Big Data and Data Mining

NoSQL

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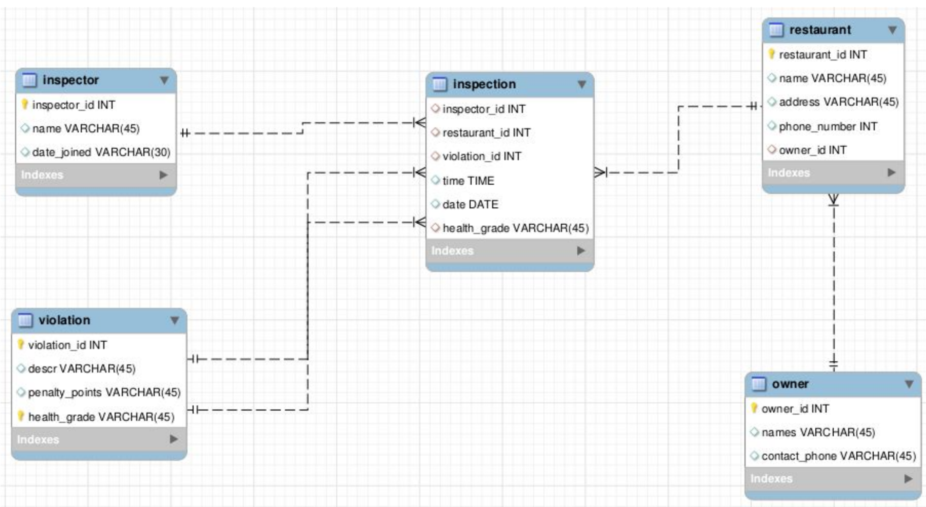
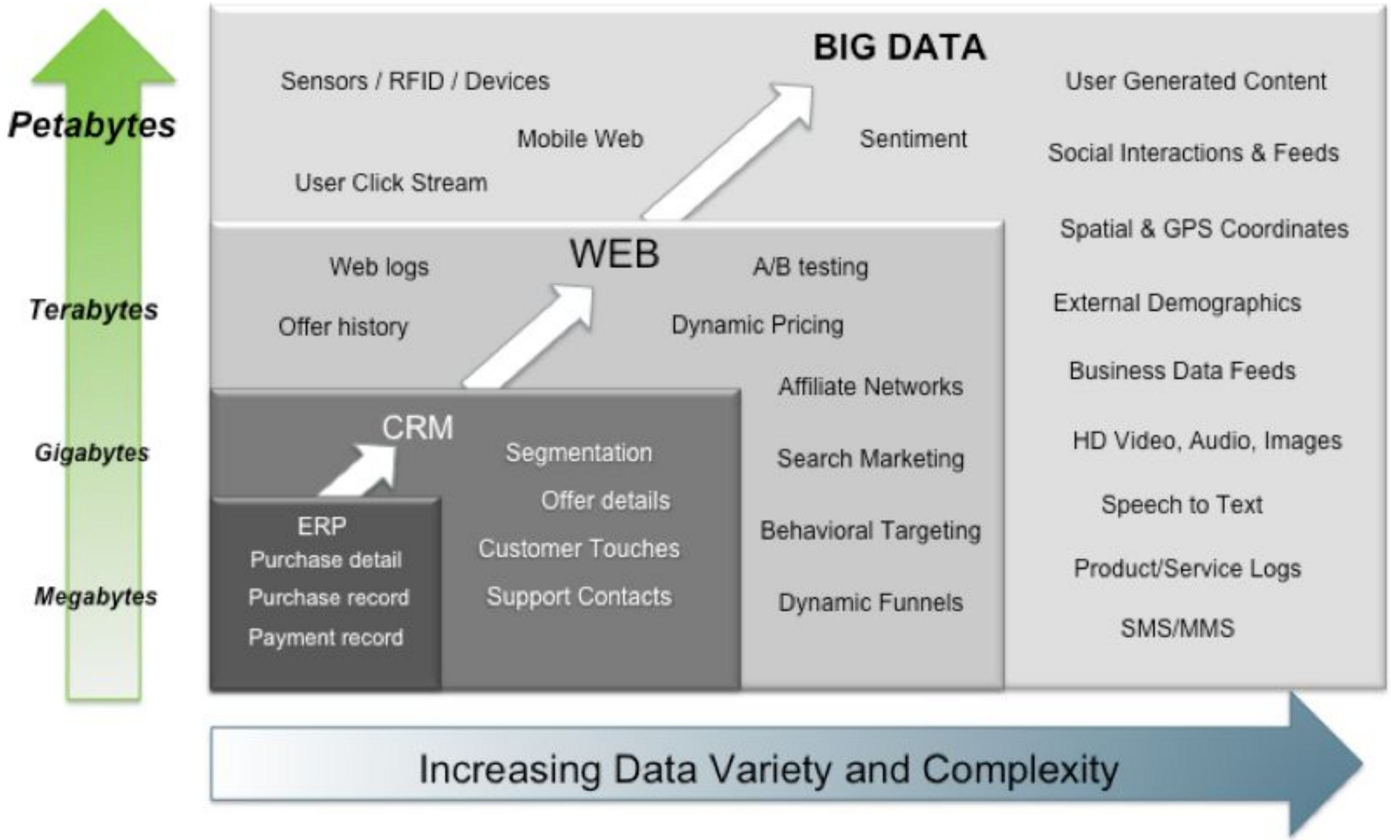
Relational DBMS: Properties

- **Strong foundation**: Relational Model
- **Highly Structured**: rows, columns, data types
- **Structured Query Language**: standardized
- **ACID properties**: all or nothing
- **Joins**: new views from relationships



Changes in scenario: Big Data

- The five (six) V(s) of Big Data:
  - **V**olume
  - **V**elocity
  - **V**ariety
  - **V**ariability
  - **V**eracity
  - (**V**alue)



- Needs for:
  - Flexible schema for variability and veracity **or no schema at all!**
  - Distributed data for volume
  - High availability for velocity

