# Software Architecture

## Leftovers from last week.

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# (Some) Common Architectural Styles

**Program structure**

- Layers
- Client / Server
- Peer-to-Peer
- MVC

**Data Flow**

- Pipes and Filters
- Event-Driven Architecture
- Blackboard (Factory / Worker)

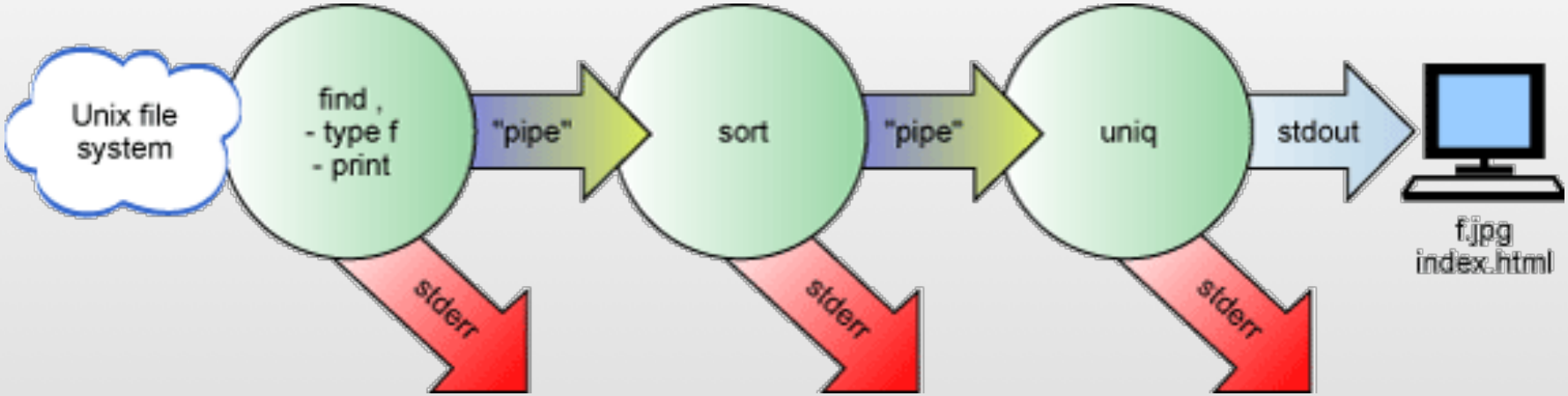
# Pipes and Filters

Filters are the components that read an input data stream and transform it into an output data stream

Pipes are the connectors that provide the output of a filter as input to another filter

# Pipes and Filters: Example

**find . -type f -print | sort | uniq**



# Pipes and Filters: Advantages

- **Simple**; no complex component interactions
- Filters as black-box; substitutable
- High maintainability and reusability of individual components

# Pipes and Filters: Disadvantages

- Whether separation into processing steps is feasible strongly depends on application domain and problem
- Filters require a **common data format**
- Redundancy in parsing/unparsing
- Process overhead

# Event-driven Architecture (EDA)

Components are event emitters (publishers, agents) or consumers (subscribers, sinks)

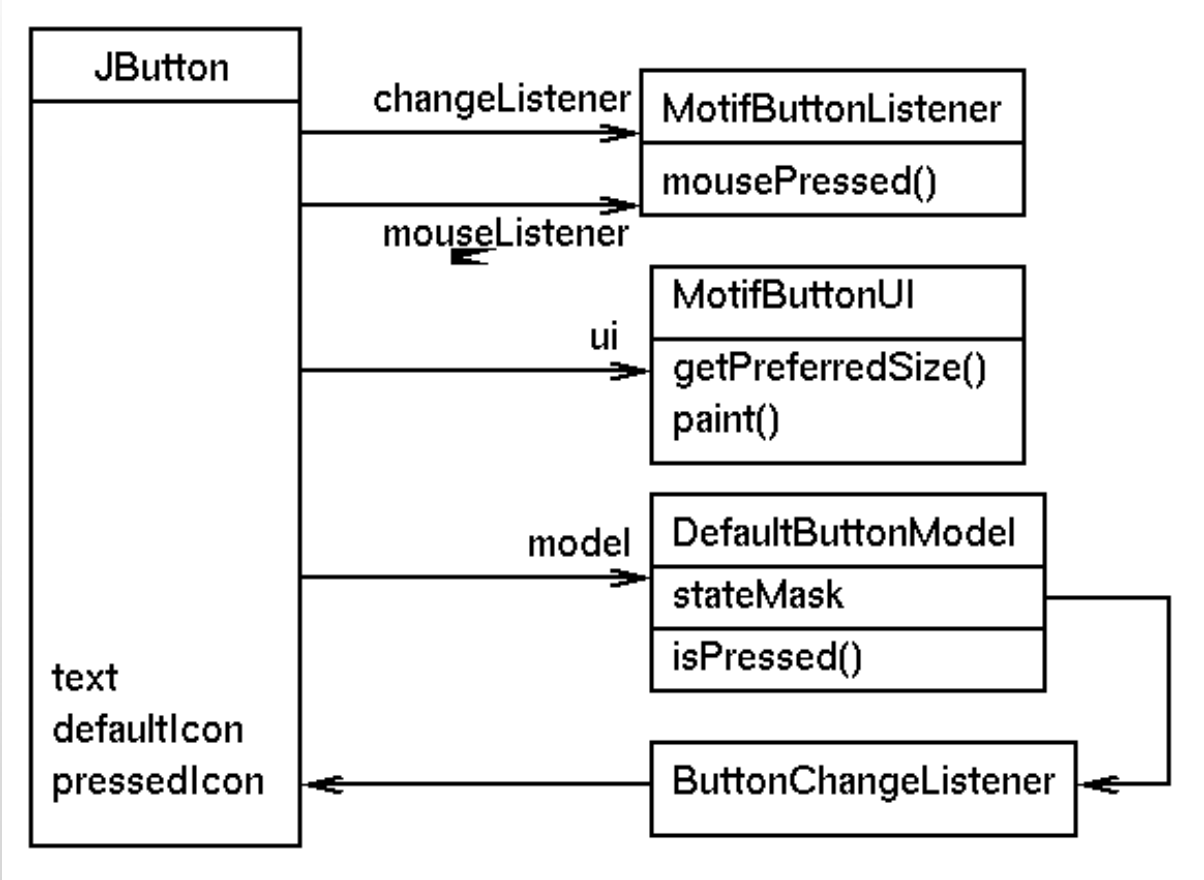
An event dispatcher distributes events to subscribers

—> fundamentally **asynchronous**

# EDA Example

**Java Swing**

(or more generally - most GUI frameworks)



# EDA: Advantages

- Components are loosely coupled
- High (runtime) extensibility and reusability; components can be easily exchanged
- Especially apt to unpredictable and asynchronous environments
- Often “feels” fast and responsive

# EDA: Disadvantages

- No guarantees regarding execution or order of event processing
- Data exchange other than with events problematic
- Component behavior is tightly coupled with execution environment
- Difficult to “grok”

