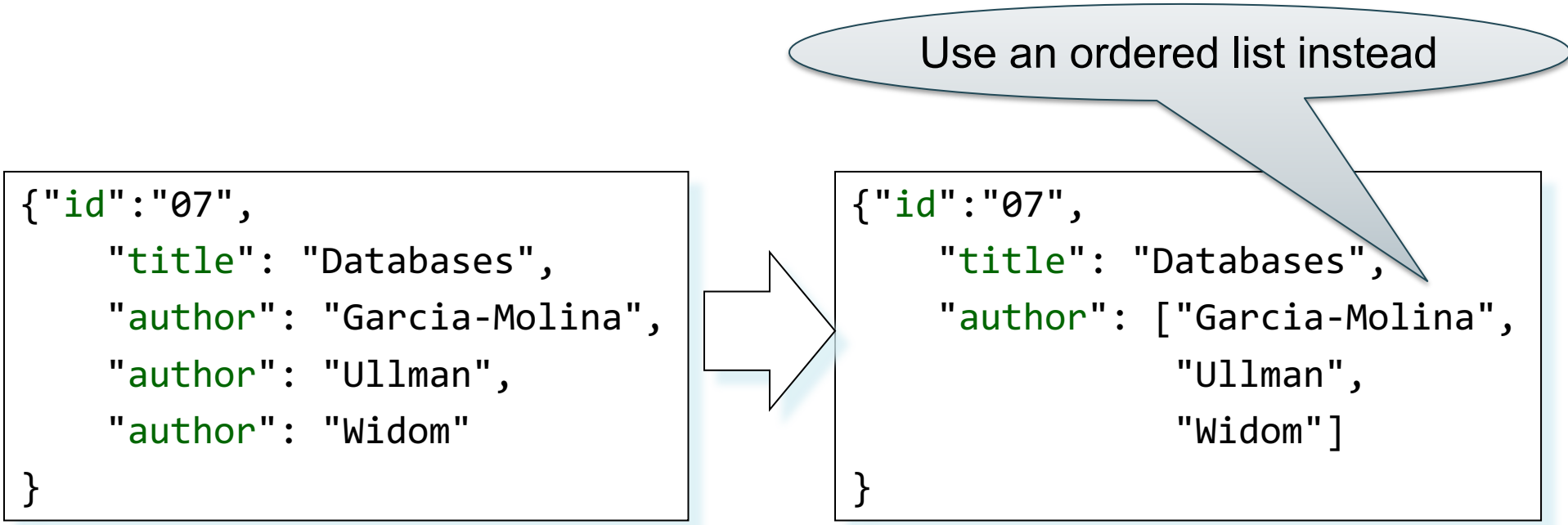
- Semistructured data model / JSON
  - Flexible, nested structure (trees)
  - Does not require predefined schema ("self-describing”)
  - Text representation: good for exchange, bad for performance
  - Most common use: Language API; query languages emerging

JSON Types

- Primitive: number, string, Boolean, null
- Object: collection of name-value pairs:
  - `{“name1”: value1, “name2”: value2, …}`
  - “name” is also called a “key”
- Array: *ordered* list of values:
  - `[obj1, obj2, obj3, ...]`

