Introduction to Database Systems

NoSQL & JSON

(mostly not in textbook…

only Ch 11.1)

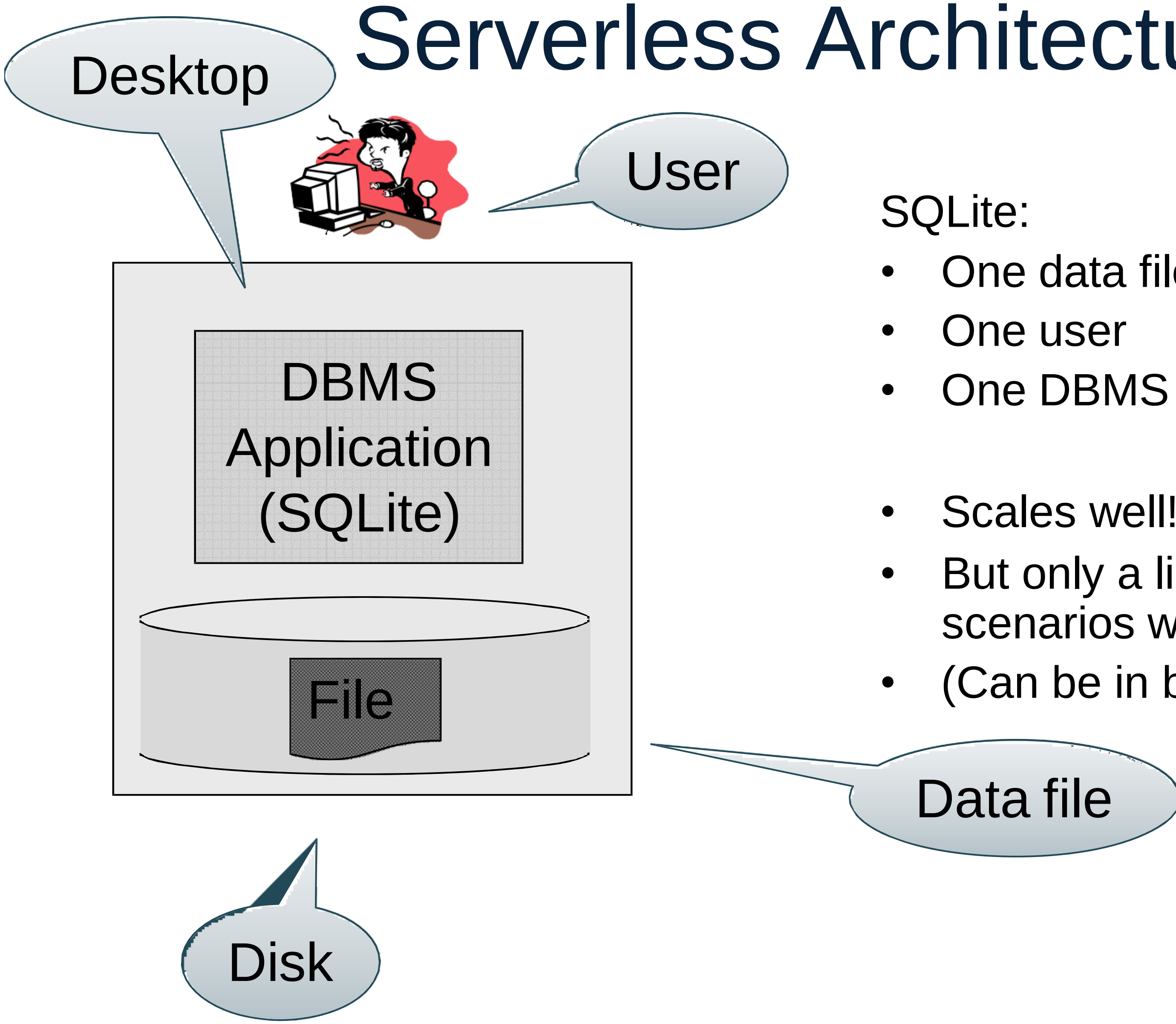
NoSQL Motivation

- Originally motivated by Web 2.0 applications
- Goal is to scale simple OLTP-style workloads to millions or billions of users
  - Ex: Facebook has 1.2B *daily* active users
    - use often correlated in time in each region
    - > 10M req/sec if 25% of users arrive within one hour
    - SQL Server would collapse under that workload
- Users are doing both updates and reads

What is the Problem?

