Distributed Architecture, Interaction, and Data Models

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Ack:

Some slides are based on previous lectures in SS 2013-2015

Outline

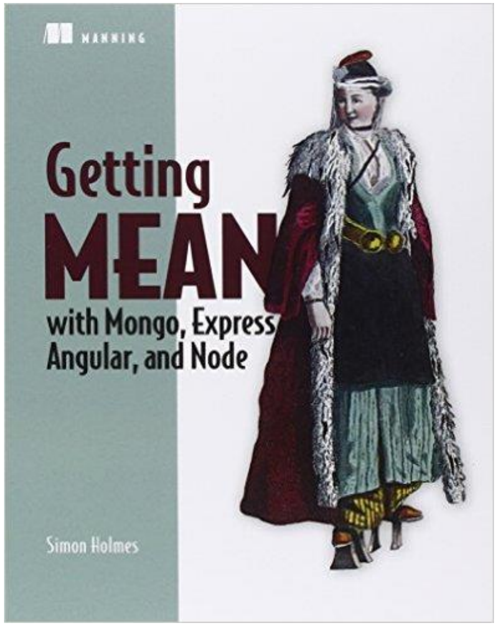
- Overview
- Key design concepts
- Architecture styles and Interaction Models
- Data models
- Optimizing interactions
- Summary

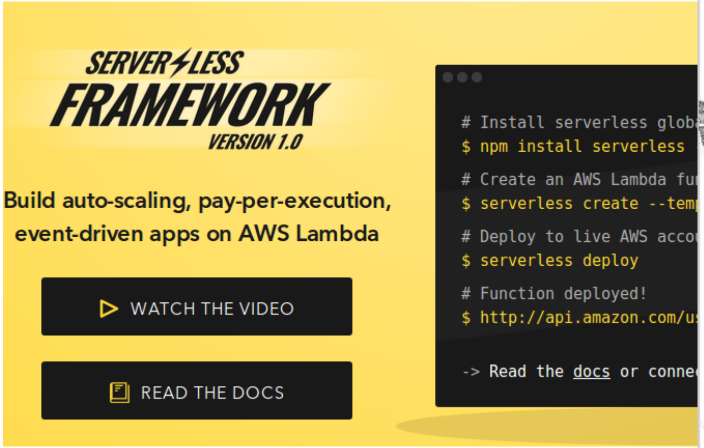
DST Lectures versus Labs

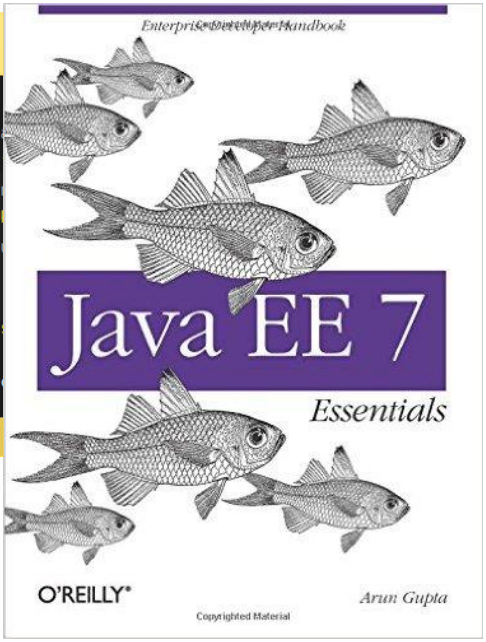
- Cover some important topics in the current state-of-the-art of distributed systems technologies
  - We have focusing topics
- Few important parts of the techniques for your labs
  - Most techniques you will learn by yourself
- Stay in the concepts: no specific implementation or programming languages

DST Lectures versus Labs

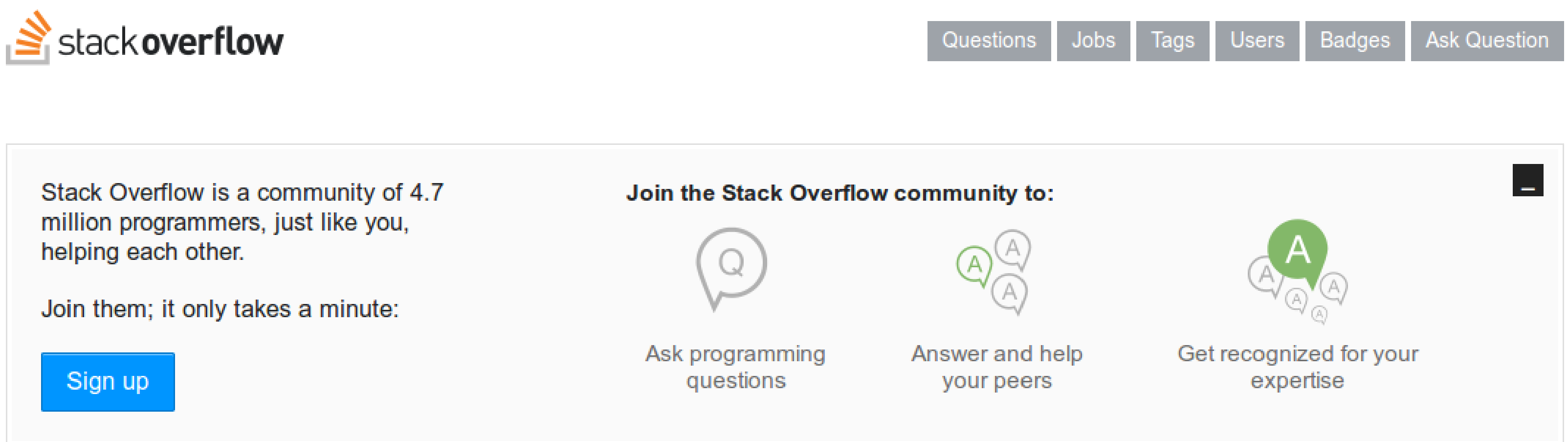
- It is not about Java or Enterprise Java Beans!
  - The technologies you learn in the lectures are for different applications/systems







Have some programming questions?



slack

Or send the questions to the tutors

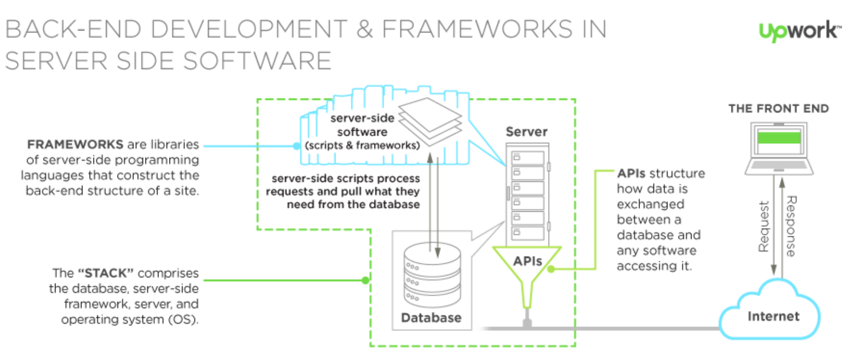
Where is our focus?

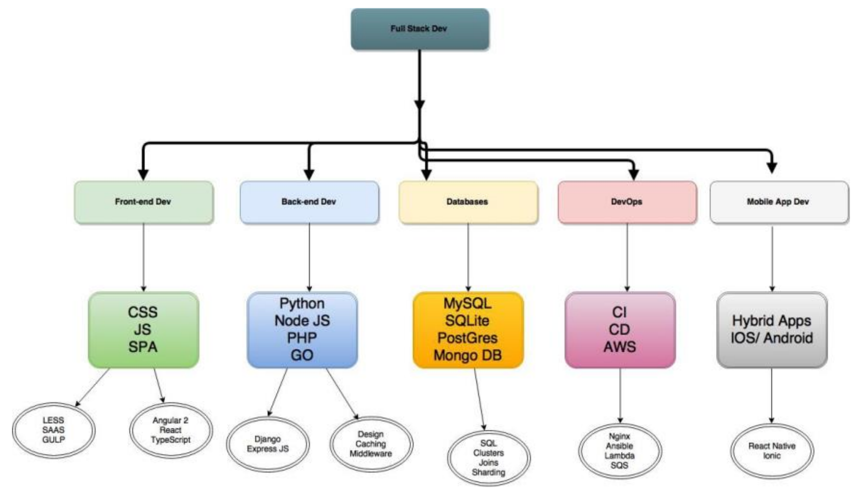
Backend versus front-end

Figure source - https://www.upwork.com/hiring/development/a-beginners-guide-to-back-end-development/

Full stack developer

Figure source - https://medium.com/dev-bits/why-full-stack-development-is-too-good-for-you-in-2017-3fd6fe207b34





DST topics: Backend services in multi-cloud environments

DST topics: Communications with Front-end

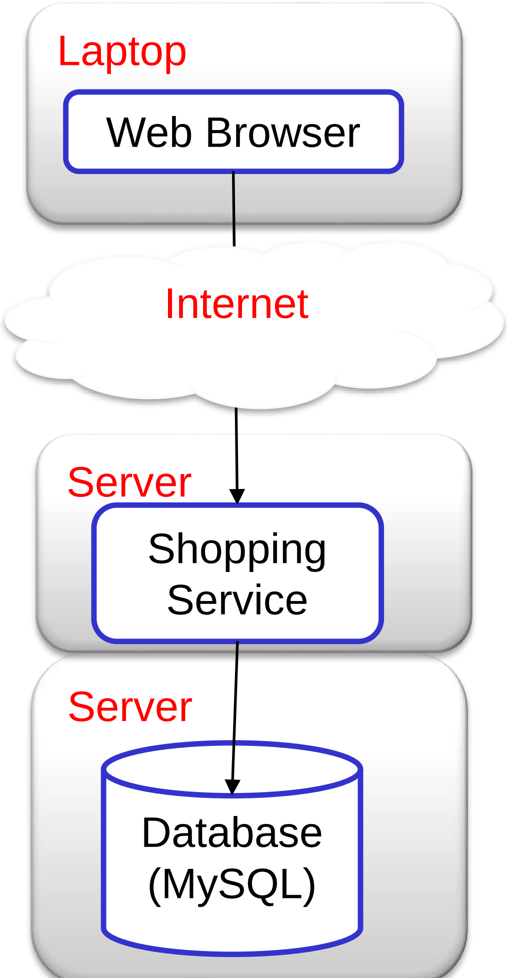
Non DST topics Front-end

TRENDS & KEY DESIGN CONCEPTS

Rapid changes in application requirements and technologies for distributed applications

- On-premise servers → public clouds and on-premise clouds
- Static, small infrastructures → large-scale virtualized dynamic infrastructures
- Heavy monolithic services → microservices
- Server → Serverless Architecture
- Data → Data, Data and Data

A not so complex distributed application



Technologies

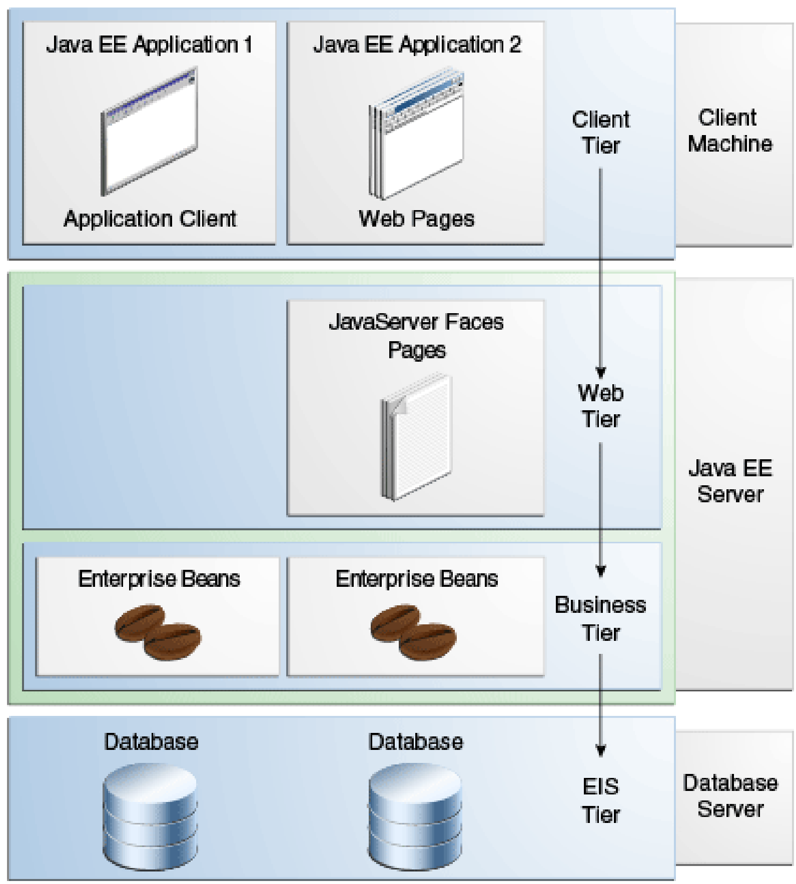


Figure source: https://docs.oracle.com/javaee/7/tutorial/overview003.htm

Distribution

Figure source: http://drbacchus.com/files/serverrack.jpg

A complex, large-scale distributed system

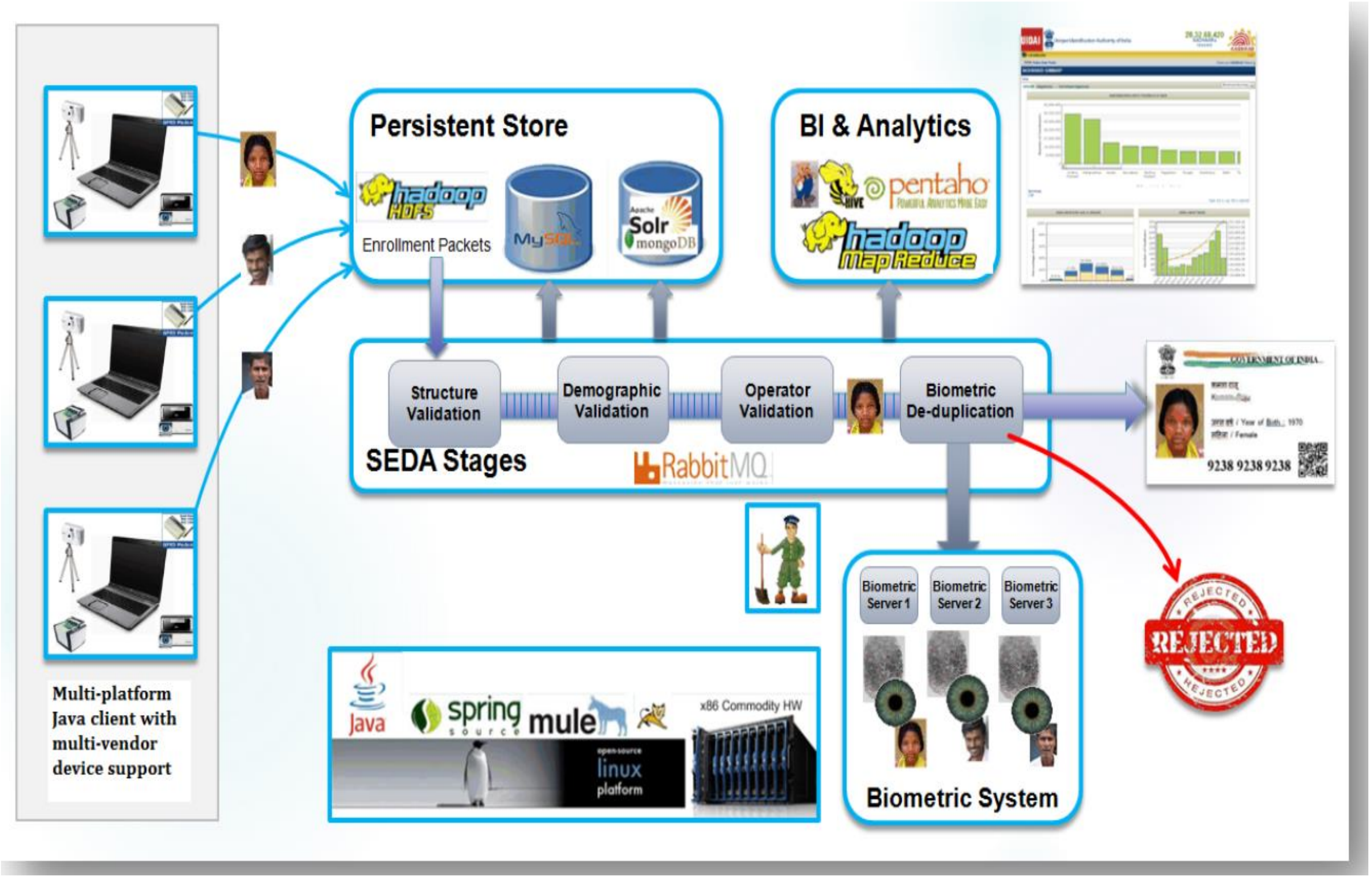


Figure source: http://uidai.gov.in/images/AadhaarTechnologyArchitecture_March2014.pdf

What we have to do?