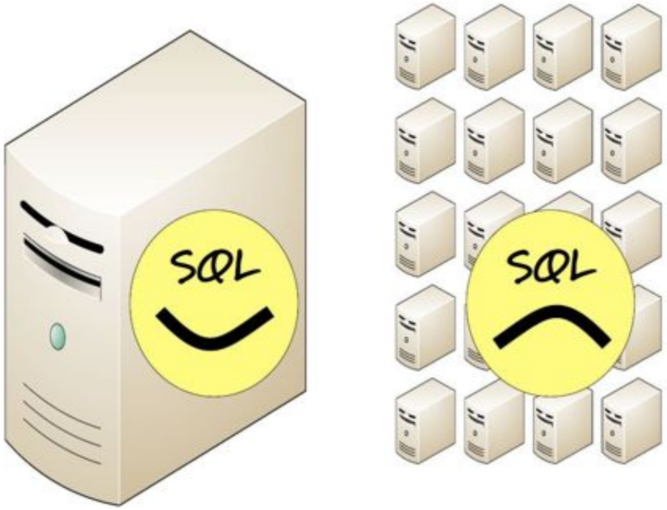
A real example

- A vehicle at the **lower end of the autonomous spectrum** will produce about 3 Gbit/s of data, which amounts to about **1.4 terabytes every hour**
- At **higher levels of autonomy**, the total sensor bandwidth will be closer to 40 Gbit/s and approximately **19 terabytes per hour**
- Over a whole year, a vehicle could generate **434 TB for lower level autonomy** or up to **5,894 TB of data for higher-level autonomy**

[Siemens, The Data Deluge: What do we do with the data generated by AVs?]

Relational DBMS: Weakness

- **Joins**: not scalable
- **Transactions**: read & write operations will be slow because of locking resources
- **Fixed definitions (schema)**: difficult to work with highly variable data
- **Document integration**: difficult create reports based on structured & unstructured data



NoSQL: Why, What and When

- In 2004 Google and Amazon built their own **non-relational** (do not feature primary / foreign keys, JOINs, or relational calculus of any type) databases designed to scale to **petabyte** of data across **thousands of machines** (Google BigTable and Amazon Dynamo)
- In 2008, Facebook releases its own non-relational database, with a design similar to Google BigTable (Cloud NoSQL database service)
- **Other (very) important reasons**: SQL licenses costs for hundreds of thousands machines!
- **#NoSQL was a twitter hashtag** for a conference in 2009
- The name refers to "non SQL", "non relational" or "not only SQL", but it does not indicate its characteristics
- There is **no strict definition** for NoSQL

NoSQL DBMSs

- There are currently more than 225 NoSQL databases systems!
  [source: https://hostingdata.co.uk/nosql-database/]

- We will see now the main differences from relational DBMSs (one or both the following):
  - NoSQL systems are **BASE**: they don’t follow ACID properties
  - NoSQL systems are **schema-less**: they have a non-relational data model (*e.g.,* key-value, document, graph)

NoSQL systems are BASE

Recall ACID

Atomicity

Each transaction is “all or nothing”

Consistency

Data should be valid according to all defined rules

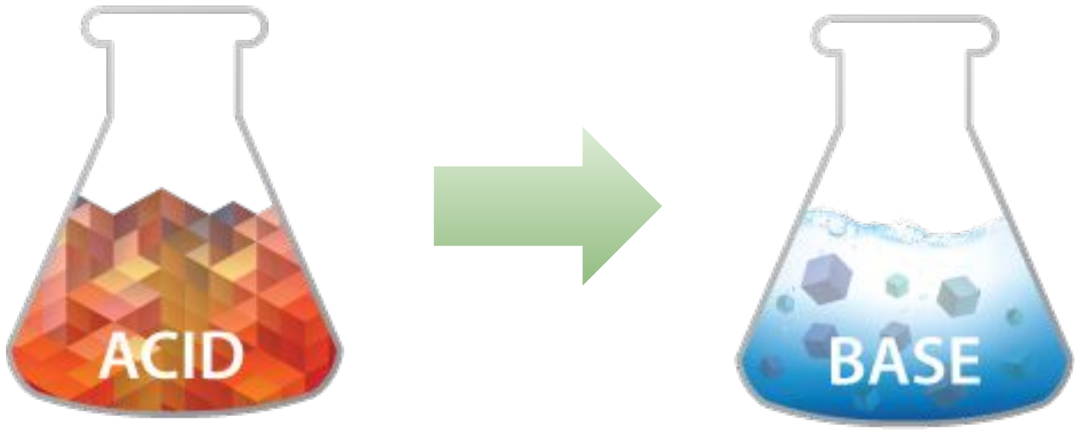
Isolation

Transactions do not affect each other

Durability

Committed data would not be lost, even after power failure.

SQL (ACID properties) vs NoSQL (BASE properties)



- **Basic Availability**: there will be a response to any request (can be failure too)
- **Soft State**: the state of the system could change over time
- **Eventual Consistency**: may be inconsistent in short term, consistent in long term

➢ **It’s OK to use stale data**
➢ **it’s OK to give approximate answers**

Basically Available

- **Basically Available**
  - The system does guarantee the availability of the data as regards CAP Theorem (a.k.a. Brewer's theorem)
  - There will be a response to any request but:
    - That response could still be ‘failure’ to obtain the requested data
    - The data may be in an inconsistent or changing state

Soft state

- **Soft state**
  - The state of the system could change over time
  - Even during times without input there may be changes going on due to ‘eventual’ consistency
  - The state of the system is always ‘soft’

Eventual consistency

- **Eventual consistency**
  - The system will *eventually* become consistent once it stops receiving input
  - The data will propagate to everywhere it should sooner or later
  - The system will continue to receive input in the meantime
  - The system does not check the consistency of every transaction before it moves onto the next one

ACID vs BASE

- **ACID**
  - Strong consistency
  - Less availability
  - Pessimistic concurrency
  - Complex
- **BASE**
  - Availability is the most important thing! Willing to sacrifice other properties for this (like consistency)
  - Weaker consistency (Eventual)
  - Best effort
  - Simple and fast
  - Optimistic
- Why can’t we have both together?
  - A tradeoff exists between consistency, availability, and partition tolerance → **CAP Theorem**

Another view: CAP trade off

- **Consistency** refers to whether a system operates fully or not. Do all nodes within a cluster see all the data they are supposed to? This is the same idea presented in ACID
- **Availability** means just as it sounds. Is the given service or system available when requested? Does each request get a response outside of failure or success?
- **Partition Tolerance** represents the fact that a given system continues to operate even under circumstances of data loss or system failure. A single node failure should not cause the entire system to collapse

- In large scale, distributed, non relational systems, they need availability and partition tolerance, so consistency suffers and ACID collapses

CAP Theorem (or triangle)

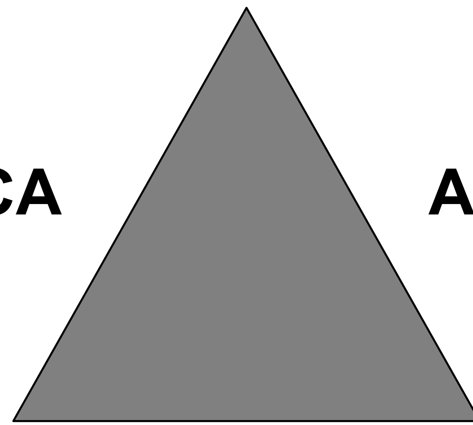
Only **two properties out of three** can be satisfied in the same data model! **Pick any two**

Availability

Each client can always read and write

CA

RDBMS's
SQL Server
Oracle
MySQL etc.



