Distributed Architecture, Interaction, and Data Models

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Ack:

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

Outline

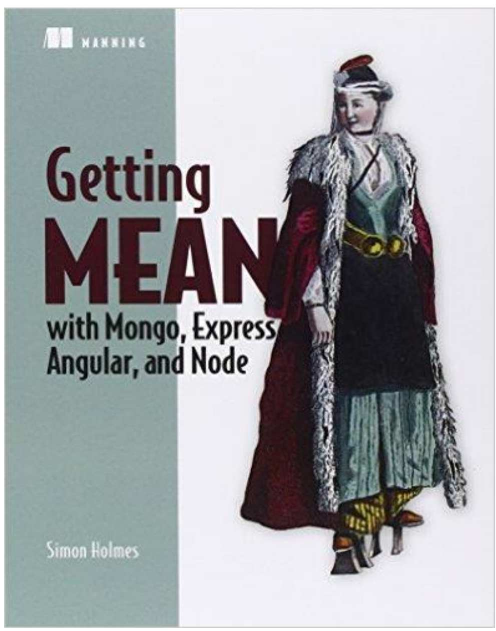
- Overview
- Key design concepts
- Architecture styles and Interaction Models
- Data models
- Optimizing interactions
- Summary

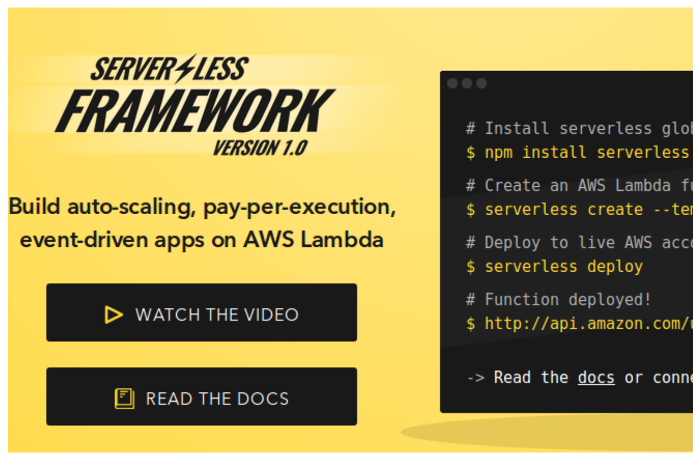
DST Lectures versus Labs

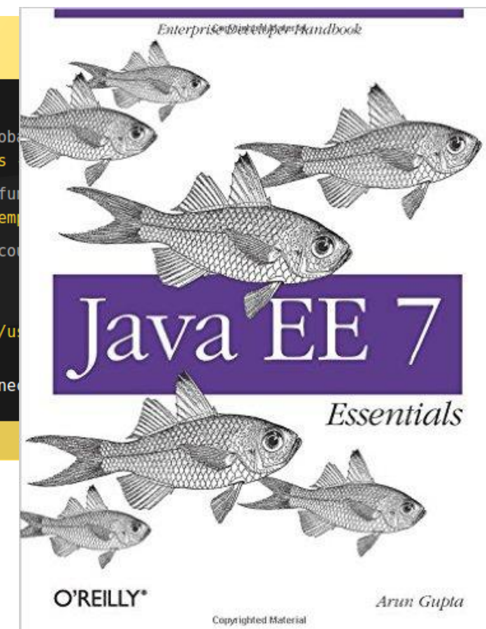
- Cover some important topics in the current state-of-the-art of distributed systems technologies
  - We have focusing topics
- Few important parts of the techniques for your labs
  - Most techniques you will learn by yourself
- Stay in the concepts: no specific implementation or programming languages

DST Lectures versus Labs

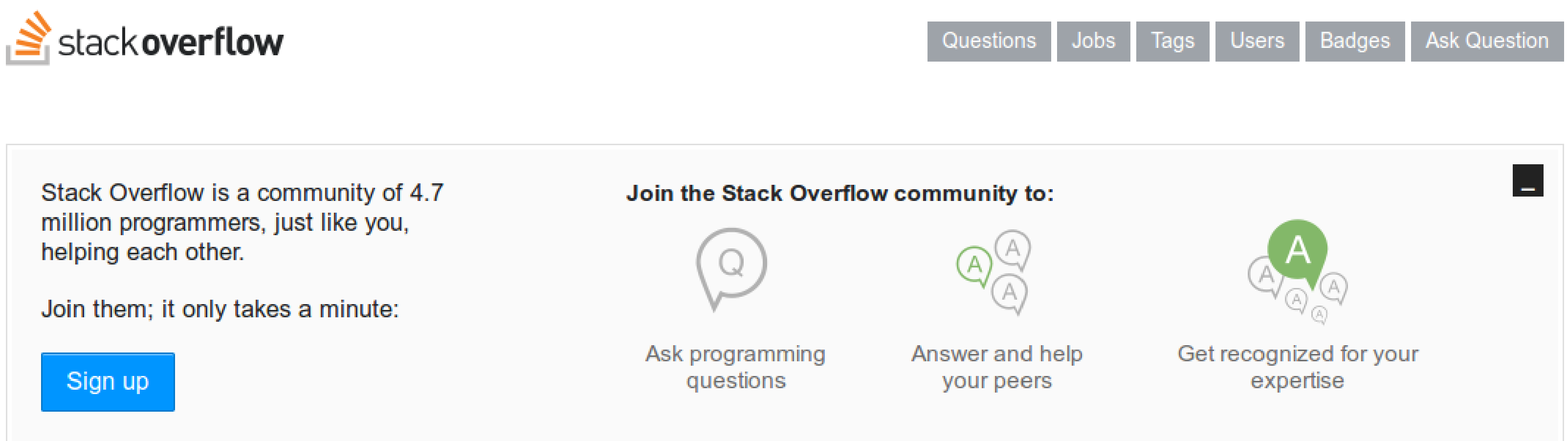
- It is not about Java or Enterprise Java Beans!
  - The technologies you learn in the lectures are for different applications/systems







Have some programming questions?



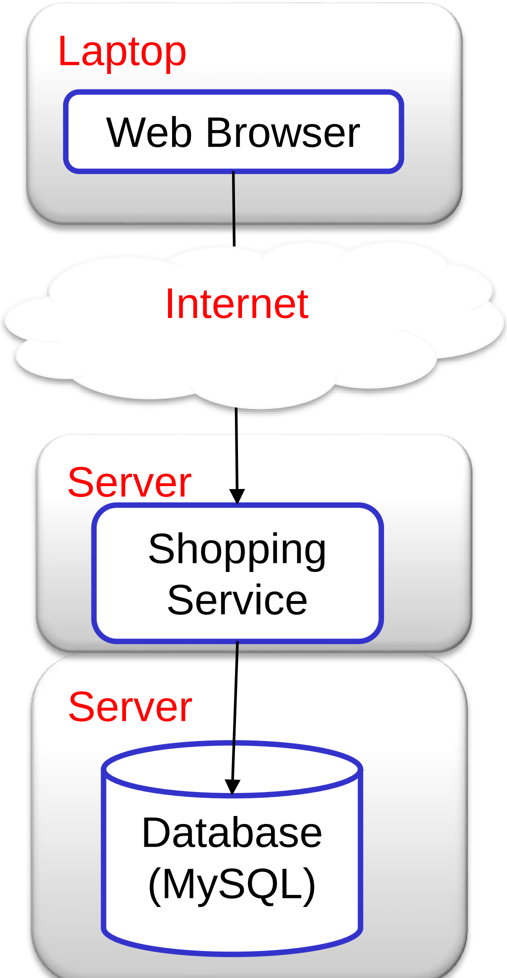
Or send the questions to the tutors

TRENDS & KEY DESIGN CONCEPTS

Rapid changes in Application Requirements and Technologies for Distributed Applications

- On-premise → Internet-scale enterprise applications
- Static, small infrastructures → large-scale dynamic infrastructures
- Heavy services → microservices
- Server → Serverless Architecture
- Data → Data, Data and Data

A not so complex distributed application



Technologies

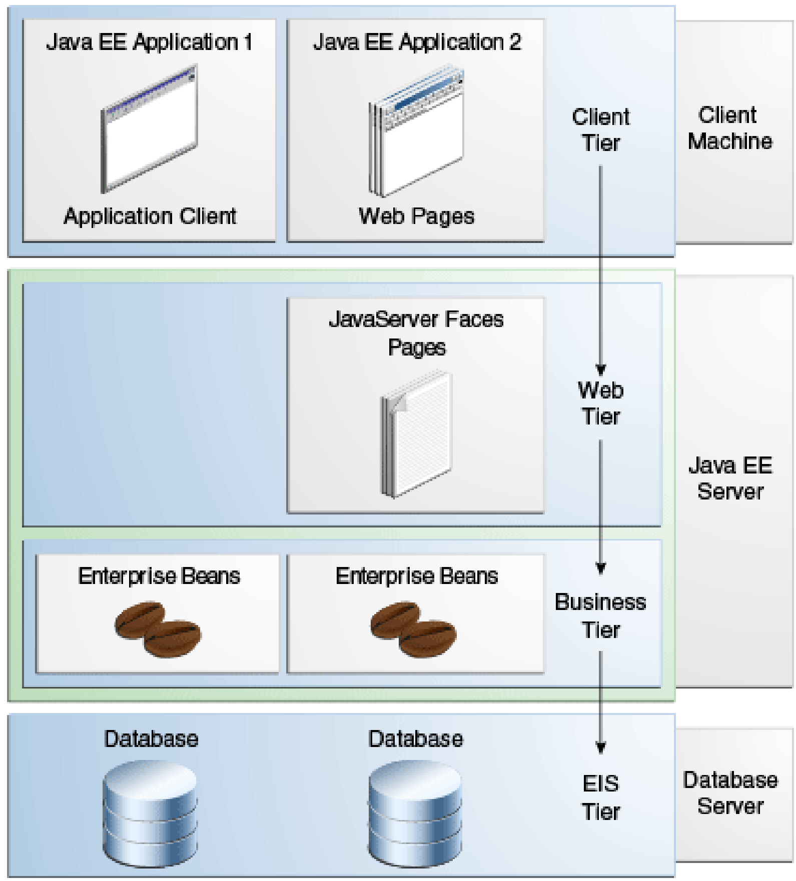


Figure source: https://docs.oracle.com/javaee/7/tutorial/overview003.htm

Distribution

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

amazon web services™

A complex, large-scale distributed system

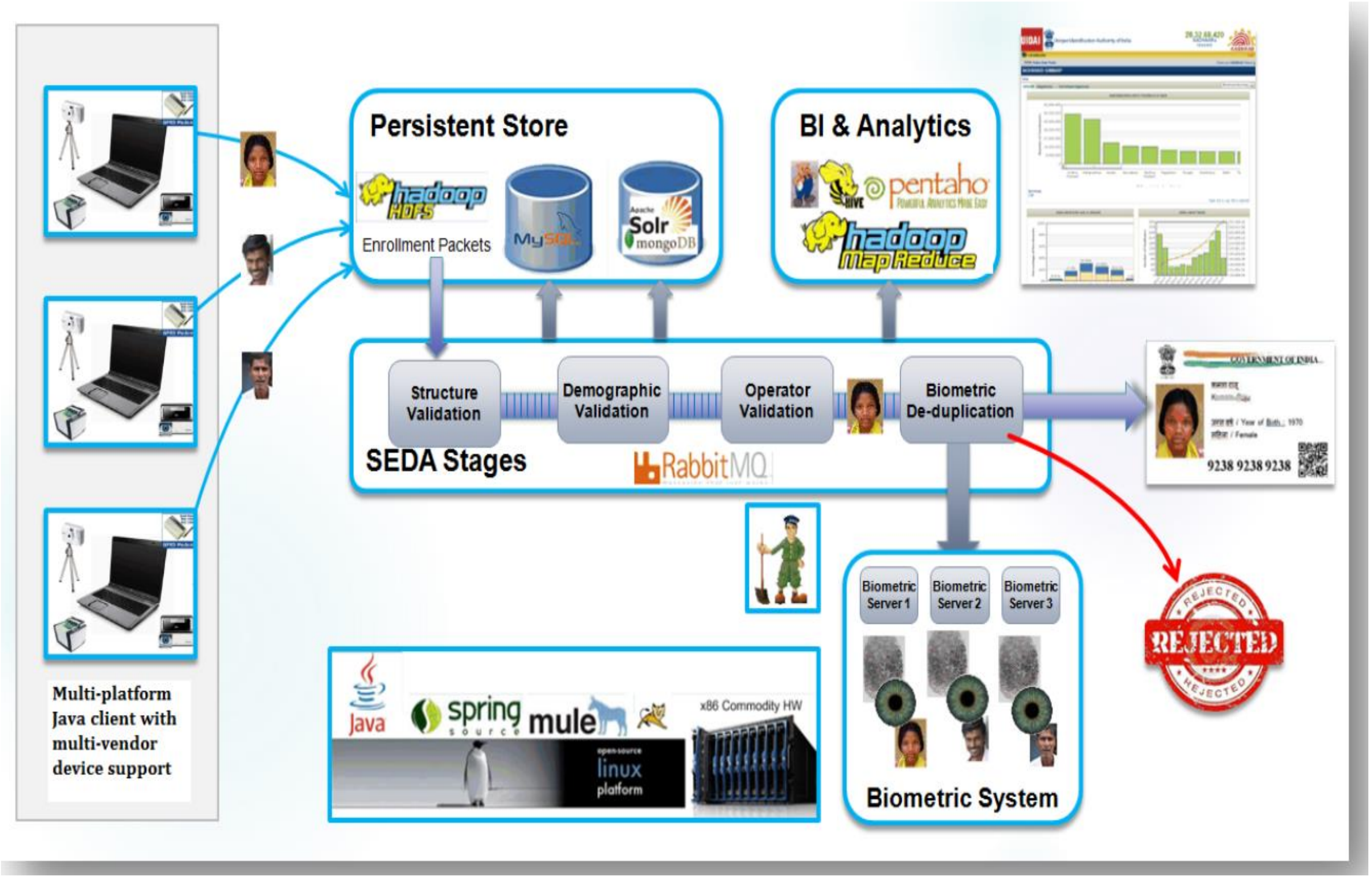


Figure source: http://uidai.gov.in/images/AadhaarTechnologyArchitecture_March2014.pdf

What we have to do?

System/application business logic

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

Deliver ←

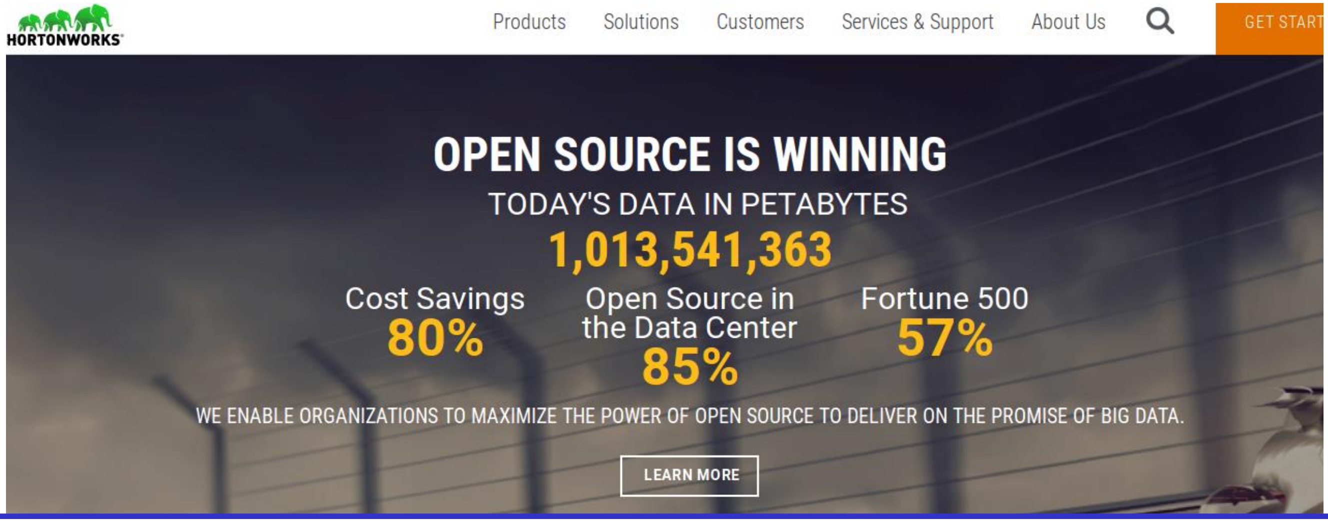
Development and operation tasks

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

selecting the right technologies as well as design methodology

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?
- **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 (design)
  - Distribution: where and how to deploy
- Using best practice design and performance patterns
- Principles, e.g., Microservices Approach

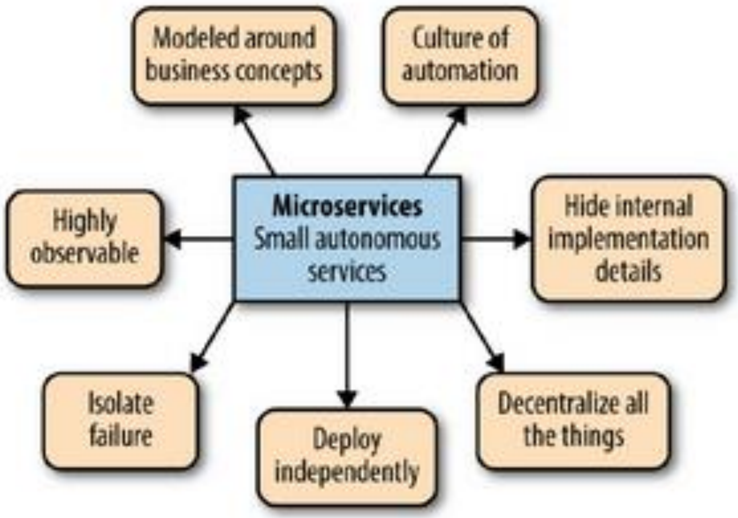


Figure source:Sam Newman, Building Microservices, 2015

Abstraction

Deal with technical complexity by hiding it behind (comparatively) nice 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 harm performance
- Extra layers require additional development effort