System/application business logic

- Data
- Communication
- Processing
- Visualization
- Routing
- Load balancing
- Monitoring & Logging
- Etc.

Deliver ←

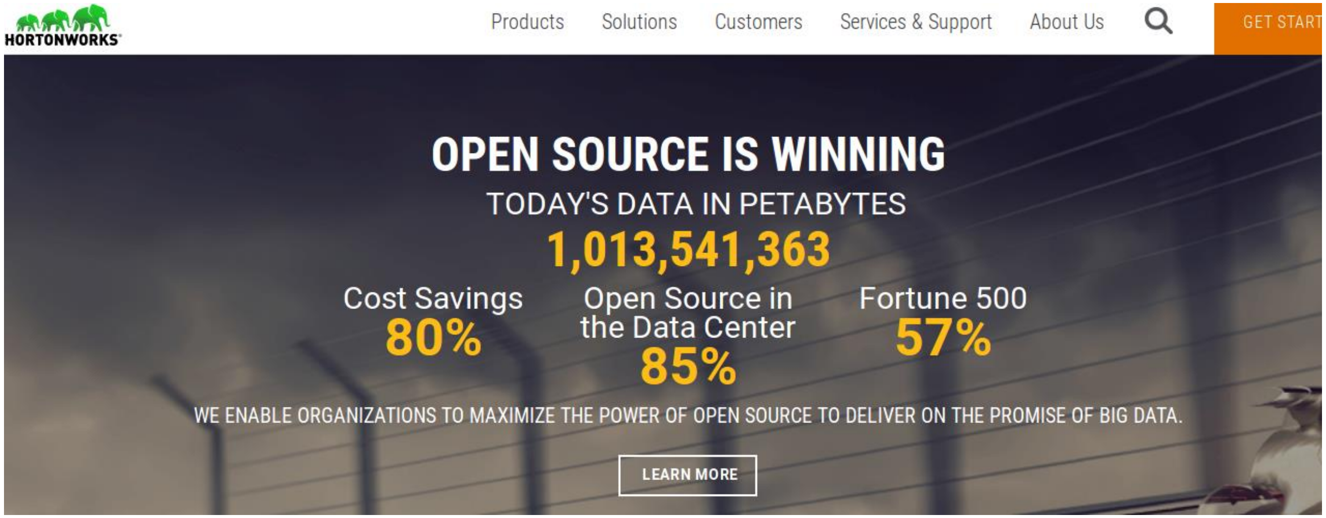
Development and operation tasks

- Development
- Deployment
- Testing
- Monitoring
- Performance analysis
- Teamwork

selecting the right technologies as well as design methodologies

Understand the requirements

- **Data**
  - Structured, semi-structured or unstructured data?
  - Do we need data being persistent for several years?
  - Is accessed concurrently (from different applications)?
  - Mostly read or write operations?
- **Data intensive or computation intensive application**



This course is not about big data but distributed applications today have to handle various types of data at rest and in motion!

Understand the requirements

- **Physically distributed systems**
  - Different clients and back-ends
  - On-premise enterprise or cloud systems?
- **Complex business logics**
  - Complexity comes from the domain more than from e.g., the algorithms
- **Integration with existing systems**
  - E.g., need to interface with legacy systems or other applications
- **Scalability and performance limitation**
- **Etc.**

How do we build distributed applications

- Using fundamental concepts and technologies
  - Abstraction: make complicated things simple
  - Layering, Orchestration, and Chorography: put things together
  - Distribution: where and how to deploy
- Using best practice design and performance patterns
- Principles, e.g., Microservices Approach

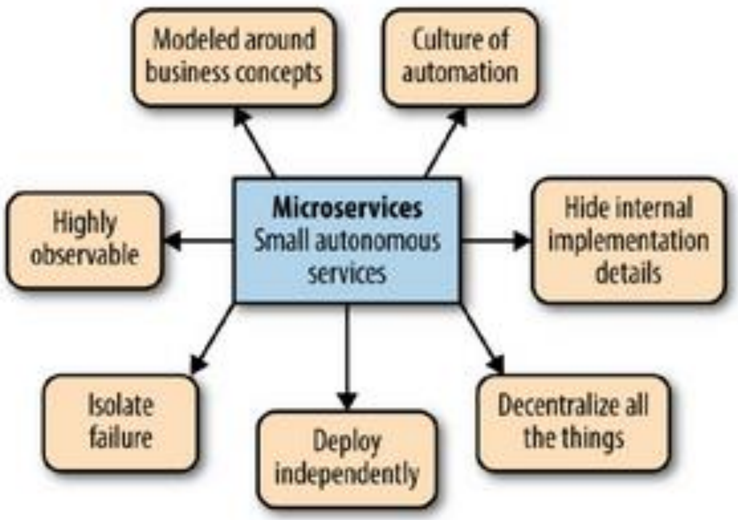


Figure source:Sam Newman, Building Microservices, 2015

Abstraction

Deal with technical complexity by hiding it behind clear simple interfaces

- APIs abstracting complex communications and interactions
- Interfaces abstracting complex functions implementation

Layering

Deal with maintainability by logically structuring applications into functionally cohesive blocks

Benefits of Layering

- You can understand a single layer without knowing much about other layers
- Layers can be substituted with different implementations
- Minimized dependencies between layers
- Layers can be reused

Downsides of Layering

- Layers don't encapsulate all things well: do not cope with changes well.
- Extra layers can create performance overhead
- Extra layers require additional development effort

Examples: abstraction and layering side-by-side

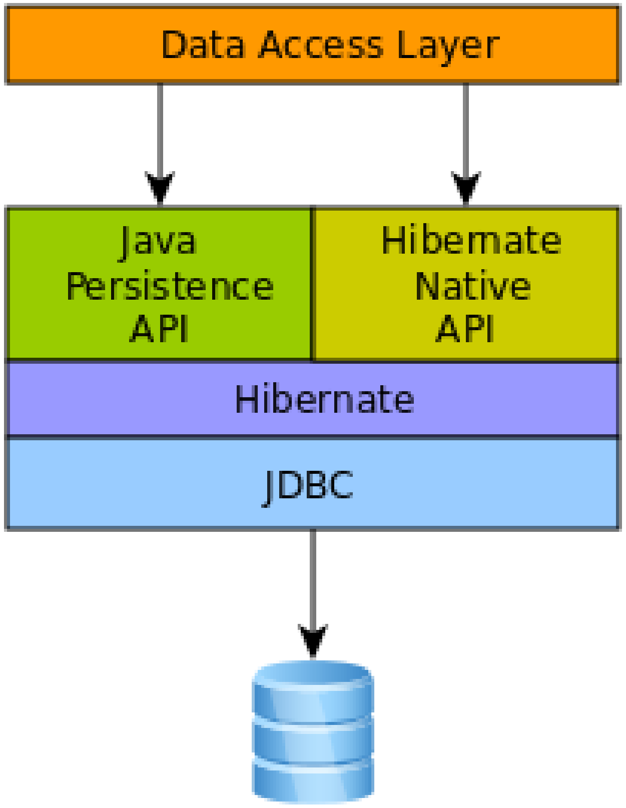


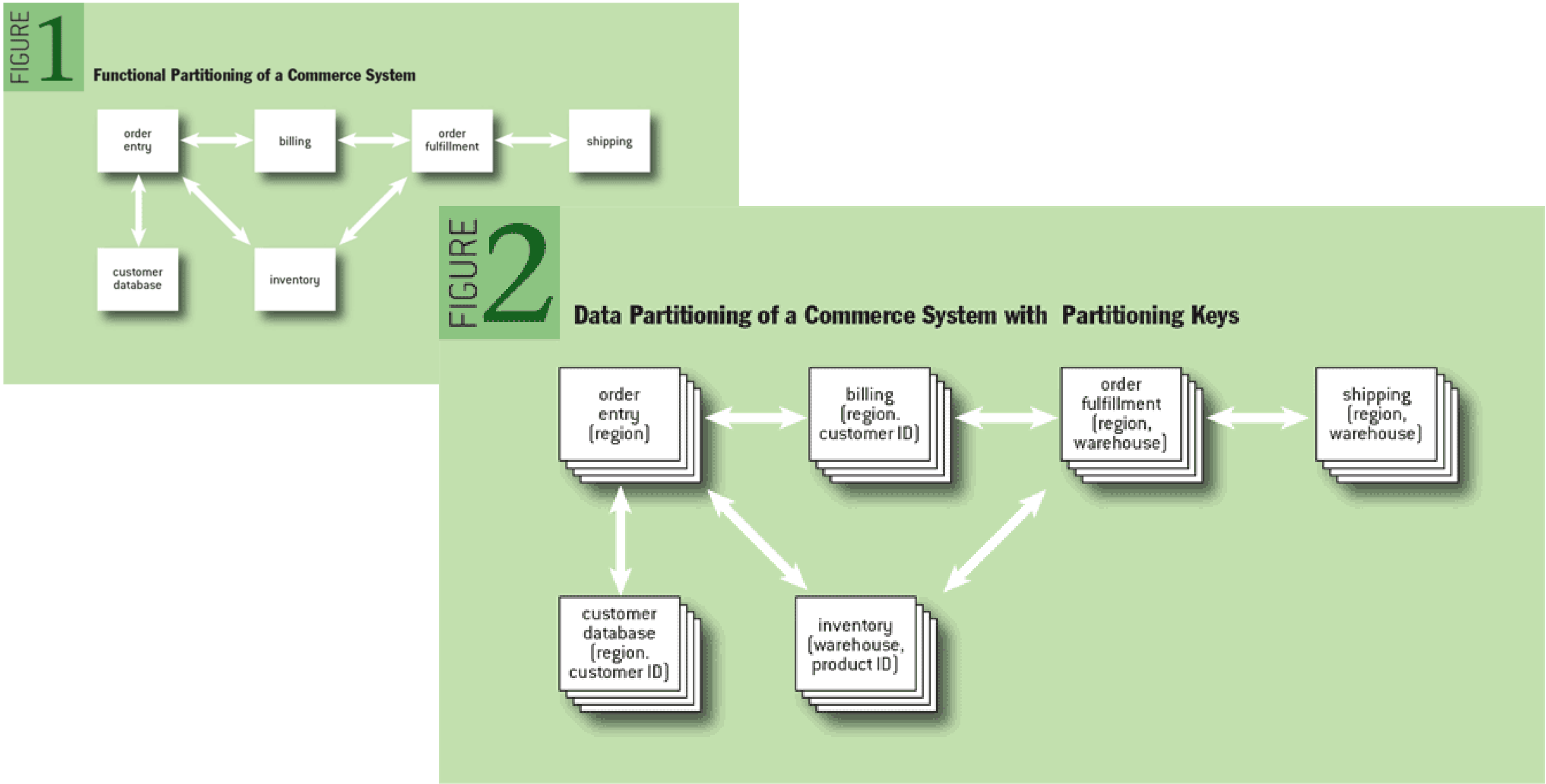
Figure source: http://docs.jboss.org/hibernate/orm/5.1/userguide/html_single/Hibernate_User_Guide.html

Partitioning functionality & data

- Why?
  - Breakdown the complexity
  - Easy to implement, replace, and compose
  - Deal with performance, scalability, security, etc.
  - Support teams in DevOps
  - Cope with technology changes

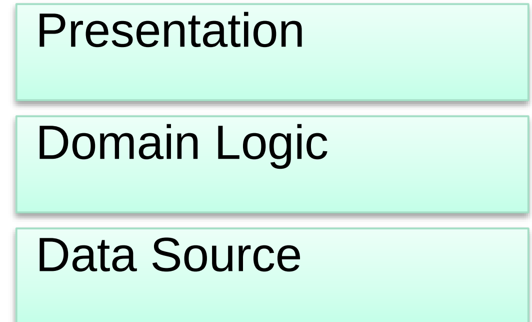
Enable abstraction and layering/orchestration, and distribution

Example of functional and data partitioning



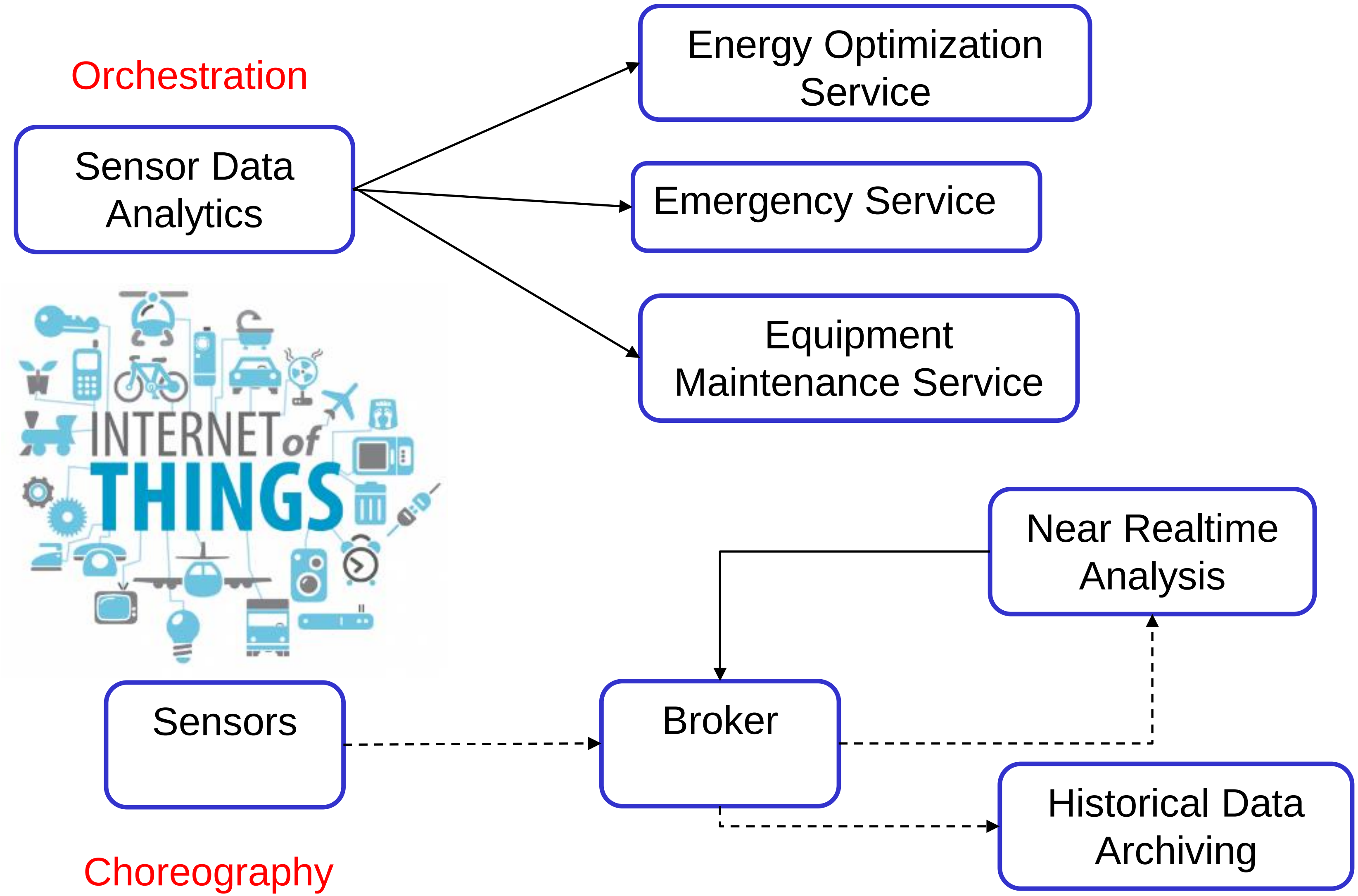
Figures source: http://queue.acm.org/detail.cfm?id=1971597

Partitioning functionality: 3-Layered Architecture



- **Presentation**
  - Interaction between user and software
- **Domain Logic** (Business Logic)
  - Logic that is the real point of the system
  - Performs calculations based on input and stored data
  - Validation of data, e.g., received from presentation
- **Data Source**
  - Communication with other systems, usually mainly databases, but also messaging systems, transaction managers, other applications, ...

Orchestration and Choreography



Distribution: where to run the layers?