- Single server DBMS are too small for Web data
- **Solution**: scale out to multiple servers
- This is hard for the *entire* functionality of DBMS
  - as we will see next…
- NoSQL: reduce functionality for easier scaling
  - Simpler data model
  - Fewer guarantees

Serverless Architecture

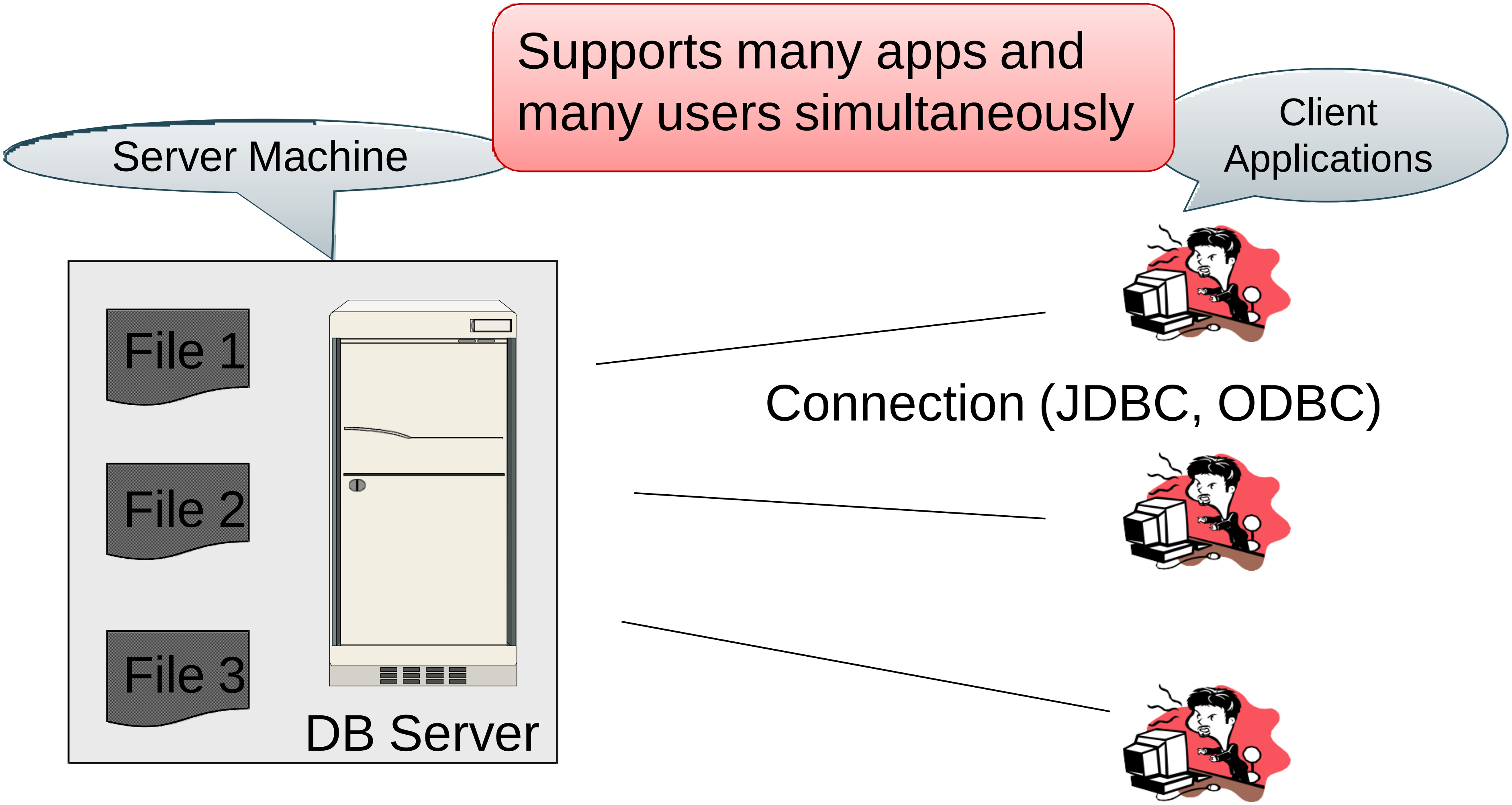


SQLite:

- One data file
- One user
- One DBMS application

- Scales well!
- But only a limited number of scenarios work with such model
- (Can be in browser / phone!)

Client-Server Architecture

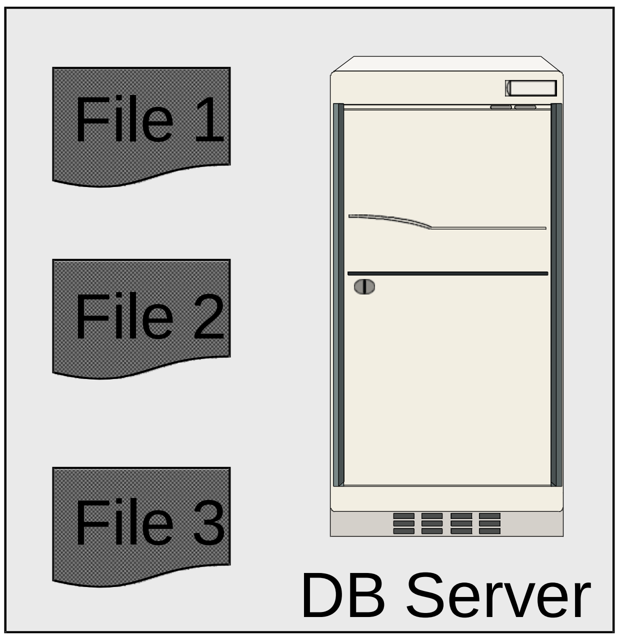


- One server running the database
- Many clients, connecting via the ODBC or JDBC (Java Database Connectivity) protocol