Examples: Abstraction and Layering side-by-side

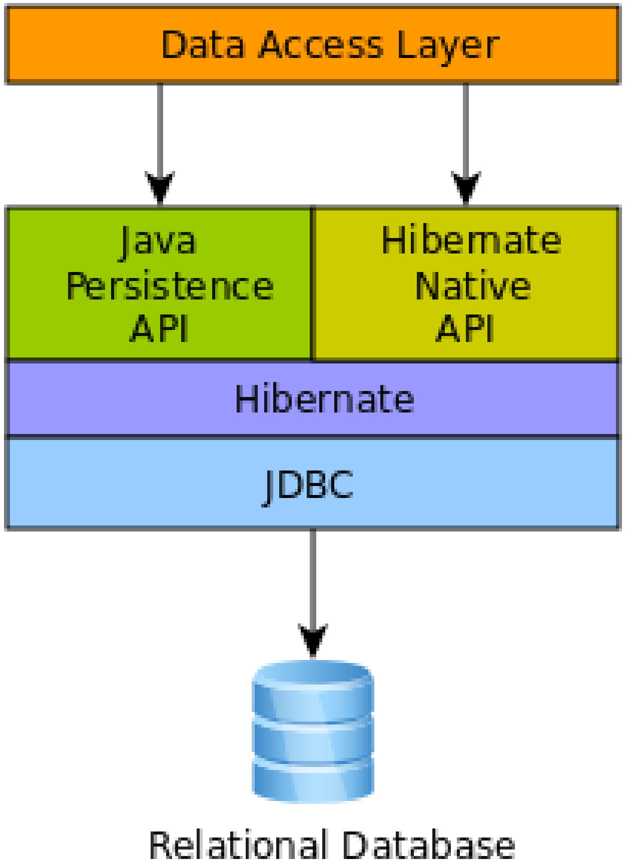


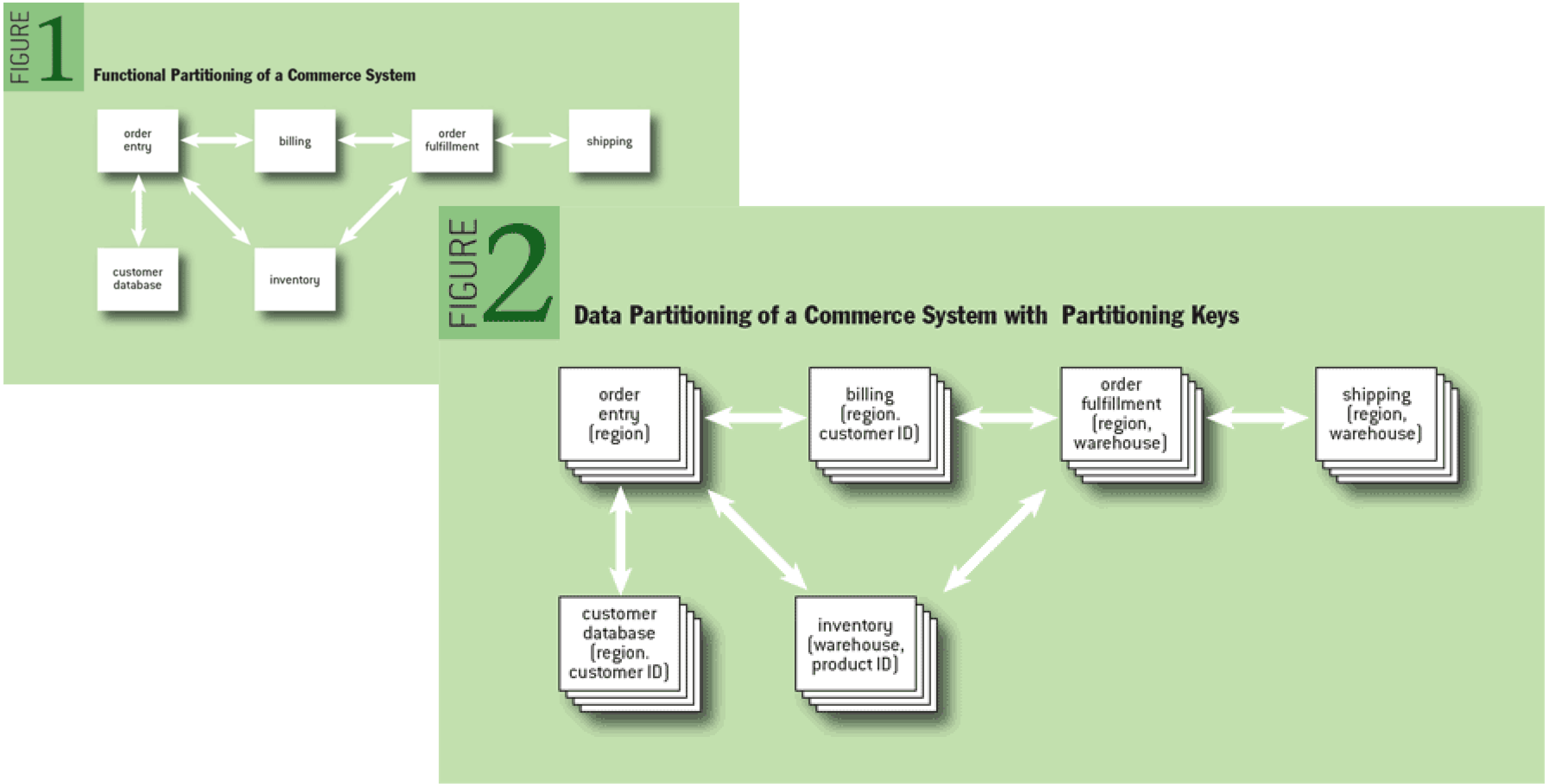
Figure source: http://docs.jboss.org/hibernate/orm/5.1/userguide/html_single/Hibernate_User_Guide.html

Partitioning/Splitting 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

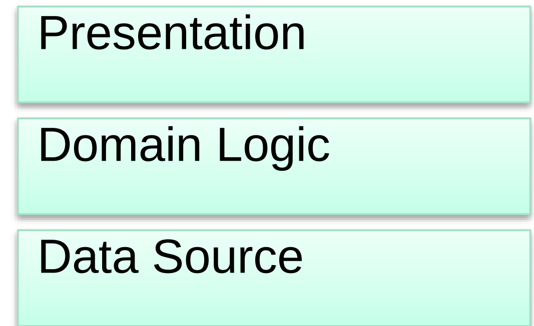
Enable abstraction and layering/orchestration, and distribution

Example of Functional and Data Partionting



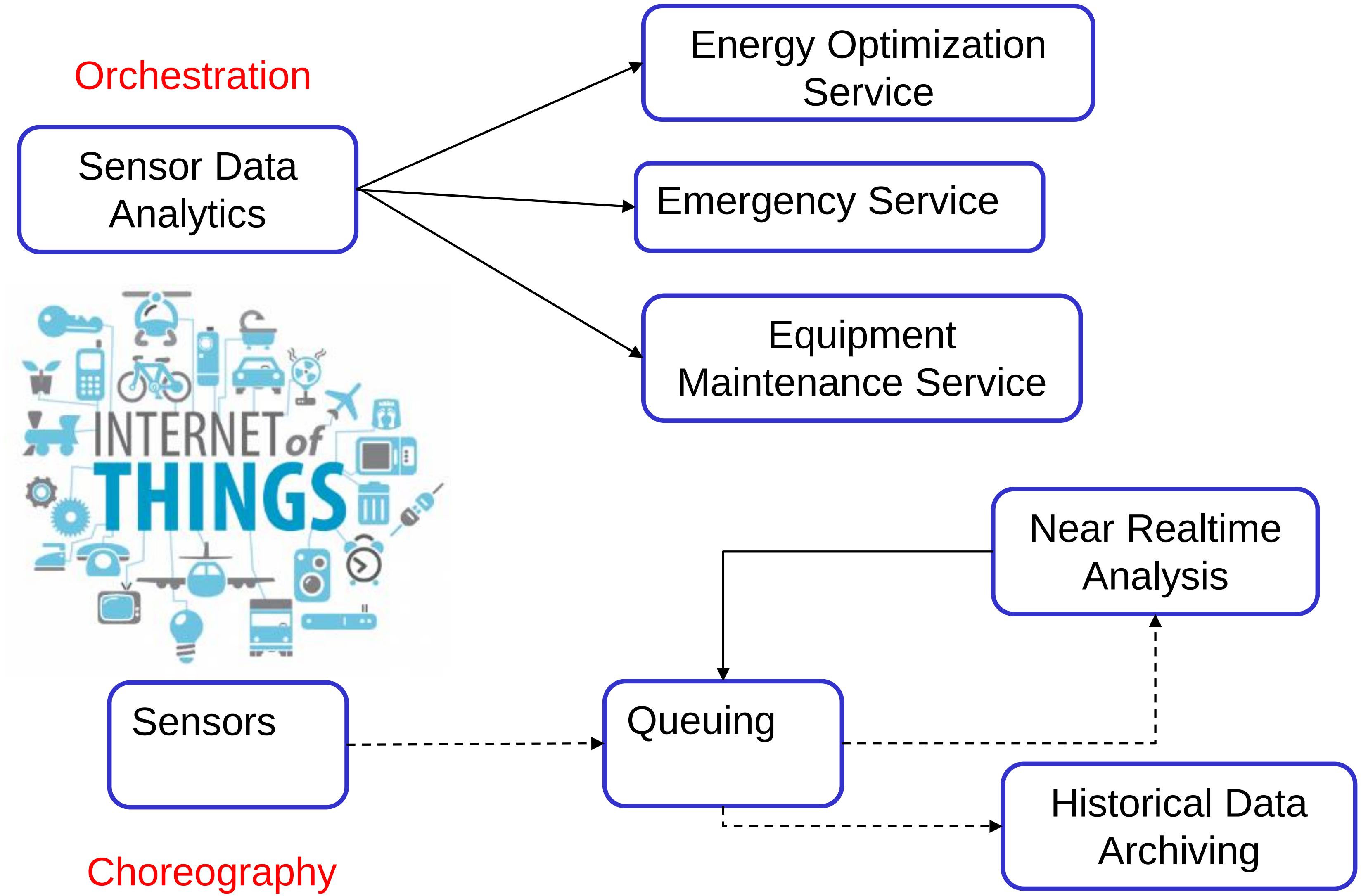
Figures source: http://queue.acm.org/detail.cfm?id=1971597

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

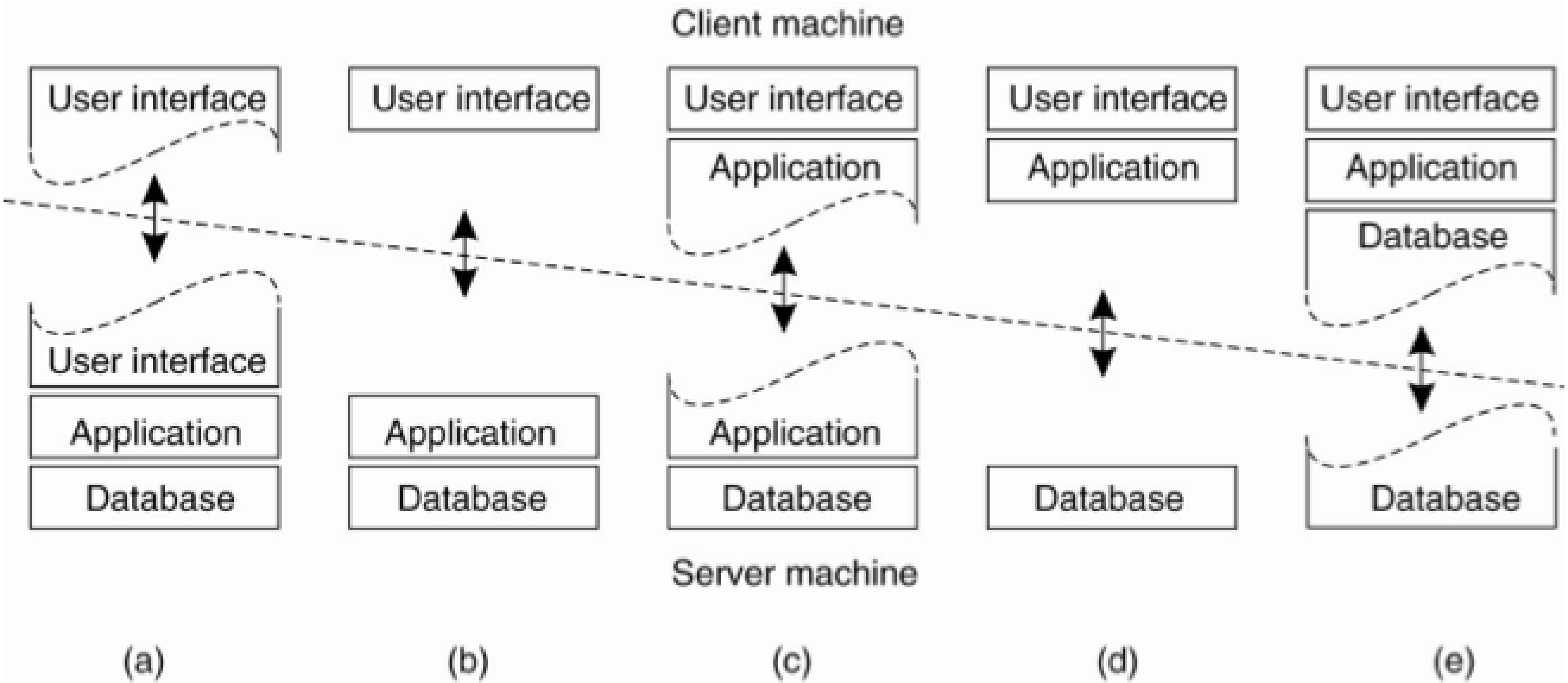
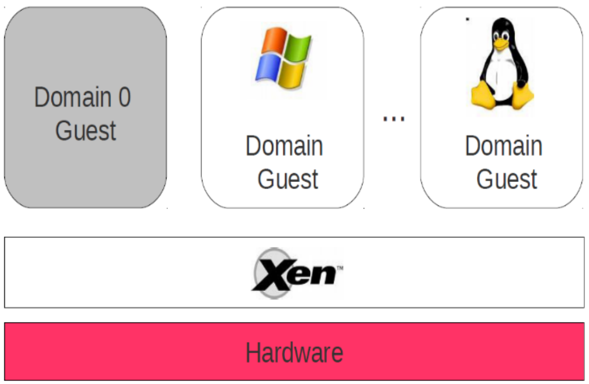


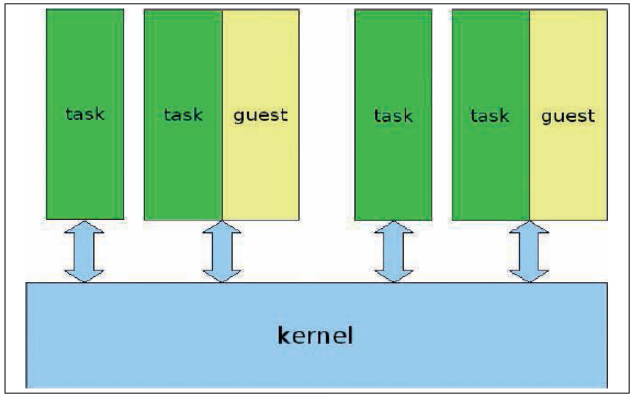
Figure source: Andrew S. Tanenbaum and Maarten van Steen, Distributed Systems – Principles and Paradigms, 2nd Edition, 2007, Prentice-Hall

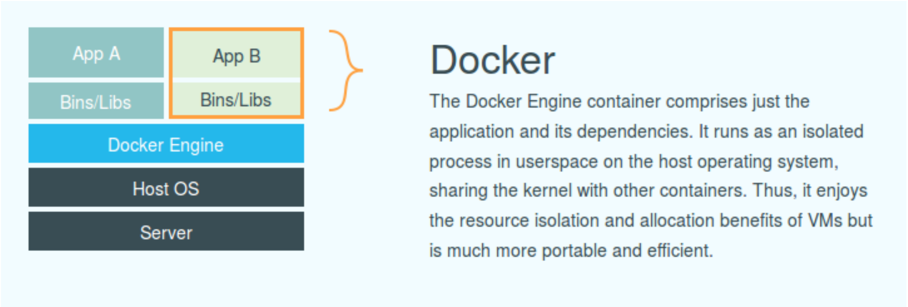
Distribution: OS, VM, or Container?

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



Source: Kernel-based Virtual Machine (http://www.linux-kvm.org/page/Main_Page)





Distribution: Edge, Network or Data Centers?

Use Case 3: Video Analytics

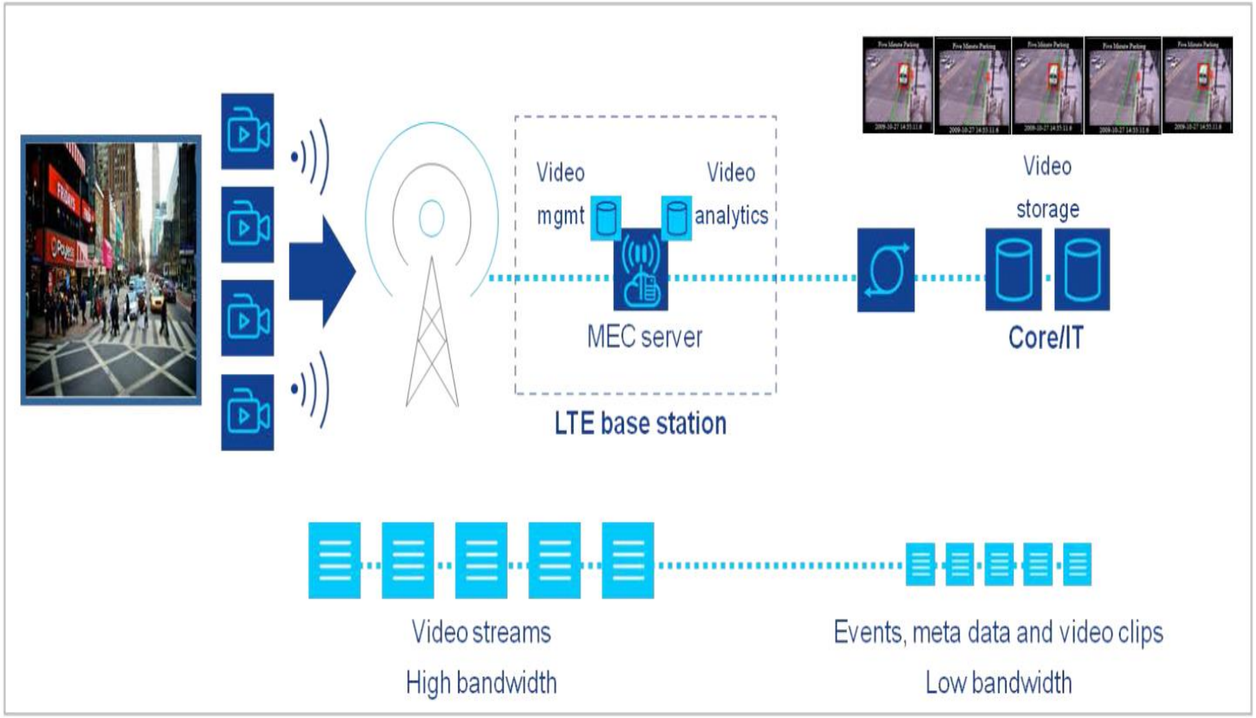


Figure 4: Example of video analytics

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

Programming

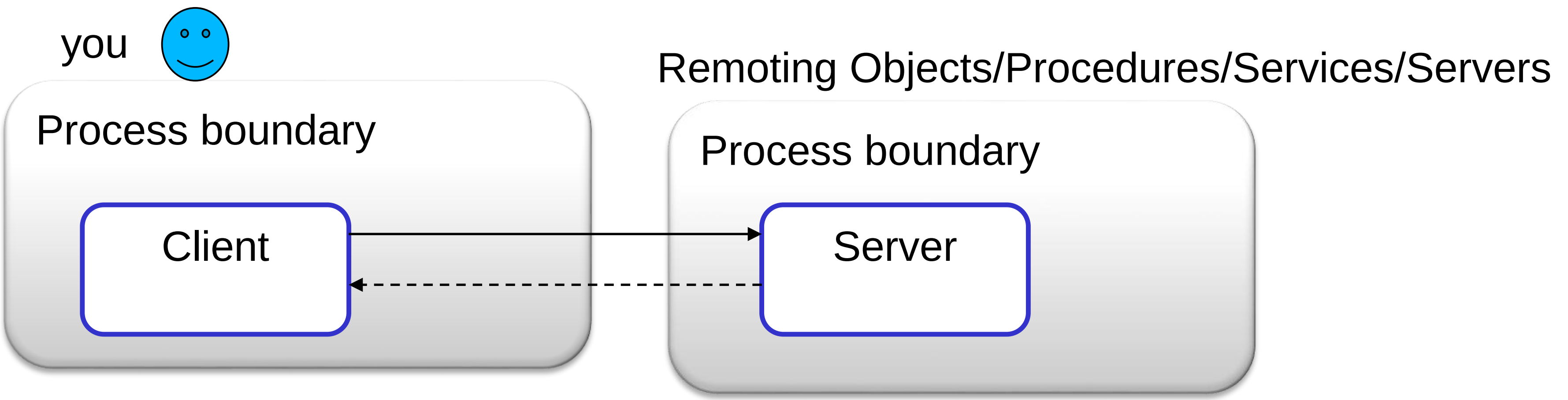
Language Rank		Types	Spectrum Ranking
1.	C	Mobile, Desktop, Embedded	100.0
2.	Java	Web, Mobile, Desktop	98.1
3.	Python	Web, Desktop	98.0
4.	C++	Mobile, Desktop, Embedded	95.9
5.	R	Desktop	87.9
6.	C#	Web, Mobile, Desktop	86.7
7.	PHP	Web	82.8
8.	JavaScript	Web, Mobile	82.2
9.	Ruby	Web, Desktop	74.5
10.	Go	Web, Desktop	71.9

Source: http://spectrum.ieee.org/computing/software/the-2016-top-programming-languages

What is the downside of functional and data partitioning?