More in lecture 4

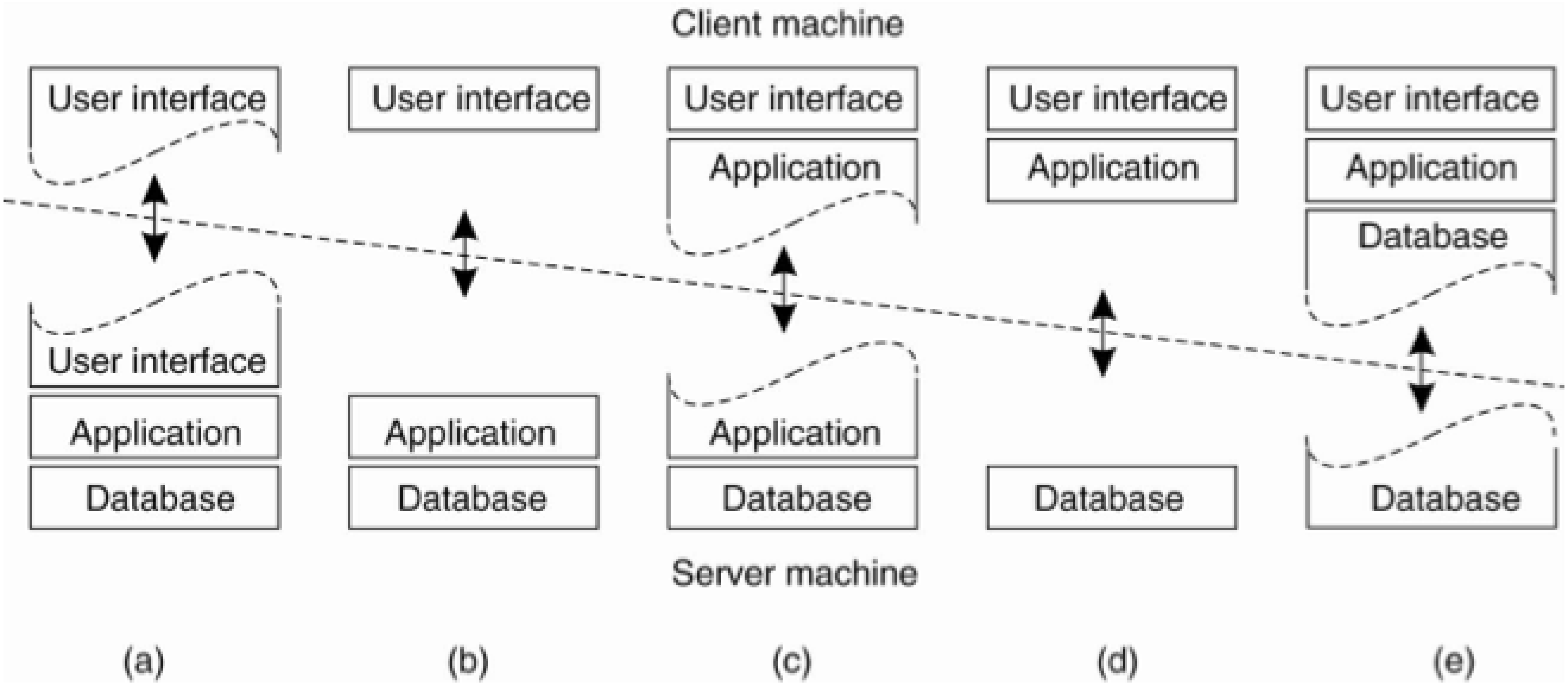
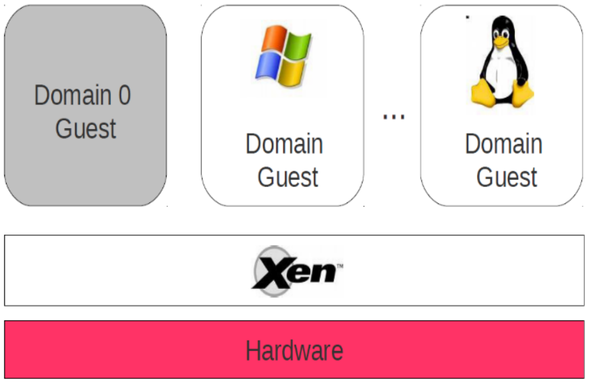
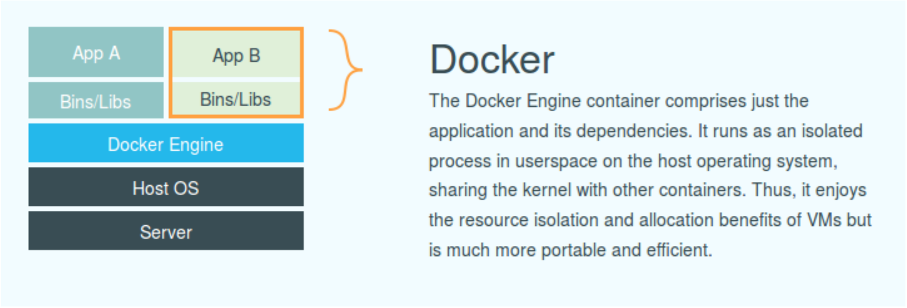


Figure source: Andrew S. Tanenbaum and Maarten van Steen, Distributed Systems – Principles and Paradigms, 2nd Edition, 2007, Prentice-Hall

Distribution: OS, VM, Container, or Function-as-a-Service?

Source: The XEN Hypervisor (http://www.xen.org/)





Distribution: edge systems, core network backbone or data centers?

Figure source: https://techcrunch.com/2018/02/08/chinese-police-are-getting-smart-glasses/

Use Case 3: Video Analytics

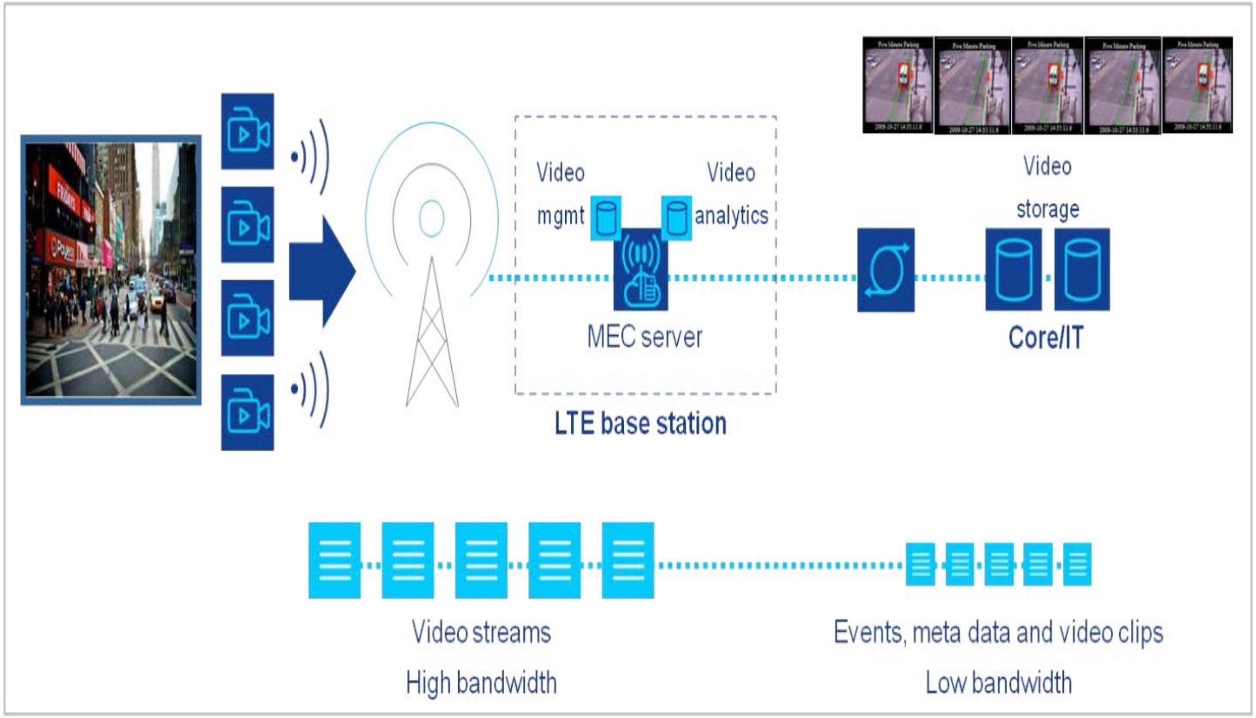
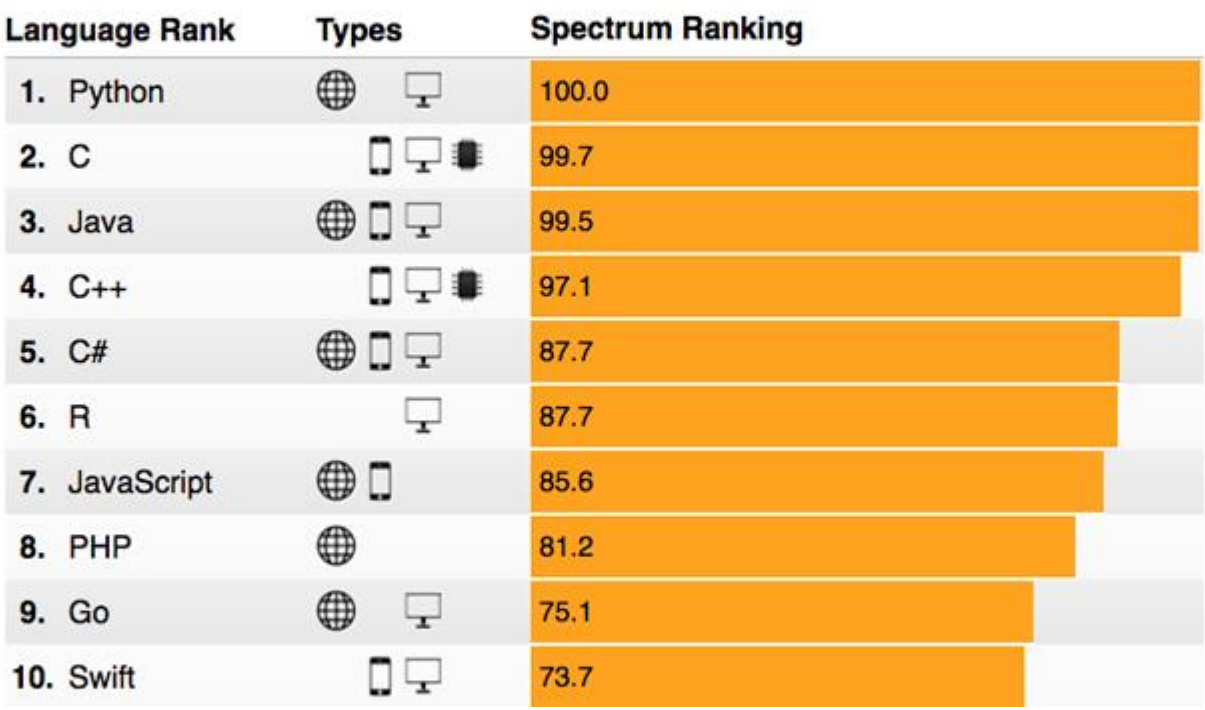


Figure 4: Example of video analytics

Figure source: https://portal.etsi.org/portals/0/tbpages/mec/docs/mobile-edge_computing_-_introductory_technical_white_paper_v1%2018-09-14.pdf

Programming

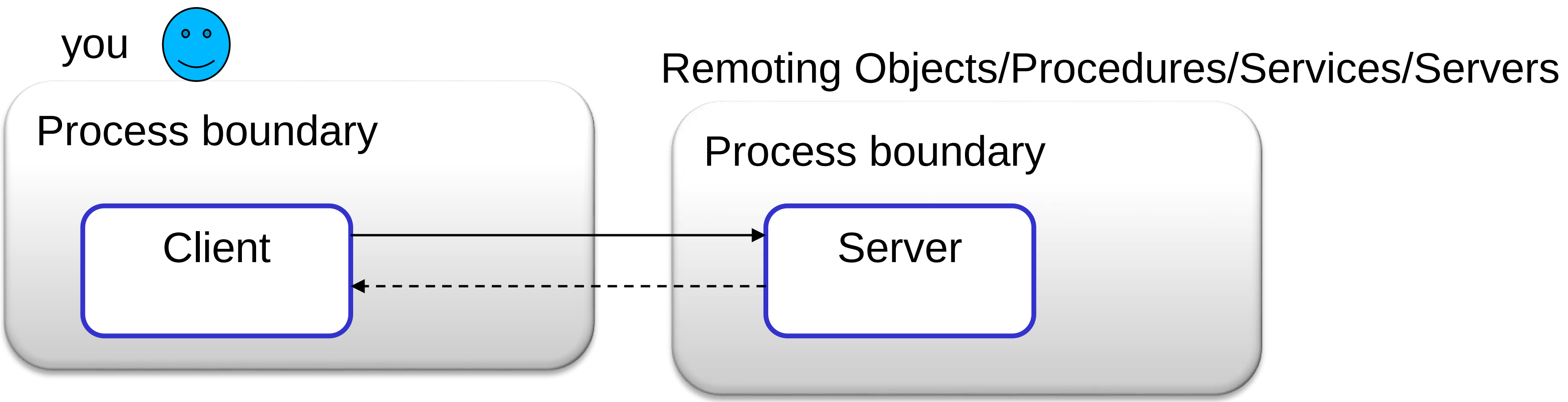


Source: https://spectrum.ieee.org/computing/software/the-2017-top-programming-languages

What is the downside of functional and data partitioning?

ARCHITECTURE STYLES AND INTERACTION MODELS

Basic direct interaction



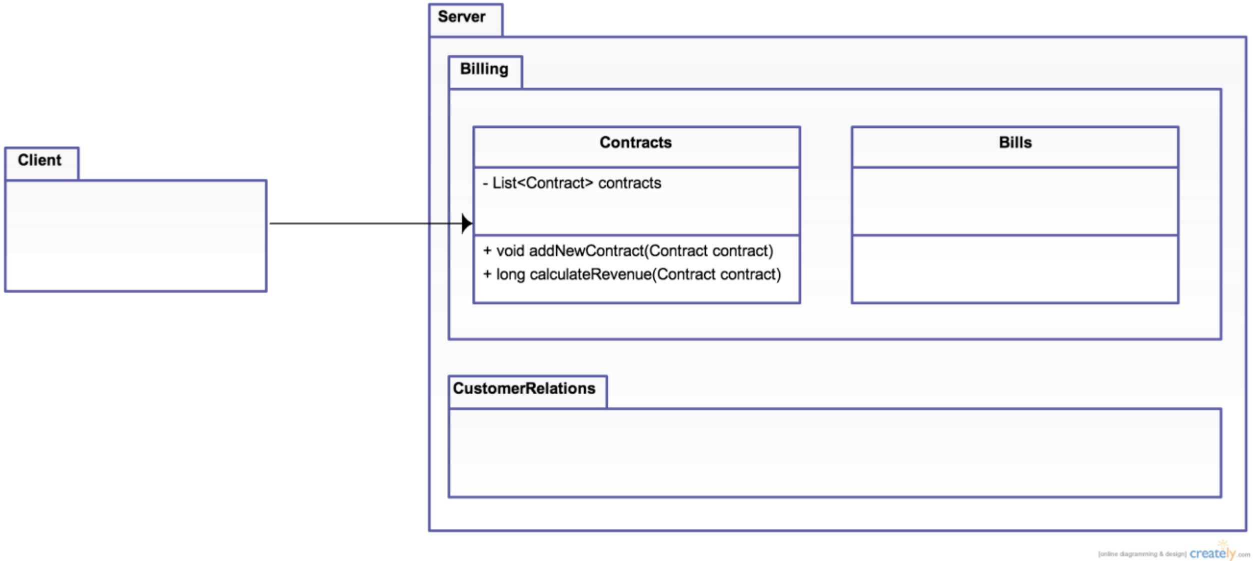
- Using abstraction, we hide the complexity within these boxes
- But we need to integrate between two components, enabling them communicate across process boundaries
  - In the same host, in the same application in different hosts, in different applications
  - How would they exchange data/commands? e.g., Synchronous or asynchronous communication
- Complex in context of complex distributed systems

Basic interaction models

- Large number of communication protocols and interfaces
- Interaction styles, protocols and interfaces
  - REST, SOAP, RPC, Message Passing, Stream-oriented Communication, Distributed Object models, Component-based Models
  - Your own protocols
- Other criteria
  - Architectural constraints
  - Scalability, performance, adaptability, monitoring, logging, etc.