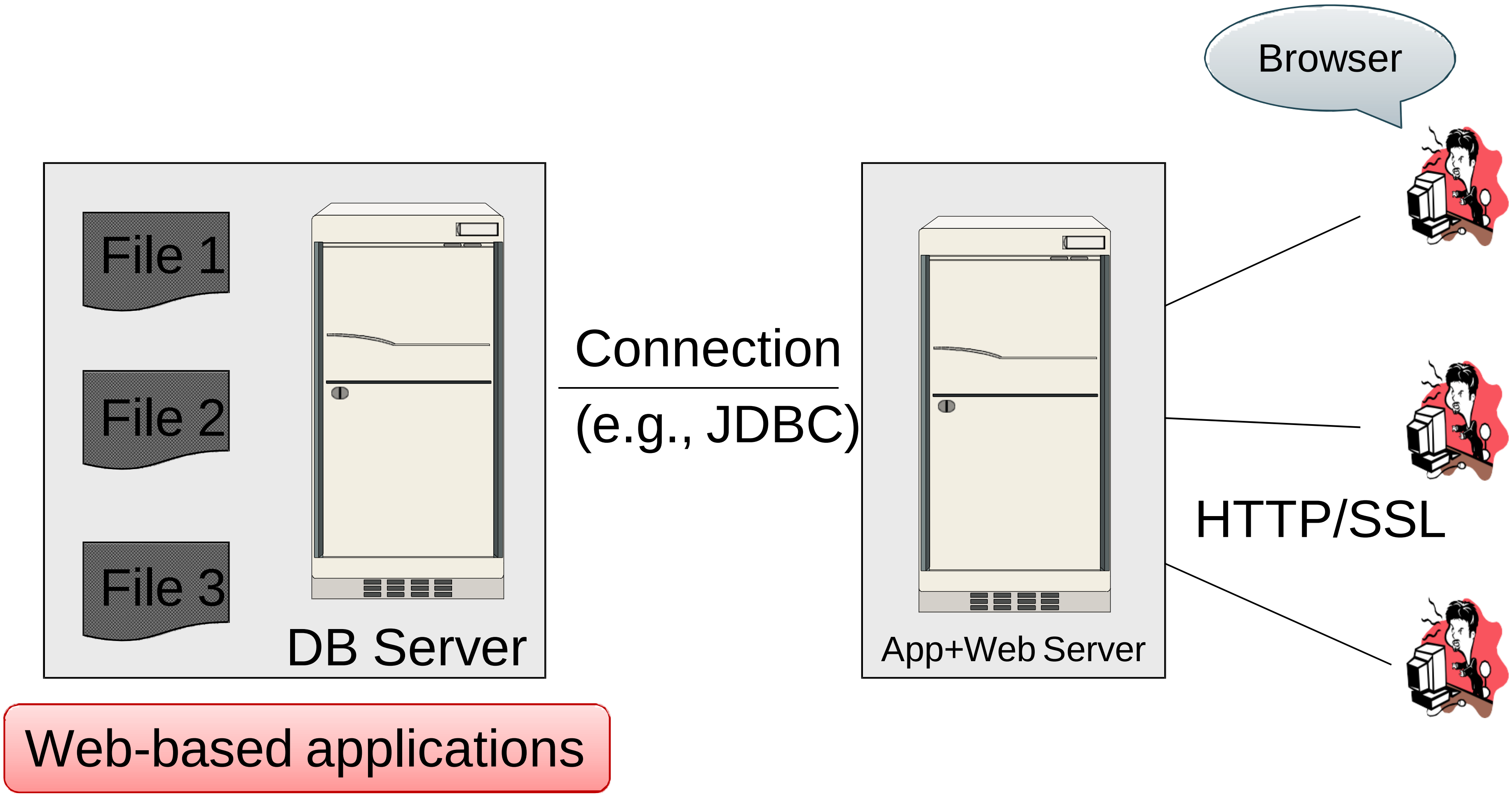
Client-Server

- One *server* that runs the DBMS (or RDBMS):
  - Your own desktop, or
  - Some beefy system, or
  - A cloud service (SQL Azure)
- Many *clients* run apps and connect to DBMS
  - Microsoft's Management Studio (for SQL Server), or
  - psql (for postgres)
  - Some Java program (HW8) or some C++ program
- Clients "talk" to server using JDBC/ODBC protocol