ARCHITECTURE STYLES AND INTERACTION MODELS

Basic direct interaction



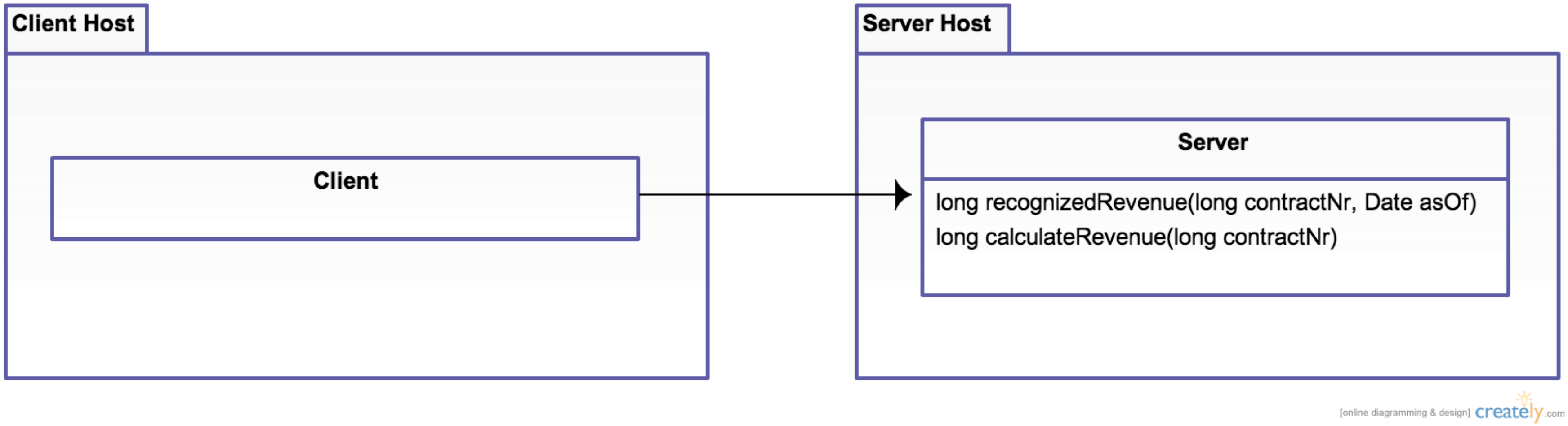
- Using abstraction, we hide the complexity within these boxes
- But we need to integrate between two components, enabling them communicate across process boundaries
  - In the same host, in the same application in different hosts, in different applications
  - How would they exchange data/commands?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

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.

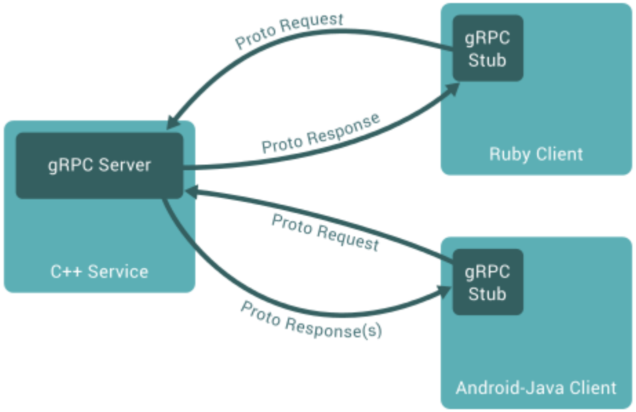
Remote Procedure Call Systems

- Server provides procedures that clients can call
- Most RPC-style middleware follows a small set of architectural principles
- Strongly tied to specific platforms
- Understanding those principles will help you understand how / why your RPC middleware of choice works



Example of State-of-the-art Tool

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

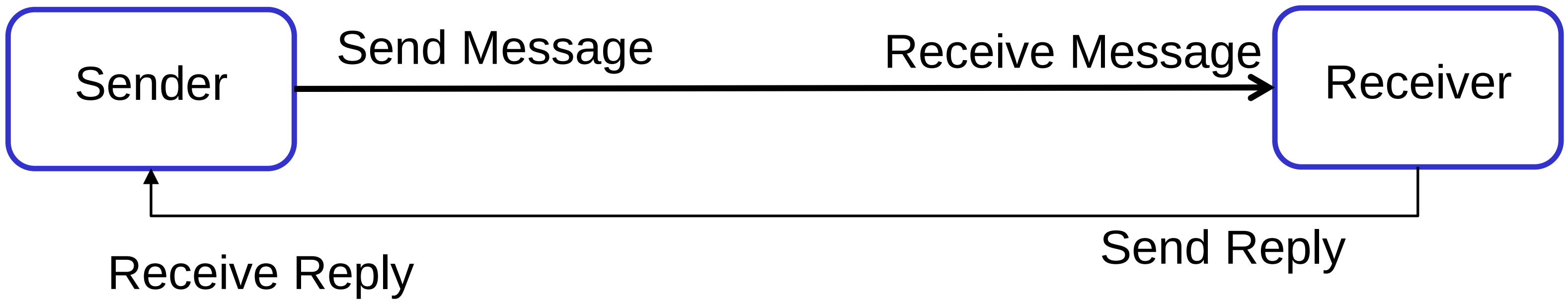
The Apache Thrift software framework, for scalable cross-language services development, combines a software stack with a code generation engine to build services that work efficiently and seamlessly between C++, Java, Python, PHP, Ruby, Erlang, Perl, Haskell, C#, Cocoa, JavaScript, Node.js, Smalltalk,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

Download

Apache Thrift v0.10.0

Message Passing

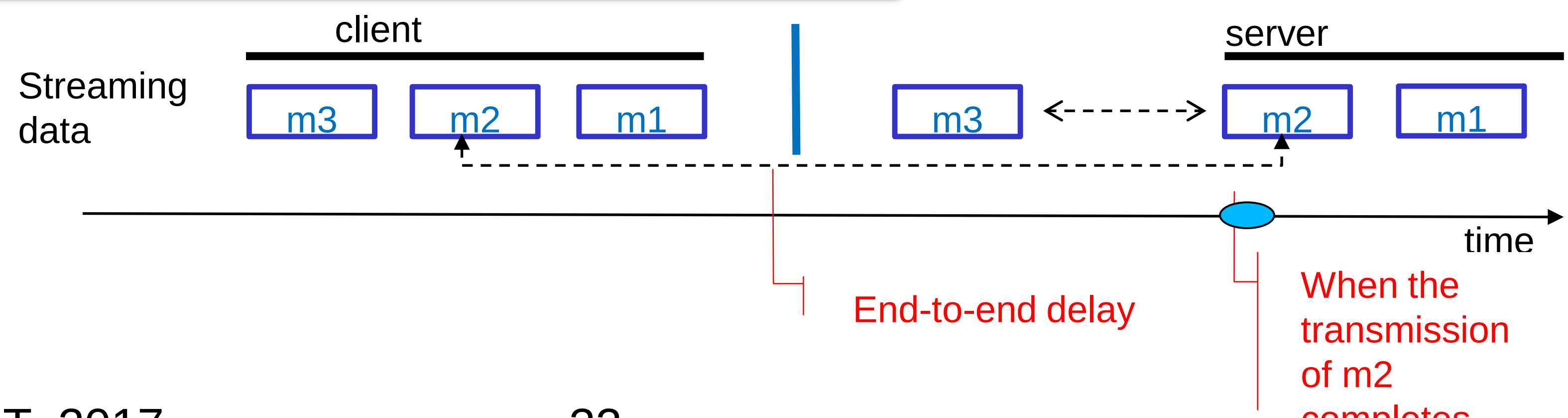
More in lecture 2 (fundamental) and lecture 5 (large-scale)



- Servers and clients communicate by exchanging messages

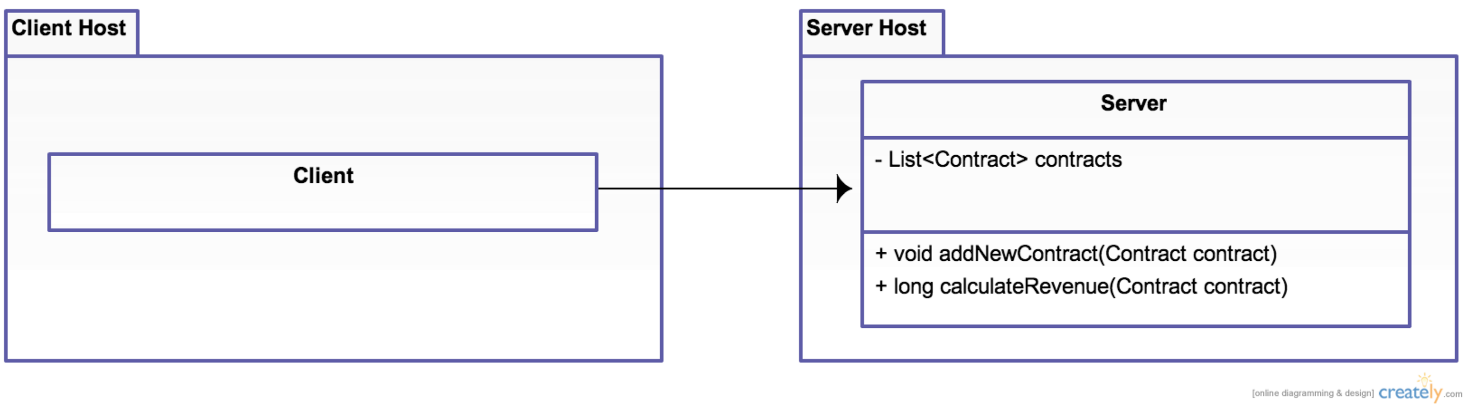
Stream-oriented communication

When delivery times matter!



Distributed Object Systems

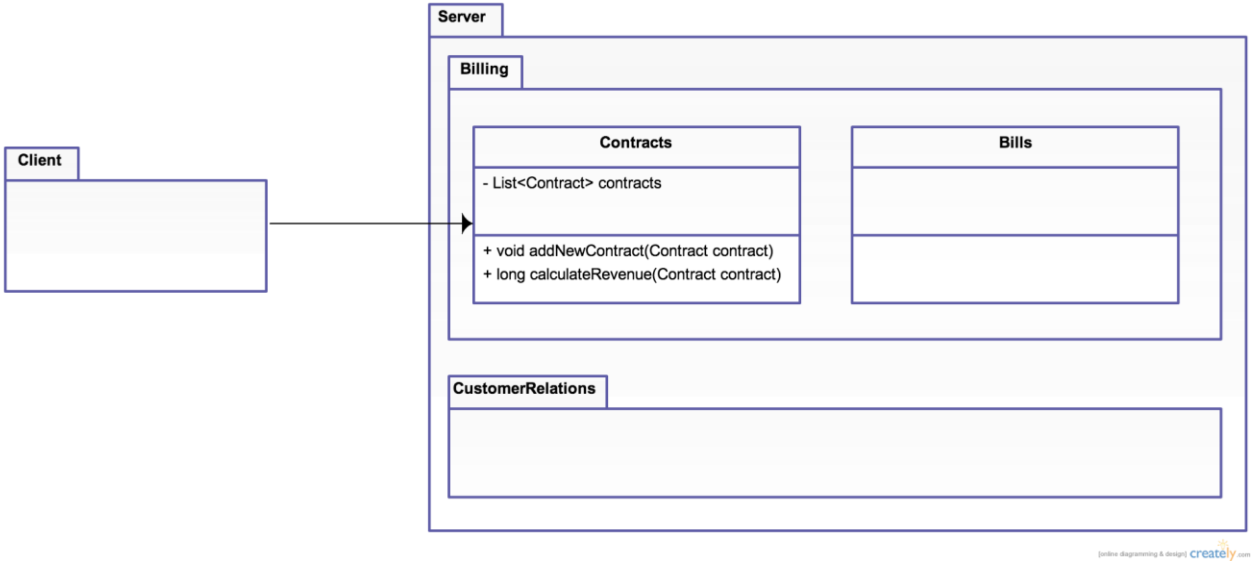
- Natural progression for object-oriented programming languages
  - Fits naturally into object-oriented programs
  - Imperative language → RPC
  - OO language → distributed objects
- Server provides objects (data + methods) that clients can interact with



Distributed Systems Group

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,

  Context-free (and hence reusable),

  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

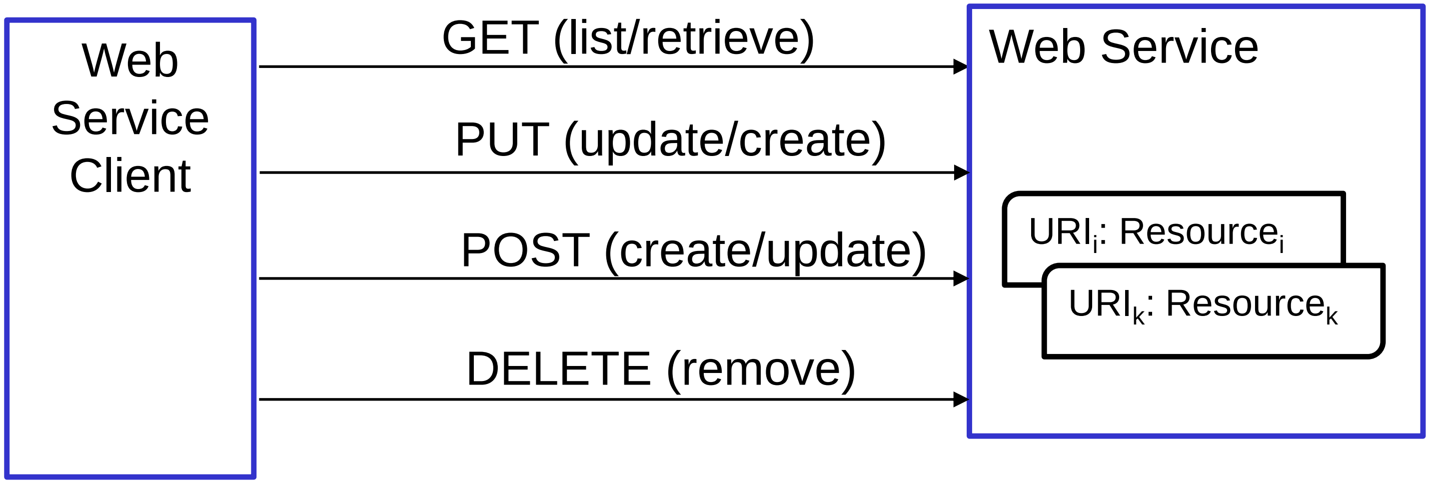
- Loose coupling
  - Message exchanges
  - Policy
- Peer-to-peer
- Composable
- Some overhead
- Medium to coarse granularity
  - Pay-per-use remote services

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, XML)
- Architectural Constraints:
  - Client-Server, Stateless, Cacheable, Layered System, Uniform Interface

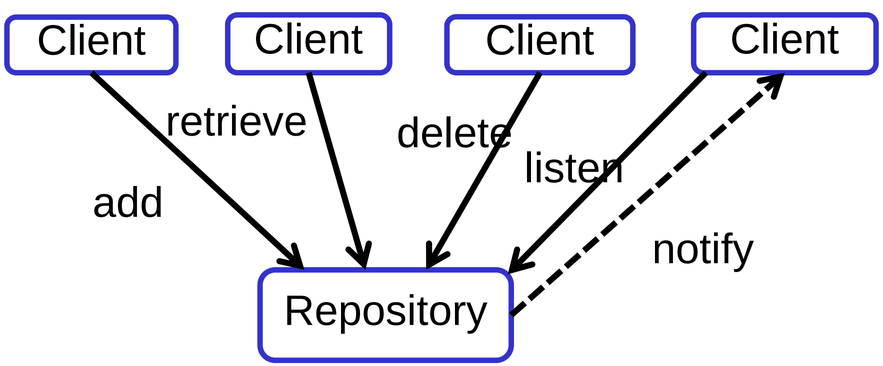
Example of REST Interactions

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

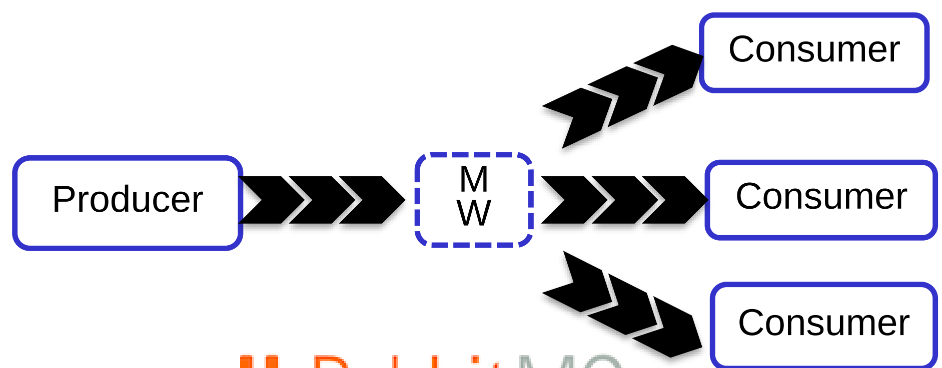


Complex interactions

- One-to-many, Many-to-one, Many-to-One
  - Message Passping Interface
  - Public/Subscribe, Message-oriented Middleware
  - Shared Repository
  - Application/Systems specific models