Component Based Systems

- Components:
  - Reusable collections of objects
  - Clearly defined interfaces
  - Focus on reuse and integration
- Implementations: Enterprise Java Beans, OSGi, System.ComponentModel in .NET



Service-Oriented Systems

- Service-oriented Computing:
  - Applications are built by composing (sticking together) services (lego principle)
- Services are supposed to be:

  Standardized,

  Replaceable,

  Reusable/Composable,

  Stateless

Components vs. Services

Components

- Tight coupling
  - Client requires library
- Client / Server
- Extendable
- Fast
- Small to medium granularity
  - Buying components and installing them on your HW

Services

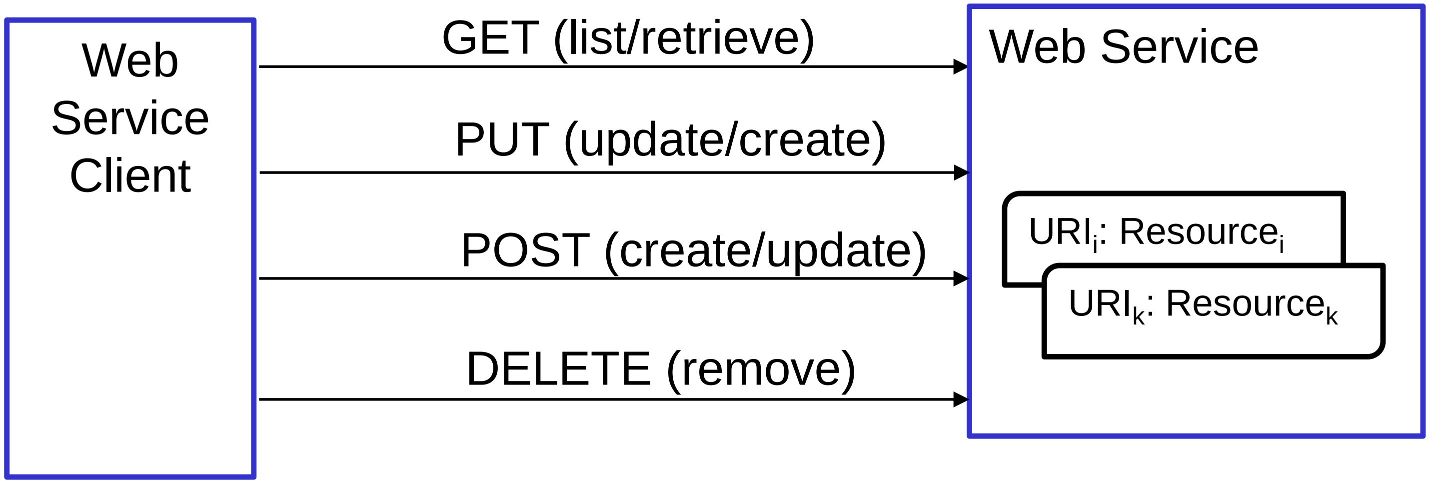
- Loose coupling
  - Message exchanges
  - Policy
- Peer-to-peer
- Composable
- Some overhead
- Medium to coarse granularity
  - Pay-per-use on-demand services

REST

- REST: **RE**presentational **S**tate **T**ransfer
- Is an architectural style! (not an implementation or specification)
  - See Richardson Maturity Model (http://martinfowler.com/articles/richardsonMaturityModel.html)
  - Can be implemented using standards (e.g., HTTP, URI, JSON, XML)
- Architectural Constraints:
  - Client-Server, Stateless, Cacheable, Layered System, Uniform Interface

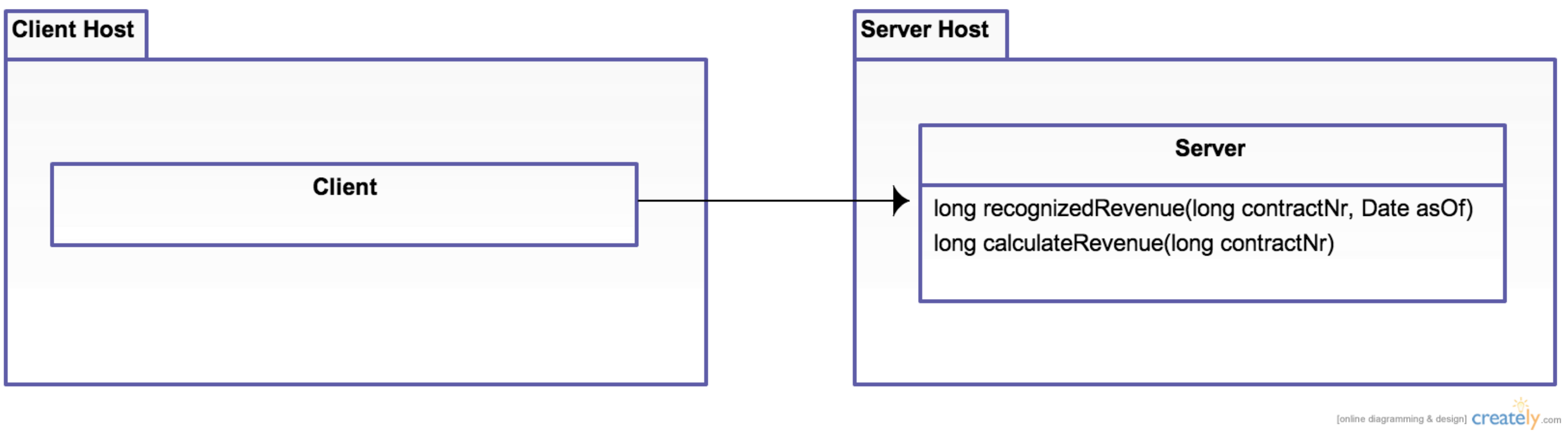
Example of REST Interactions

- Important concepts
  - Resources
  - Identification of Resources
  - Manipulation of resources through their representation
  - Self-descriptive messages
  - Hypermedia as the engine of application state (aka. HATEOAS)



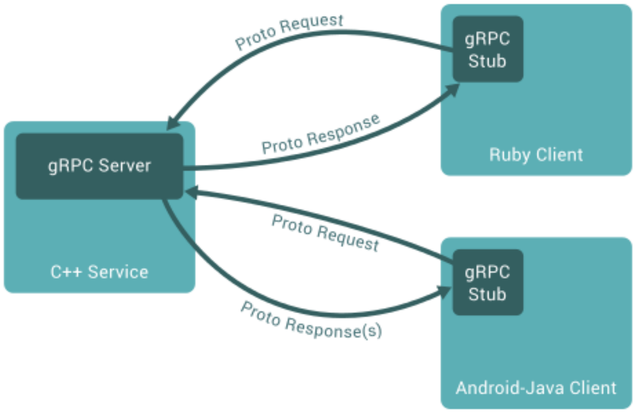
Recall: Remote Procedure Call Systems

- Server provides procedures that clients can call
- Most RPC-style middleware follows a small set of architectural principles
- Strongly tied to specific platforms
- Why is it relevant in complex distributed systems?



gRPC as state-of-the-art framework

http://www.grpc.io/



Works across languages and platforms

Automatically generate idiomatic client and server stubs for your service in a variety of languages and platforms

READ MORE

Apache Thrift ™ Download Documentation Developers Libraries Tutorial Test Suite About Apache

The Apache Thrift software framework, for scalable cross-language services development, combines a software stack with a code generation engine to build services that work efficiently and seamlessly between C++, Java, Python, PHP, Ruby, Erlang, Perl, Haskell, C#, Cocoa, JavaScript, Node.js, Smalltalk, OCaml and Delphi and other languages.

Download

Apache Thrift v0.10.0

What kind of benefits we get, compared with REST Interactions and data exchange formats?

Server-sent Events and WebSocket

- Server-sent Events
  - Remember polling results from servers?
  - Server pushes data to clients through HTTP when the clients connect to the server.
- WebSocket (https://tools.ietf.org/html/rfc6455)
  - Remember socket?
  - Two ways of communication through TCP
  - Example, socket.io (more than just a typical WebSocket)

For which use cases/scenarios we can use them?

WebHook

URL accepting HTTP POST

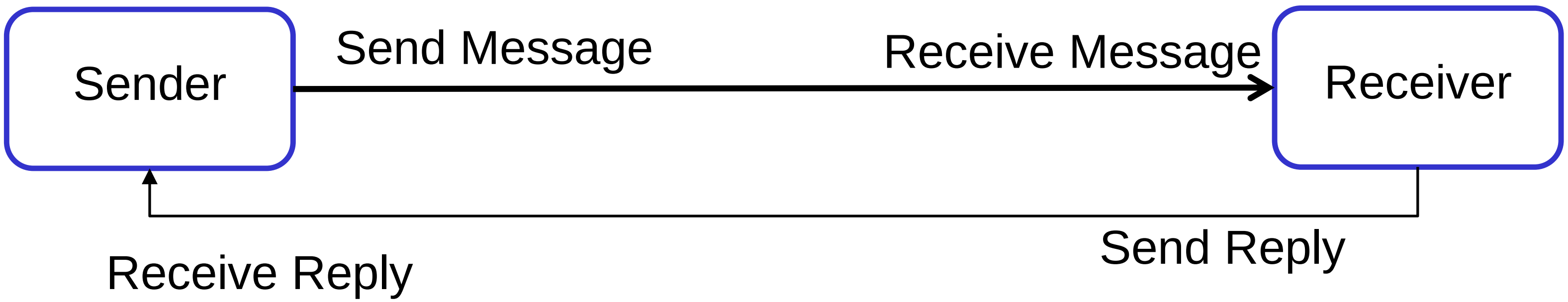
Ruby Python PHP Java Node .NET

```
// Set your secret key: remember to change this to your live secret key in productio
// See your keys here: https://dashboard.stripe.com/account/apikeys
var stripe = require("stripe")("sk_test_BQokikJOvBiI2HlWgH4olfQ2");

// This example uses Express to receive webhooks
const app = require("express")();

// Retrieve the raw body as a buffer and match all content types
app.use(require("body-parser").raw({type: "*/*"}));

app.post("/my/webhook/url", function(request, response) {
  // Retrieve the request's body and parse it as JSON
  var event_json = JSON.parse(request.body);

  // Do something with event_json

  response.send(200);
});
```

Source: https://stripe.com/docs/webhooks

Message Passing/Message-Oriented Communications

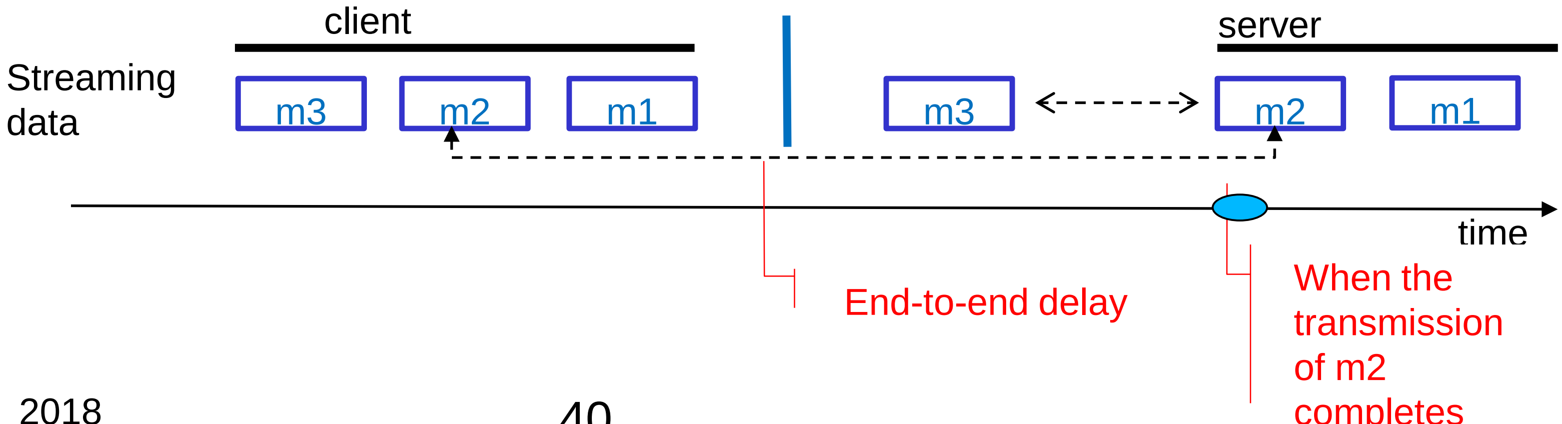
More in lecture 2 (fundamental) and lecture 5 (large-scale)



- Servers and clients communicate by exchanging messages

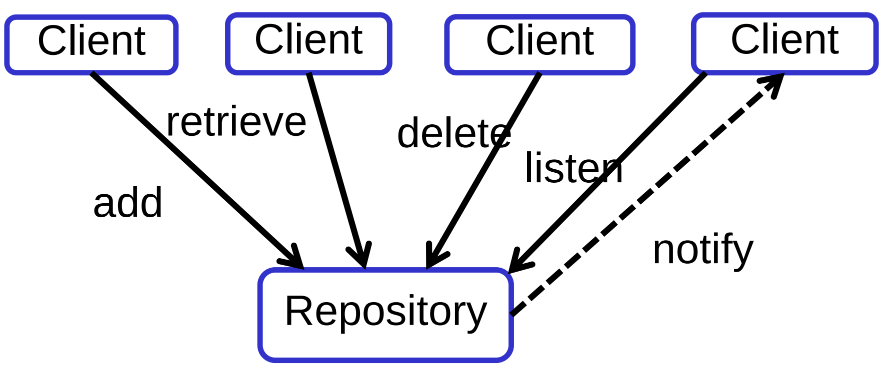
Stream-oriented communication

When delivery times matter!

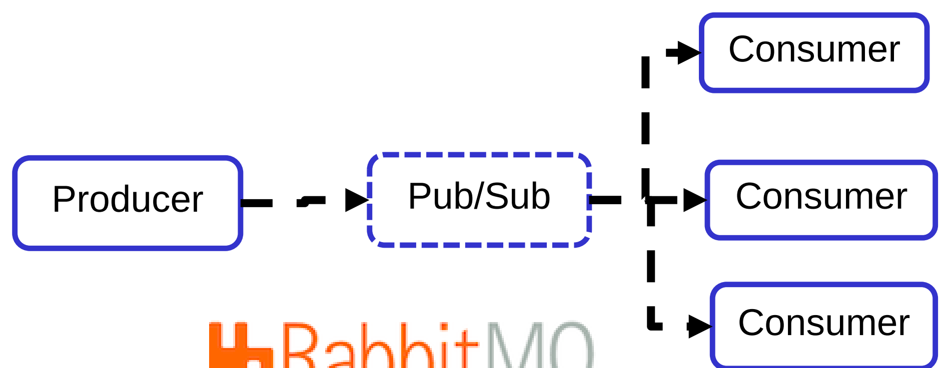


Complex interactions

- One-to-many, Many-to-one, Many-to-One
  - Message Passping Interface
  - Public/Subscribe, Message-oriented Middleware
  - Shared Repository
  - Websocket (also support broadcast)
  - Application/Systems specific models



Amazon S3

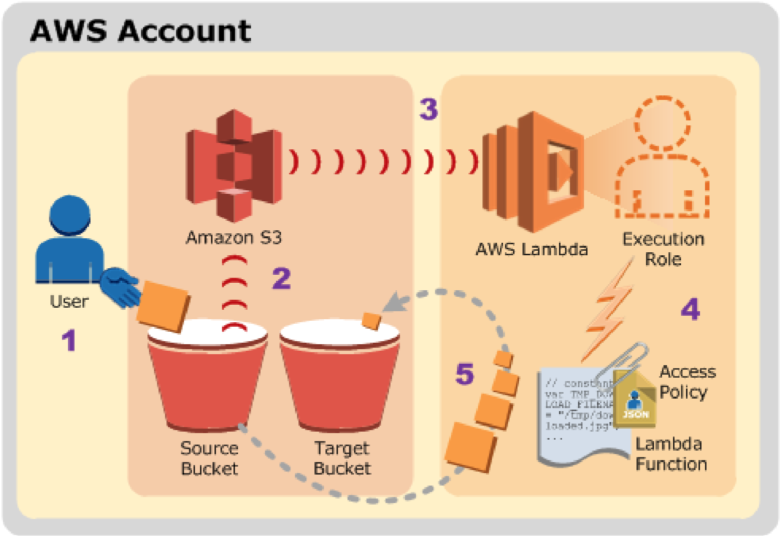


Serverless

- Most of the time we need to build and setup various services/server
- But with the cloud and PaaS providers → we do not have to do this
- Serverless computing:
  - Function as a service
- Examples
  - AWS Lambda
  - Google Cloud Function (beta - https://cloud.google.com/functions/)
  - IBM OpenWhisk
  - https://serverless.com/

Serverless

- Key principles
  - Running code without your own back-end server/application server systems
  - Tasks in your application: described as functions
    - With a lifecycle
  - Functions are uploaded to FaaS and will be executed based on different triggers (e.g., direct call or events)
  - **Event-driven triggers**!