3-Tiered Architecture

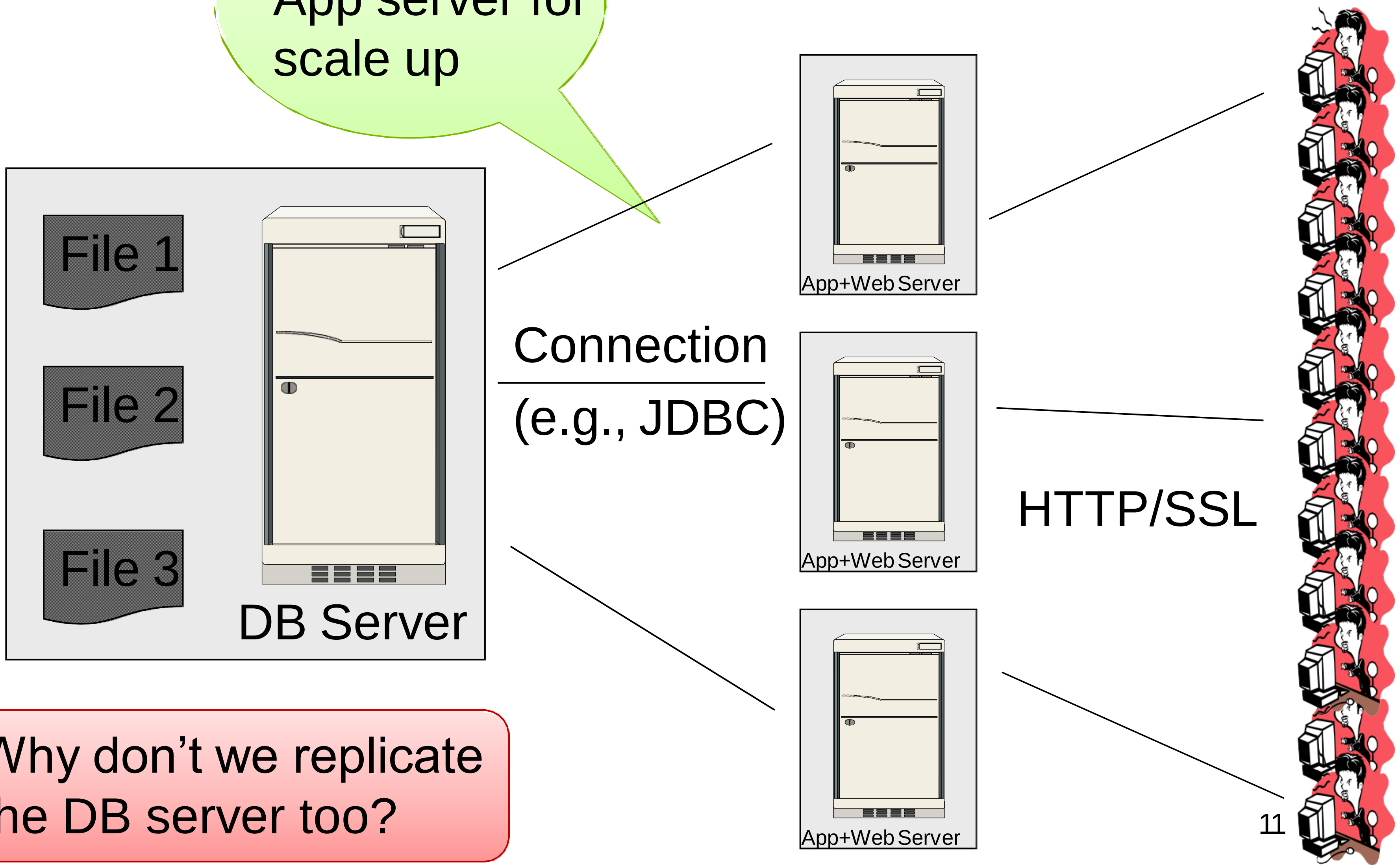


3-Tiered Architecture



3-Tiered Architecture

Replicate App server for scale up



Why don’t we replicate the DB server too?

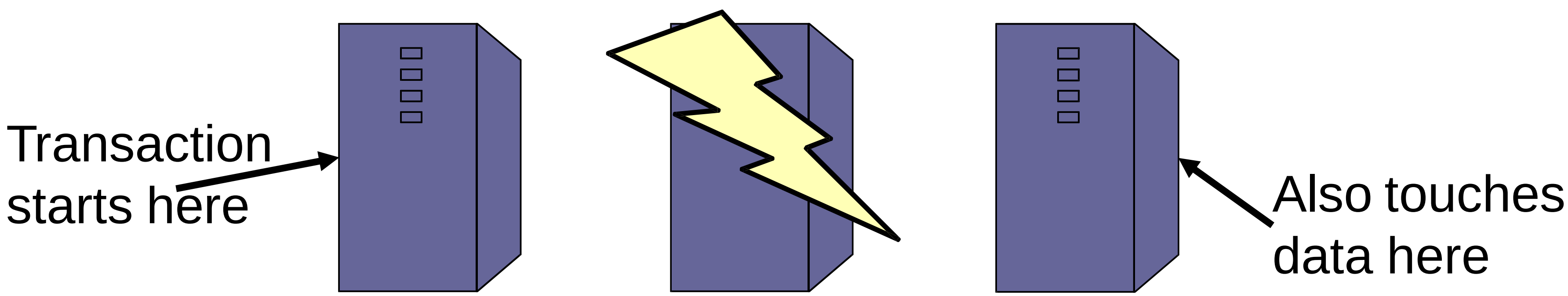
Replicating the Database

- Much harder because the state must be unique. In other words, the database must act as a whole
  - Current DB instance must always be *consistent*
    - Ex: foreign keys must exist
    - as a result, some updates must occur simultaneously