AP

Cassandra,
CouchDB,
Dynamo,
Voldemort

Consistency

All clients always have the same view of data

CP

BigTable, MongoDB,
BerkleyDB,
MemcacheDB,
Hbase etc

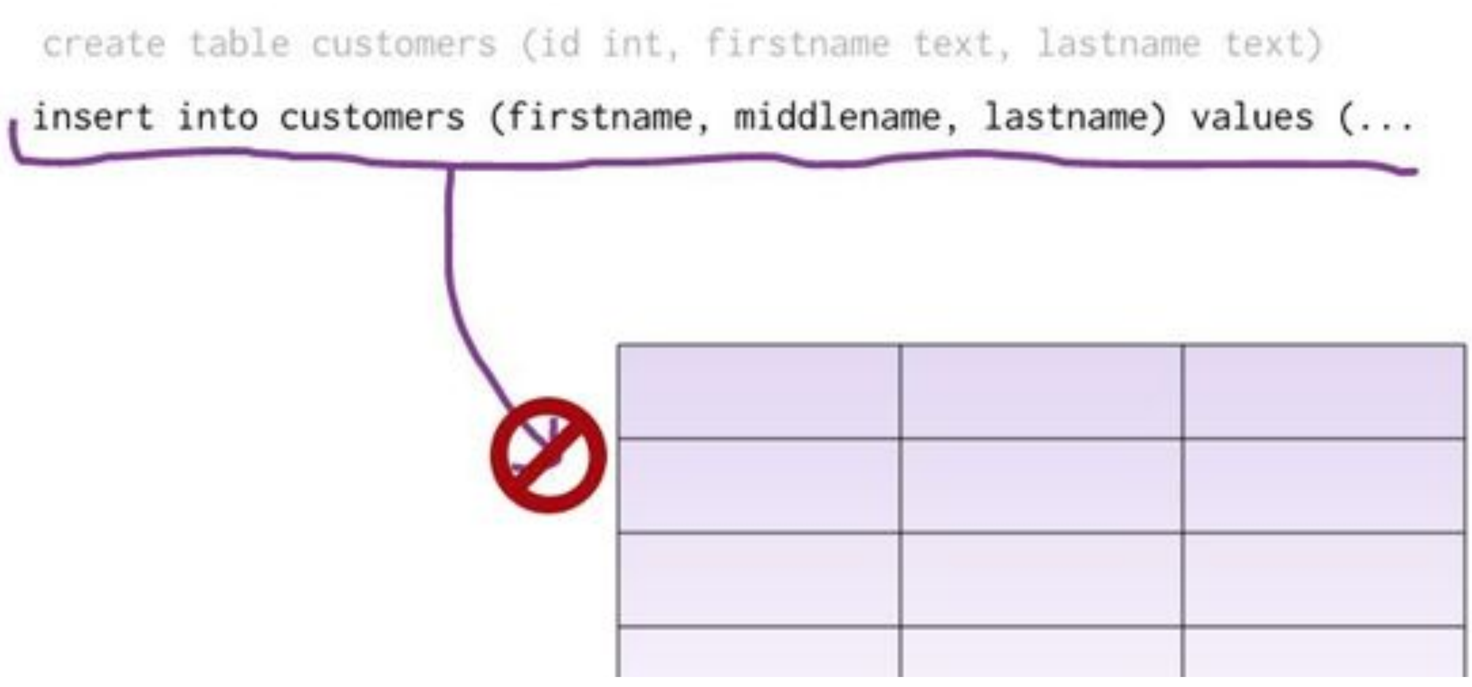
Partition Tolerance

The system works well despite physical network partitions

NoSQL systems are schema-less

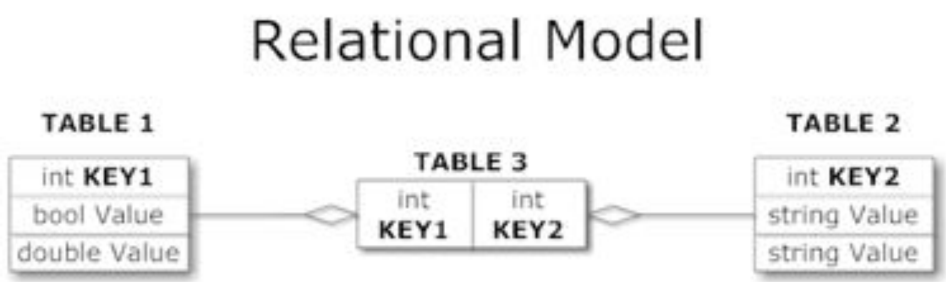
Relational vs Schema-less 1/2

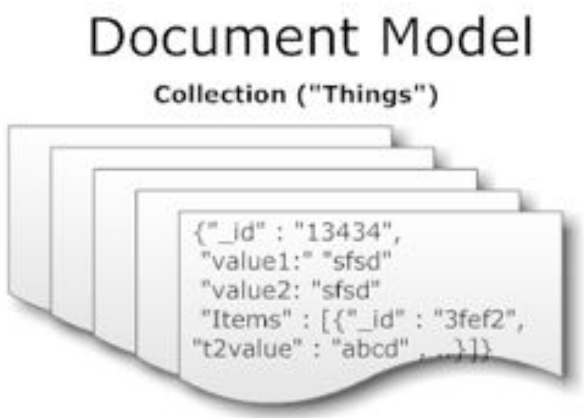
- In relational Databases:
  - You can’t add a record which does not fit the schema
  - You need to add NULLs to unused items in a row
  - We should consider the data types, i.e. you can’t add a string to an integer field
  - You can’t add multiple items in a field (you have to create another table: primary-key, foreign key, joins, normalization, ... !!!)