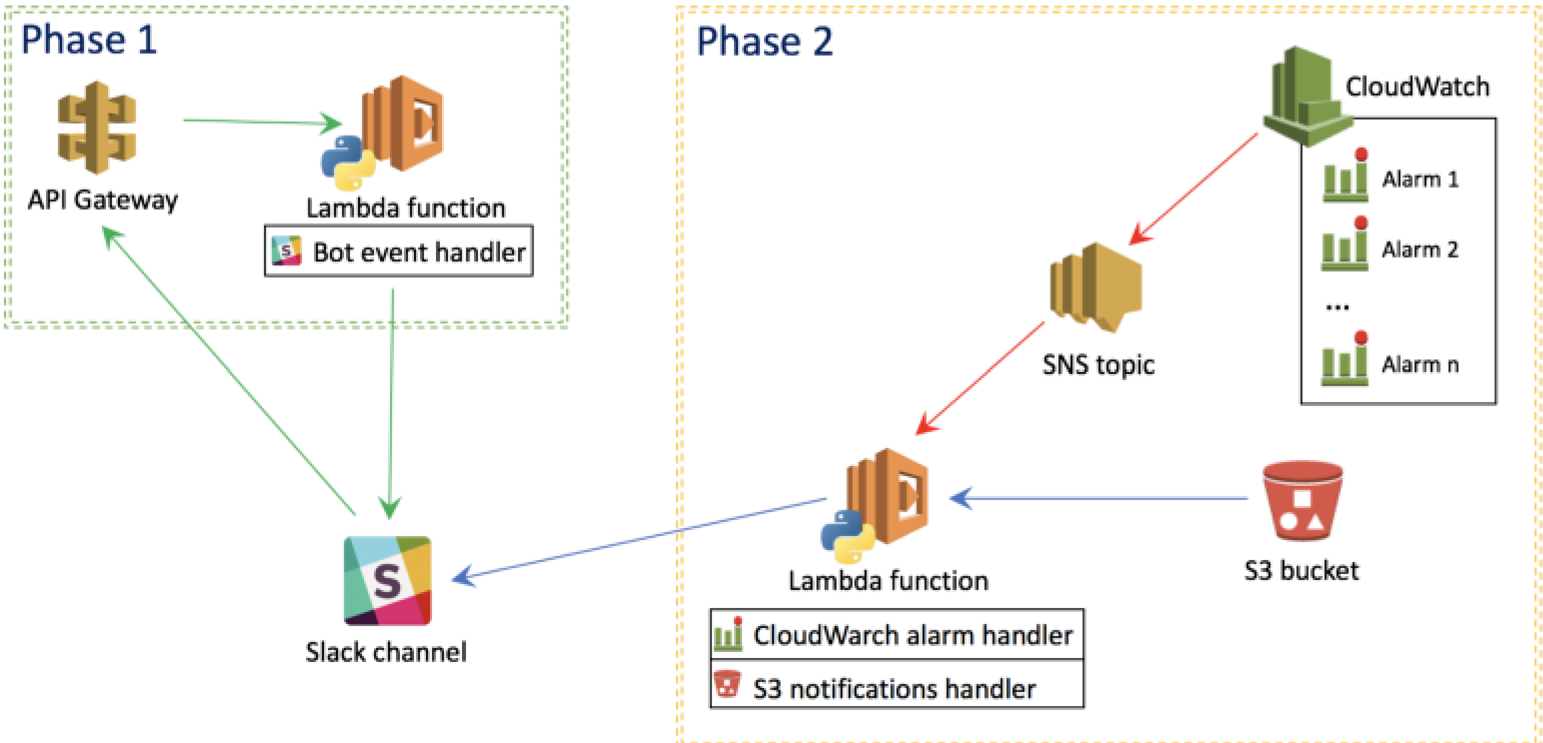


Source: http://docs.aws.amazon.com/lambda/latest/dg/with-s3-example.html

Check: https://martinfowler.com/articles/serverless.html

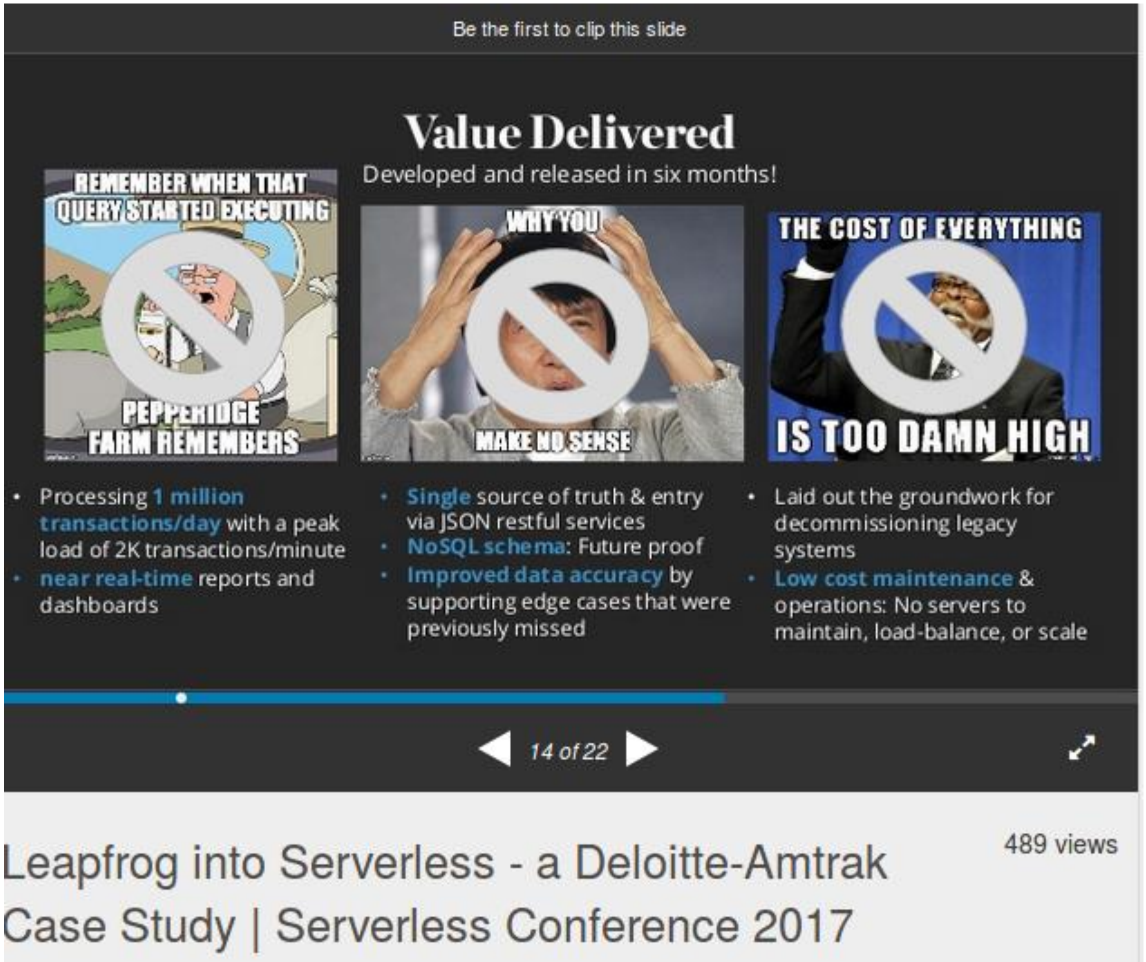
Example: chat

From Anton Chernysh, Source: https://medium.com/devoops-and-universe/serverless-slack-bot-on-aws-vs-azure-getting-notified-instantly-ab0916393e1d



Case study serverless Deloitte-Amtrak

Source: https://www.slideshare.net/GaryArora/leapfrog-into-serverless-a-deloitteamtrak-case-study-serverless-conference-2017/



Depending on the requirements: we can build everything or build few things and manage the whole system or not.

→ We need to carefully study and examine suitable technologies/architectures for our complex distributed applications

A big homework:
Microservices approach versus serverless approach

DATA MODELS

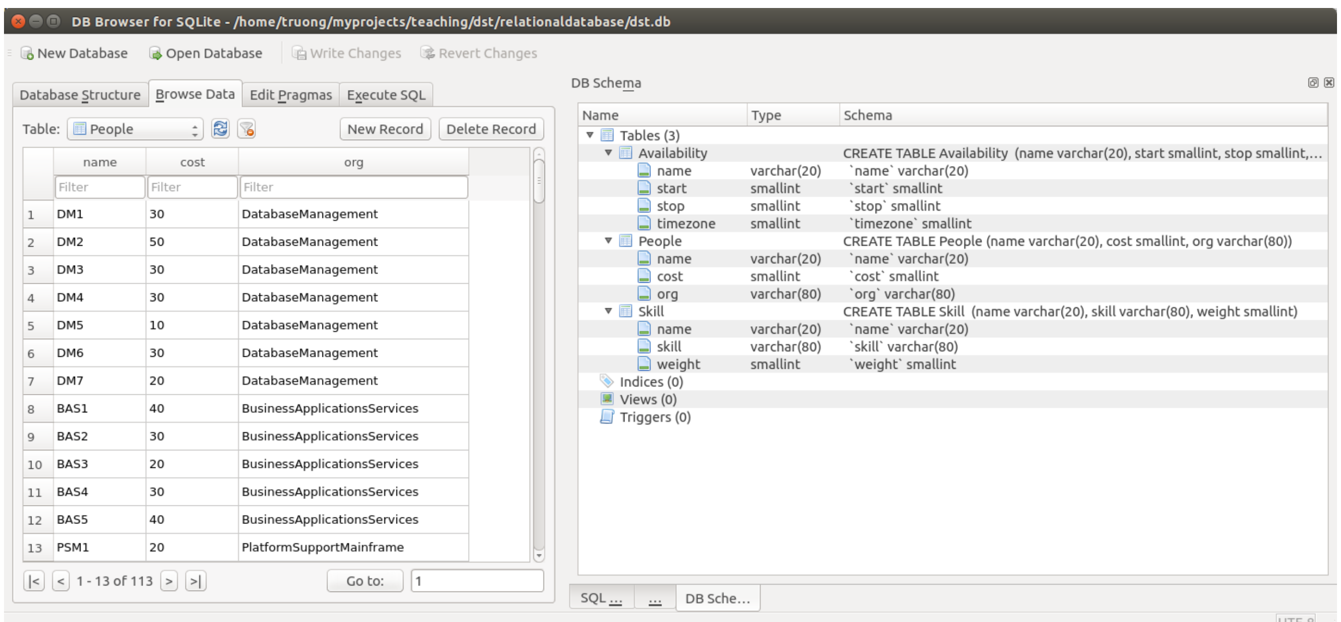
Data Storage Models

- Relational Model
  - Traditional SQL model
- Key-Value Model
  - Data is stored as simple list of keys and values (hashtable style)
- Column-oriented Model
  - Data is stored in tables, but stored column-wise rather than row-wise
- Document-oriented Model
  - Data is stored in (schemaless) documents
- Graph-oriented Model
  - Data is stored as an interconnected graph

NoSQL versus SQL

Relational Model

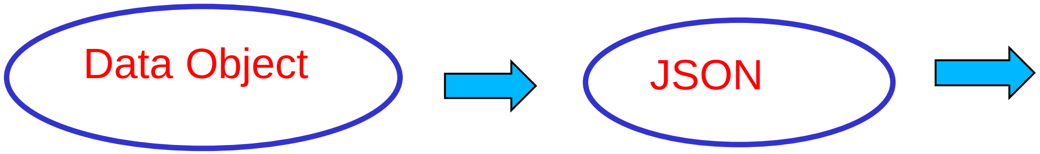
- Implemented as collection of two-dimensional tables with rows and columns
- Powerful querying & strong consistency support
- Strict schema requirements
- E.g.: Oracle Database, MySQL Server, PostgreSQL

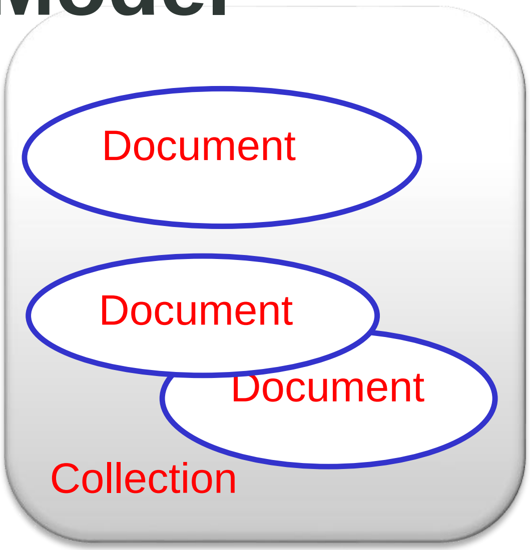


Key-Value Model

- Basically an implementation of a map in a programming language
- Values do not need to have the same structure (there is no schema associated with values)
- Primary use case: caching
- Simple and very efficient, fast (e.g., in memory storage)
- Querying capabilities usually very limited
  - Oftentimes only “By Id” pattern
- E.g.:
  - Memcached, Riak, Redis