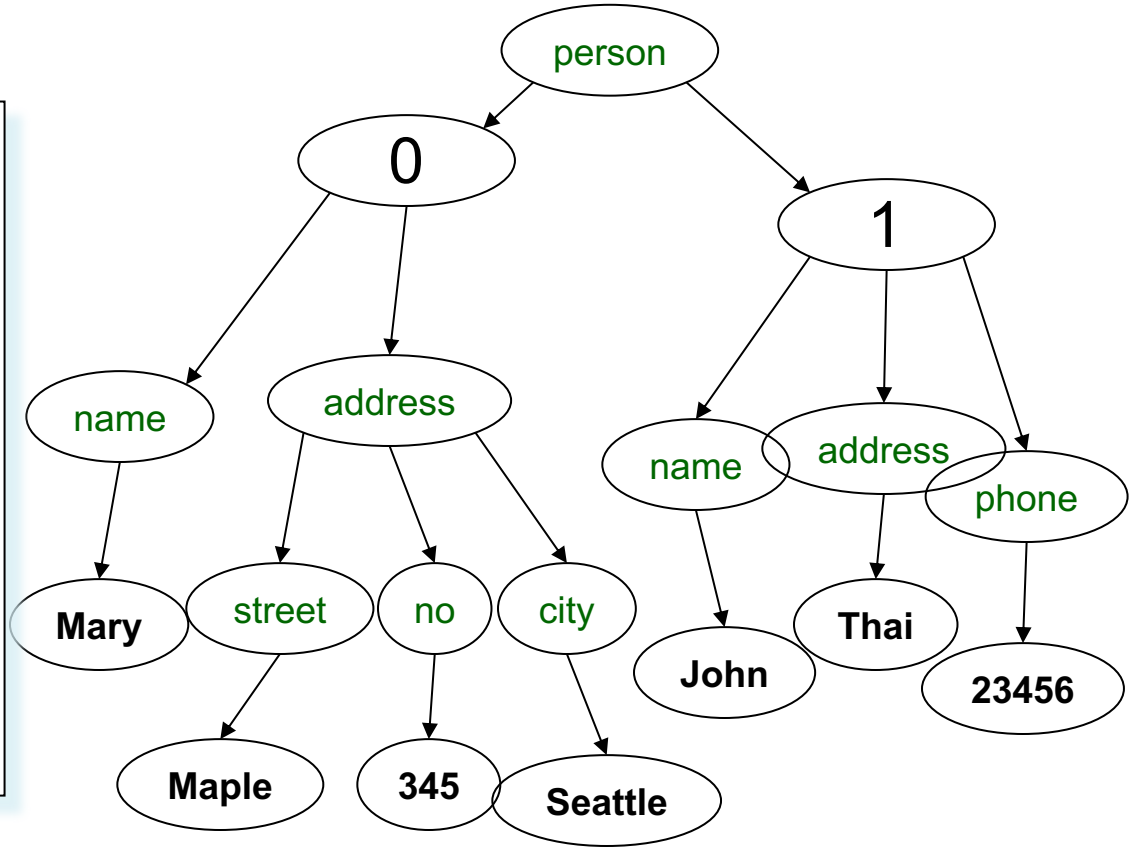
Avoid Using Duplicate Keys

The standard allows them, but many implementations don't



JSON Semantics: a Tree !

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



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   ]
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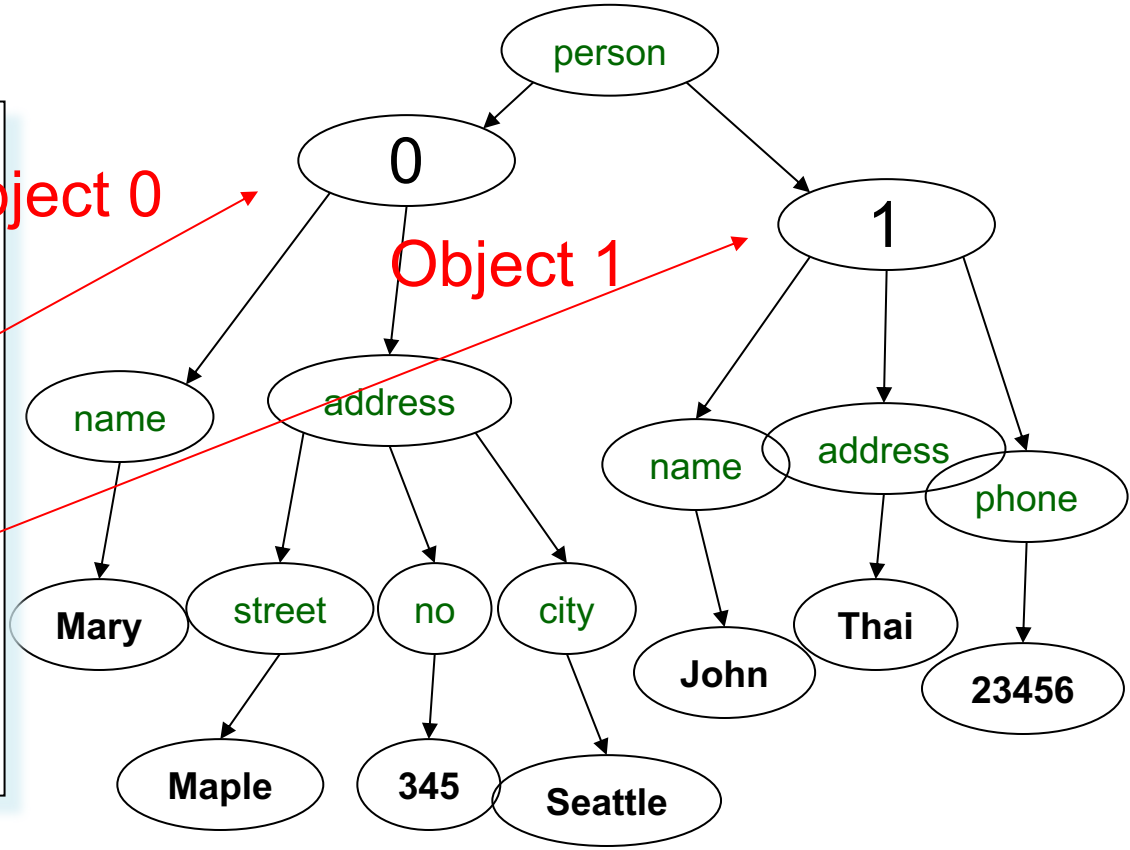
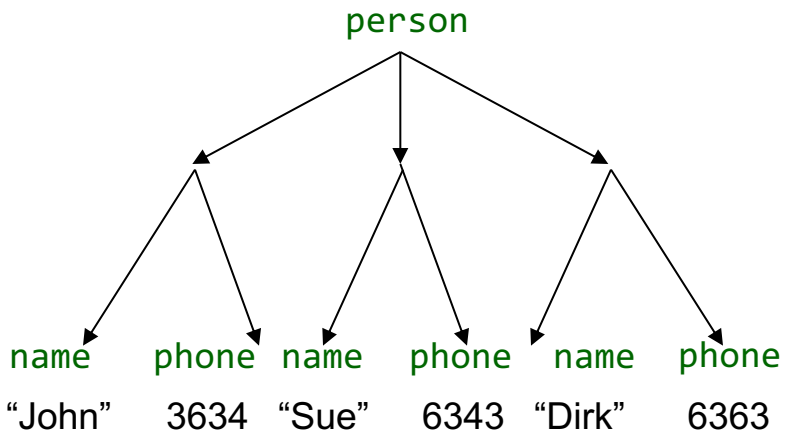