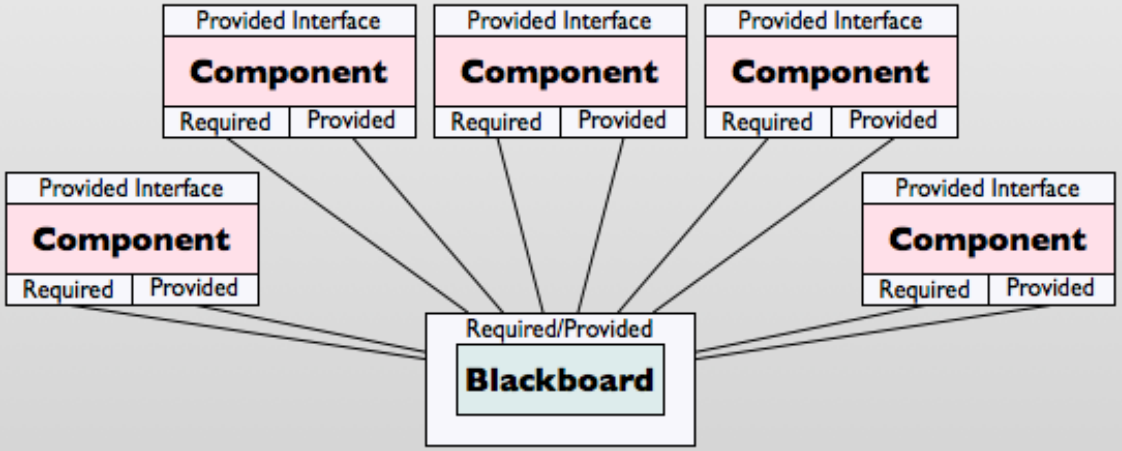
# Blackboard

## Two kinds of components:

- Central data management
- Independent components for computation (knowledge sources)

## Activation of computation:

- Database trigger
- Actual state



# Blackboard: Advantages

- High changeability and maintainability
- Reusable knowledge sources
- **Factory/Worker:** support for fault-tolerance, robustness and redundancy because of loose coupling of workers

# Blackboard: Disadvantages

- Hard to test
- Difficult to establish good control strategy
- Low efficiency

# Distributed Systems Architectures

## Common Architectural Styles and Patterns.

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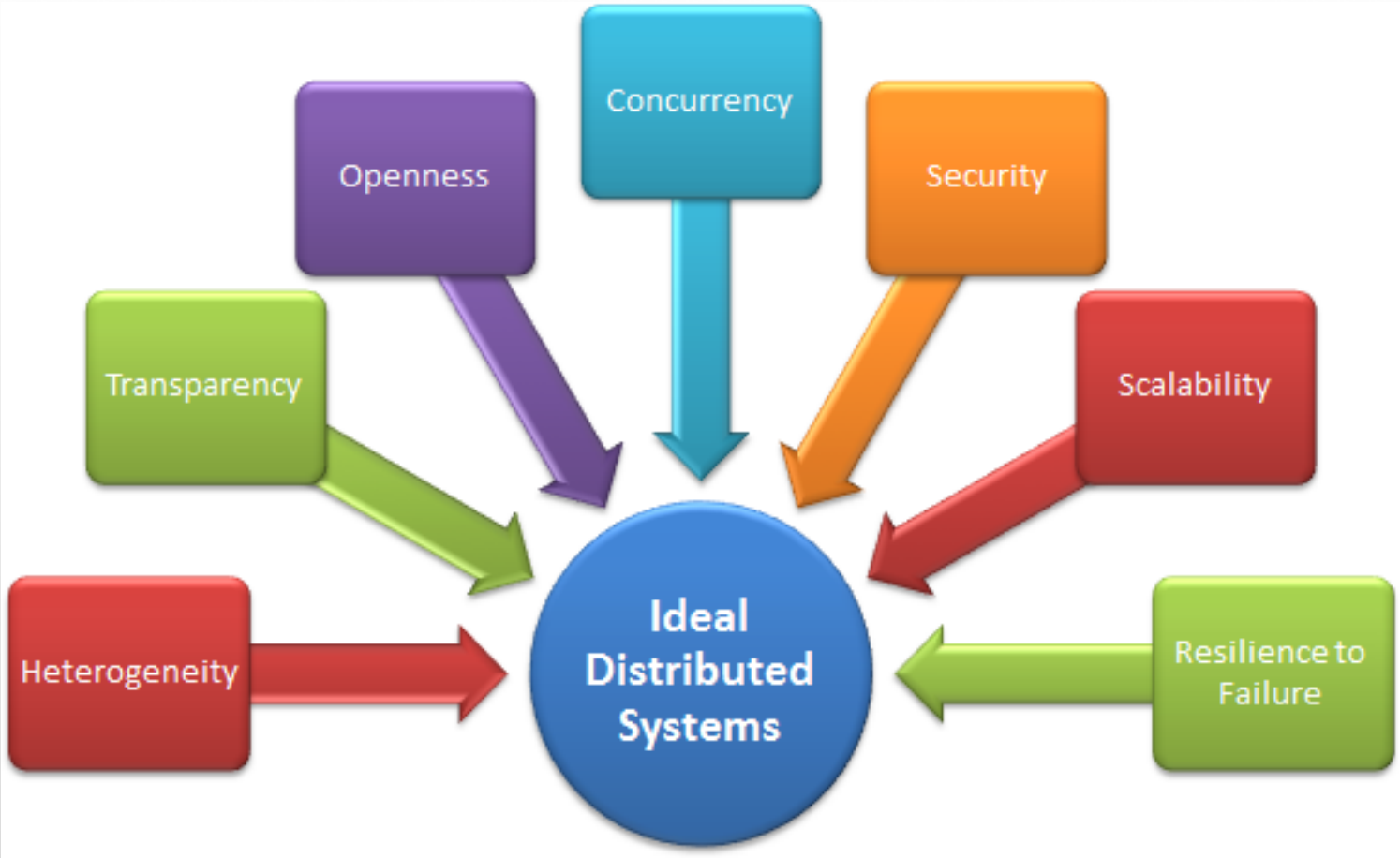
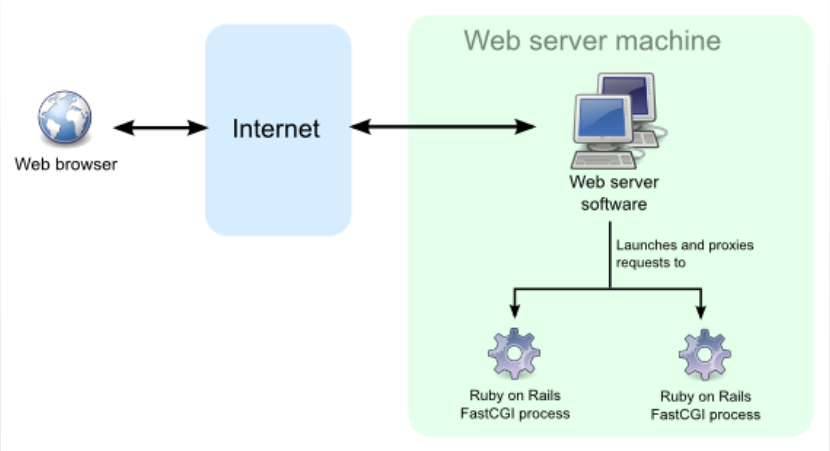
# Motivation




http://www.ejbtutorial.com/distributed-systems/challenges-for-a-distributed-system