Document-oriented Model

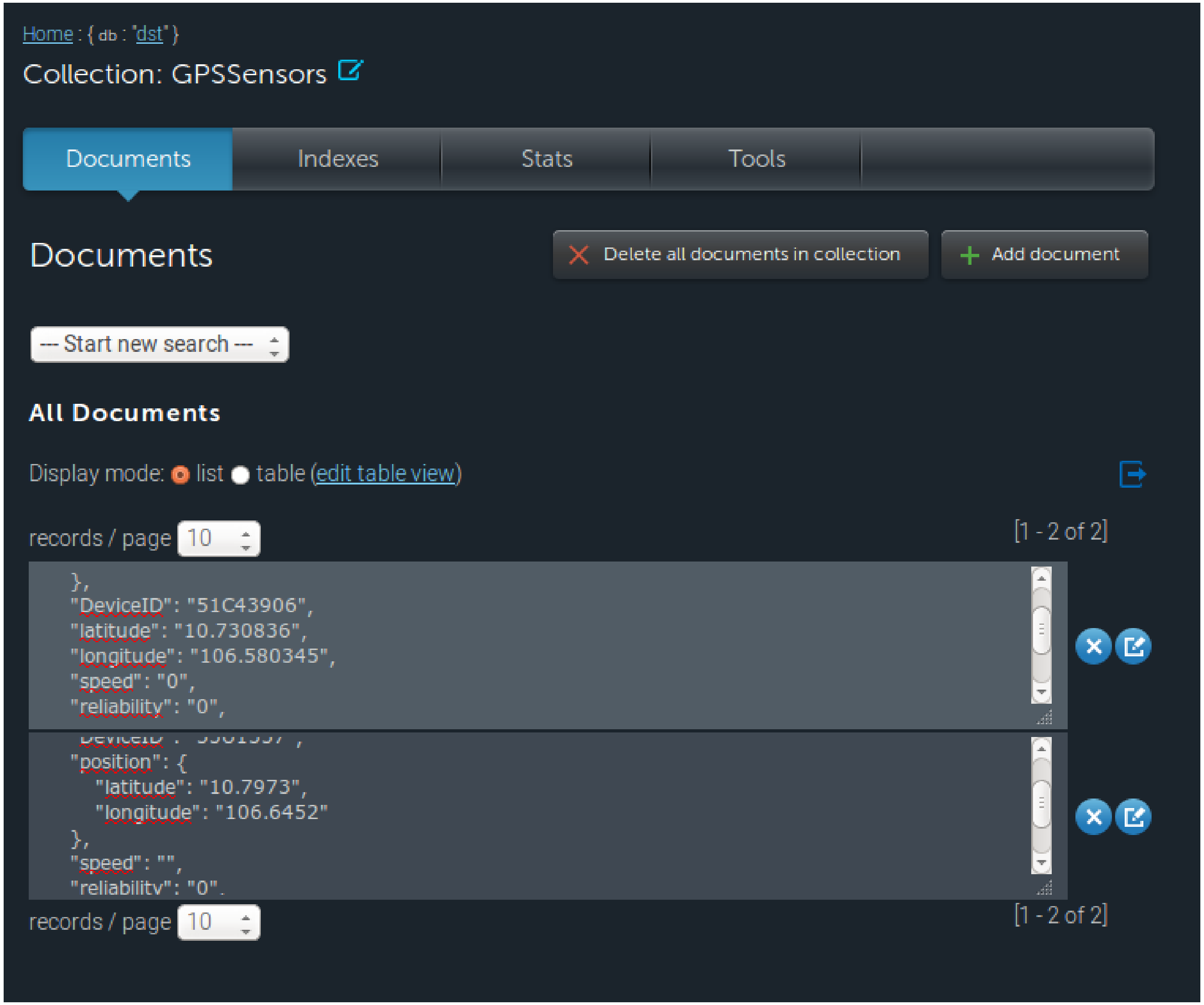




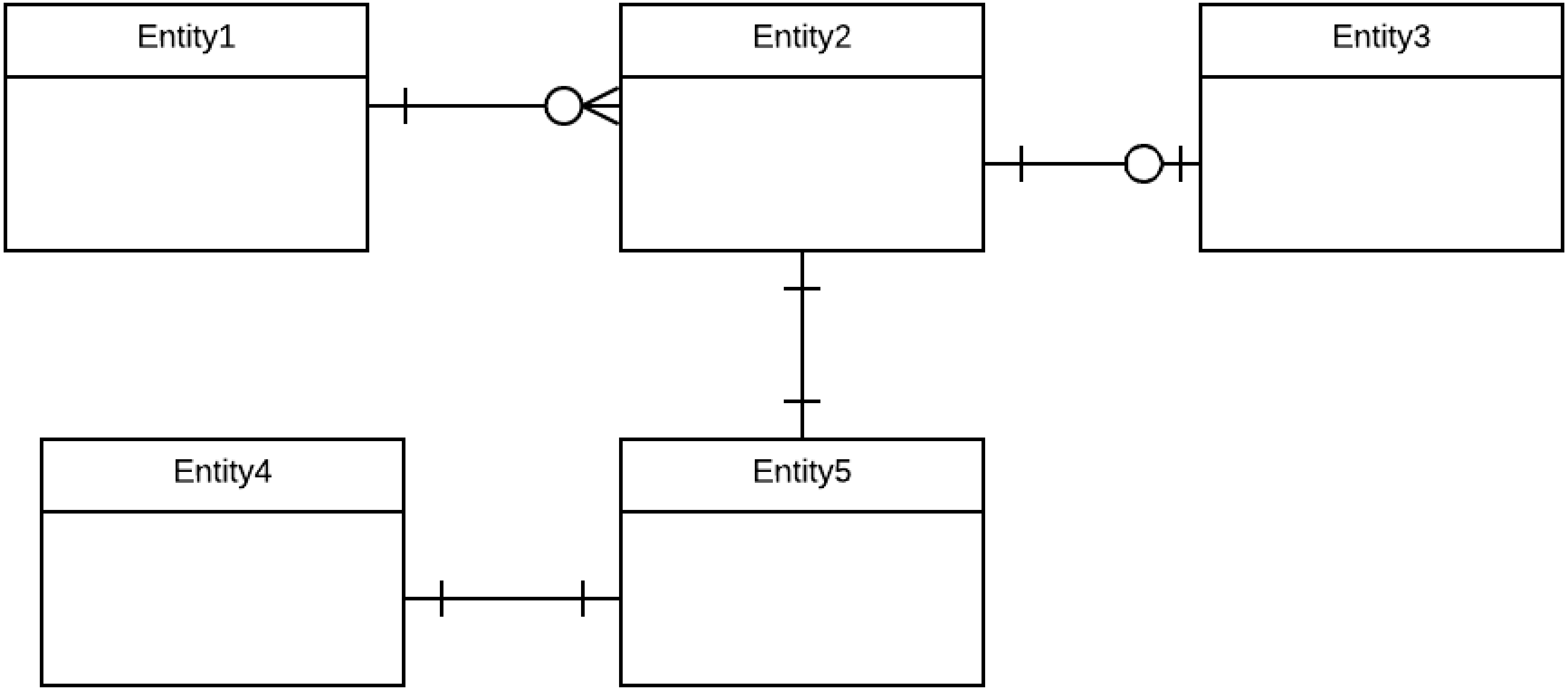
A simple analogy

- Simple, comparable to key-value
- All values are schema-free and typically complex
- Primary use cases: managing large amounts of unstructured or semi-structured data
- Sharding and distributed storage is usually well-supported
- Schema-freeness means that querying is often difficult and/or inefficient
- E.g.:, CouchDB, MongoDB

Example: MongoDB with mLab.org



Complex Relationships?



How do we represent such relationships with documents?

Column-oriented data model

Rows are allowed to have different columns

- Data Model
  - Table consists of rows
  - Row consists of a key and one or more columns
  - Columns are grouped into column families
  - A column family: a set of columns and their values

- Systems: Hbase, Hypertable, Cassandra

Examples: HBase

Row Key	Time Stamp	ColumnFamily contents	ColumnFamily anchor	ColumnFamily people
"com.cnn.www"	t9		anchor:cnnsi.com = "CNN"	
"com.cnn.www"	t8		anchor:my.look.ca = "CNN.com"	
"com.cnn.www"	t6	contents:html = "<html>..."		
"com.cnn.www"	t5	contents:html = "<html>..."		
"com.cnn.www"	t3	contents:html = "<html>..."		

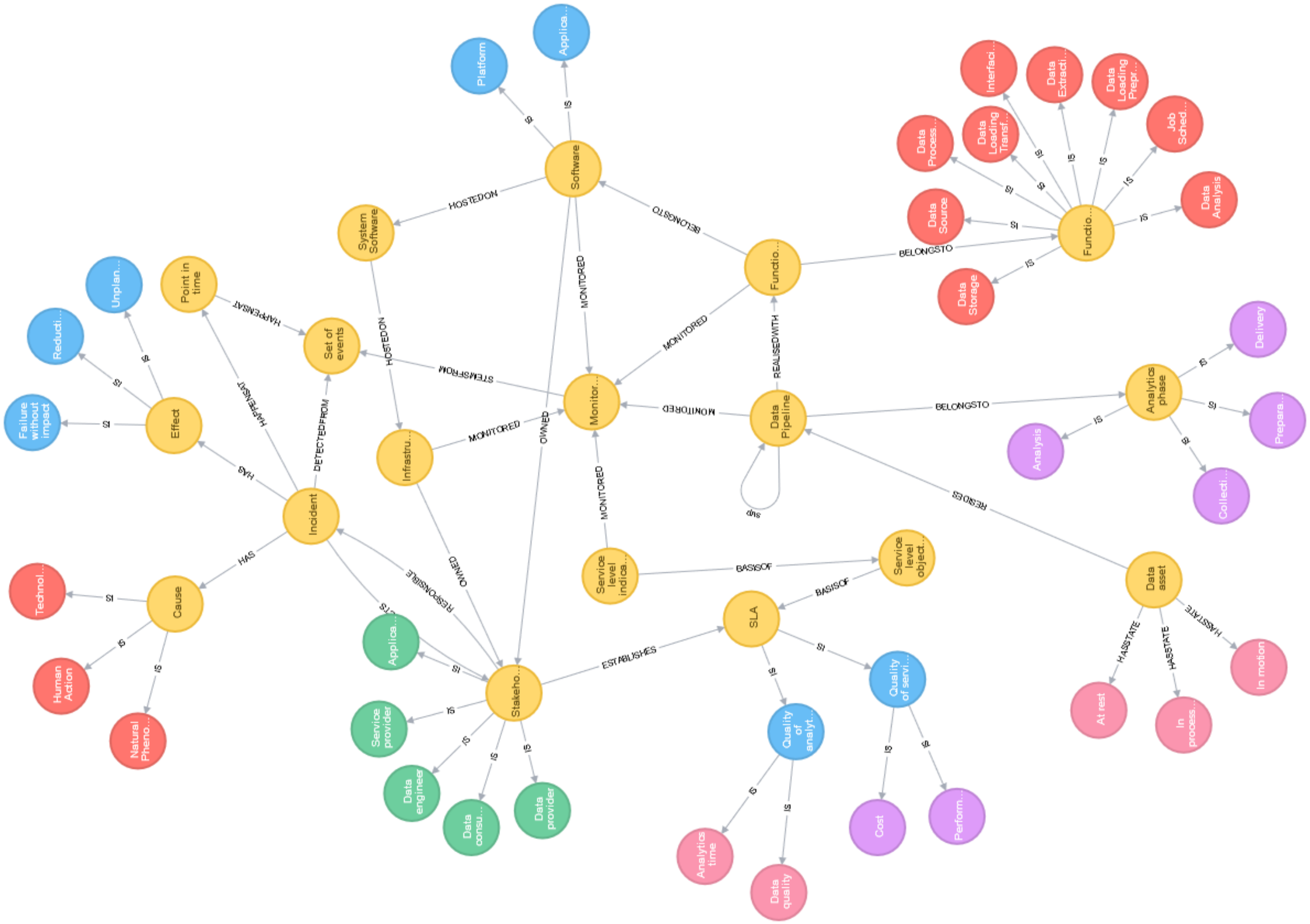
```
{
  "com.cnn.www": {
    contents: {
      t6: contents:html: "<html>..."
      t5: contents:html: "<html>..."
      t3: contents:html: "<html>..."
    }
    anchor: {
      t9: anchor:cnnsi.com = "CNN"
      t8: anchor:my.look.ca = "CNN.com"
    }
    people: {}
  }
  "com.example.www": {
    contents: {
      t5: contents:html: "<html>..."
    }
    anchor: {}
    people: {
      t5: people:author: "John Doe"
    }
  }
}
```

Source: http://hbase.apache.org/book.html#datamodel

Graph-oriented Model

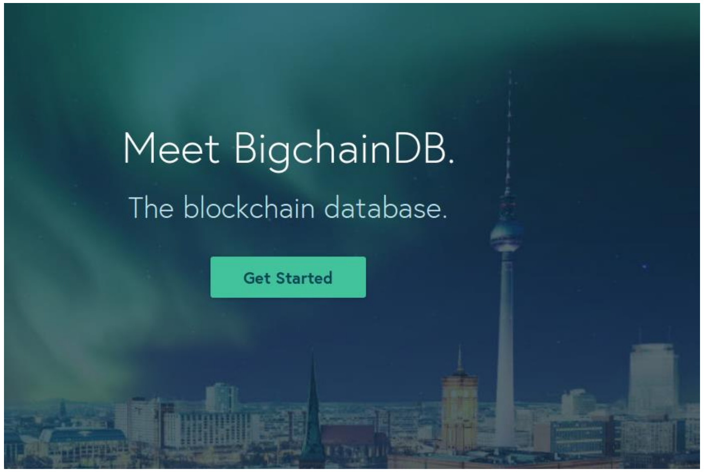
- Data relationships as first-class citizens
- Data is stored as a network (graph)
- Primary use cases: whenever one is more interested in the relations between data than the data itself (for instance, social media analysis)
  - Highly connected and self-referential data is easier to map to a graph database than to the relational model
  - Relationship queries can be executed fast
- E.g.: Neo4J, Orient DB, ArangoDB
  - Many of them are actually multi-model (combine graph, document, key/value, etc., models)

Examples wih Neo4j

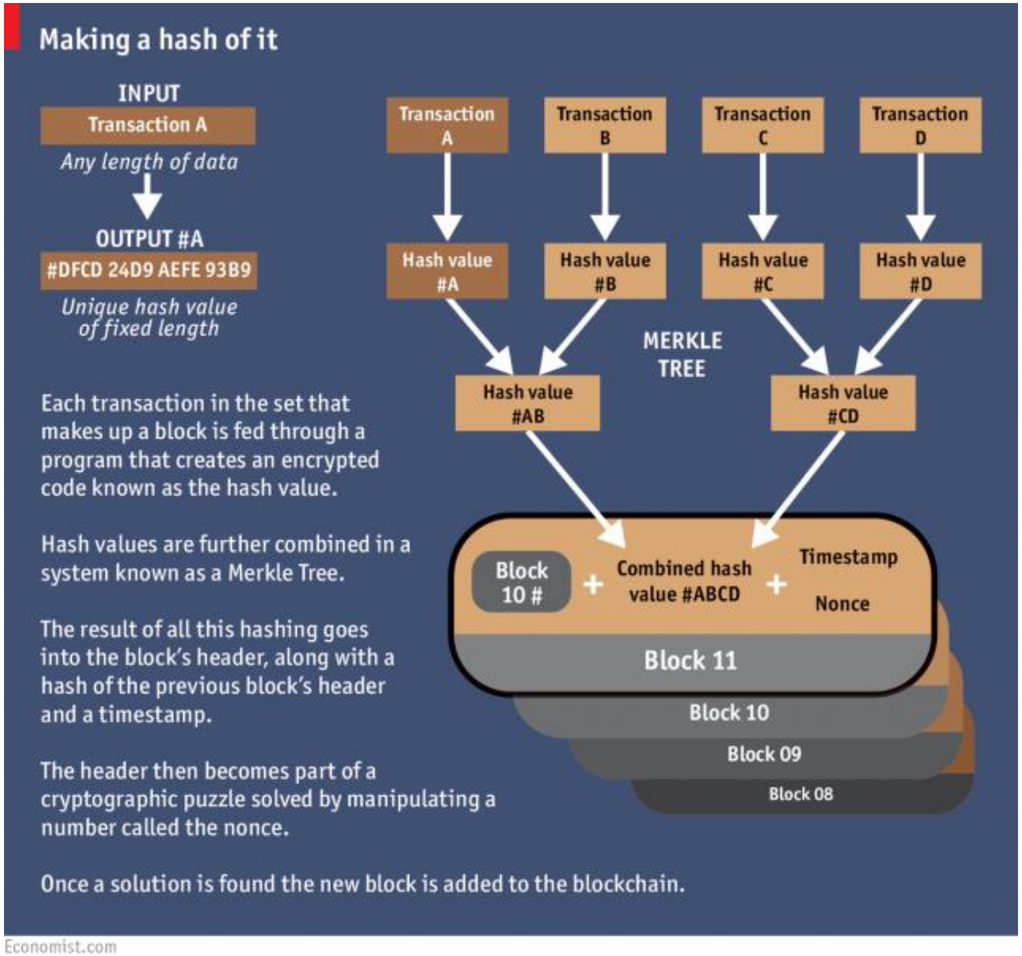


Source: Manfred Halper, Master thesis, TU Wien, https://github.com/rdsea/bigdataincidentanalytics

Blockchain as a database



Bigchain DB: https://www.bigchaindb.com/



Source: https://www.economist.com/news/briefing/21677228-technology-behind-bitcoin-lets-people-who-do-not-know-or-trust-each-other-build-dependable

Key issues: we need to use many types of databases/data models

Example - Healthcare

- Personal or hospital context

- Very different types of data for healthcare
  - Electronic Health Records (EHRs)
  - Remote patient monitoring data (connected care/telemedicine)
  - Personal health-related activities data
- Combined with other types of data for insurance business models

Question for design thinking

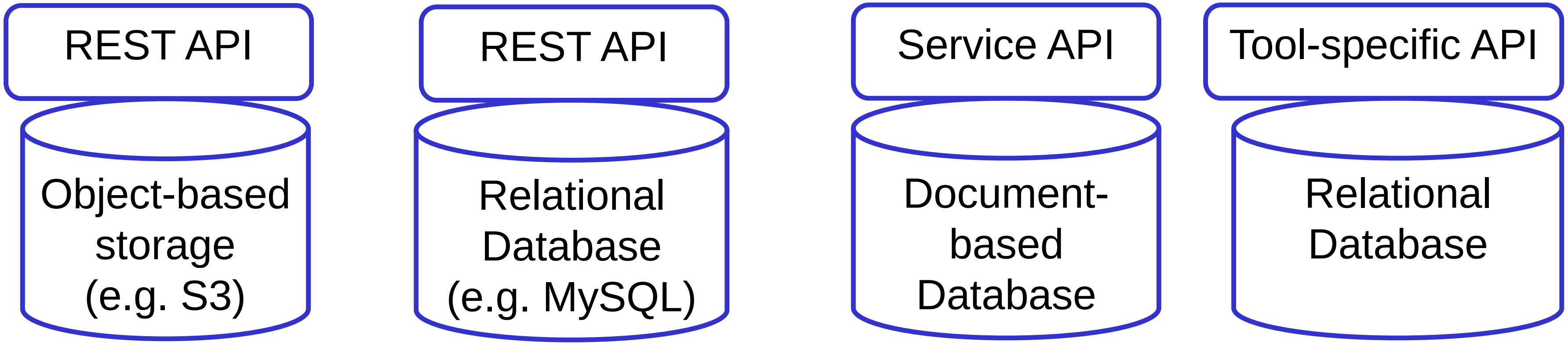
If you have to build a system that includes many individuals connected through a SocialNetwork for discussing products they sell and buy and they have a lot of different products to sell

How would you select database technologies for your implementation?