Amazon S3

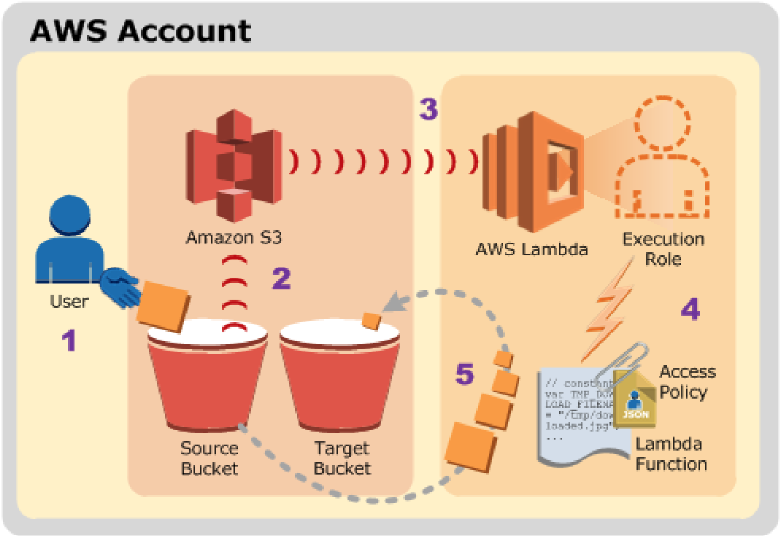


Serverless

- 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)



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

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

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 distributed applications

A big homework:
Microservices approach versus serverless approach

DATA MODELS

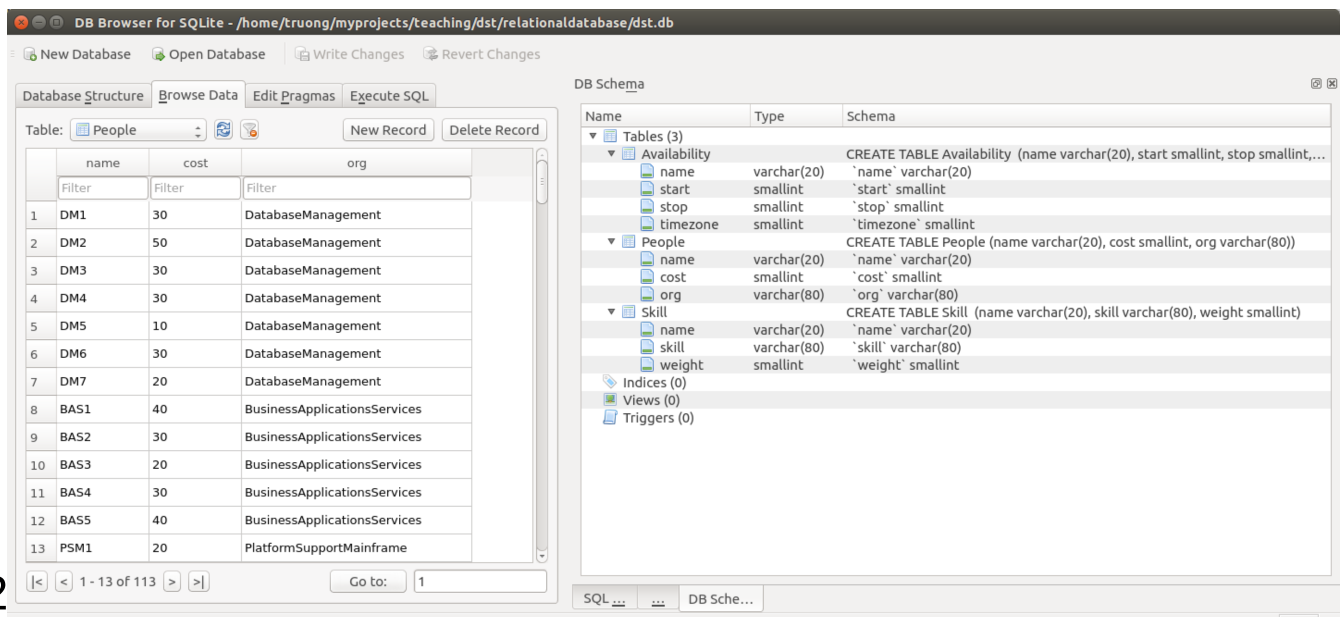
Data Storage Models

- 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 is everything but SQL

Relational Model

- Set-theory based systems
- 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

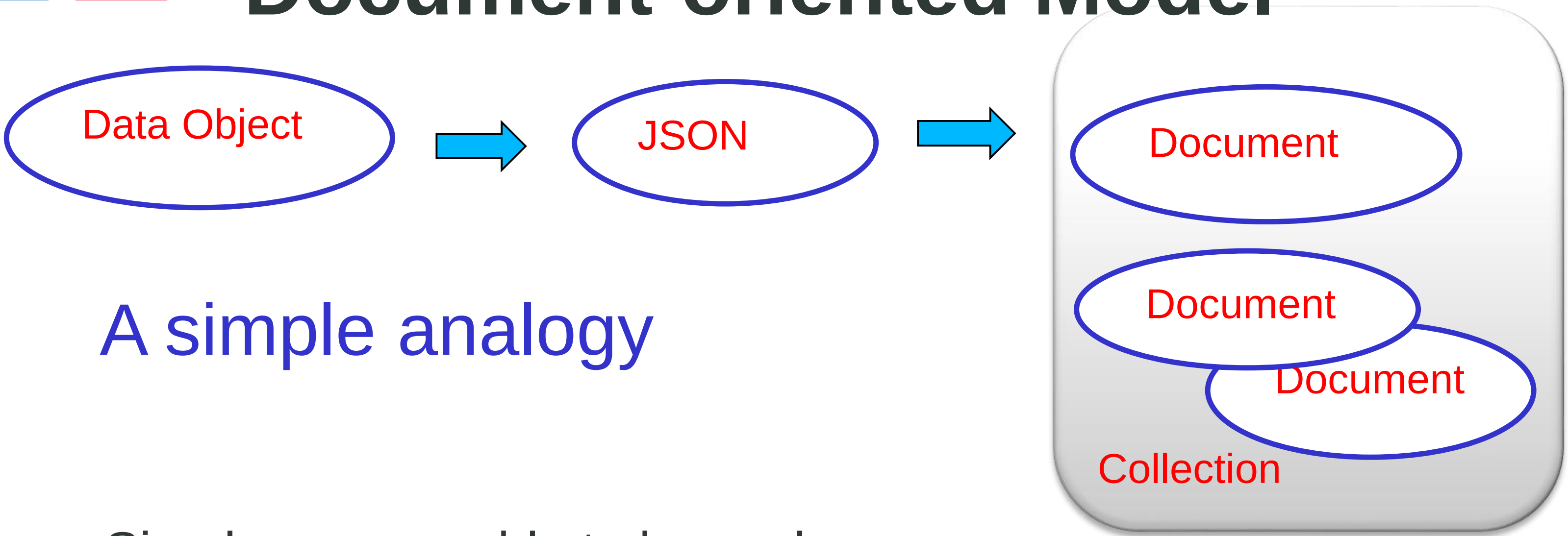


Key-Value Model

- 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, very efficient, as usually no consistency is ensured
- Querying capabilities usually very limited

  Oftentimes only “By Id” pattern
- E.g.:
  - Memcached, Riak, Redis

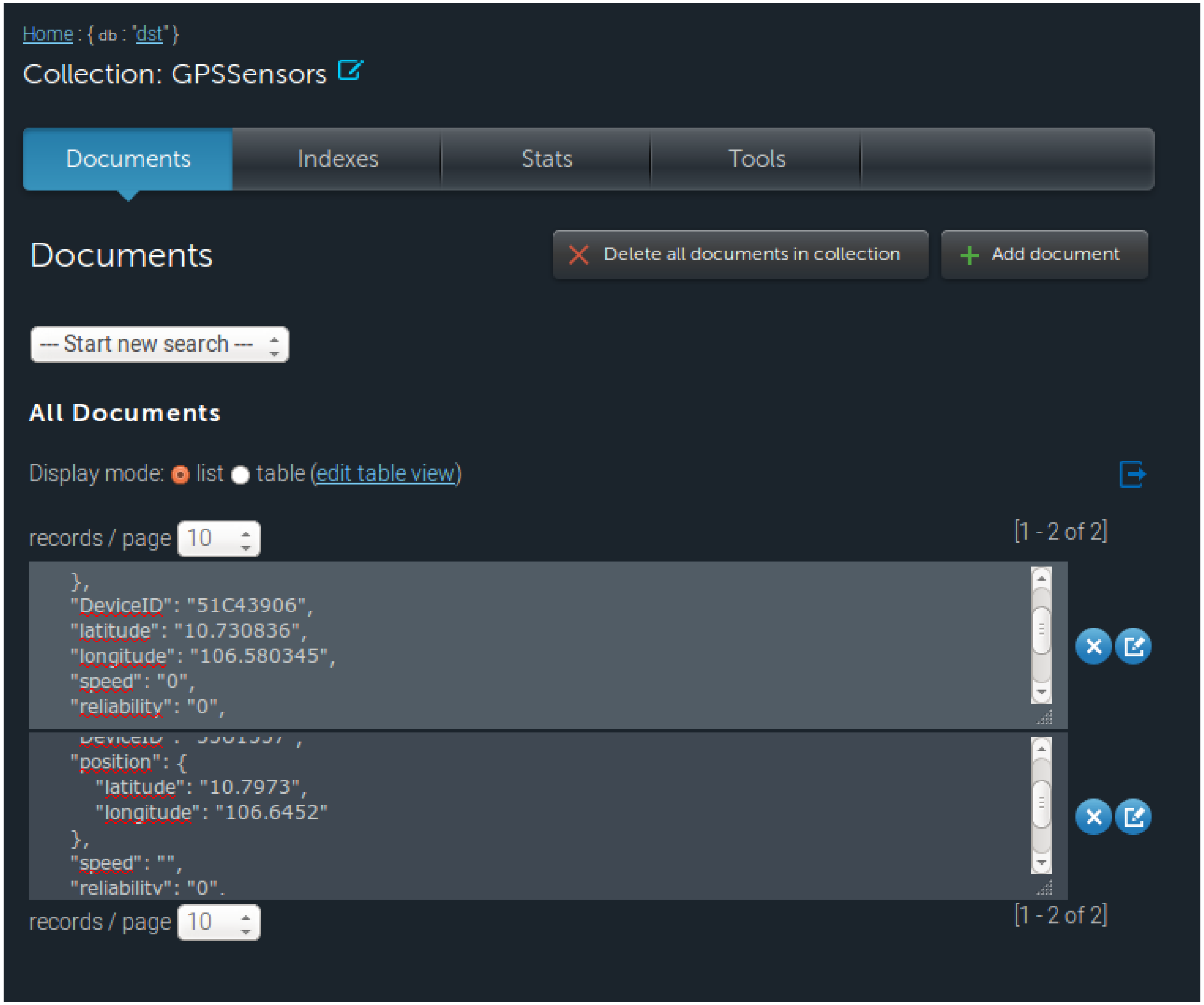
Document-oriented Model



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 awkward and/or inefficient
- E.g.:, CouchDB, MongoDB

Example: MongoDB with mLab.org



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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>..."		

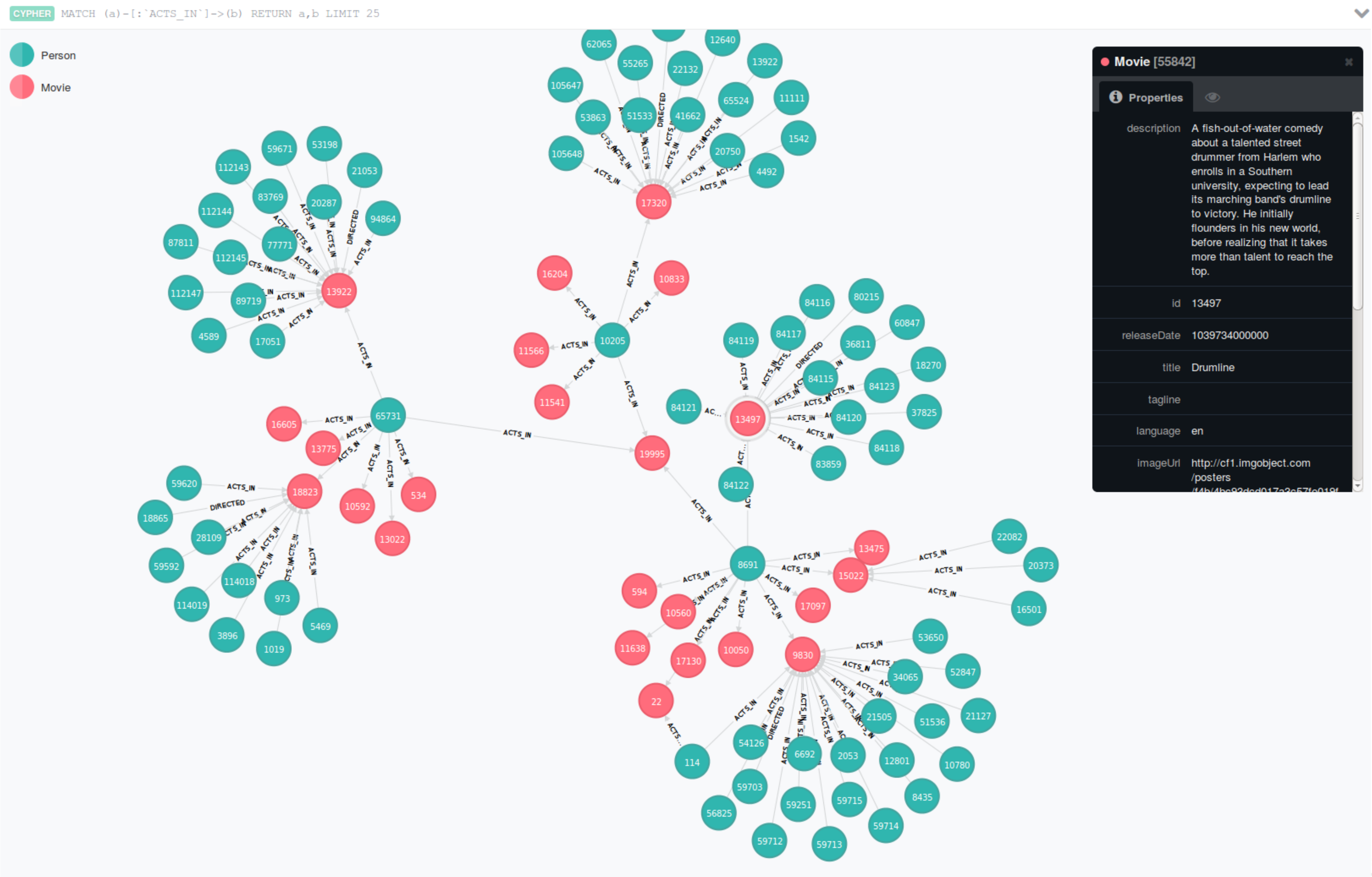
```
{
  "com.cnn.www": {
    contents: {
      t6: contents:html: "<html>..."
      t5: contents:html: "<html>..."
      t3: contents:html: "<html>..."
    }
    anchor: {
      t9: anchor:cnnsi.com = "CNN"
      t8: anchor:my.look.ca = "CNN.com"
    }
    people: {}
  }
  "com.example.www": {
    contents: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

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

Graph-oriented Model

- Elevates data relationships to 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 blazingly fast
- Notoriously hard to understand for people coming from traditional data storage models
- E.g.: Neo4J

Examples wih Neo4j



Which ones are the best?

Check: http://kkovacs.eu/cassandra-vs-mongodb-vs-couchdb-vs-redis

Kristof Kovacs

Software architect, consultant

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Cassandra vs MongoDB vs CouchDB vs Redis vs Riak vs HBase vs Couchbase vs OrientDB vs Aerospike vs Neo4j vs Hypertable vs ElasticSearch vs Accumulo vs VoltDB vs Scalaris vs RethinkDB comparison

(Yes it's a long title, since people kept asking me to write about this and that too :) I do when it has a point.)

While SQL databases are insanely useful tools, their monopoly in the last decades is coming to an end. And it's just time: I can't even count the things that were forced into relational databases, but never really fitted them. (That being said, relational databases will always be the best for the stuff that has *relations*.)

But, the differences between NoSQL databases are much bigger than ever was between one SQL database and another. This means that it is a bigger responsibility on software architects to choose the appropriate one for a project right at the beginning.

In this light, here is a comparison of Cassandra, Mongodb, CouchDB, Redis, Riak, RethinkDB, Couchbase (ex-Membase), Hypertable, ElasticSearch, Accumulo, VoltDB, Kyoto Tycoon, Scalaris, OrientDB, Aerospike, Neo4j and HBase:

The most popular ones

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

Example - Healthcare

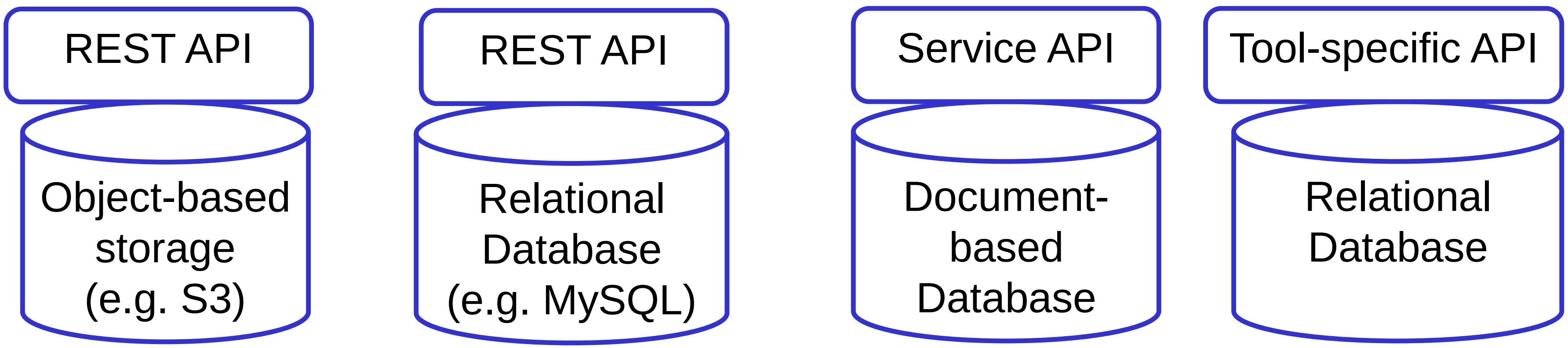
- Personal or hospital context

- 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

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)

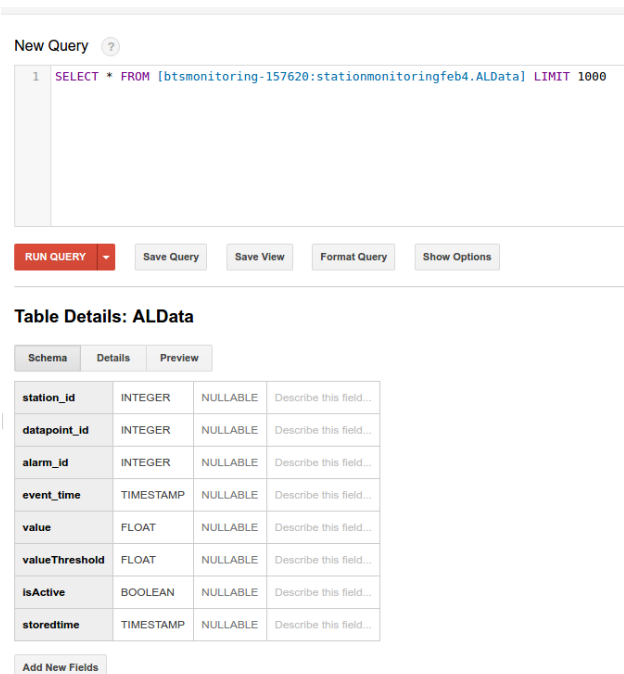
Data Access API Approach

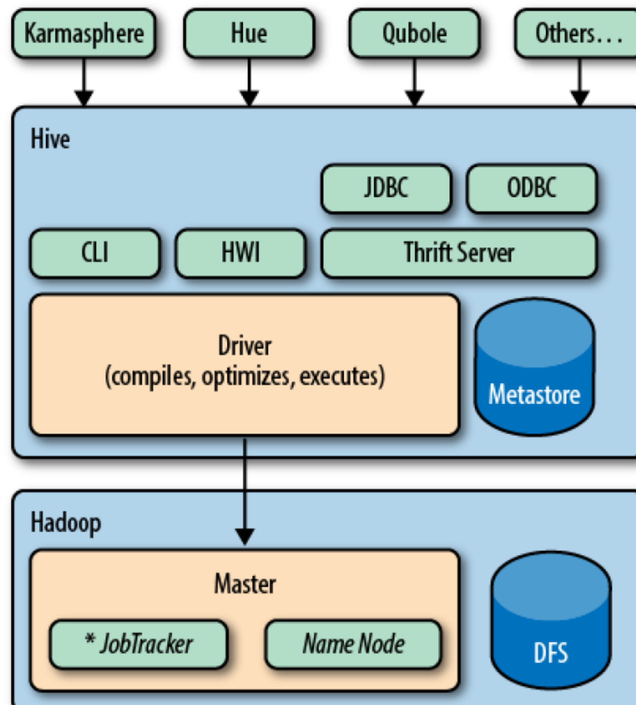


- Data access APIs can be built based on well-defined interfaces
- Currently mostly based on REST
- Help to bring the data object close to the programming language objects

SQL-based API

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



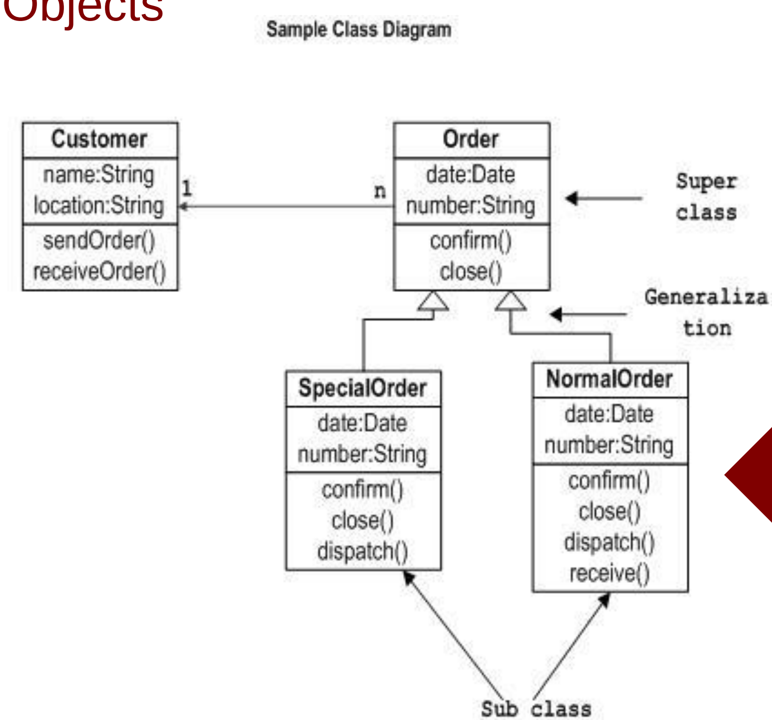


Source: Programming Hive, ***Edward Capriolo, Dean Wampler, and Jason Rutherglen***

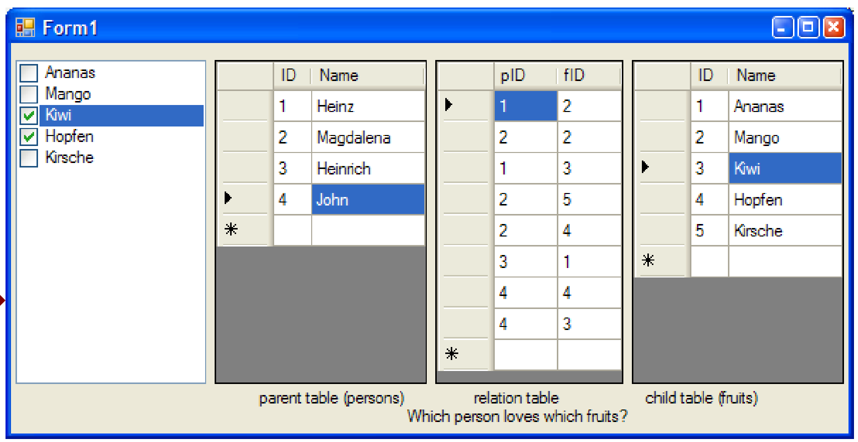
Object-Relational/Grid Data Mapping (ORM/OGM)

Conceptual mismatch, especially with relational database

Programming Language Objects



Native Database Structure (e.g., relations)



What you want to avoid