# Motivation

## Client-Server Systems




## Peer-to-Peer Systems

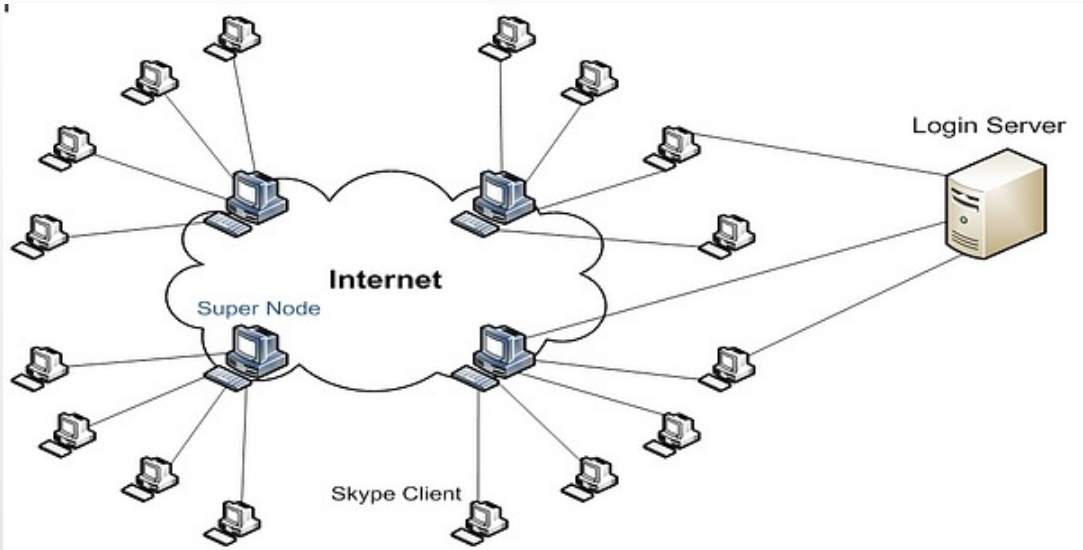



*Figure 1: Skype Network*

## Implementation of Connectors?

# Hierarchy of Styles of Distributed Interaction

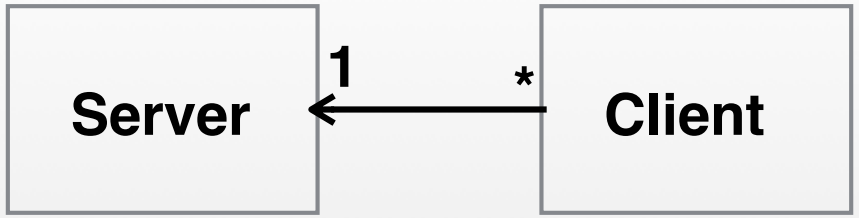
| | |
|---|---|
| **Service-Oriented Systems** | *(SOAP / REST)* |
| ↑ | |
| **Component-Based Systems** | *(Enterprise Java Beans)* |
| ↑ | |
| **Distributed Object Systems** | *(.NET Remoting)* |
| ↑ | |
| **Remote Procedure Call Systems** | *(XML-RPC)* |
| ↑ | |
| **Message Passing** | *(Java Message Service)* |
| ↑ | |
| **Streaming** | *(Sockets)* |

# Streaming

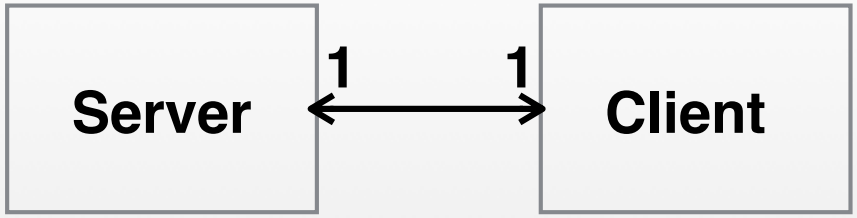
- Connector is a (semi-)permanent communication channel between client and server
- Variants:
  - Unidirectional versus bidirectional
  - Unicast versus multicast

# Variants

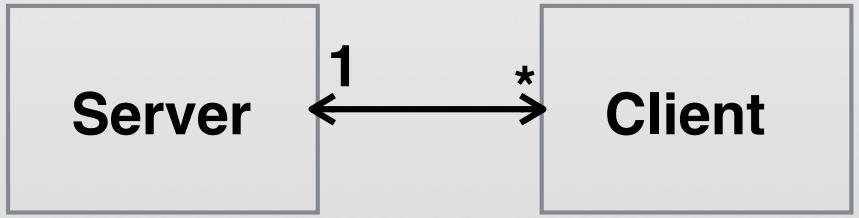
**Unidirectional**



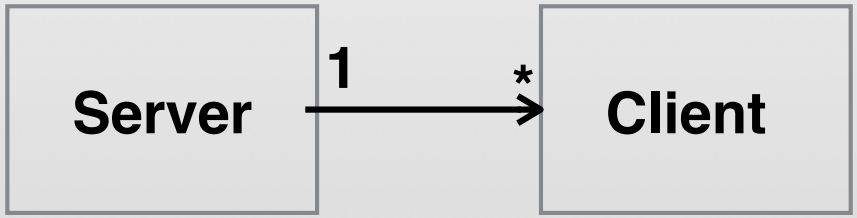

**Unicast**




**Bidirectional**




**Multicast**



# Example in Ruby

## Server

```
require 'socket'

# server

server = TCPServer.open(8080)
loop {
  Thread.start(server.accept) do |client|
    client.puts(Time.now.ctime)
    client.puts "Closing the connection. Bye!"
    client.close
  end
}
```

## Client

```
require 'socket'

# client

s = TCPSocket.open("localhost", 8080)

while line = s.gets
  puts line.chop
end
s.close
```

# Streaming: Advantages

- Low overhead
- Use cases that require continuous data transfer (e.g., VoIP) easy to implement
- No leaky abstraction

# Streaming: Disadvantages

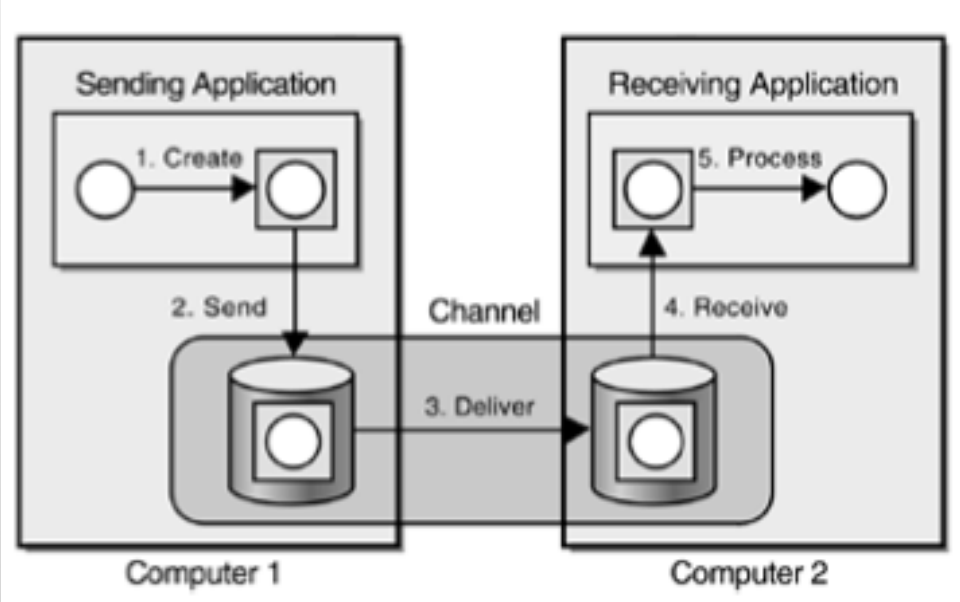
- Implementation maybe messy and verbose
- No built-in mechanisms for confirmation, resending, etc.
- Client and server need common understanding of data and protocols

# Message Passing

**Queues (channels)** connect programs and transmit messages

A **sender** (or **producer**) is a program that sends a message by writing it to a queue

A **receiver** (or **consumer**) is a program that receives a message by reading it from a queue



# Messaging: Advantages

## Referential decoupling

Producers and consumers do not need to know each other
Producers and consumers can come and go dynamically

## Temporal decoupling

Producers and consumers do not need to be online at the same time (if the queue stores messages)
Consumers can process messages at their own pace

## Inherently asynchronous model

The store-and-forward processing model of message queues lends itself very well to async communication

# Messaging: Disadvantages

**Complex programming model**

Message sequencing (out-of-order messages)
Message loss
Message duplication
Message congestion

**Performance overhead**

Additional hop in communication (message queue)
Message queue potentially becomes performance bottleneck

# Remote Procedure Calls

Make the invocation of remote code (more or less) seem like local calls

Hide remoting as far as possible (abstraction!)

```
ServerStub myServer = (ServerStub) Naming.lookup("//localhost/MyServer");
String response = myServer.getHelloWorldMessage();
System.out.println(response);
```