Accessing and Processing Data

- Component accesses data
  - Get, store, and process
  - Data is in relational model, documents, graph, etc.
- Main problems
  - Programming languages are different → Mapping data into objects in programming languages
  - Distributed and scalable processing of data (not in the focus of this lecture)

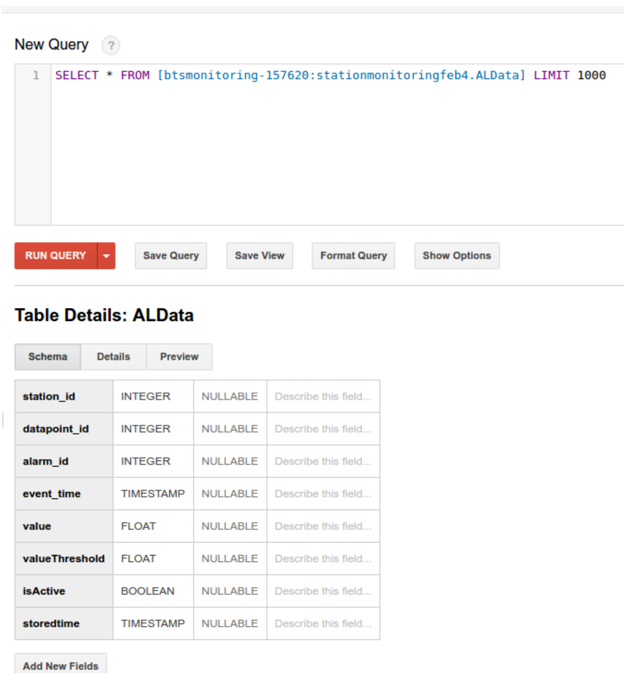
Data Access API Approach

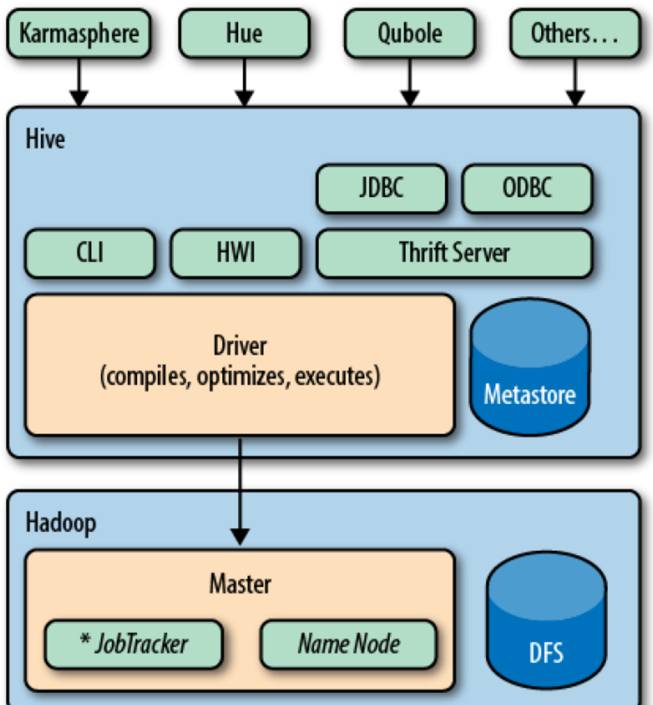


- Data access APIs can be built based on well-defined interfaces
- Currently mostly based on REST
- Help to bring the data objects close to the programming language objects

SQL-based API

- Leverage SQL as the language for accessing data
  - Hide the underlying specific technologies



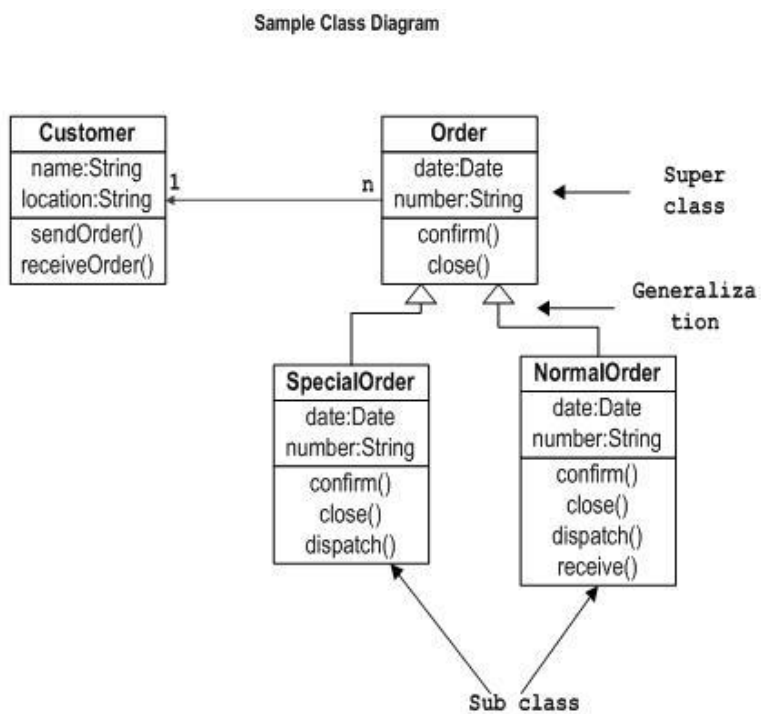


Source: Programming Hive, ***Edward Capriolo, Dean Wampler, and Jason Rutherglen***

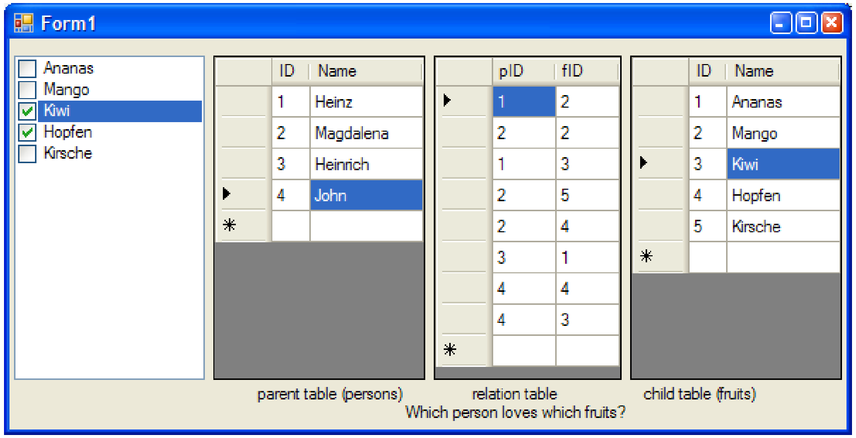
Object-Relational/Grid/Document Data Mapping (ORM/OGM/ODM)

Conceptual mismatch, especially with relational database

Programming Language Objects



Native Database Structure (e.g., relations)



What you want to avoid

Not just about security but tedious effort on coding

```
String query = "SELECT account_balance FROM user_data WHERE user_name = "
  + request.getParameter("customerName");

try {
       Statement statement = connection.createStatement( … );
       ResultSet results = statement.executeQuery( query );
}
```

Source: https://www.owasp.org/index.php/SQL_Injection_Prevention_Cheat_Sheet

Solution (1)

Build an abstraction layer that represents the database in the application

Two subproblems:

1. How do represent data in the application?
2. How to map between data storage and application?

Solution (2)

- Technologies
  - Java Persistence API
  - Hibernate ORM (relational database)
  - Hibernate OGM (NoSQL)
  - Mongoose (for MongoDB)

- Methodology: design patterns
  - http://martinfowler.com/eaaCatalog/index.html

Data-Related Architectural Patterns

- See http://martinfowler.com/eaaCatalog/index.html

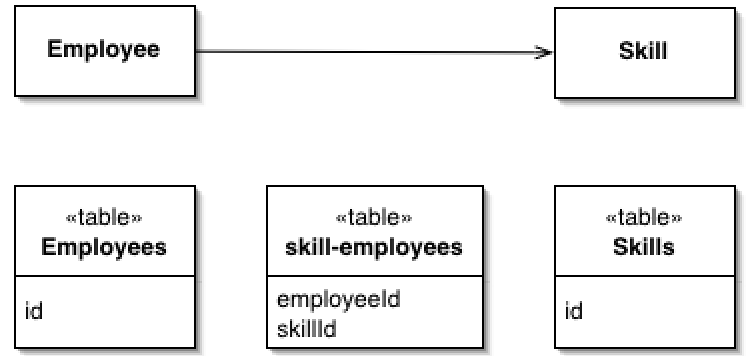
- Mapping DB Data to Code
  - Code that wraps the actual communication between business logics and data store
  - Required to „fill“ e.g., the domain model

- Goals
  - Access data using mechanisms that fit in with the application development language
  - Separate data store access from domain logic and place it in separate classes

Data Source Architectural Patterns

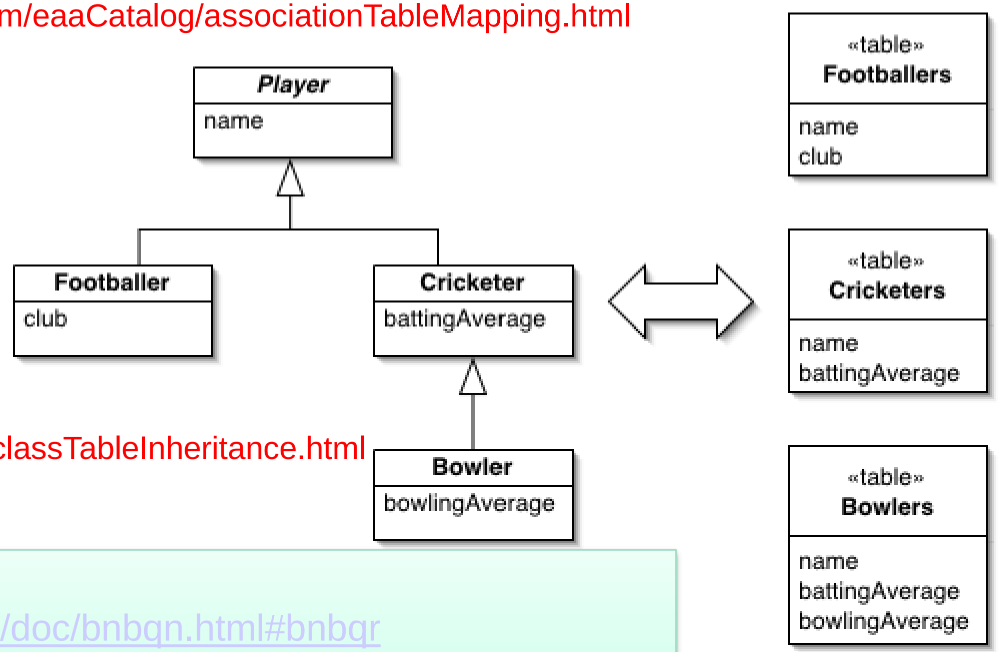
- **Row Data Gateway**
  - Based on table structure. One instance per row returned by a query.
- **Table Data Gateway**
  - Based on table structure. One instance per table.
- **Active Record**
  - Wraps a database row, encapsulates database access code, and adds business logic to that data.
- **Data Mapper**
  - Handles loading and storing between database and Domain Model

Object-Relational Structural Patterns



Association Table Mapping

Source: http://martinfowler.com/eaaCatalog/associationTableMapping.html



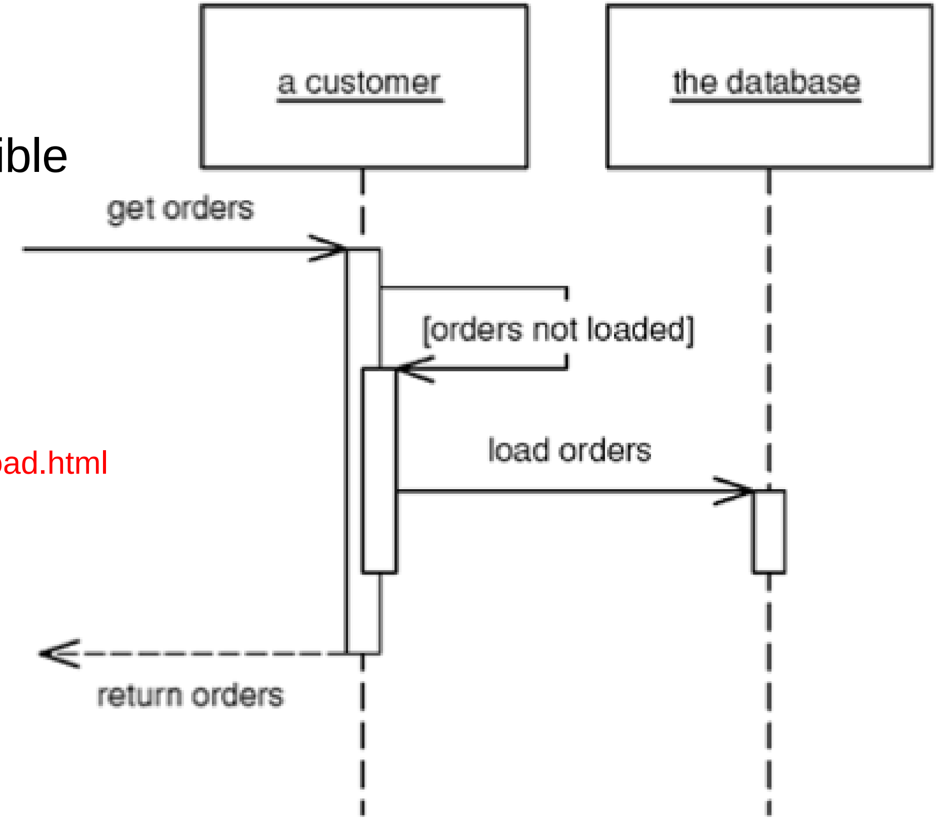
Class Table Inheritance

Source: http://martinfowler.com/eaaCatalog/classTableInheritance.html

Solutions/Strategies:
http://docs.oracle.com/javaee/6/tutorial/doc/bnbqn.html#bnbqr
http://www.javaworld.com/article/2077819/java-se/understanding-jpa-part-2-relationships-the-jpa-way.html

Object-Relational Behavioral Patterns: Lazy Loading

Do the loading as latest as possible



Source: https://martinfowler.com/eaaCatalog/lazyLoad.html

Lazy Loading

- For loading an object from a database it's handy to also load the objects that are related to it
  - Developer does not have to explicitly load all objects
- Problem
  - Loading one object can have the effect of loading a huge number of related objects
- Lazy loading interrupts loading process and loads data transparently when needed

Lazy Loading Implementation Patterns

- Lazy Initialization
  - Every access to the field checks first to see if it's null
- Value Holder
  - Lazy-loaded objects are wrapped by a specific value holder object
- Virtual Proxy
  - An object that looks like the real value, but which loads the data only when requested
- Ghost
  - Real object, but in partial state
  - Remaining data loaded on first access

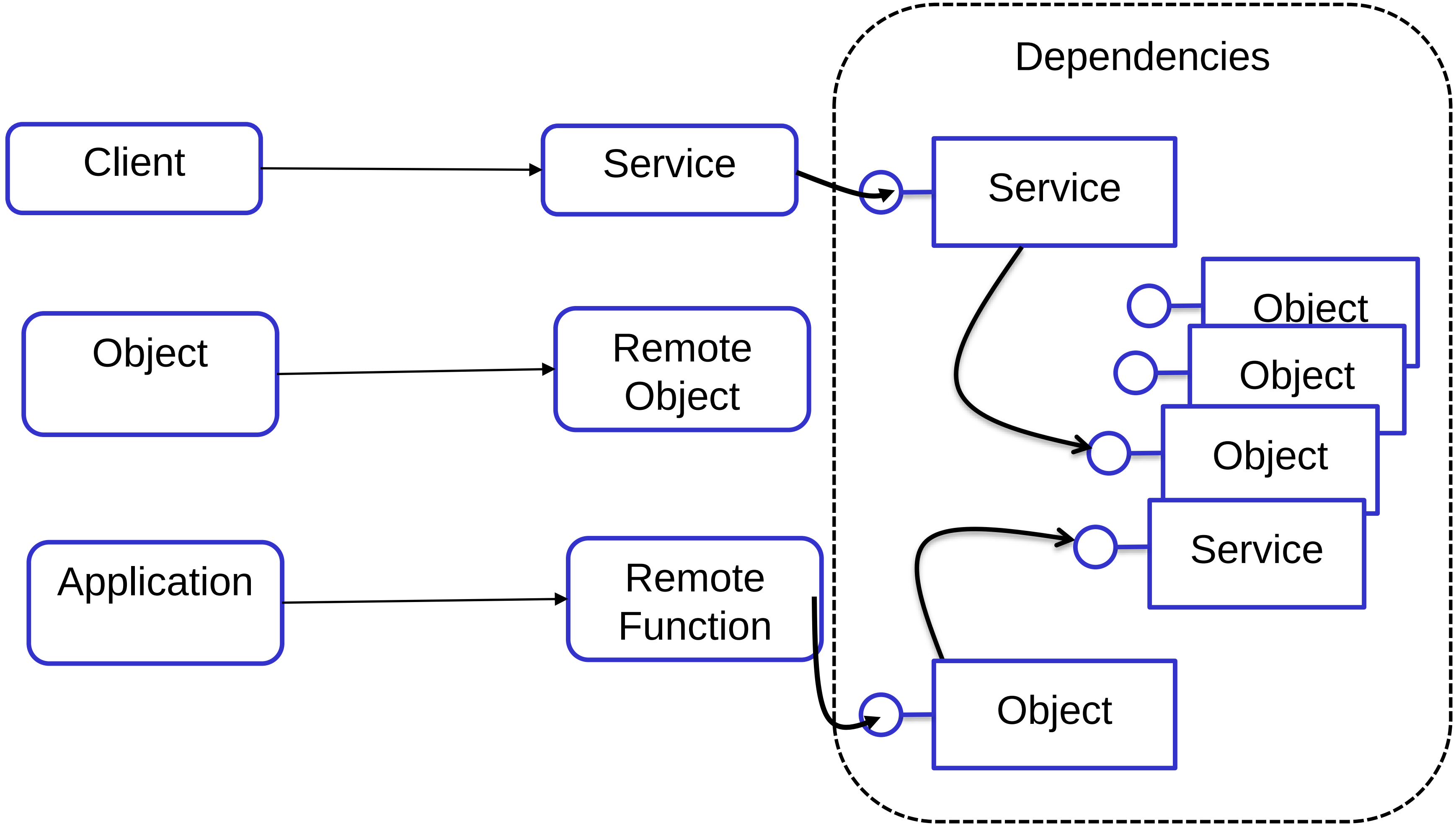
Lazy Loading Example - Hibernate

```
@Entity
public class Product {
    @OneToMany(mappedBy="product", fetch = FetchType.LAZY)
    //or FetchType.EAGER for edger loading
    public Set<Contract> getContracts() {
        ...
    }
}
```

How can we achieve the implementation? using proxy technique (Lesson 3)

OPTIMIZING INTERACTIONS

Interactions?