Relational vs Schema-less 2/2

- In NoSQL Databases:
  - There is no schema to consider
  - There is no unused cell
  - There is no datatype (implicit)
  - Most of considerations are done at the *application layer*
  - We gather all items in an aggregate (document)

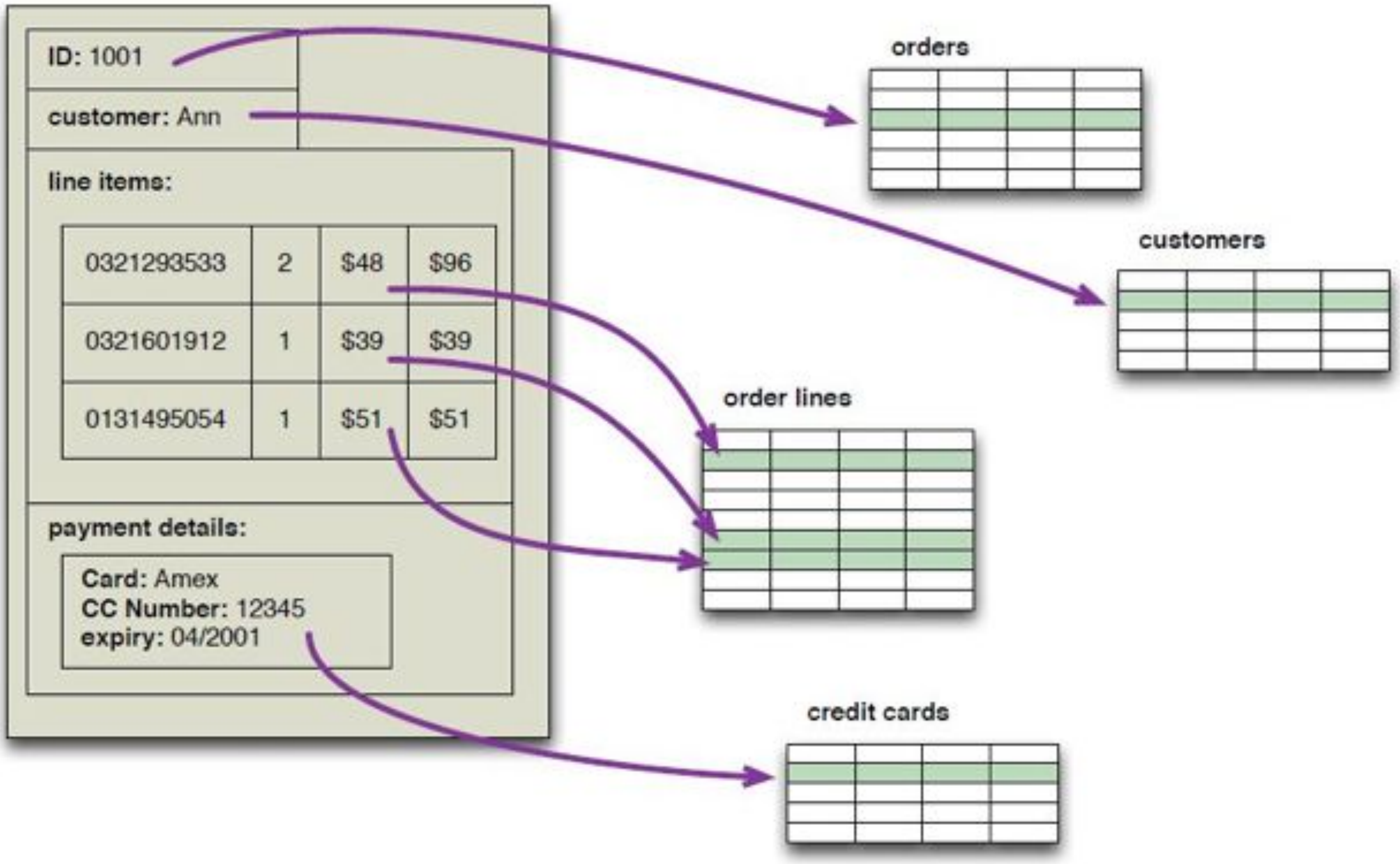




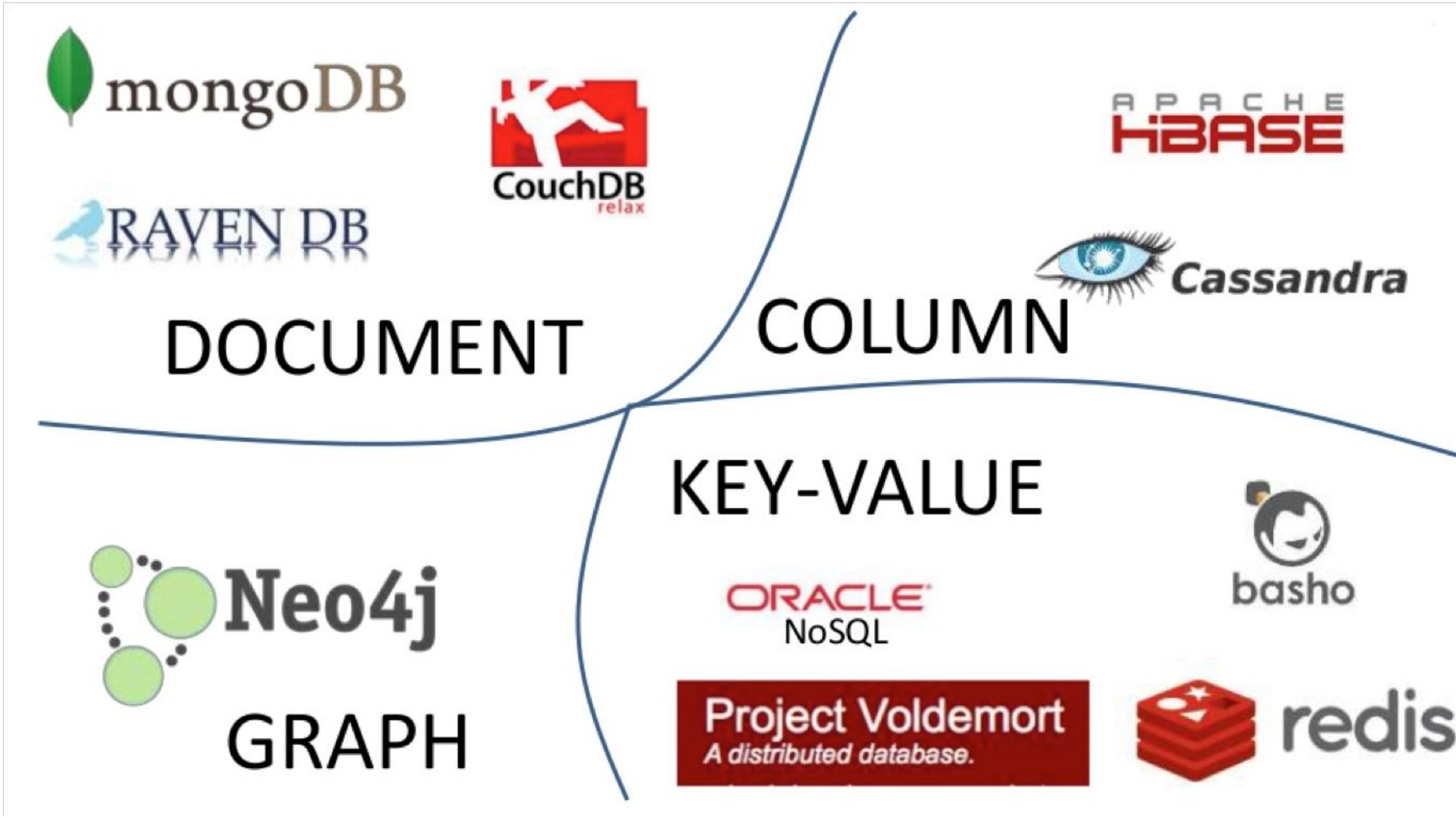
Aggregation

- The term comes from Domain-Driven Design
- An aggregate is a cluster of domain objects that can be treated as a single unit