```
public class JDBCExample extends HttpServlet {
    public void doGet(... request, ... response) throws ... {
        ps = conn.prepareStatement("UPDATE table set ColumnX = 
?;");
        ps.setInt(1, 
Integer.parseInt(request.getParameter("param1")));
        ps.executeUpdate();
        ...
        ResultSet rs = stmt.executeQuery("SELECT x, y, z FROM 
table;");
        response.setContentType("text/html");
        PrintWriter out = response.getWriter();
        out.write("<html><head /><body>\n")
        while (rs.next()) {
            out.println(rs.getString("x") + "<br>\n");
        }
        out.write("</body></html>");
    }
    ...
```

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

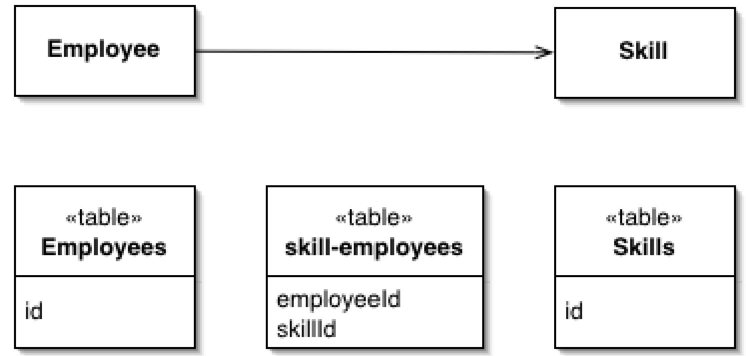
Wraps a database row, encapsulates database access code, and adds business logic to that data.

Data Mapper

Handles loading and storing between database and Domain Model.

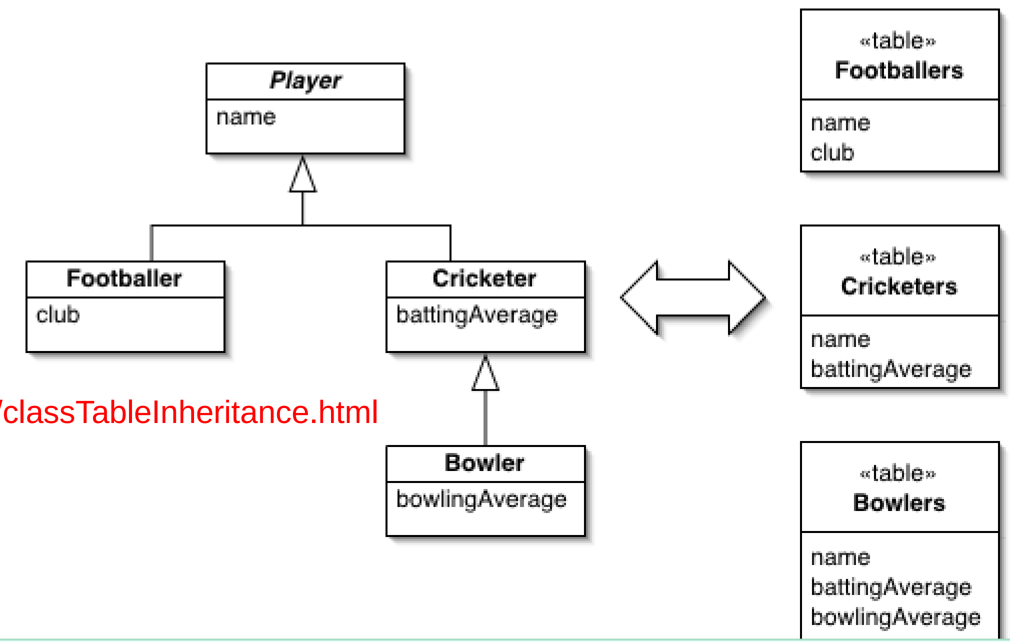
Object-Relational Structural Patterns

Association Table Mapping



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

Class Table Inheritance

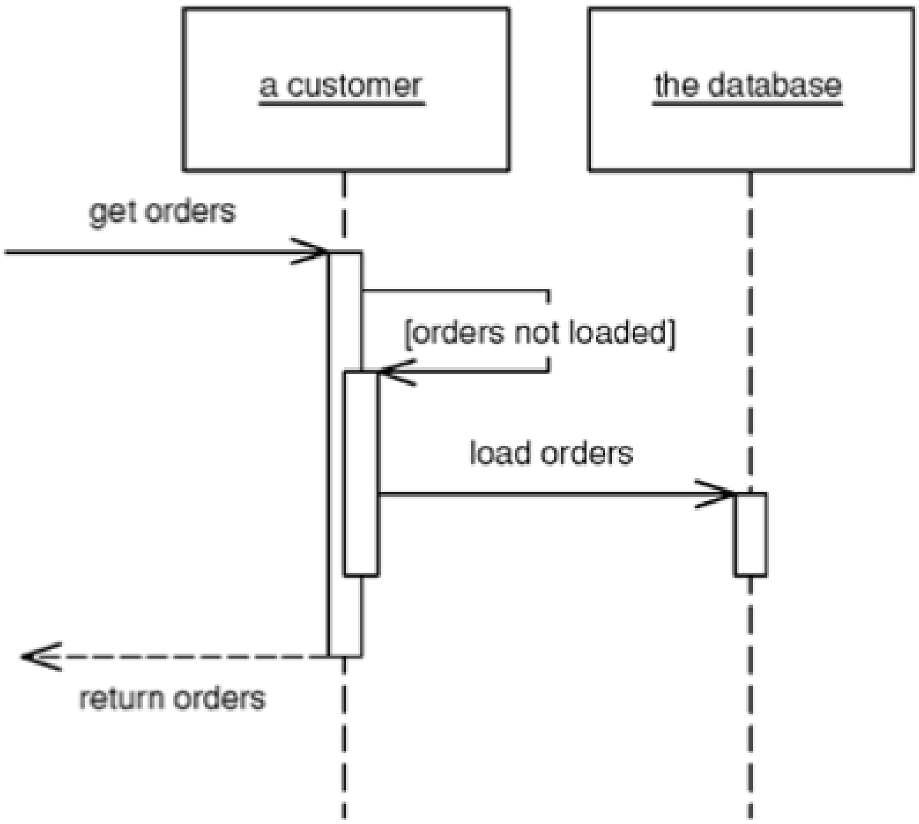


Source: http://martinfowler.com/eaaCatalog/classTableInheritance.html

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

An object that doesn't contain all of the data you need but knows how to get it .



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

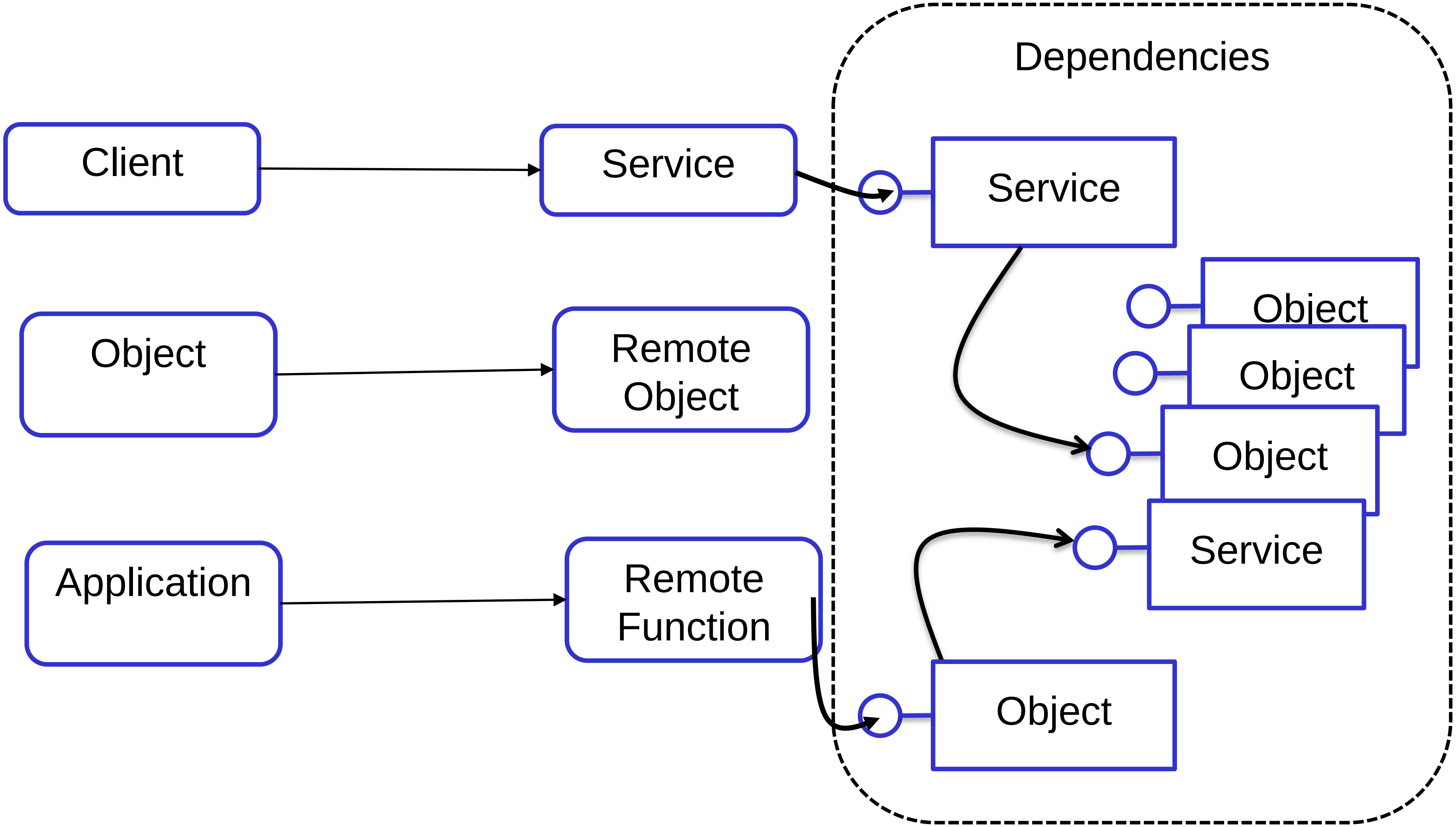
Lazy Loading Example - Hibernate