- Two basic approaches:
  - Scale up through partitioning
  - Scale up through replication

Scale Through Partitioning

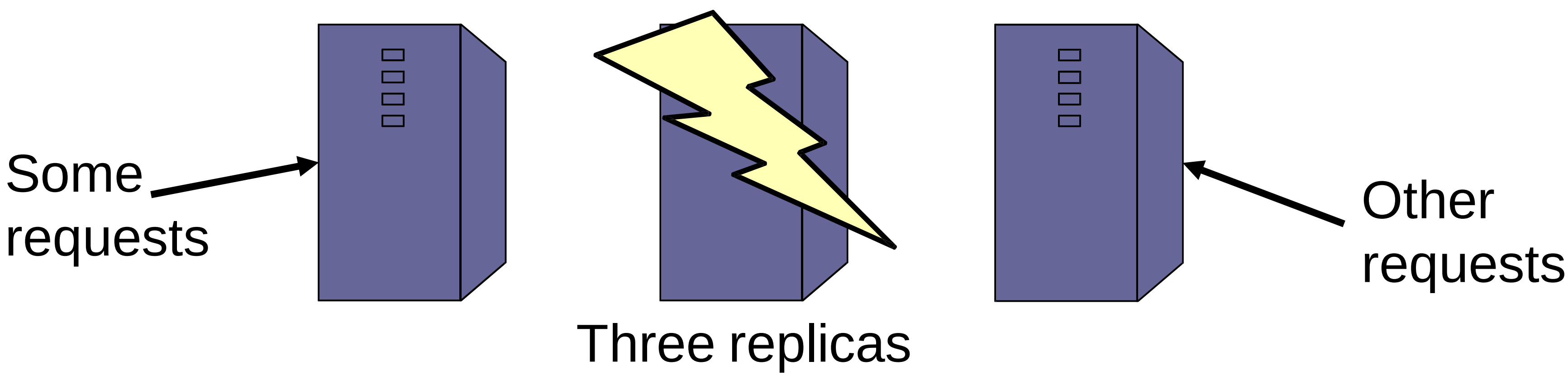
- Partition the database across many machines in a cluster
  - Database could fit in main memory
  - Queries spread across these machines
- Can increase throughput
- Easy for (simple) writes but reads become harder



Three partitions

Scale Through Replication

- 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 harder



NoSQL Data Models

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
  - Key = string/integer, unique for the entire data
  - Value = can be anything (very complex object)
- **Operations**
  - Get(key), Put(key, value)
  - Operations on value not supported
- **Distribution / Partitioning**
  - No replication: key k is stored at server h(k)
  - 3-way replication: key k is stored at h1(k), h2(k), h3(k)

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?
- 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

- Data remains in main memory
  - one implementation: distributed hash table
- Most systems also offer a persistence option
- Others use replication to provide fault-tolerance
  - Asynchronous or synchronous replication
  - Tunable consistency: read/write one replica or majority
- Some offer transactions, others do not
  - multi-version concurrency control or locking
- No secondary indices

Data Models

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Document Stores Features

- **Data model**: (key, document) pairs
  - Key = string/integer, unique for the entire data
  - Document = JSON or XML
- **Operations**
  - Get/put document by key
  - Limited, non-standard query language on JSON
- **Distribution / Partitioning**
  - Entire documents, as for key/value pairs

We will discuss JSon today or tomorrow

Data Models

Taxonomy based on data models:

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Extensible Record Stores

- Based on Google's BigTable
  - HBase is an open source implementation of BigTable
- Data model is rows and columns
  - can add both new rows and new columns
- Scalability by splitting rows and columns over nodes
  - Rows partitioned through hashing on primary key
  - Columns of a table are distributed over multiple nodes by using "column groups"

NoSQL Summary

- Simpler data model with weaker guarantees
- But they scale as far as we need them to