Optimizing Interactions

- Interactions between software components and within them
- Scale in: increasing server capability
- Load balancer
- Scale out
- Asynchronous communication
  - More in lectures 4&5
- Data sharding
- Connection Pools
- Etc.

Scale out

More in Lecture 4

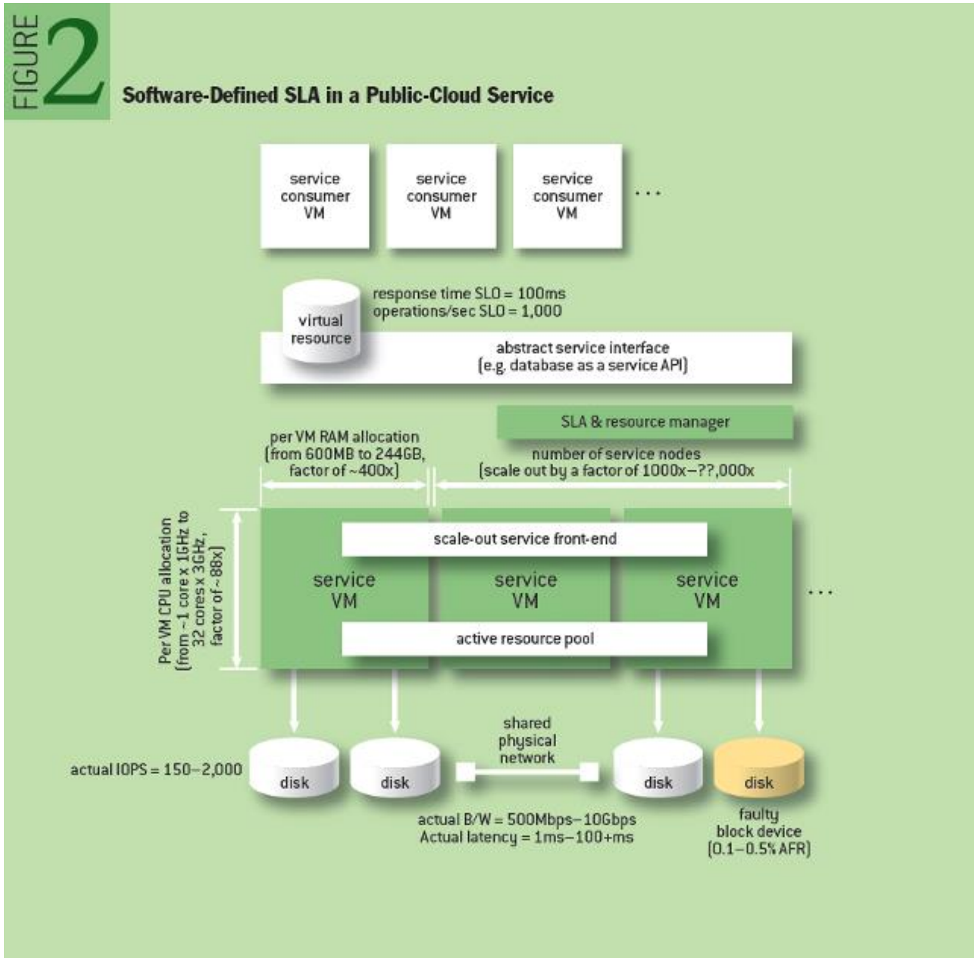


Figure source: http://queue.acm.org/detail.cfm?id=2560948

Load balancing

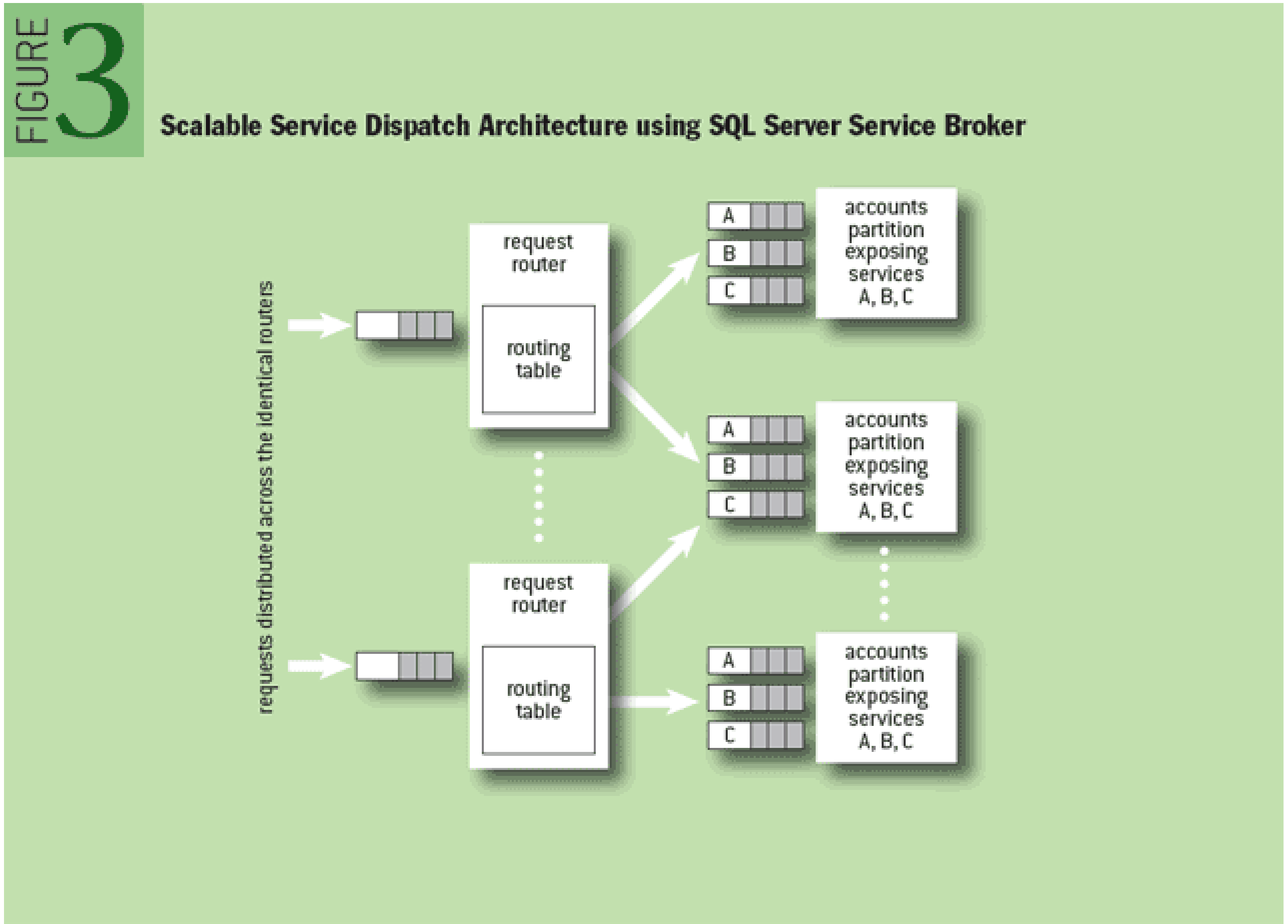
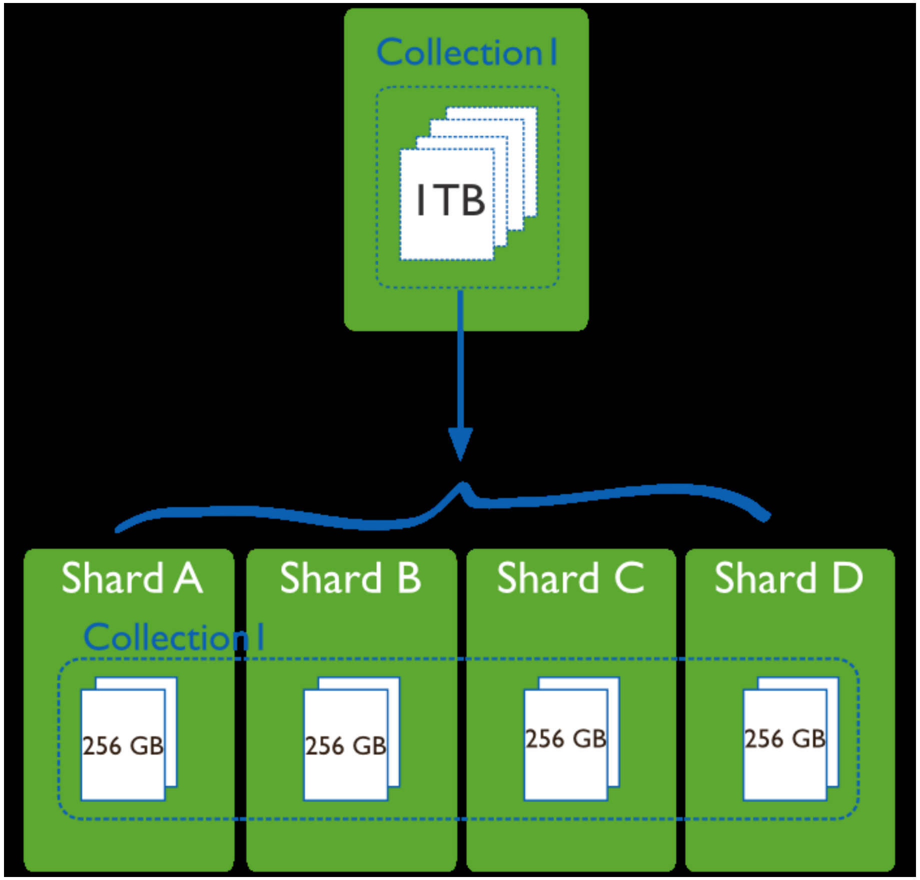
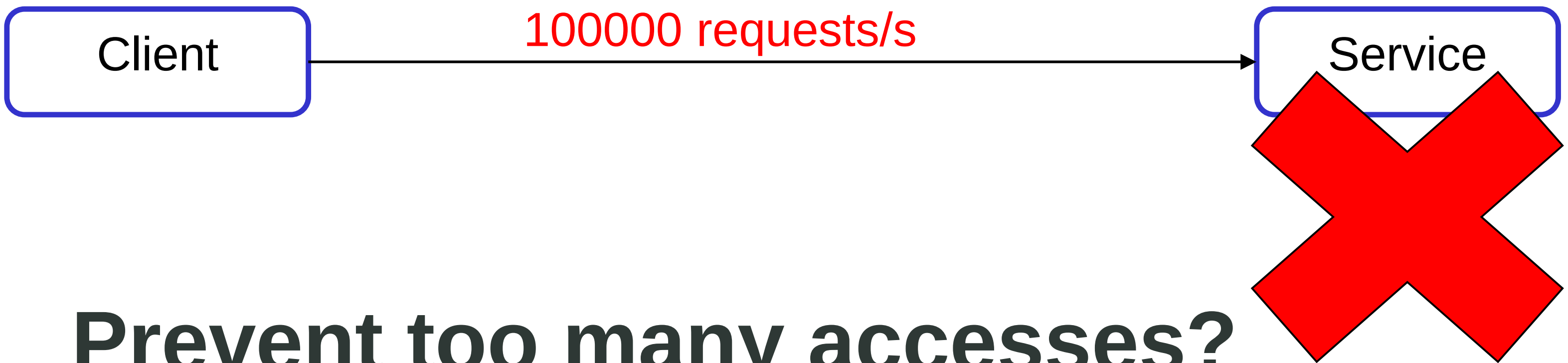


Figure source: http://queue.acm.org/detail.cfm?id=1971597

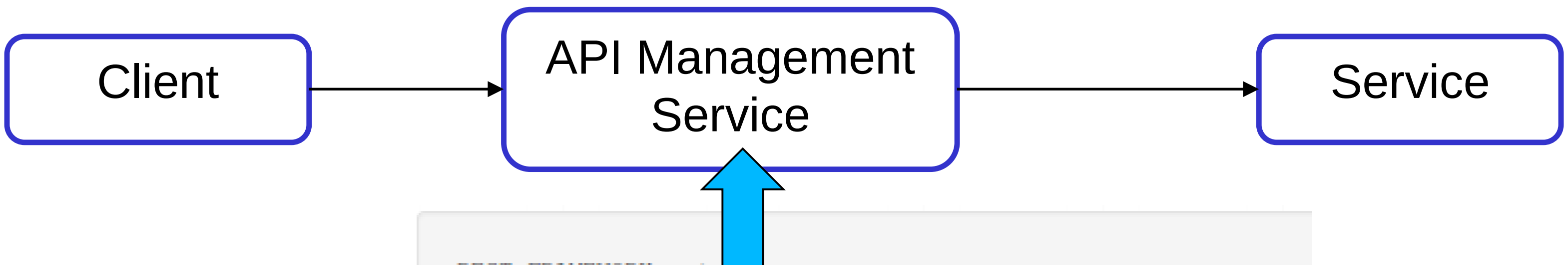
Need also Routing, Metadata Service, etc.



Soure: https://docs.mongodb.org/manual/core/sharding-introduction/



Prevent too many accesses?




```
REST_FRAMEWORK = {
    'DEFAULT_THROTTLE_CLASSES': (
        'rest_framework.throttling.AnonRateThrottle',
        'rest_framework.throttling.UserRateThrottle'
    ),
    'DEFAULT_THROTTLE_RATES': {
        'anon': '100/day',
        'user': '1000/day'
    }
}
```

Code: http://www.django-rest-framework.org/api-guide/throttling/#how-throttling-is-determined

Other patterns

- See the supplement slides
- Understanding how to use communications to implement certain patterns
  - Polling
  - Fire and forget
  - Callback

Summary

- Understand the size and complexity of your distributed applications/systems
- Pickup the right approach based on requirements and best practices
- Architecture, interaction, and data models are strongly inter-dependent
- There are a lot of useful design patterns
- Distribution design and deployment techniques are crucial → cloud models
- Embrace diversity: Not just distributed applications with relational database!

Other references

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- Roy Fielding's blog entry on REST requirements: http://roy.gbiv.com/untangled/2008/rest-apis-must-be-hypertext-driven
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- Martin Fowler: Patterns of Enterprise Application Architecture
- Fay Chang, Jeffrey Dean, Sanjay Ghemawat, Wilson C. Hsieh, Deborah A. Wallach, Mike Burrows, Tushar Chandra, Andrew Fikes, and Robert E. Gruber. 2006. Bigtable: a distributed storage system for structured data. In Proceedings of the 7th USENIX Symposium on Operating Systems Design and Implementation - Volume 7 (OSDI '06), Vol. 7. USENIX Association, Berkeley, CA, USA, 15-15
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- CAP: http://www.julianbrowne.com/article/viewer/brewers-cap-theorem
- Eventual consistency: http://queue.acm.org/detail.cfm?id=1466448
- https://hackernoon.com/blockchains-versus-traditional-databases-c1a728159f79
- https://www.coindesk.com/information/what-is-the-difference-blockchain-and-database/
- https://www.oracle.com/cloud/blockchain/index.html#compare

Thanks for your attention

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