# Law of Leaky Abstractions

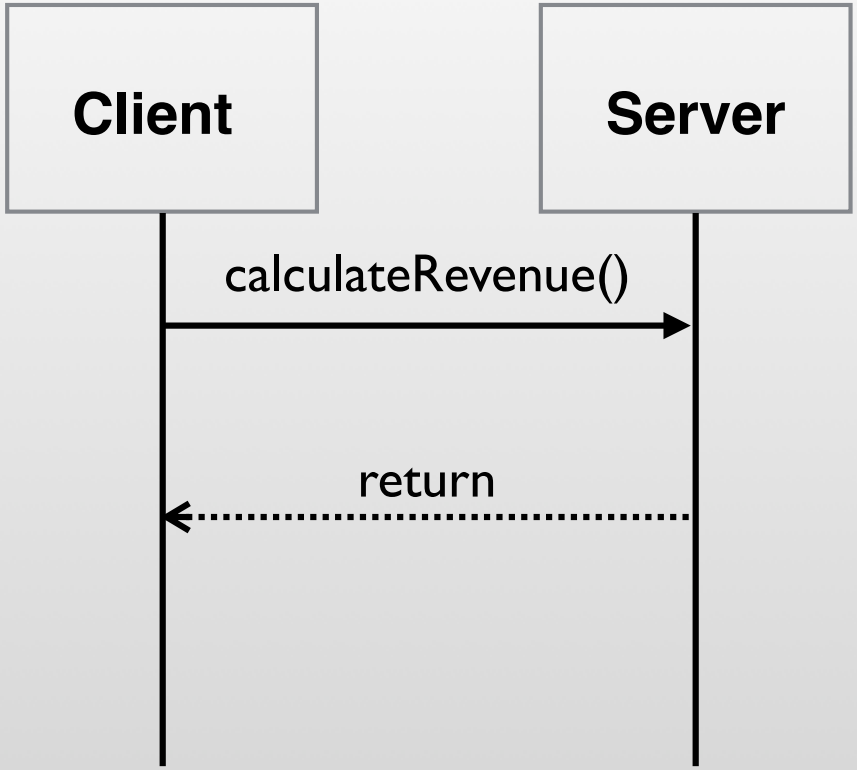
*"All non-trivial abstractions are leaky"*

http://www.joelonsoftware.com/articles/LeakyAbstractions.html

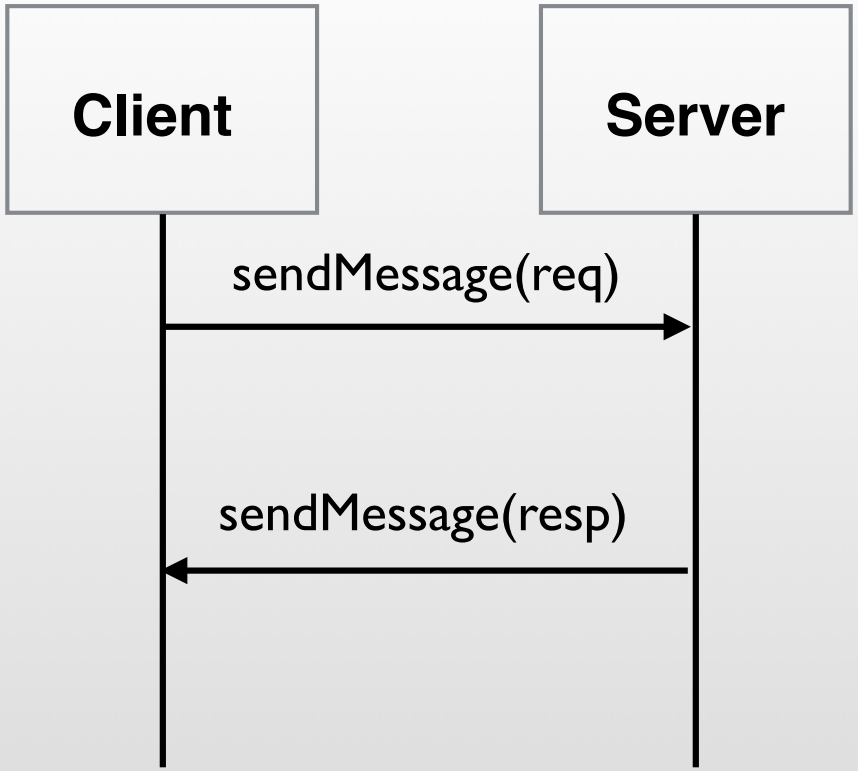
# Remote Procedure Calls

Main interaction protocol:

- (Blocking) request/response style



# Implementation using Message Passing



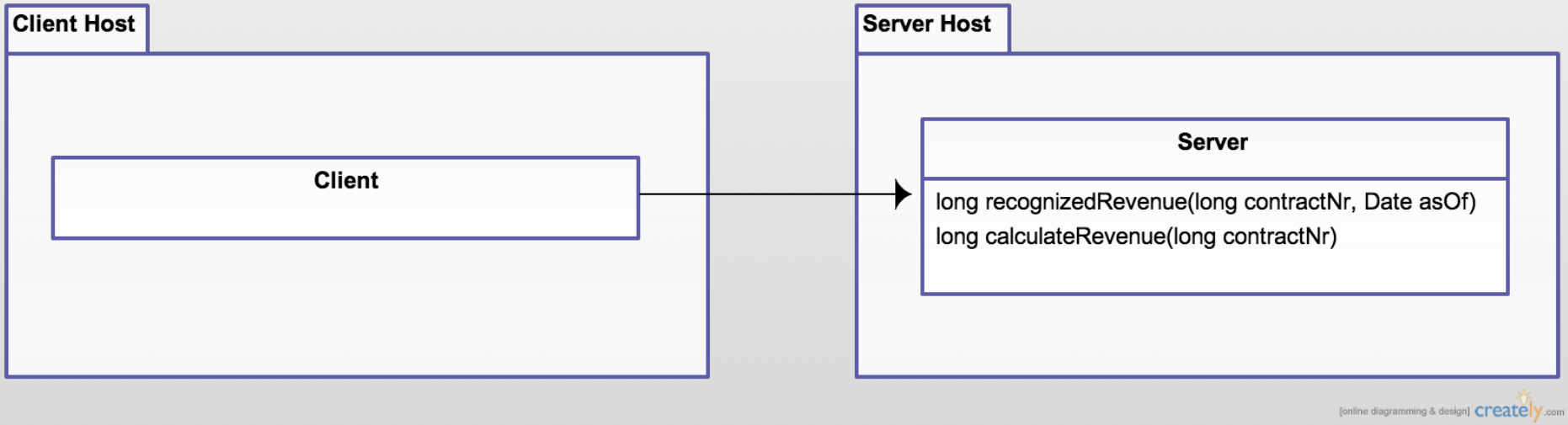

**Message(req):**
{op : calculateRevenue,
param : 16 }

**Message(resp):**
{status : success,
return : 1466.17 }

# Remote Procedure Calls

Simplest RPC-style

Server provides (independent) procedures that can be called



# Example in Groovy and XML-RPC

## Server

```
def server = new XMLRPCServer()

// define operations
server.calculateRevenue = { contractNr ->
   // … do stuff
}

def serverSocket = new ServerSocket(8080)
server.startServer(serverSocket)
```

## Client

```
def serverProxy =
  new XMLRPCServerProxy("http://localhost:8080")
serverProxy.calculateRevenue(contract)
```

## Wire

```
<?xml version="1.0"?>
<methodCall>
  <methodName>calculateRevenue</methodName>
  <params>
    <param>
        <value><i4>156</i4></value>
    </param>
  </params>
</methodCall>
```