```
@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

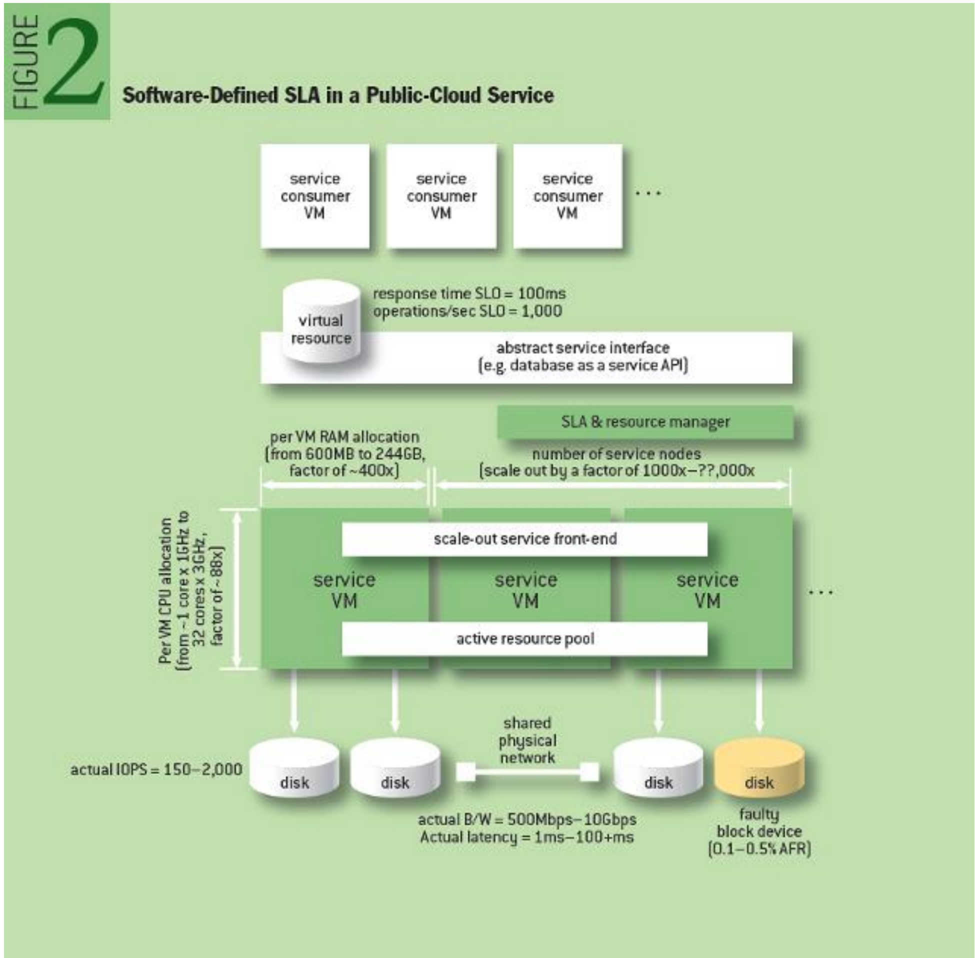


Figure source: http://queue.acm.org/detail.cfm?id=2560948

Load balancing

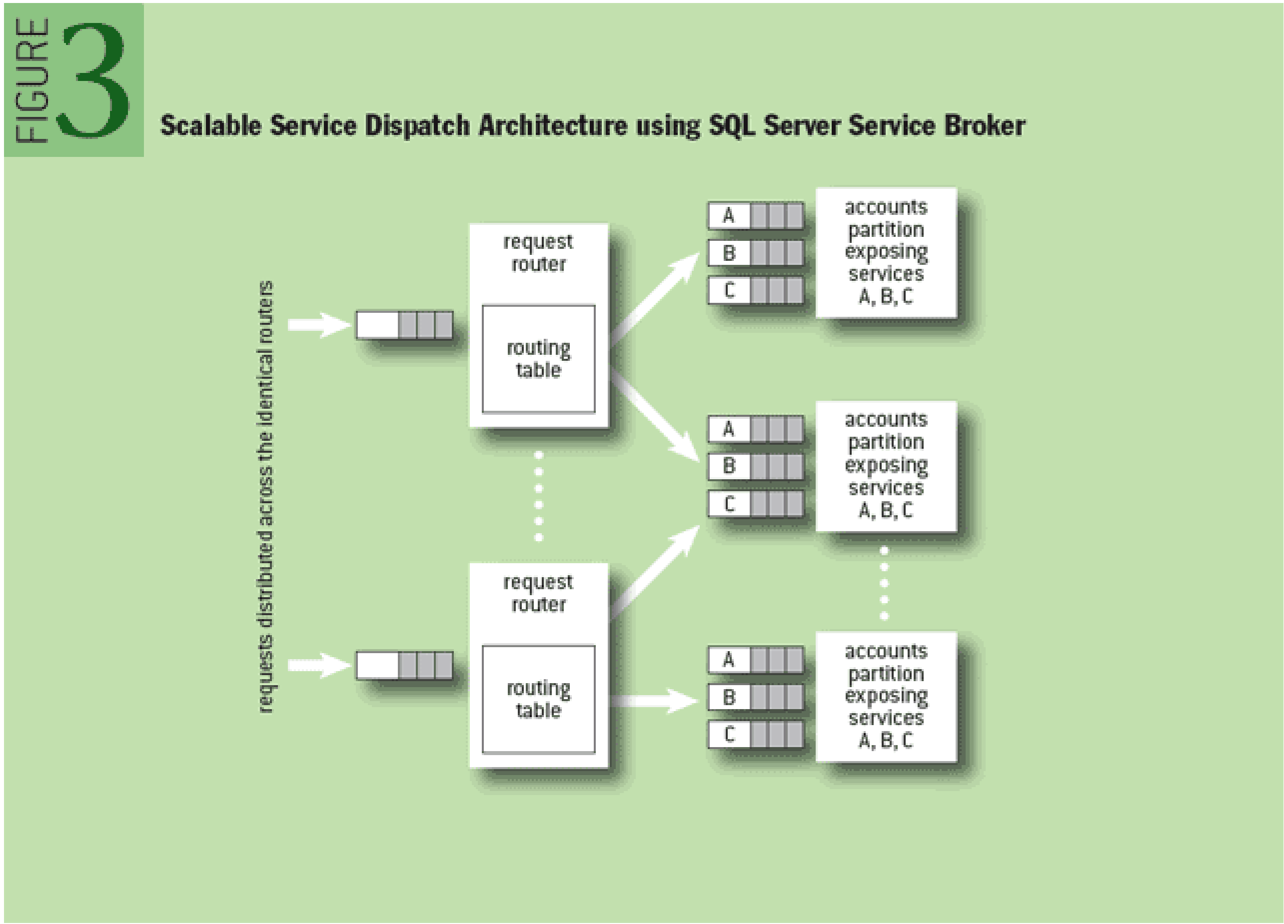
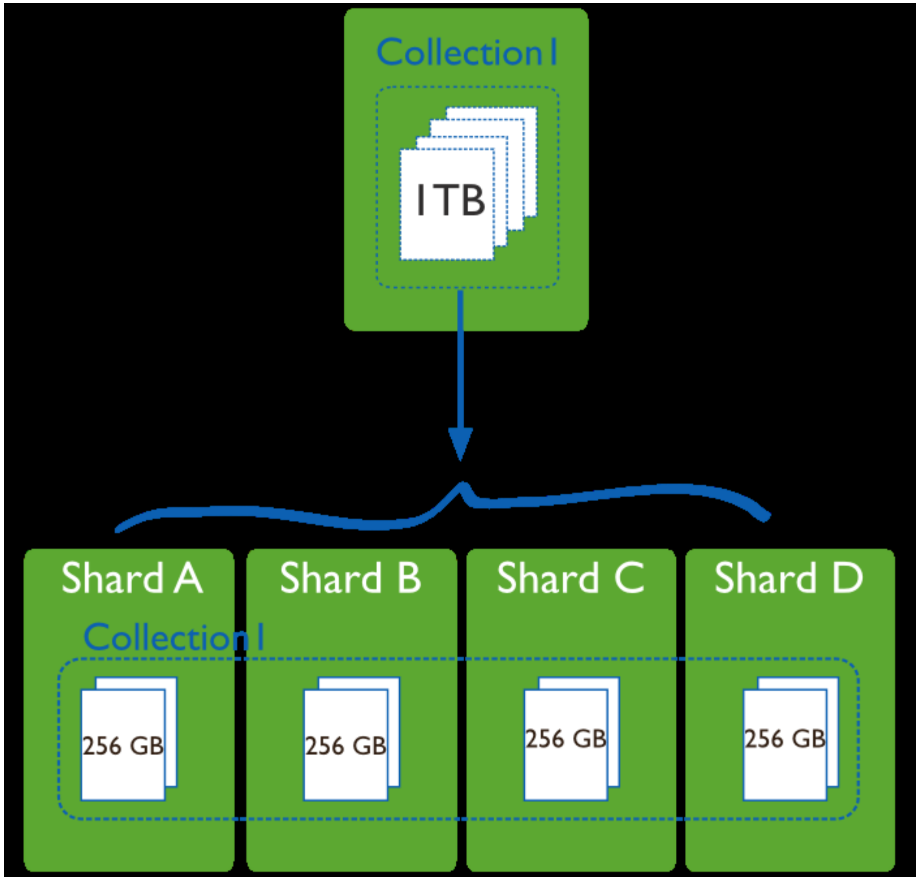