  - For example, a web document is an aggregate with a title, a body, an image inside the body with its caption etc.
- Aggregates are the basic element of transfer of data storage: you request to load or save whole aggregates
- Transactions should not cross aggregate boundaries
- This mechanism reduces the join operations to a minimal level
  - Related things are already together

Aggregated vs Relational

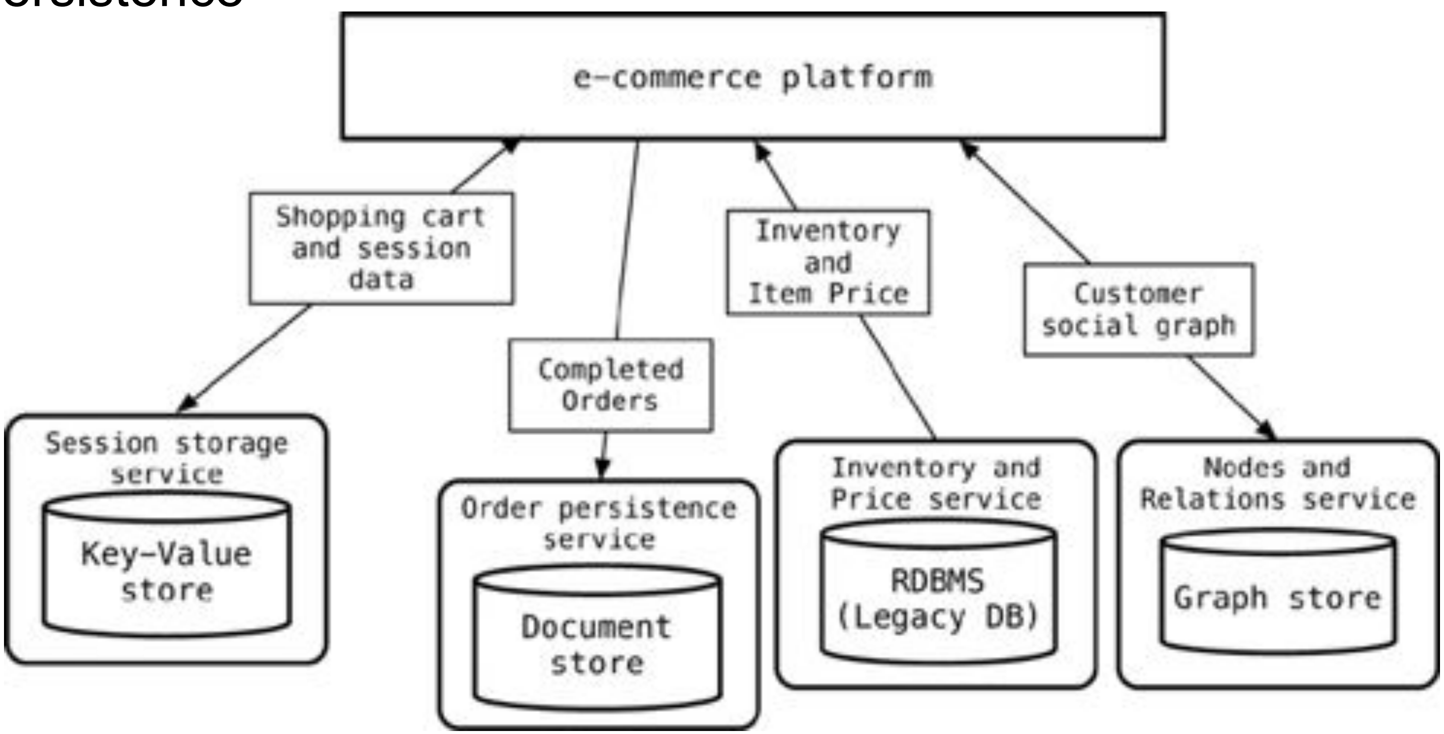


Different types of NoSQL (data models)



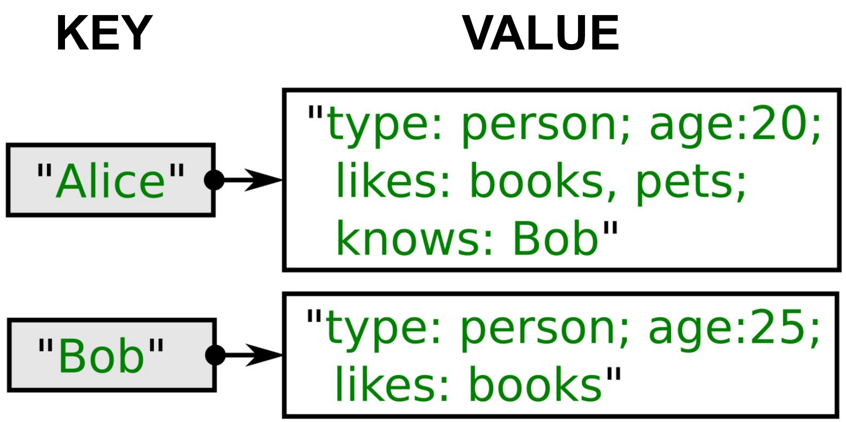
Why many models?