# Distributed Objects

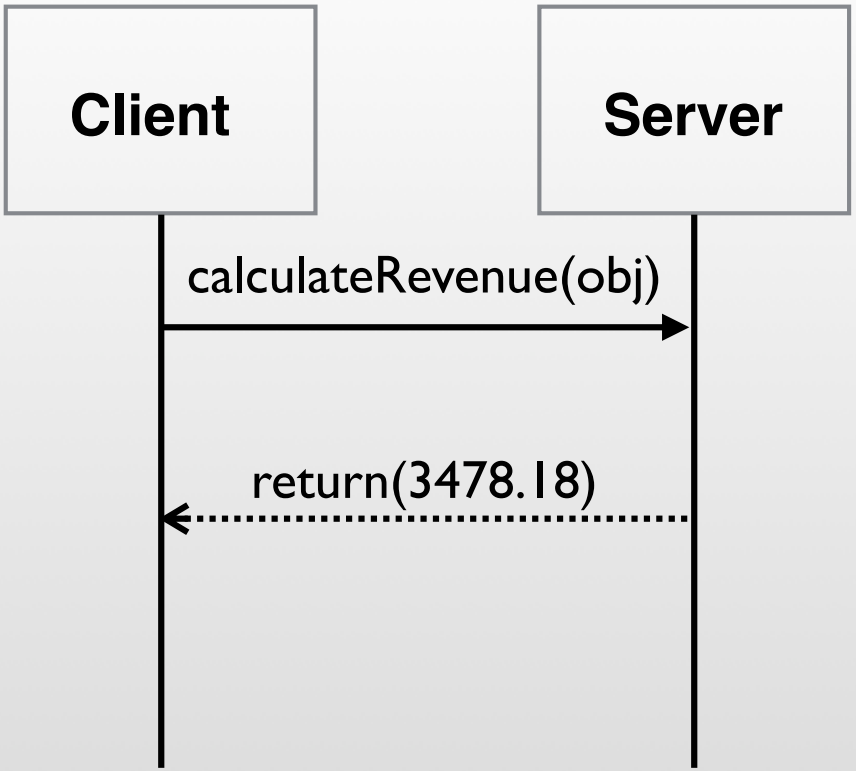
Natural progression for object-oriented programming languages

- Imperative language work well with RPC
- OO language work well with distributed objects

Server provides objects (data and methods) that clients can interact with

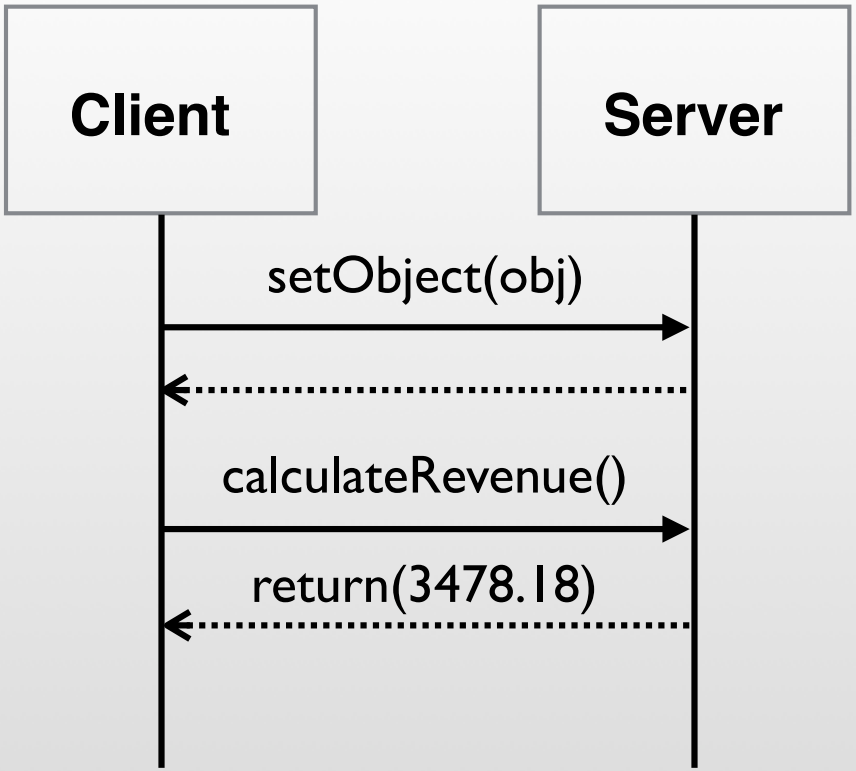
# On State

**Stateless Interaction**
(server can be a pure function)



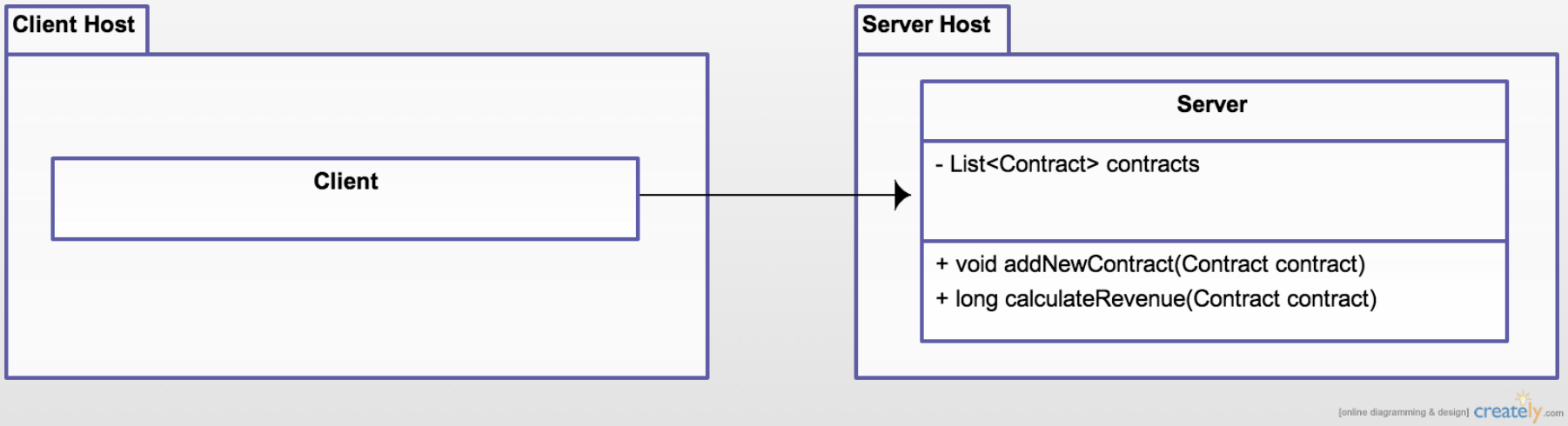

(state is maintained by client
or in a database,
every request can be served
by different server instances)

**Stateful Interaction**




(state is maintained by server,
subsequent requests need to be routed to
same server, requires session)

# Distributed Objects



# Example in C# and .NET Remoting

## Server

```
TcpServerChannel channel = new TcpServerChannel(8080);
ChannelServices.RegisterChannel(channel);
WellKnownServiceTypeEntry remObj = new
  WellKnownServiceTypeEntry(typeof(IContractRemoteObj),
    "Contract”, WellKnownObjectMode.SingleCall);
RemotingConfiguration.RegisterWellKnownServiceType(remObj);
```