Figure source: http://queue.acm.org/detail.cfm?id=1971597

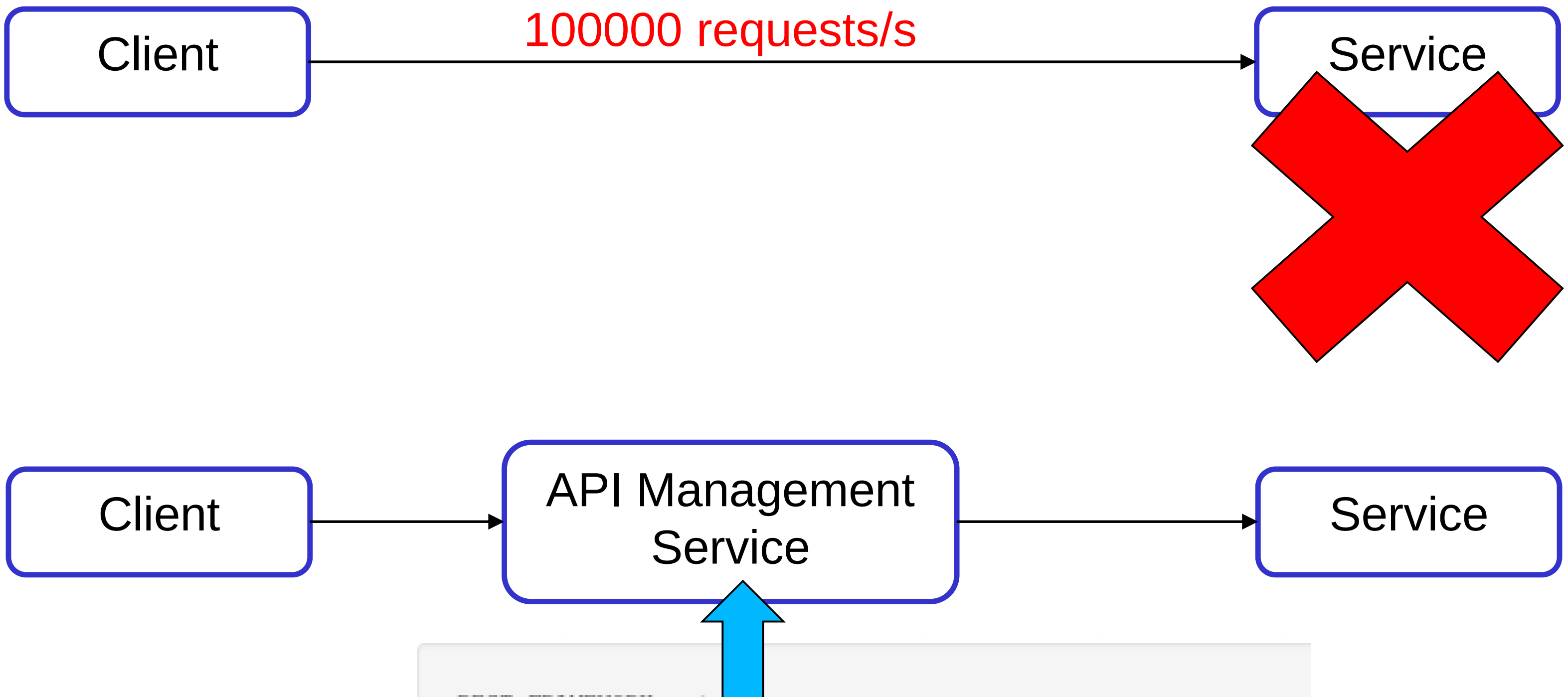
Data Sharding

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'
    }
}
```

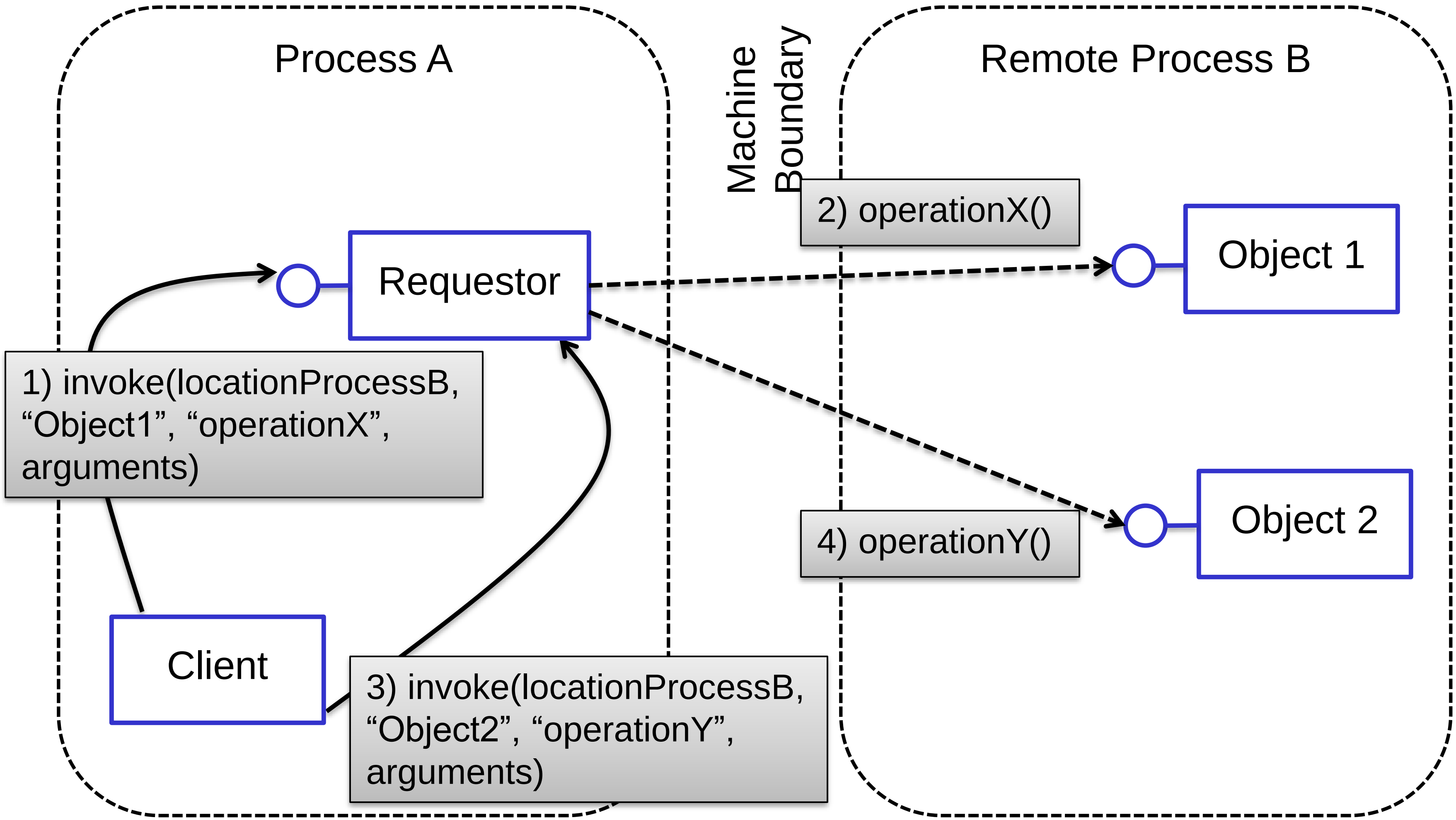
Code: http://www.django-rest-framework.org/api-guide/throttling/#how-throttling-is-determined

Pattern: Requestor

- Primary use:
  - Perform any action that is required to access the remote object (towards the client)

  → Client should focus on business logic
- Remains independent of the object's implementation
- Informs client about remoting errors
- Single instance or one per server, etc.
- Is supplied with:
  - Absolute object reference, Operation name, Arguments
  - E.g., invoke("locationProcessB", "Object2", "operationY", arguments{"x", "y", "z"})
- Little support for type safety

Pattern: Requestor

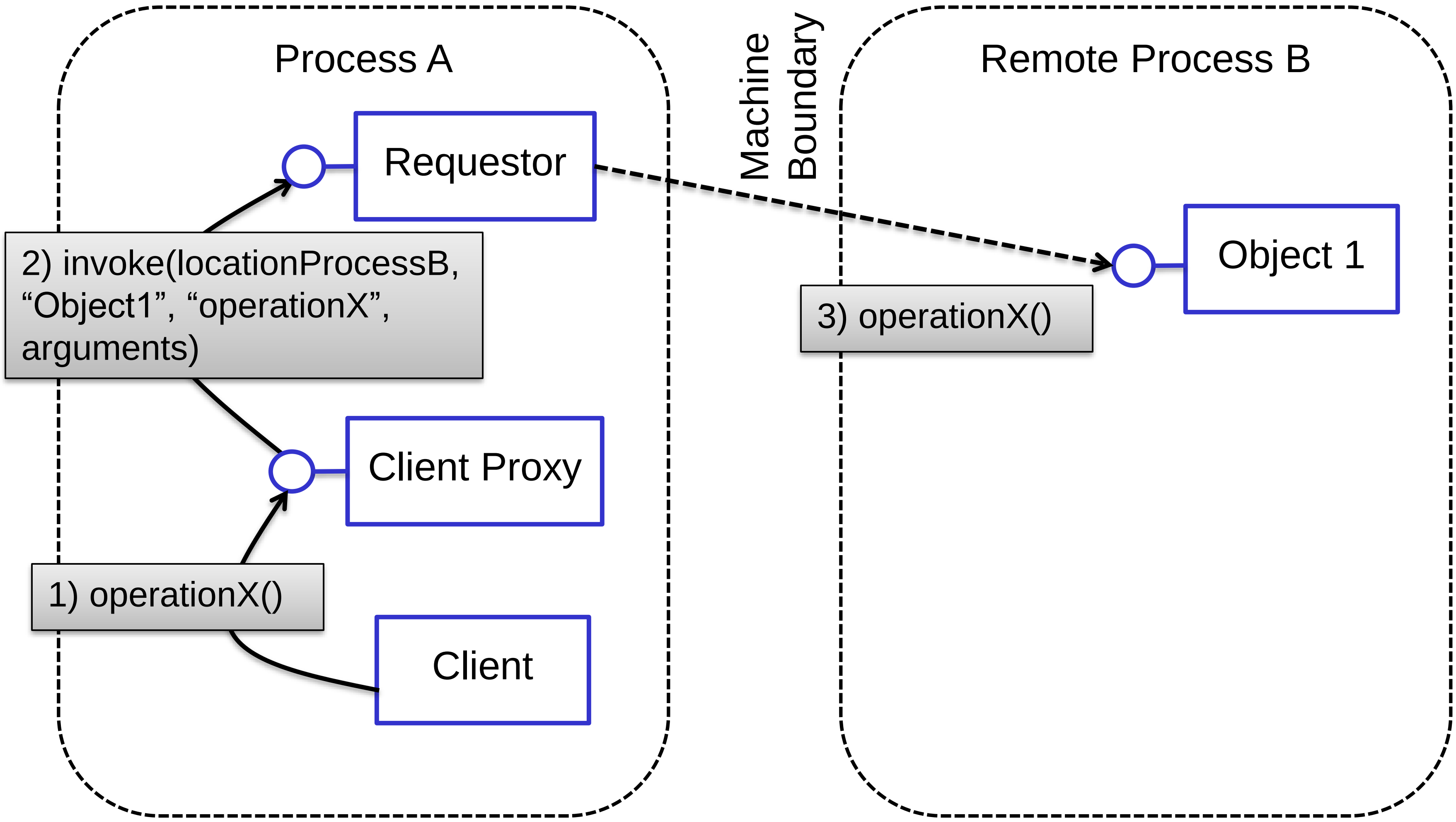


Pattern: Client Proxy

- Client Proxy
  - Sits between Client and Requestor (client now only accesses Proxy)
  - Same interface as the remote object

    Typically generated from remote object Interface Description
  - May be dynamically generated (loading, linking, runtime)
    - See Lecture 4
  - Translates all local invocations into calls to the requestor

Pattern: Client Proxy



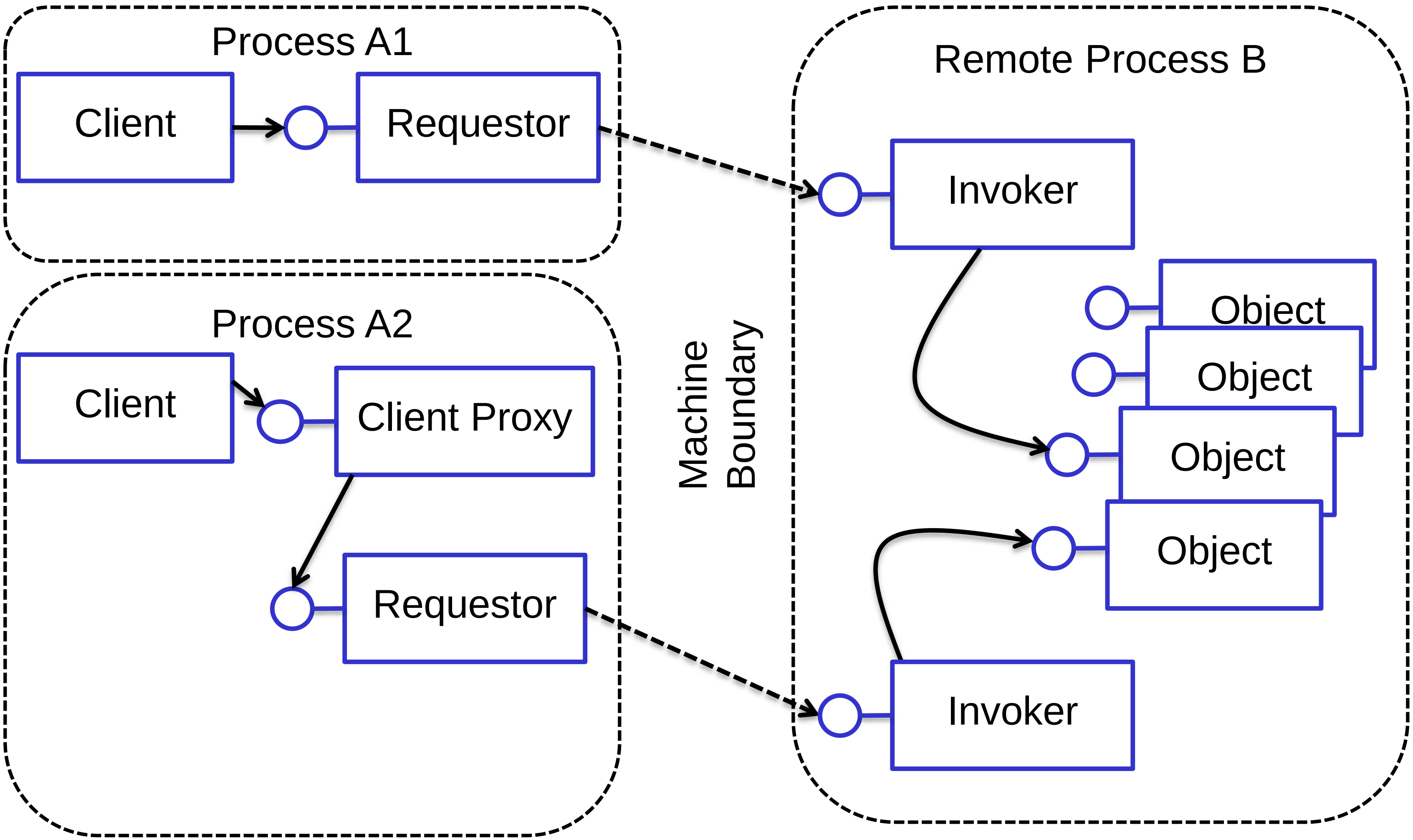
Pattern: Invoker

- Goal
  - Remote object implemented independent of communication
    (no network listening, unmarshalling, etc.)
  - Client should only identify object, server should take care of dispatching and invoking
  - Remote object might not be available all the time
- Invoker
  - Identifies object and Invokes object

    Static Dispatch (aka server stubs/skeletons): part of the invoker, for each object type → faster

    Dynamic Dispatch: dynamically invoke object (e.g., reflection) → more flexible, but not type-safe

Pattern: Invoker



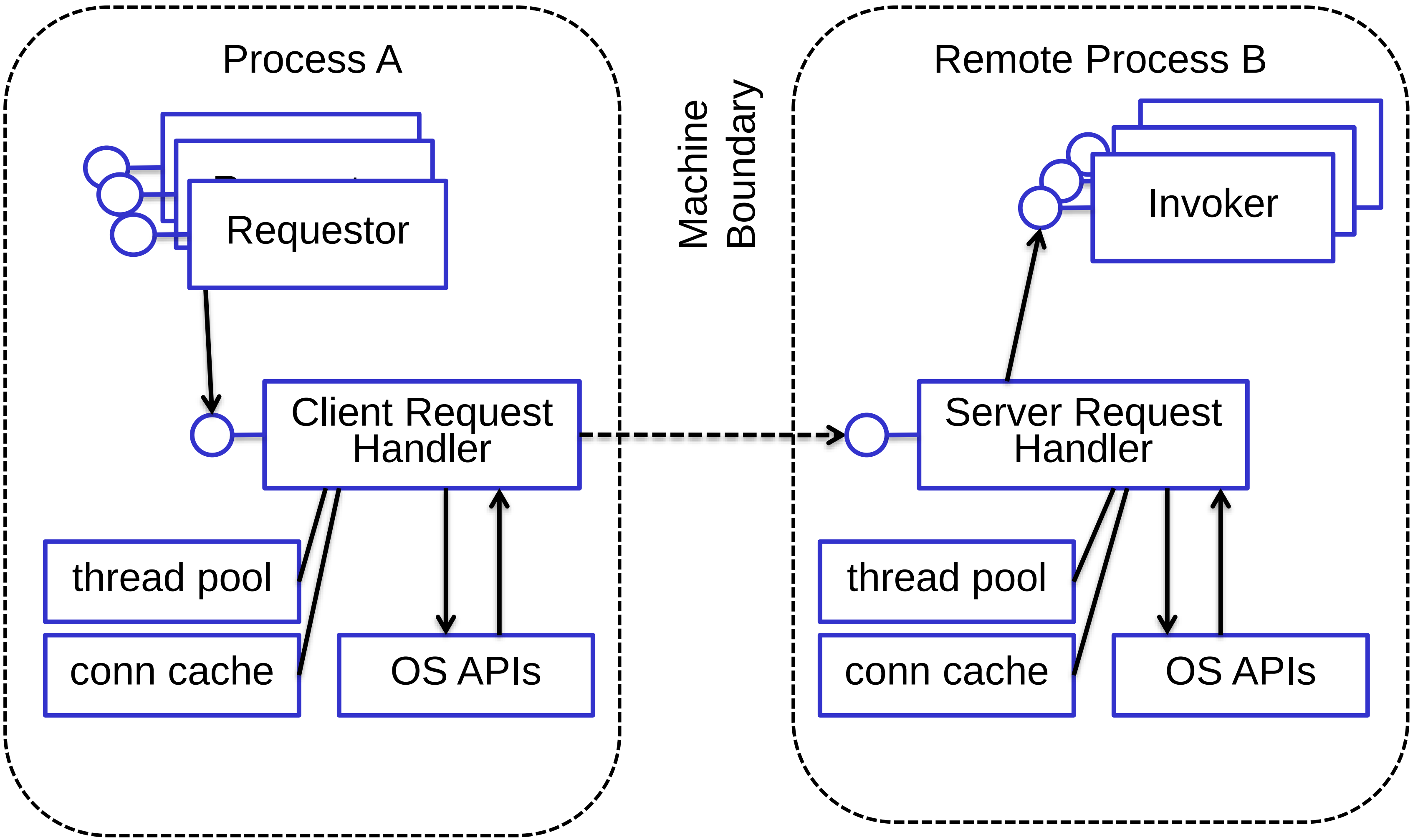
Client Request Handler

- Client Proxies provide remote object access abstraction
- Requestors provide invocation construction
- Not suitable for:
  - Connection management, server availability
  - Threading
  - Time outs, retrying
  - Result dispatching
  - Optimizing network access (e.g., connection keep alive, caching)

→ put network centric aspects into the Client Request Handler

  - Scalability through multiplexing
  - Plug-in for different transport protocols
  - Additional complexity/indirection, for high performance integrate with Requestor

Pattern: Client/Server Request Handler



Lifecycle Control

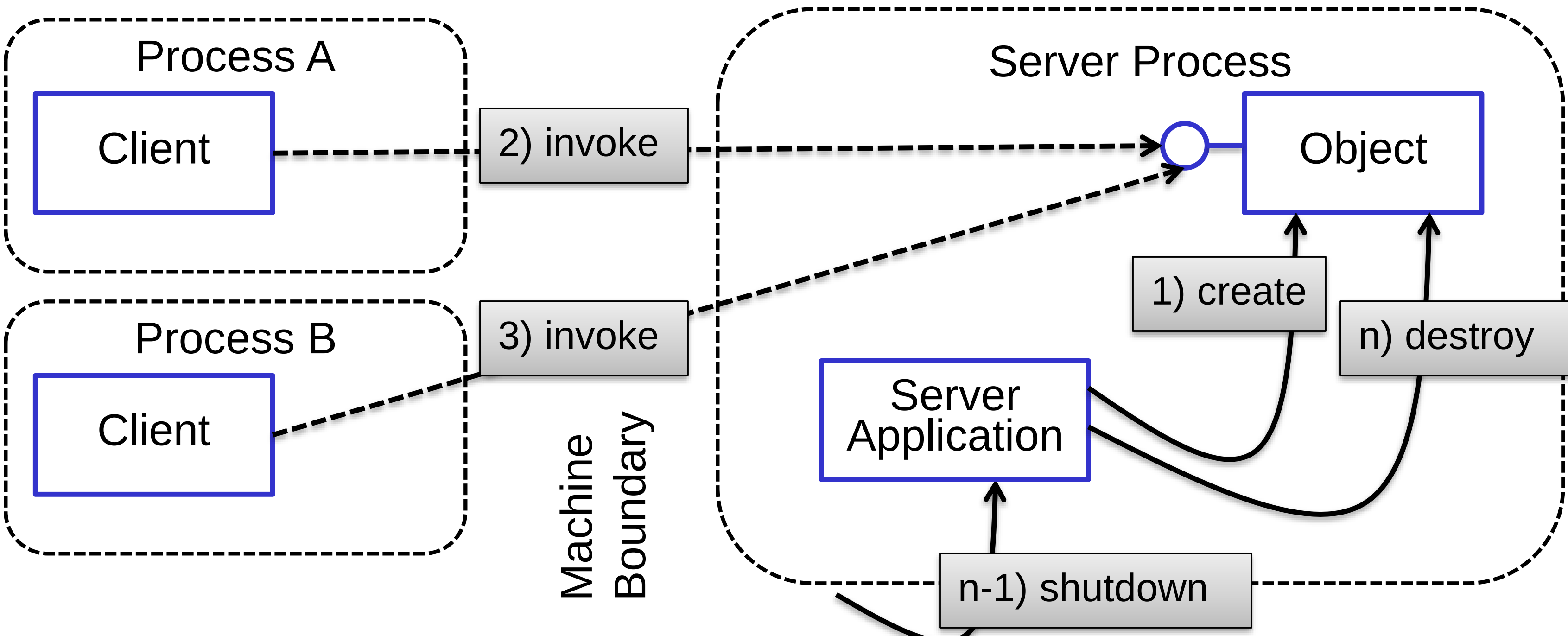
- In distributed object systems, the lifecycle of remote object instances is not well-defined
- Users may want to explicitly control the lifecycle of instances

- Patterns:
  - Static instances
  - Per-request instances
  - Client-dependent instances

  - Lazy Acquisition
  - Pooling
  - Leasing
  - Passivation

Static Instance

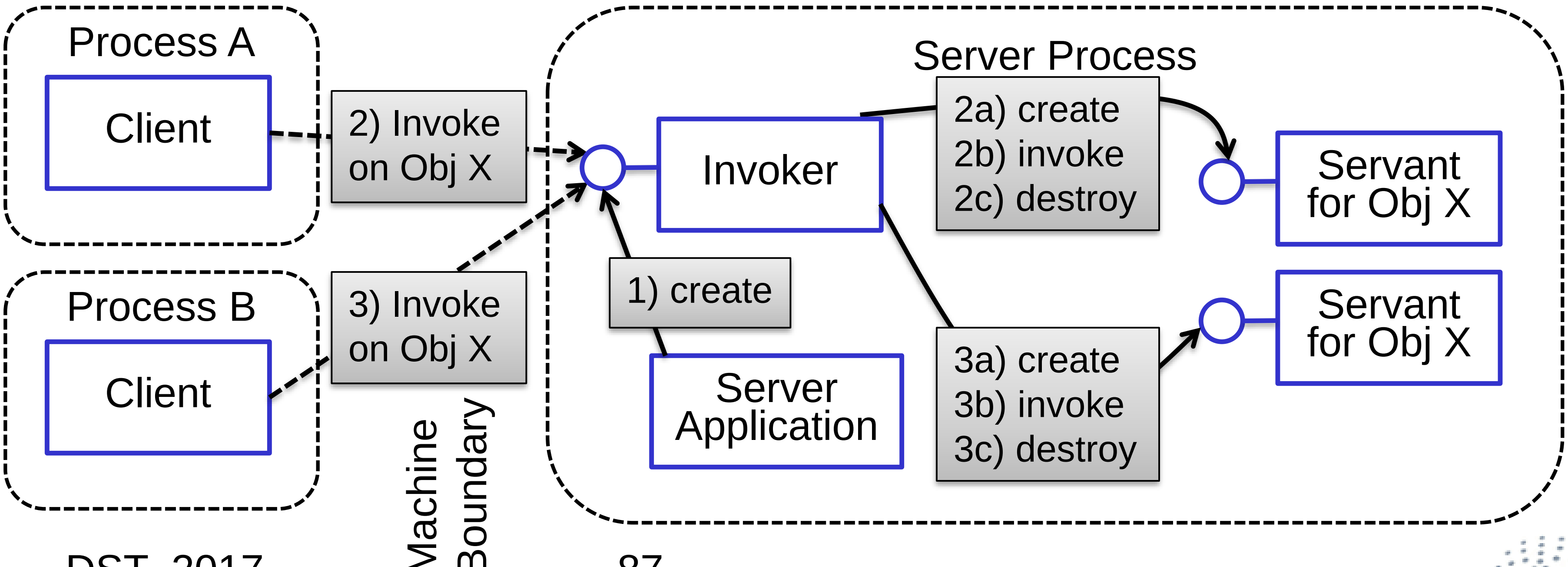
- Remote object instances exist independently of any clients or invocations
- Use it when
  - Need to Optimize runtime behavior
  - Predictable access time
  - Acquired resources for server lifetime not an issue



Continue your home work here with the following patterns

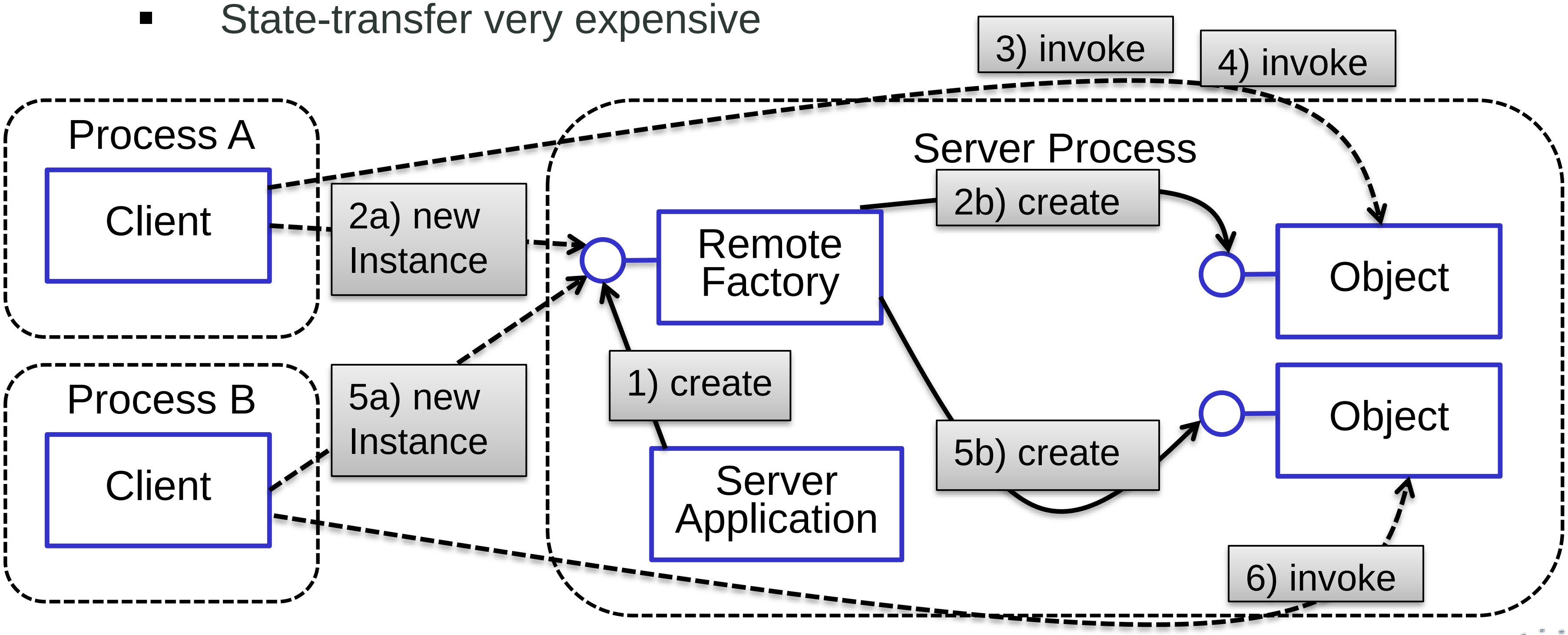
Per-request instances

- Every request / interaction / transaction is executed on a fresh instance
- Use when
  - no object state maintaining required (access state elsewhere, concurrency issues for shared state)