- Meanwhile…
  SQL systems continue to improve

Recent SQL Progress

- Modern systems need to store data across the globe
  - individual data centers go offline
  - need servers close to users to be efficient
- Speed of light is a fundamental limit
  - 200+ms latency (across US) is visible to users
- Systems must weaken guarantees
- Google's Spanner (supports SQL):
  - write data over the whole globe (a bit slowly)
  - reads occur slightly in the *past*

Prediction

- My guess: SQL will win again
- Pieces are out there already
  - Spanner: multi-node transactions
  - AsterixDB: multi-node query optimization
- For now, NoSQL still offers key benefits

JSon and Semi-structured Data

Where We Are

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

- Today: Semi-structured data model
  - Popular formats today: XML, JSon, protobuf

JSON

- 10 years ago…
  - JavaScript interpreters were very slow
  - native browser function parsed JSON 100x faster
- XML was also an option, but
  - IE had a memory leak in its XML parser
- JSON used in Gmail etc. for this reason
- Spread organically to server-side systems

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 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

- Semi-structured 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 Syntax

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

JSon Terminology

- Curly braces hold objects
  - Each object is a list of name/value pairs separated by , (comma)
  - Each pair is a name is followed by ':' (colon) followed by the value
- Square brackets hold arrays and values are separated by , (comma).
- Data made up of objects, lists, and atomic values (integers, floats, strings, booleans).

JSon Data Structures

- Collections of name-value pairs:
  - {“name1”: value1, “name2”: value2, …}
  - The “name” is also called a “key”
- Ordered lists of values:
  - [obj1, obj2, obj3, ...]

Avoid Using Duplicate Keys

The standard allows them, but many implementations don’t

```
{"id":"07",
   ”title": “Databases”,
   "author": “Garcia-Molina”,
   "author": “Ullman”,
   "author": “Widom”
}
```

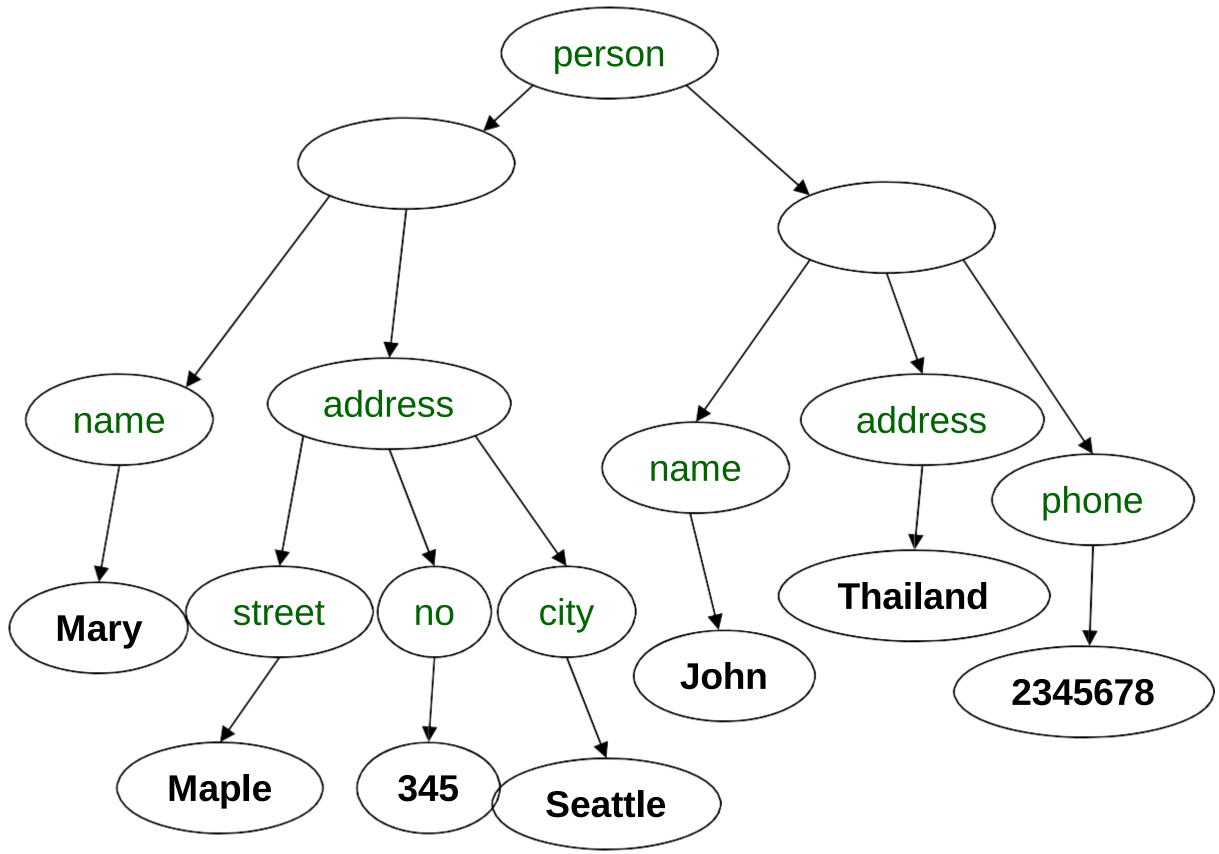
```
{"id":"07",
   "title": “Databases”,
   "author": [“Garcia-Molina”,
                     “Ullman”,
                     “Widom”]
}
```