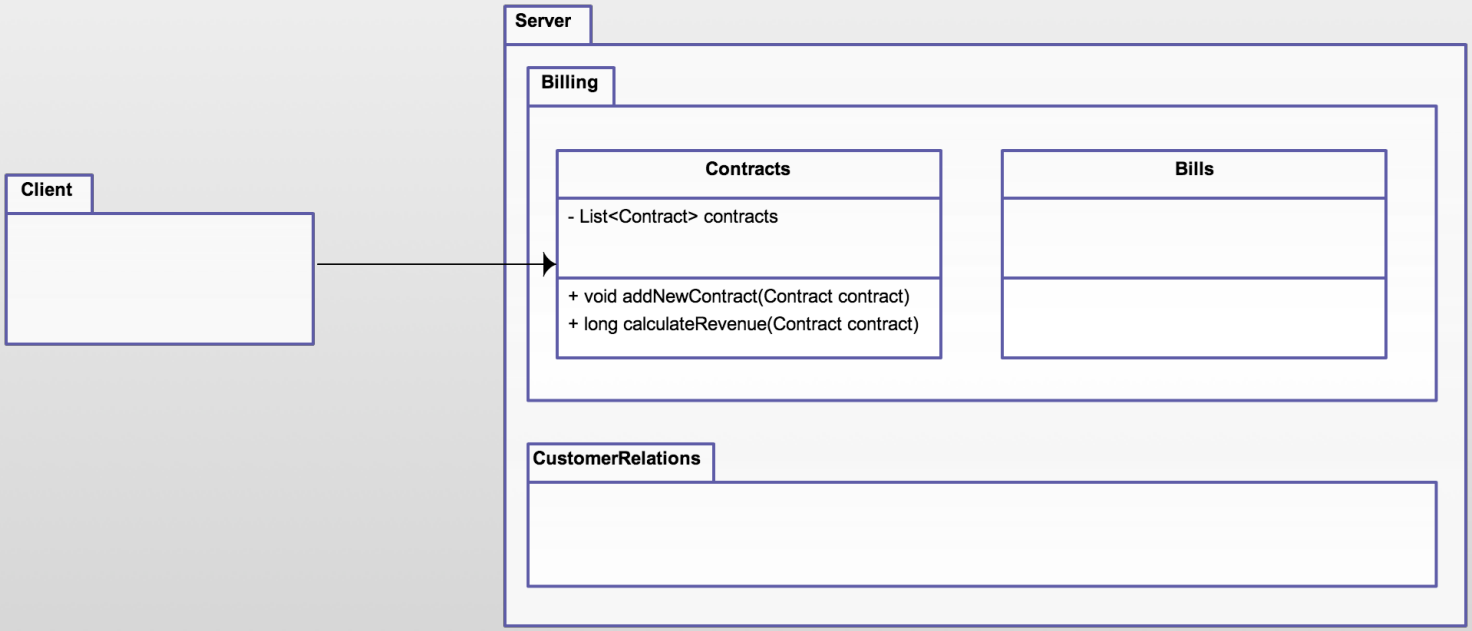
## Client

```
TcpClientChannel channel = new TcpClientChannel();
ChannelServices.RegisterChannel(channel);
IContractRemoteObj remote_object =
  (IContractRemoteObj)Activator.GetObject(
   typeof(IContractRemoteObj),
   "tcp://localhost:9000/ContractRemoteObj"
  );
remote_object.AddNewContract(contract);
```

# Component-Based Systems

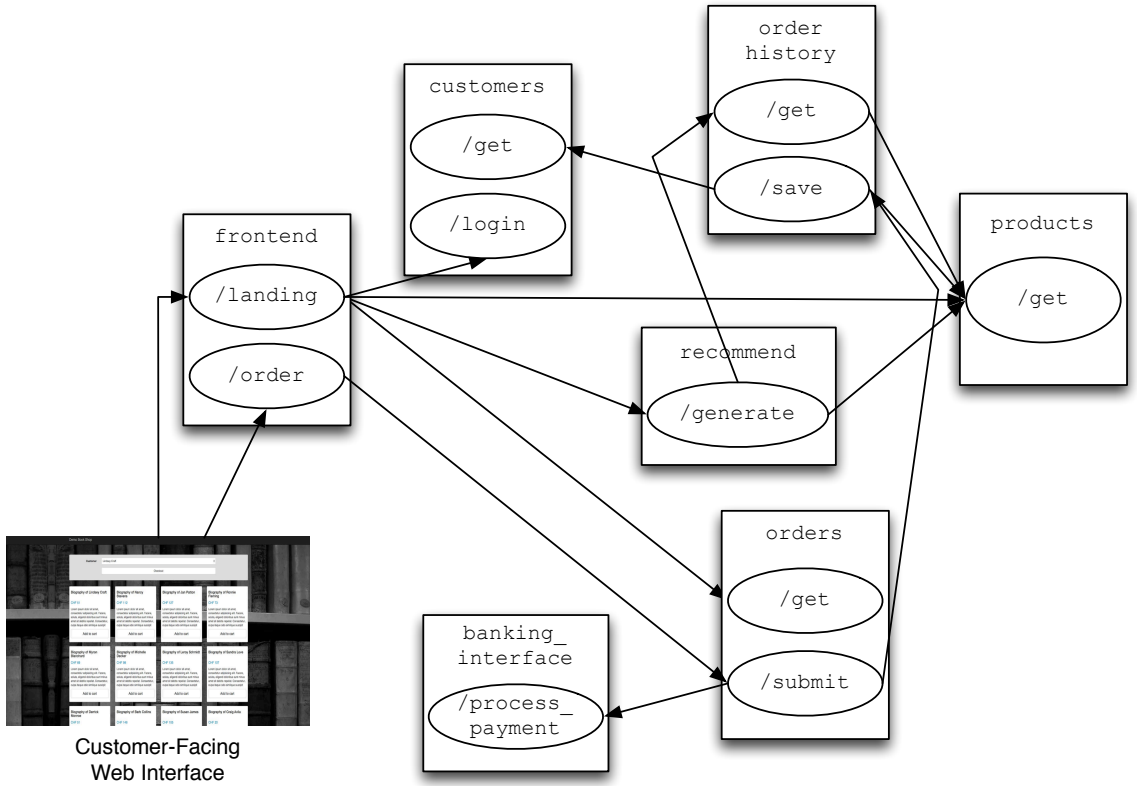
Component:

- Reusable collection of remote objects
- All of which may be stateful or stateless