Recall: arrays are *ordered* in JSON!

Intro to Semi-structured 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
- ⇨ JSON is more flexible
  - Schema can change per tuple

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”:6383}
   ]
}
```

Mapping Relational Data to JSON

May inline multiple relations based on 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"}
   ]
  }
 ]
}
```

Mapping Relational Data to JSON

Many-many relationships are more difficult to represent

Person

name	phone
John	3634
Sue	6343

Product

prodName	price
Gizmo	19.99
Phone	29.99
Gadget	9.99

Orders

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

Options for the JSON file:

- 3 flat relations: Person,Orders,Product
- Person→Orders→Products products are duplicated
- Product→Orders→Person persons are duplicated

Semi-structured data

- Missing attributes:

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

no phone !

- Could represent in a table with nulls

name	phone
John	1234
Joe	NULL

Semi-structured data

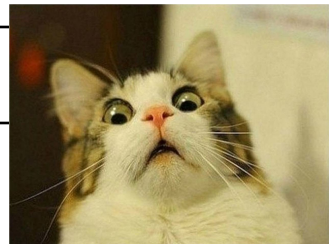
- Repeated attributes

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

Two phones !

- Impossible in one table:

name	phone	
Mary	2345	3456



Semi-structured data

- 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

- These are difficult to represent in the relational model

Discussion: Why Semi-Structured Data?

- Semi-structured data works well as *data exchange formats*
  -- i.e., exchanging data between different apps
  -- Examples: XML, JSON, Protobuf (protocol buffers)

- Increasingly, systems use them as a data model for databases:
  -- SQL Server supports for XML-valued relations
  -- CouchBase, MongoDB, Snowflake: JSON
  -- Dremel (BigQuery): Protobuf

Query Languages for Semi-Structured Data

- XML: XPath, XQuery (see textbook)
  - Supported inside many RDBMS (SQL Server, DB2, Oracle)
  - Several standalone XPath/XQuery engines

- Protobuf: SQL-ish language (Dremel) used internally by google, and externally in BigQuery

- JSON:
  - CouchBase: N1QL
  - AsterixDB: SQL++ (based on SQL)
  - MongoDB: has a pattern-based language
  - JSONiq: http://www.jsoniq.org/