  - individual requests independent



Client-dependent Instance

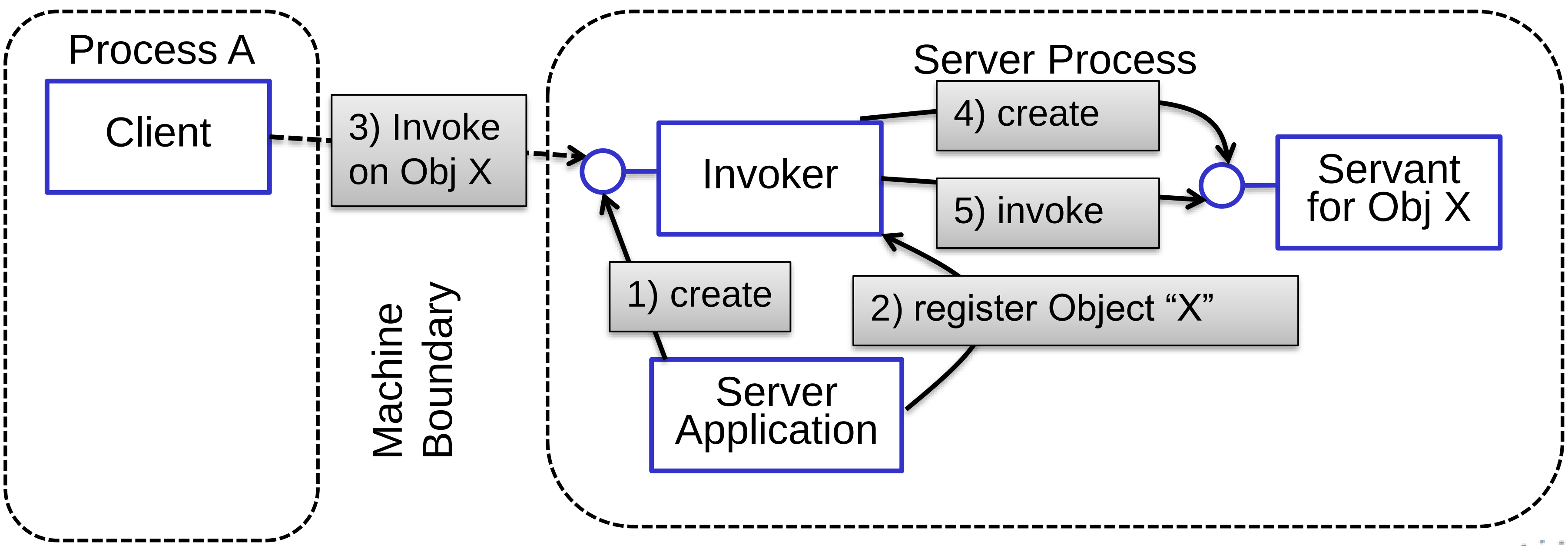
- If no instance for a client exists, it is created on first request
- not necessarily any client process can have only 1 instance
- Use when
  - Object logic extends client logic, common state
  - State-transfer very expensive



Lazy Acquisition

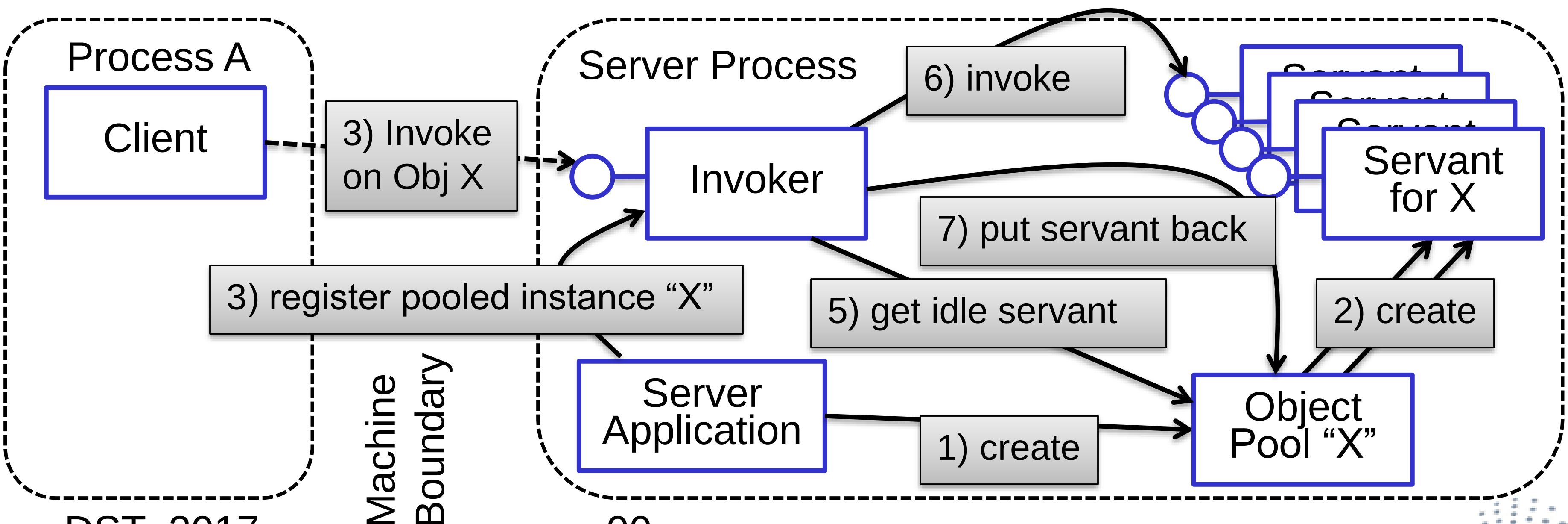
- Static instances may decrease performance, so:
- Only register object (available to clients)
- Instantiate object upon first access

→ Avoid allocating resources without use and Improved start-up time



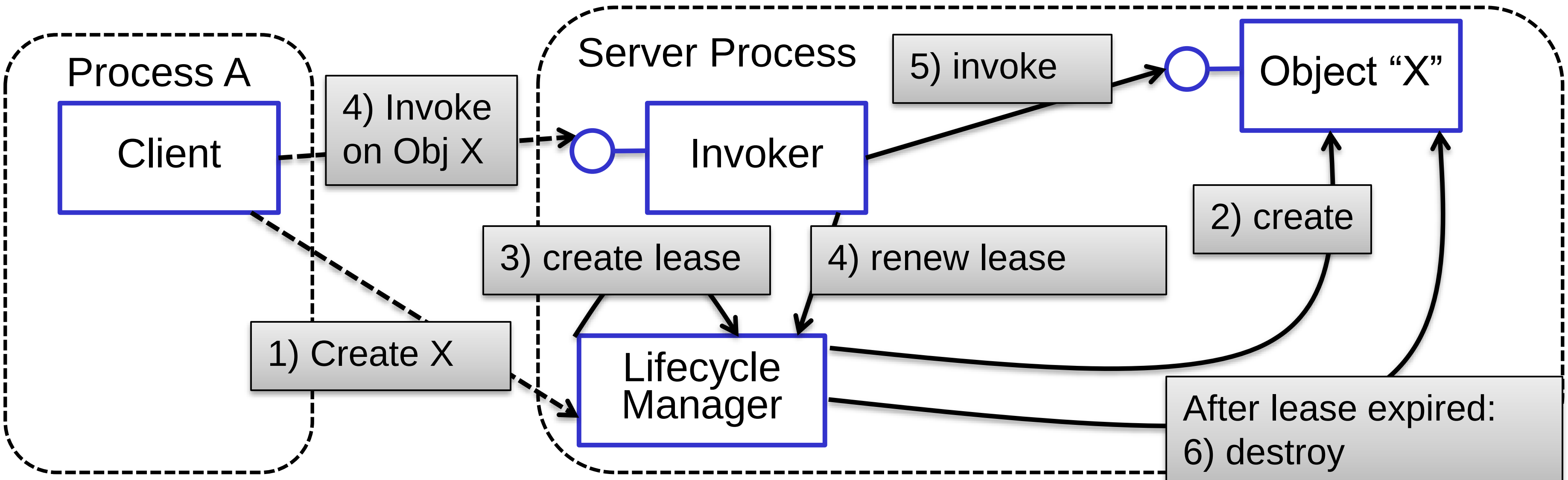
Pooling

- Don't create servants for each request (memory, registering, init, destruction, resource release …)
- Requests are handled by an arbitrary instance from a pool typically resized dynamically
- Servants stripped of state upon returning to pool, initialized with object upon taking from pool → best for stateless objects



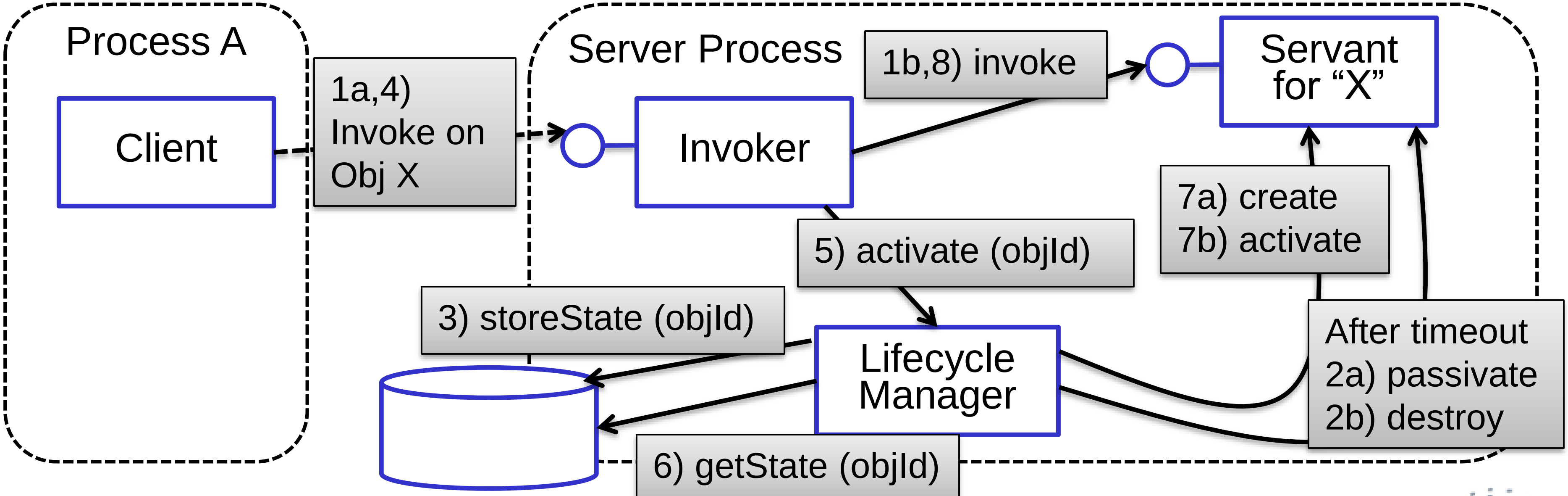
Leasing

- Per-client instances may remain "left over" from clients that are not actually there anymore (crashed / forgot to release)
- Occasionally, the middleware needs to remove unused per-client instances
- To prevent this, clients (Client Proxy) can periodically renew their lease on the per-client instance



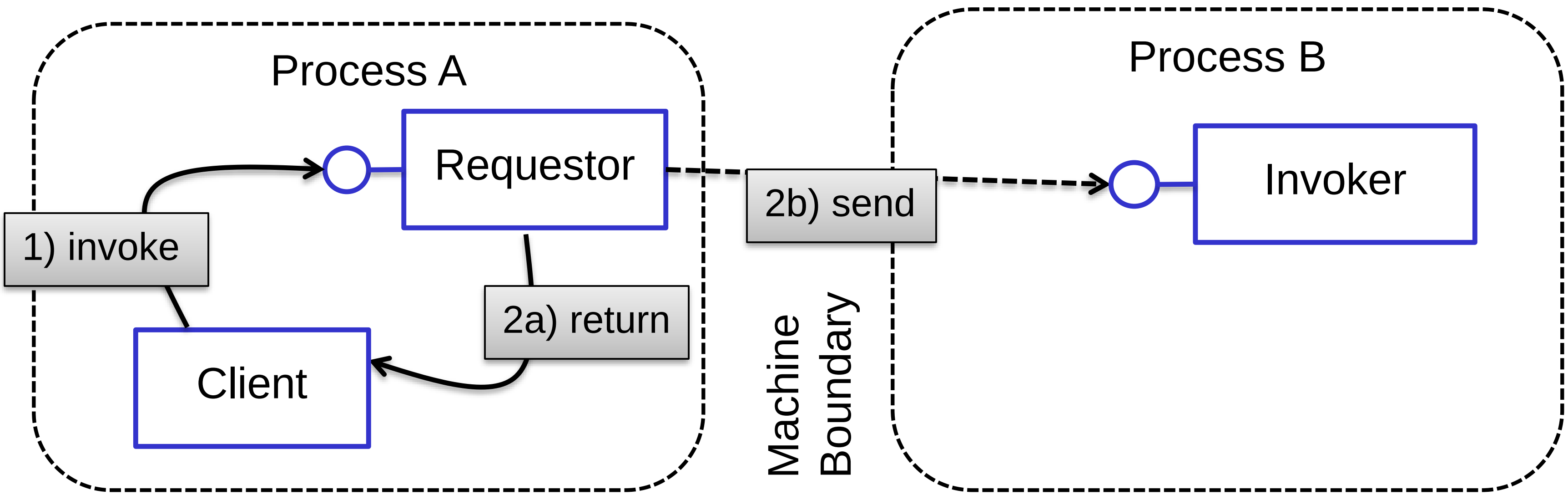
Passivation

- Per-client instances might exist for a long time without actually being used – take up server resources such as memory
- During this times, objects are typically removed from memory (and e.g., persisted to a database) – resources released
- When the next request comes in, the object is activated (defrosted) – resources re-acquired
- Expensive operation → minimize use



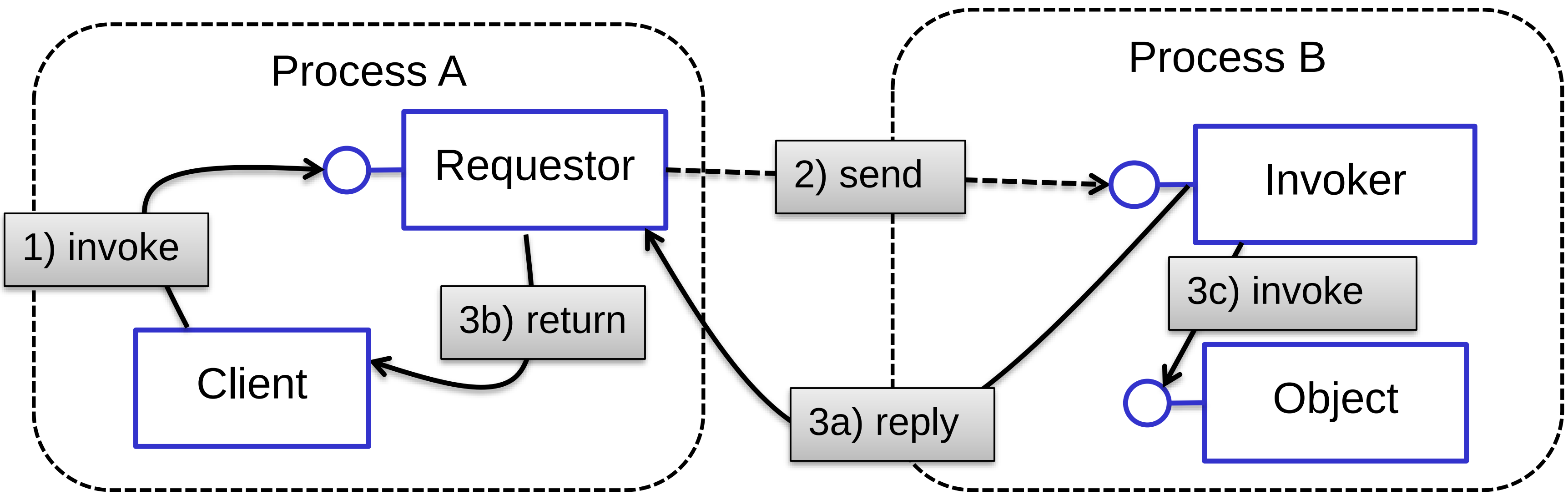
Fire and Forget

- Client invokes remote code and continues immediately
- Best effort semantics: Client receives neither answer, nor faults, nor delivery confirmation
- Only useful if the client does not particularly care about the request being successful (e.g., logging, new data overrides old data)



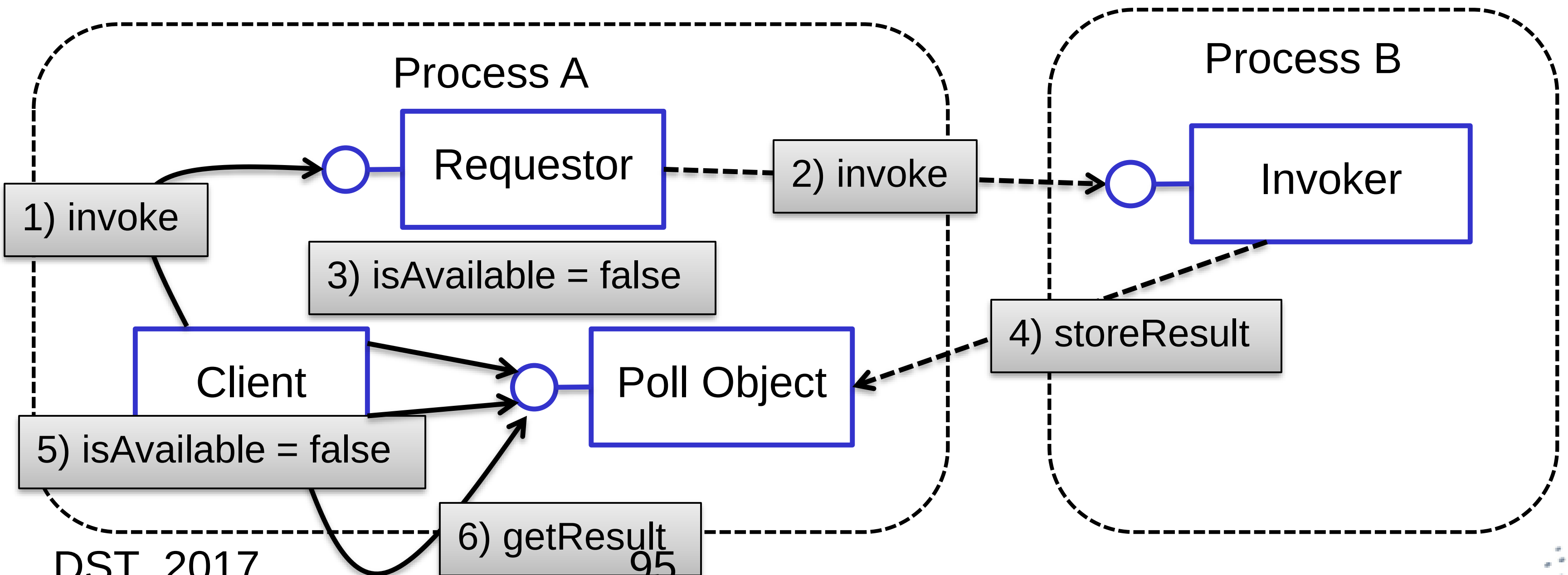
Sync with Server

- Use when: neither afford the risk of incomplete transmission, nor wait for processing to complete
- Client invokes remote code and waits for delivery confirmation from server before continuing
- This confirmation only guarantees that the request has arrived at the server, not that it will not lead to a fault



Poll Object (or Future)

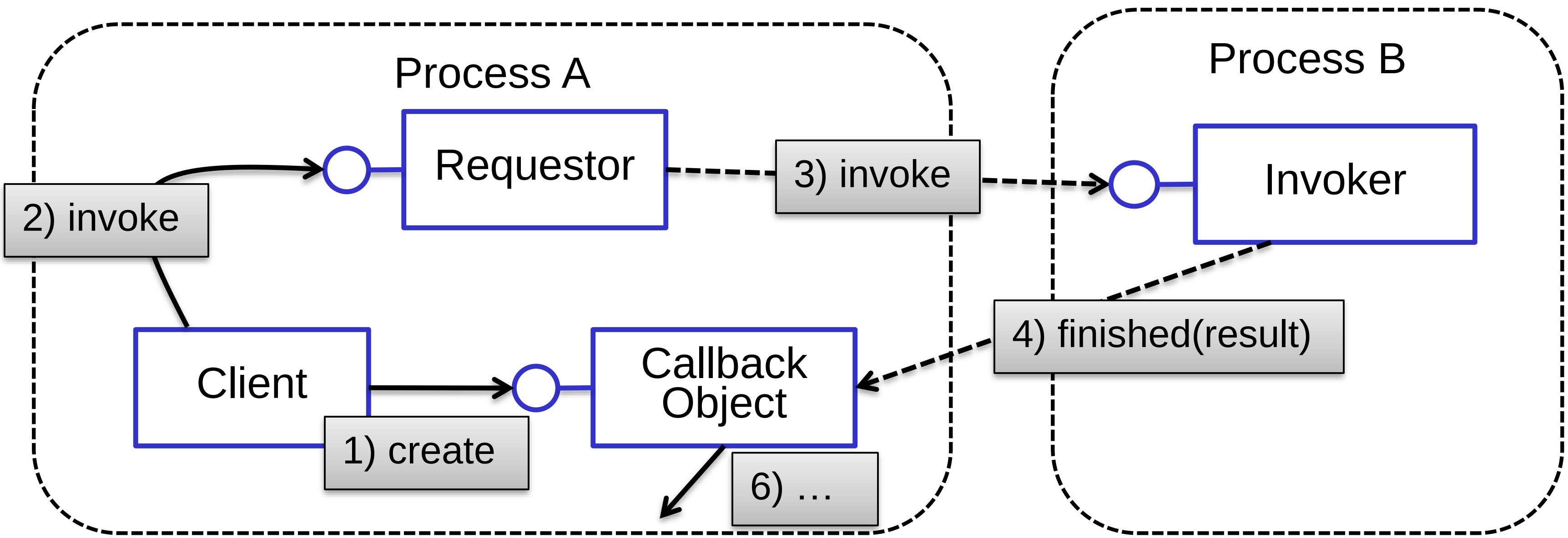
- Client invokes remote code and receives a stub for the result
- Client can continue executing and check, in a asynchronous or blocking mode, its poll object for the invocation result in due time
- Use when
  - Not absolutely necessary to continue immediately after result available
  - Remote execution time expected to be short



Distributed Systems Group

Callback

- Client invokes remote code and use a callback object which will be called with the result, once it is available
- Note that technically the only difference between poll object and callback is who creates the callback object
  - Client creates object → callback
  - Server creates object → poll object



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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- Eventual consistency: http://queue.acm.org/detail.cfm?id=1466448

Thanks for your attention

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