- Different data models are designed to solve different problems
  - Different kind of data
  - Different needs of access (temporary, very fast, historical)
- Using single database engine for all the requirements leads to non-performant solutions
- The solution is **polyglot persistence**: a hybrid approach to data persistence



Key-value data model

- **Key-value**: A very simple structure. Sets of named keys and their value(s), typically an uninterpreted chunk of data
  - Sometimes that simple value may in fact be a JSON or binary document
- Can be in memory only, or be backed by disk persistence
- Designed to handle massive data loads
- Supports versioning
- Examples:
  - Voldemort (LinkedIn)
  - Amazon SimpleDB
  - Redis
  - Memcache
  - BerkleyDB
  - Oracle NoSQL



Key-value main idea

- Data model: (key, value) pairs
- Access data (values) by strings called keys
- The main idea is the use of a hash table
- Data has no required format – data may have any format
- Basic Operations:
  - *Insert(key,value)*
  - *Fetch(key)*
  - *Update(key,value)*
  - *Delete(key)*

Car	
Key	Attributes
1	Make: Nissan Model: Pathfinder Color: Green Year: 2003
2	Make: Nissan Model: Pathfinder Color: Blue Color: Green Year:2005 Transmission: Auto

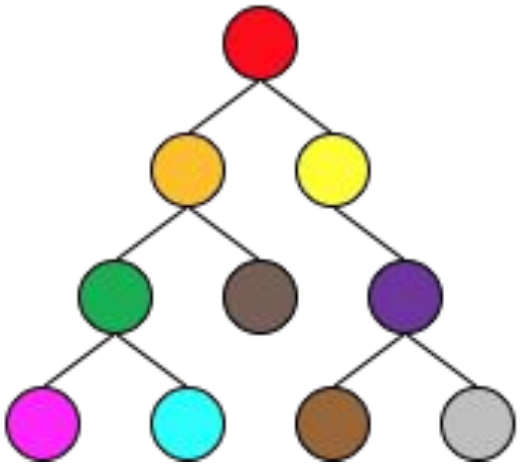
Key-value store in practice

- "Value" is stored as a "blob"
  - Without caring or knowing what is inside, or how long it is
  - **Application is responsible for understanding the data**

- Main observation from Amazon (using Dynamo)
  - "There are many services on Amazon's platform that only need primary-key access to a data store."
  - *e.g.,* Best seller lists, shopping carts, customer preferences, session management, sales rank, product catalog

Document data model

- **Document**: XML, JSON, text, or binary blob
- Any treelike structure can be represented as an XML or JSON document, including things such as an order that includes a delivery address, billing details, and a list of products and quantities
- Similar to Key-value, except value is a document!
- Examples:
  - Couchbase
  - MongoDB
  - RavenDB
  - ArangoDB
  - MarkLogic
  - OrientDB
  - Redis
  - RethinkDB



Document is a tree-like hierarchical structure

Data model: Relational to Document

Relational

Person:

Pers_ID	Surname	First_Name	City
0	Miller	Paul	London
1	Ortega	Alvaro	Valencia
2	Huber	Urs	Zurich
3	Blanc	Gaston	Paris
4	Bertolini	Fabrizio	Rom

no relation

Car:

Car_ID	Model	Year	Value	Pers_ID
101	Bentley	1973	100000	0
102	Rolls Royce	1965	330000	0
103	Peugeot	1993	500	3
104	Ferrari	2005	150000	4
105	Renault	1998	2000	3
106	Renault	2001	7000	3
107	Smart	1999	2000	2

MongoDB Document

```
{
  first_name: 'Paul',
  surname: 'Miller'
  city: 'London',
  location: [45.123,47.232],
  cars: [
    { model: 'Bentley',
      year: 1973,
      value: 100000, … },
    { model: 'Rolls Royce',
      year: 1965,
      value: 330000, … }
  ]
}
```

Example: SQL vs MongoDB

RDBMS		MongoDB
Database	↔	Database
Table	↔	Collection
Row	↔	Document
Index	↔	Index
JOIN	↔	Embedded / Reference

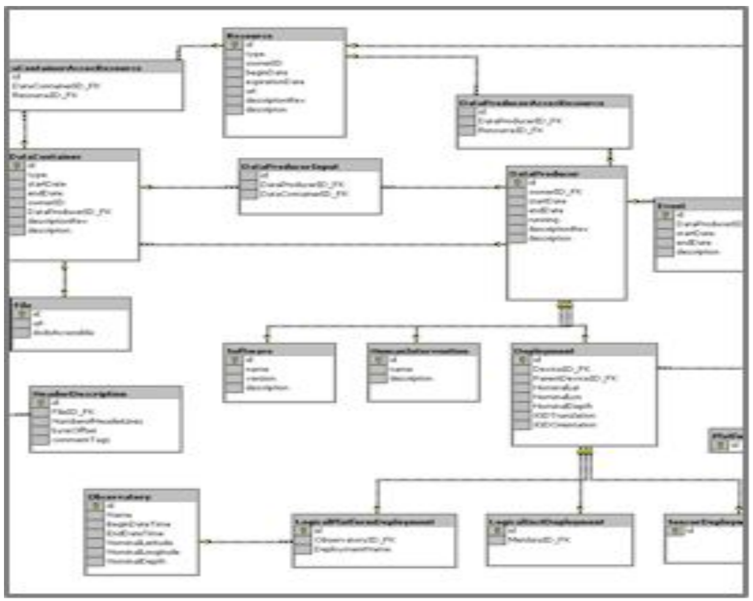
Document Model Benefits

- Rich data model, natural data representation
  - Embed related data in sub-documents & arrays
  - Support indexes and rich queries against any element
- Data aggregated to a single structure (pre-JOINed)
  - Programming becomes simple
  - Performance can be delivered at scale
- Dynamic schema
  - Data models can evolve easily
  - Adapt to changes quickly: agile methodology