JSon Data Types

- Number
- String = double-quoted
- Boolean = true or false
- null / empty

JSon Semantics: a Tree !

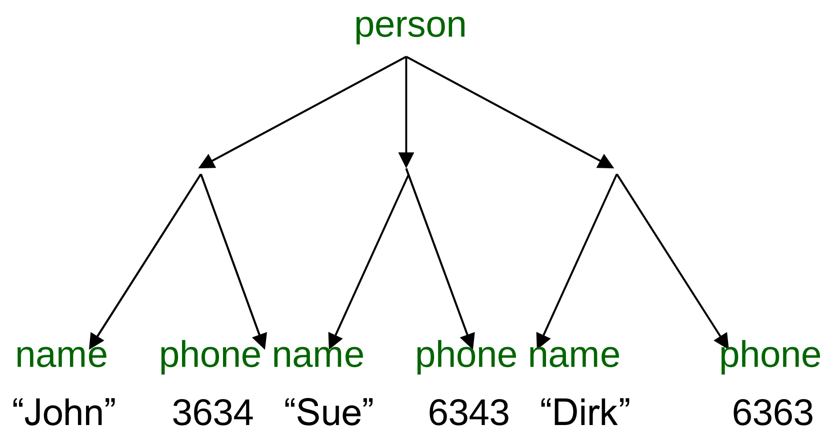
```
{"person":
   [ {"name": "Mary",
      "address":
         {"street": "Maple",
          "no": 345,
          "city": "Seattle"}},
     {"name": "John",
      "address": "Thailand",
      "phone": 2345678}
   ]
}
```



JSon Data

- JSon is self-describing
- Schema elements become part of the data
  - Relational schema: person(name, phone)
  - In Json "person", "name", "phone" are part of the data, and are repeated many times
- Consequence: JSon is much more flexible
  - also uses more space (but can be compressed)
- JSon is an example of semi-structured data

Mapping Relational Data to JSON



Person

name	phone
John	3634
Sue	6343
Dirk	6363

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

Mapping Relational Data to JSON

May inline foreign keys

Person

name	phone
John	3634
Sue	6343

Orders

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

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

JSON = Semi-structured Data (1/3)

- Missing attributes:

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

no phone !

- Could represent a table with nulls

name	phone
John	1234
Joe	-

JSON = Semi-structured Data (2/3)

- Repeated attributes

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

Two phones !

- Impossible in one table:

name	phone	
Mary	2345	3456

???

JSON = Semi-structured Data (3/3)

- Attributes with different types in different objects

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

Structured name !

- Nested collections
- Heterogeneous collections

Discussion

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

Query Languages for Semi-Structured Data

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