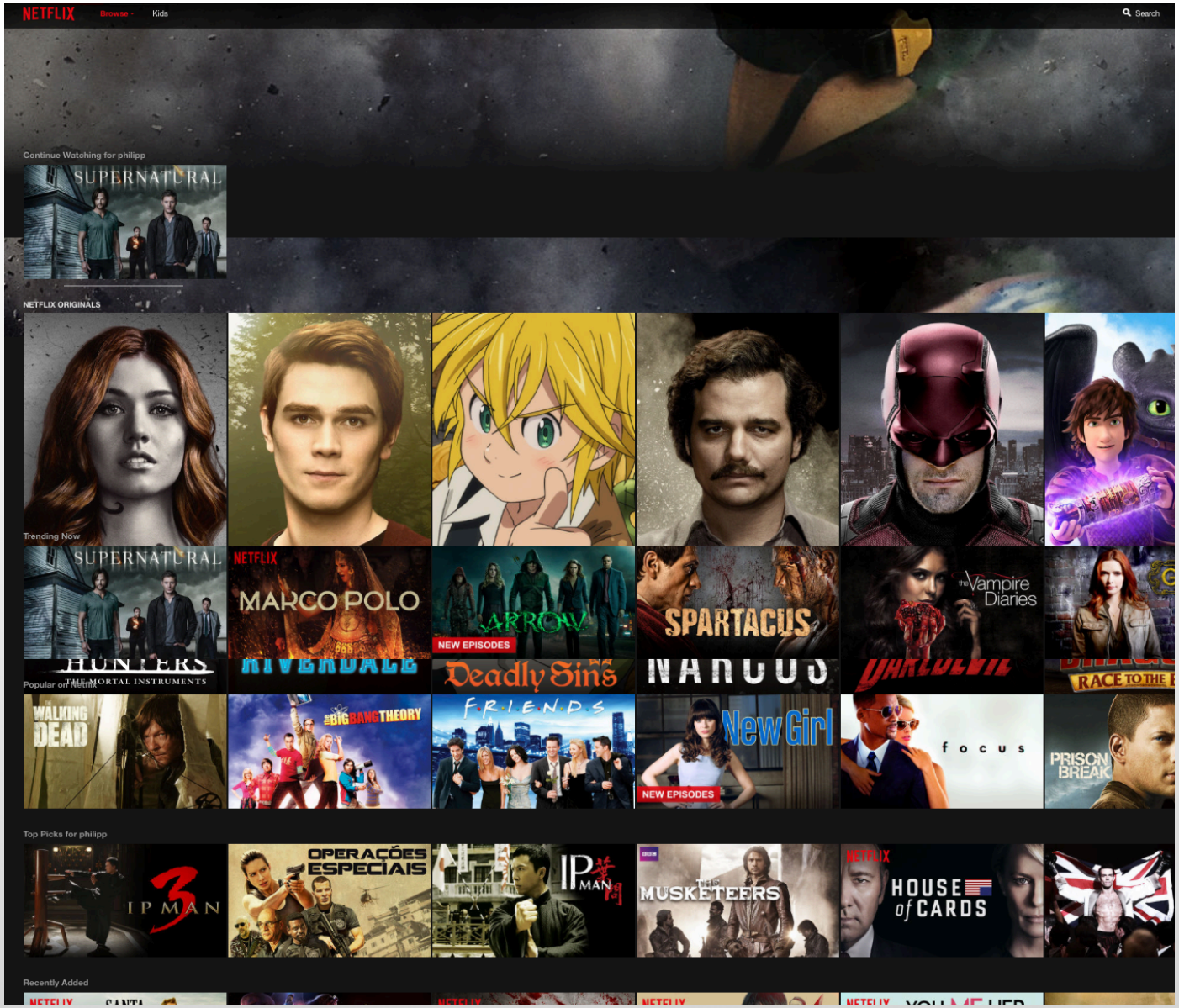


# Service-Based Systems

Applications are built as composition of services (lego principle)



# Example: Netflix



# Service Characteristics

Core characteristics of services:

- **Standardised interface**
- **Replaceable**
- **Context-free (and hence reusable)**
- **Stateless**
- **(Observable Quality-of-Service)**

# Standardised Interface

**Service has a "contract" that defines what the service does, and how it can be used (the API)**

**Usually assumed to be programming language and environment independent**

Can be explicitly specified

(e.g., WSDL)

Eases Integration!

Or implicit

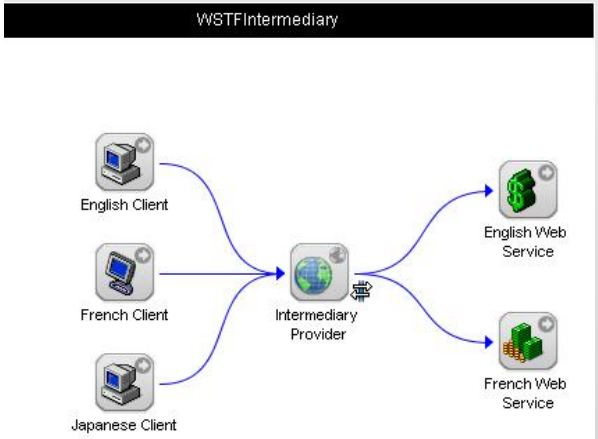
(e.g., REST)

# Replaceable

**Many different services could (potentially) implement a given contract.**

- **Maybe different copies of the same service**
- **Maybe functionally different implementations**

**Your application should be able to switch between those services at will.**




Eases Maintenance, allows for failover and redundancy!

# Context-Free

**Services should not know or care about the context they are used in.**

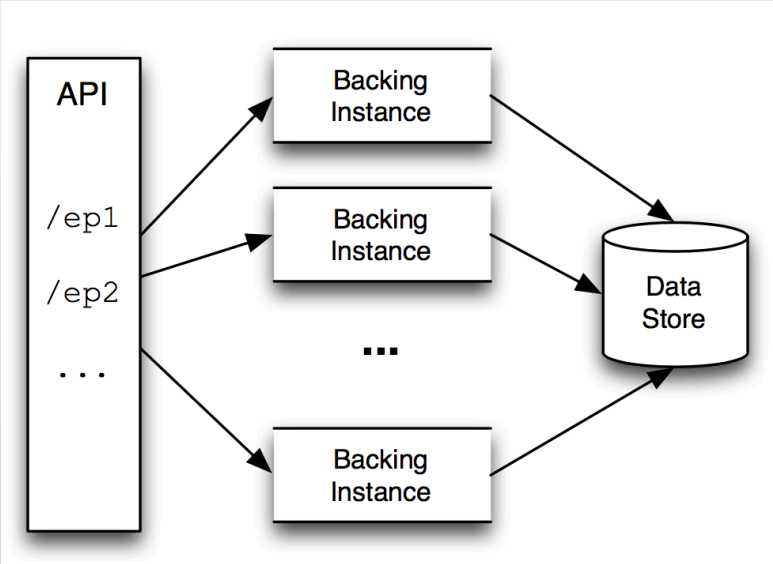
Example:

- A service that manages products can be used in the context of ordering, or for a recommender service, or for inventory management

Fosters reuse!

# Stateless

**State is maintained on the client side, the service does not know more about the interaction than what is necessary to serve the current request.**




Eases horizontal scaling!

# Common Ways to Implement Services

**SOAP / WSDL**

- Standardised, heavy-weight
- Mostly used in enterprise context

**REST**

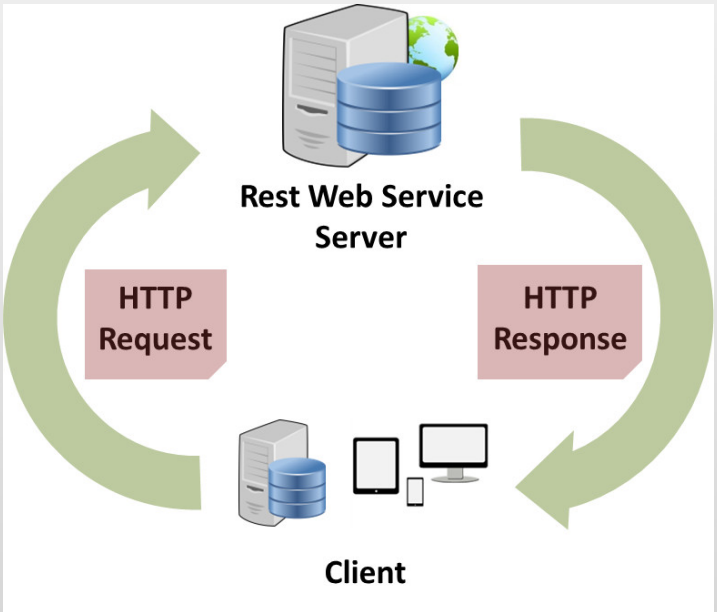
- Light-weight, thin layer on top of HTTP
- Commonly used for Web APIs