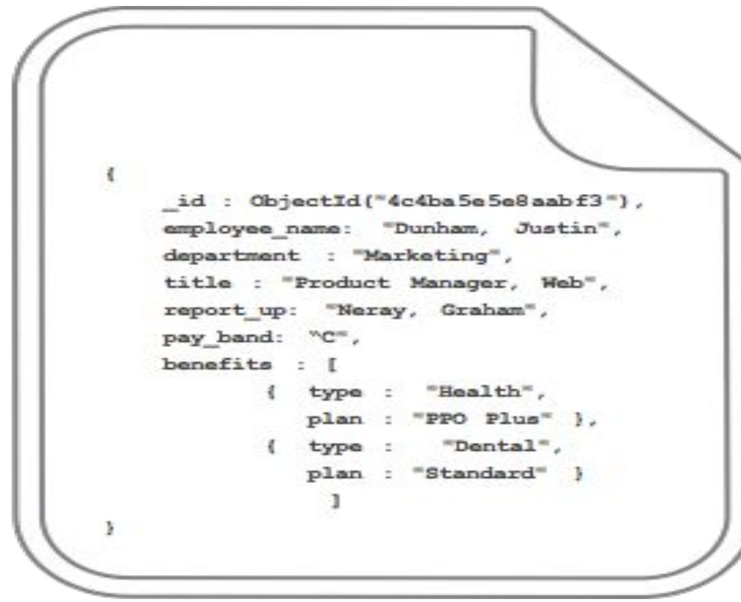
Join vs Aggregate

- Complex objects are maintained in a single place, not across tables

Relational

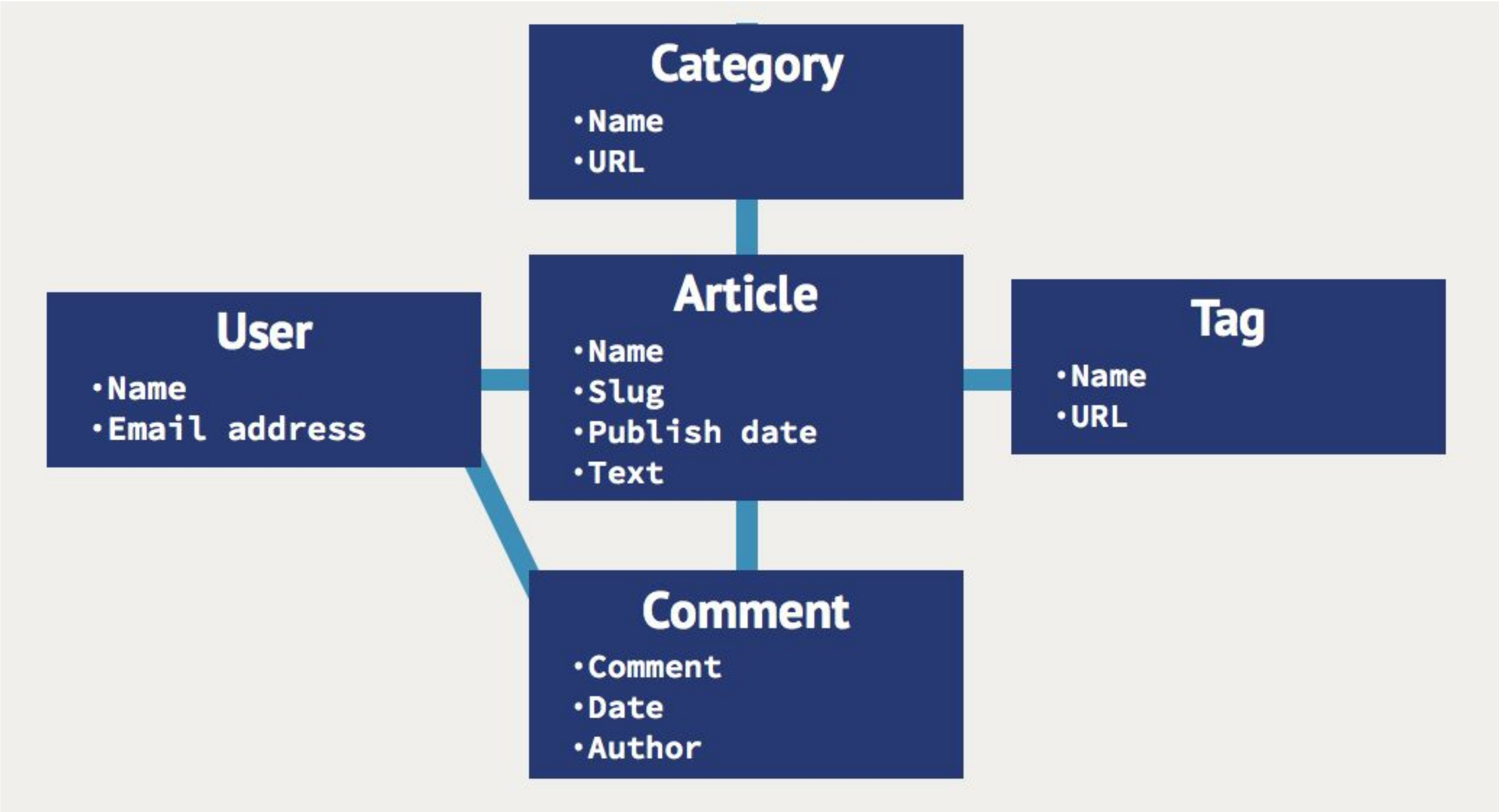


Document Model



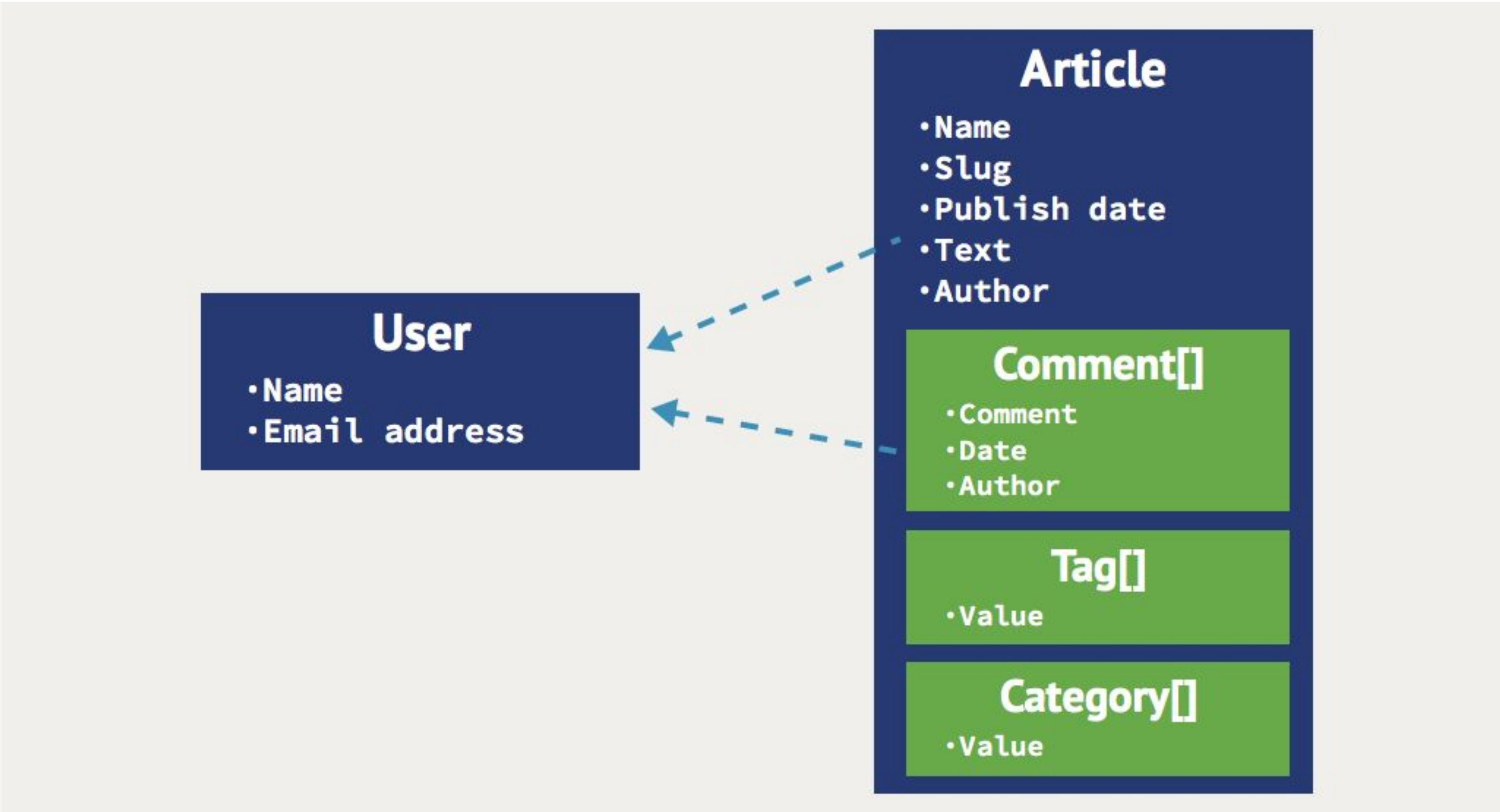
- Schema-less models do not need beforehand design!

Example: Blogging Platform (Relational)



- Join between 5 table is needed!

Example: Blogging Platform (Document model)



- Higher Performance: Data Locality

Relational vs Document model: Operations

Application	Relational model Action	Document model Action
Create Product Record	**INSERT** to **(n)** tables (product description, price, manufacturer, etc.)	**insert()** to 1 document with sub-documents, arrays
Display Product Record	**SELECT** and **JOIN** (n) product tables	**find()** aggregated document
Add Product Review	**INSERT** to "review" table, foreign key to product record	**insert() to "**review" collection, reference to product document

Columnar data model 1/3

- Columnar data models store tables by columns of data instead of by rows of data

ID	Last	First	Bonus
1	Doe	John	8000
2	Smith	Jane	4000
3	Beck	Sam	1000

ROW-BASED	COLUMN-BASED

`1,Doe,John,8000;`
`2,Smith,Jane,4000;`
`3,Beck,Sam,1000;`
	`1,2,3;`
	`Doe,Smith,Beck;`
	`John,Jane,Sam;`
	`8000,4000,1000;`

Columnar data model 2/3

- **Columnar**: extension to traditional table structures
- Supports variable sets of columns (column families) and is optimized for column-wide operations (such as count, sum, and mean average)
- Compression: column data is of uniform type
- Multiple values (columns) per key
- Examples:
  - Cassandra
  - Hbase
  - Amazon Redshift
  - HP Vertica
  - Teradata

Columnar data model 3/3

- The column is lowest/smallest instance of data
- It is a tuple that contains a key, a value and a timestamp

<table>
<tr><th colspan="3">ColumnFamily: Authors</th></tr>
<tr><th>Key</th><th colspan="2">Value</th></tr>
<tr><td rowspan="5">"Eric Long"</td><td colspan="2">Columns</td></tr>
<tr><td>Name</td><td>Value</td></tr>
<tr><td>"email"</td><td>"eric (at) long.com"</td></tr>
<tr><td>"country"</td><td>"United Kingdom"</td></tr>
<tr><td>"registeredSince"</td><td>"01/01/2002"</td></tr>
<tr><td rowspan="5">"John Steward"</td><td colspan="2">Columns</td></tr>
<tr><td>Name</td><td>Value</td></tr>
<tr><td>"email"</td><td>"john.steward (at) somedomain.com"</td></tr>
<tr><td>"country"</td><td>"Australia"</td></tr>
<tr><td>"registeredSince"</td><td>"01/01/2009"</td></tr>
<tr><td rowspan="5">"Ronald Mathies"</td><td colspan="2">Columns</td></tr>
<tr><td>Name</td><td>Value</td></tr>
<tr><td>"email"</td><td>"ronald (at) sodeso.nl"</td></tr>
<tr><td>"country"</td><td>"Netherlands, The"</td></tr>
<tr><td>"registeredSince"</td><td>"01/01/2010"</td></tr>
</table>

Columnar data model: Performance

- Some statistics about Facebook Search (using Cassandra)

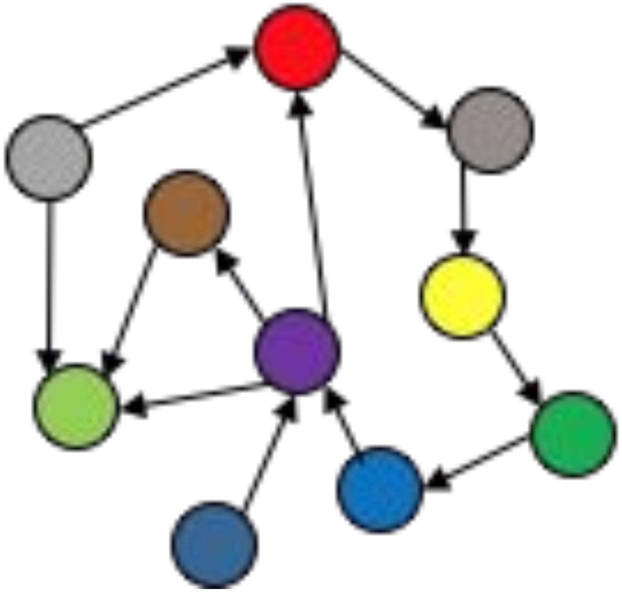
MySQL > 50 GB Data
Writes average: ~300 ms
Reads average: ~350 ms

Rewritten with Cassandra > 50 GB Data
Writes average: 0.12 ms
Reads average: 15 ms

Cassandra is 2500x faster!

Graph data model

- **Graph**: structure of data is graph based
- Uses Property Graph data model (Nodes, Relationships, properties)
- Based on Graph Theory
- Scale vertically, no clustering
- You can use graph algorithms easily
- ACID-compliant transactions
- Examples:
  - Neo4j
  - InfiniteGraph
  - OrientDB
  - Titan GraphDB



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- **Distributed Systems: Concepts and Design** (5th Edition) (2011) - Coulouris, George; Jean Dollimore; Tim Kindberg; Gordon Blair. Boston: Addison-Wesley. ISBN 0-132-14301-1