- Others:
  - OSGi, SCA, Jini, …

# REST

Acronym for *"Representational State Transfer"*

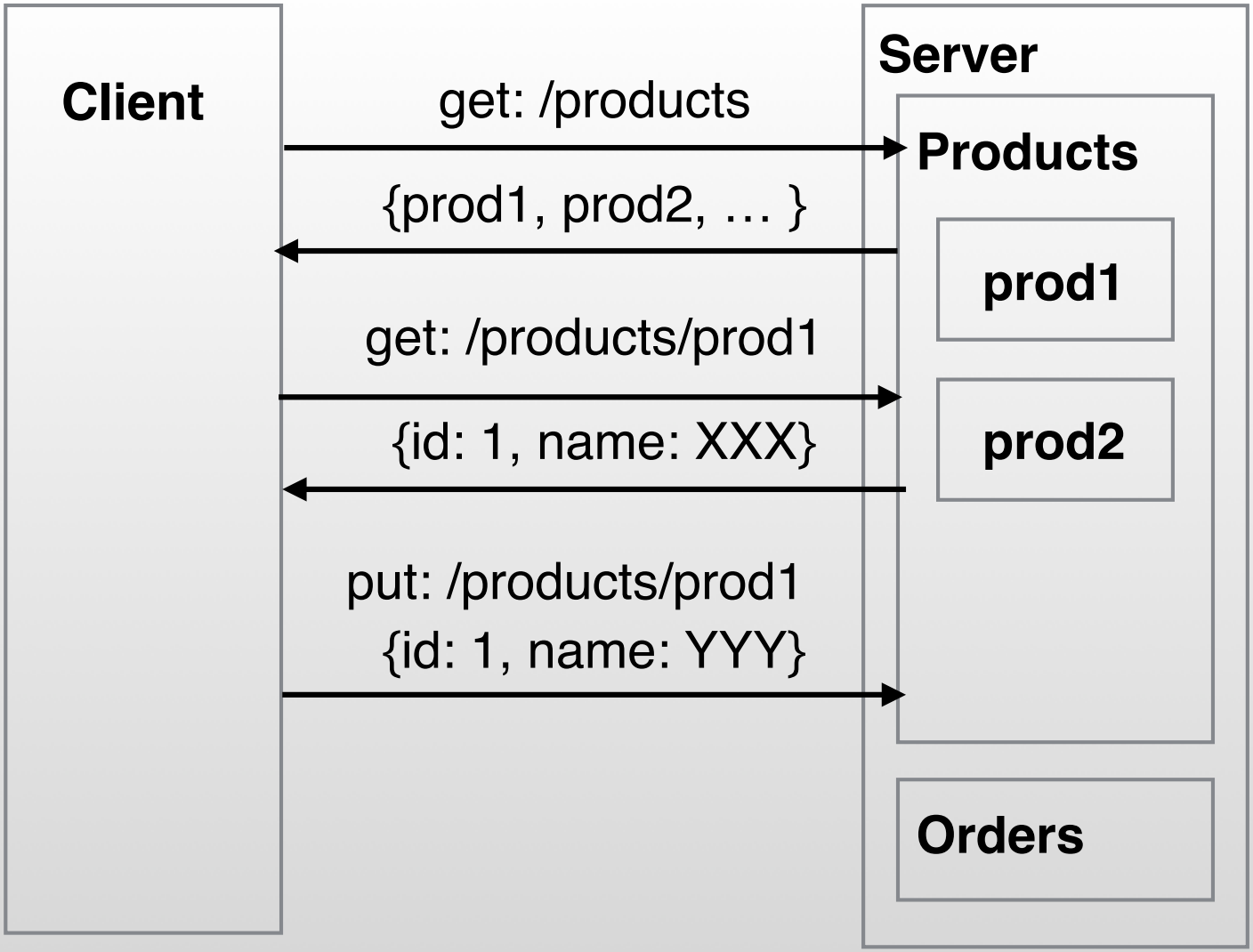
- Client manages the state
- And "transfers" the state to the server with every request



# Five Main REST Characteristics

- Resource-Orientation
  - Key elements of any RESTful service are resources
- Naming
  - Every resource is associated with an unique and descriptive name
- Uniform Interface
  - Every resource is accessed through the same interface
- Statelessness
  - Every request is self-contained
- Layering
  - Intermediaries can be inserted transparently
  - Proxies, caches, …

# An Example Interaction



# On The Wire

```
GET /products HTTP/1.1
Host: my.remote.server
Accept: application/json
```

```
HTTP/1.1 200 OK
Date: Tue, 02 Nov 2016 14:38:00 CET
Content-Type: application/json

{[prod1, prod2, prod3, prod4, prod5]}
```

# HATEOAS

"Hypermedia as the Engine of Application State"

" (…) *the principle is that the hypermedia in each server response will contain links that correspond to all the actions that the client can currently perform.* (…) *every server response describes the new actions that are available.* (…) *A client of a RESTful application need only know a single fixed URL to access it. All future actions should be discoverable dynamically from hypermedia links included in the representations of the resources that are returned from that URL.* (…) "

[Wikipedia]

# Uniform Interface: HTTP

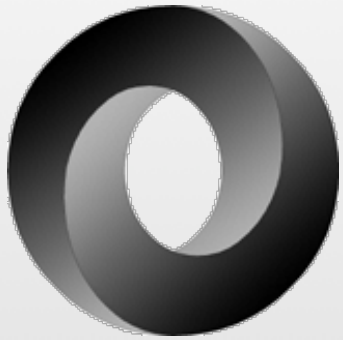
| Verb | Safe | Idempotent | Body | Description |
|---|---|---|---|---|
| **GET** | Yes | Yes | No | **GET** a resource identified by an URL |
| **PUT** | No | Yes | Yes | **UPDATE** a resource identified by a client-specified URL |
| **POST** | No | No | Yes | **CREATE** a new resource |
| **DELETE** | No | Yes | No | **DELETE** a resource identified by a URL |

See: http://www.w3.org/Protocols/rfc2616/rfc2616-sec9.html

# Representations

REST foresees that resources may be marshalled into many different formats for wire transfer

- “Representation”, Content Type



Common examples:

- XML, JSON, CSV (for programmatic clients)
- HTML, TXT (for human clients)

# Content Type Negotiation

Server decides which representation to use for an answer based on:

- Capabilities of the server
- Wishes of client

Communication through HTTP headers:

```
GET /products HTTP/1.1
Host: my.remote.server
Accept: application/json,application/xml,text/html
```

```
HTTP/1.1 200 OK
Date: Tue, 02 Nov 2016 14:38:00 CET
Content-Type: application/json

{[prod1, prod2, prod3, prod4, prod5]}
```

# Summary and Comparison

Service-Oriented Systems

↑

Component-Based Systems

↑

Distributed Object Systems

↑

Remote Procedure Call Systems

↑

Message Passing

↑

Streaming

# Sync / Async Interactions?

| | |
|---|---|
| **Can be either** | Service-Oriented Systems |
| **Synchronous** | Component-Based Systems |
| **Synchronous** | Distributed Object Systems |
| **Synchronous** | Remote Procedure Call Systems |
| **Asynchronous** | Message Passing |
| **Not applicable** | Streaming |

# Duration of an Individual Connection?

| | |
|---|---|
| **Long** | Service-Oriented Systems |
| **Long** | Component-Based Systems |
| **Long** | Distributed Object Systems |
| **Long** | Remote Procedure Call Systems |
| **Short** | Message Passing |
| **Arbitrary, can be very long** | Streaming |

# Unicast or Multicast?

| | |
|---|---|
| **Unicast** | Service-Oriented Systems |
| **Unicast** | Component-Based Systems |
| **Unicast** | Distributed Object Systems |
| **Unicast** | Remote Procedure Call Systems |
| **Both** | Message Passing |
| **Both** | Streaming |

# Statefulness?

| | |
|---|---|
| **Stateless** | Service-Oriented Systems |
| **Mostly stateful** | Component-Based Systems |
| **Stateful** | Distributed Object Systems |
| **Stateless** | Remote Procedure Call Systems |
| **Stateless** | Message Passing |
| **Not applicable** | Streaming |

# Coupling

| | |
|---|---|
| **Maybe referentially decoupled, temporally coupled** | Service-Oriented Systems |
| **Referentially and temporally coupled** | Component-Based Systems |
| **Referentially and temporally coupled** | Distributed Object Systems |
| **Referentially and temporally coupled** | Remote Procedure Call Systems |
| **Ideally referentially and temporally decoupled** | Message Passing |
| **Referentially and temporally coupled** | Streaming |

# Support for Heterogeneous Clients

| | |
|---|---|
| **Yes** | Service-Oriented Systems |
| **Mostly No** | Component-Based Systems |
| **No** | Distributed Object Systems |
| **Maybe** | Remote Procedure Call Systems |
| **Mostly Yes** | Message Passing |
| **Yes** | Streaming |

# Next Weeks

Next week:

- Next week we will discuss ATAM, a concrete evaluation model for software architectures
- The week after, we slightly change topic and focus on cloud computing technologies
- We will come back to the (micro-)services topic when we discuss scalability and resilience in cloud computing