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Software Engineering and Architecture

Distributed Systems

An Introduction

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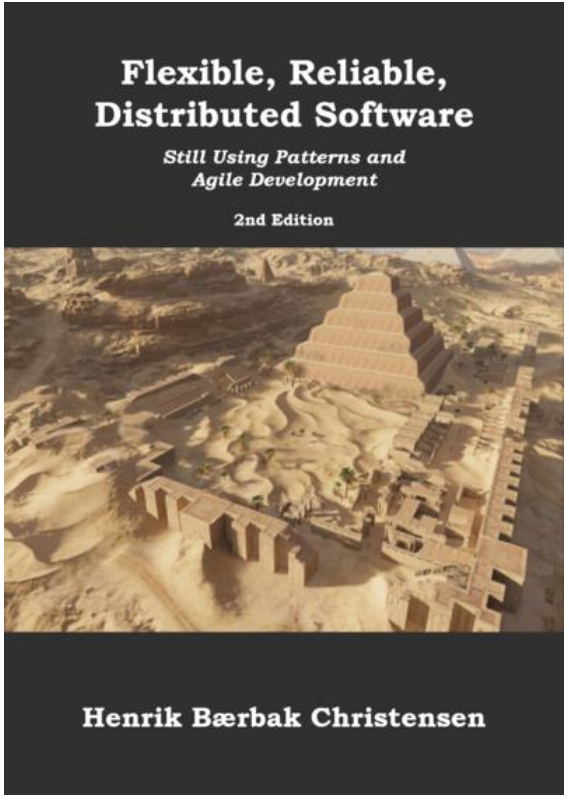
Intro…

- Distributed Computing is the last major SWEA topic
  - Our perspective: *Programming and Pattern Perspective*

- Curriculum: My second book ☺
  - Confusion: Looks much the the first…
  - Get it from **https://leanpub.com/frds**
    - For the price of a box of beer…
  - *Yes, I like pyramids !*



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Distributed System

Definition: Distributed System

A distributed system is one in which components located at networked computers communicate and coordinate their actions only by passing messages. (Coulouris, Dollimore, Kindberg, and Blair 2012)

- Why?
  - To speed up computation
    - Google search, machine learning, and (a few) other cases
  - ***To share information***
    - Everything else! (Slight exaggeration!)

Limitations

- Distributed systems and distributed computing is a…

… vast subject area !!!

- We will limit ourselves to a ”niche”

Client-server Architectures using Remote Method Invocation

… this niche covers *a lot of* systems in practice ☺

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And Limiting ourselves

- Even that is

… difficult to make!!!

- … because it must be
  - Highly available, performant, and secure
- And that is topics in advanced *software architecture*

We will only consider *happy path:*
All computers and networks are working;
Few users and none that are malicious

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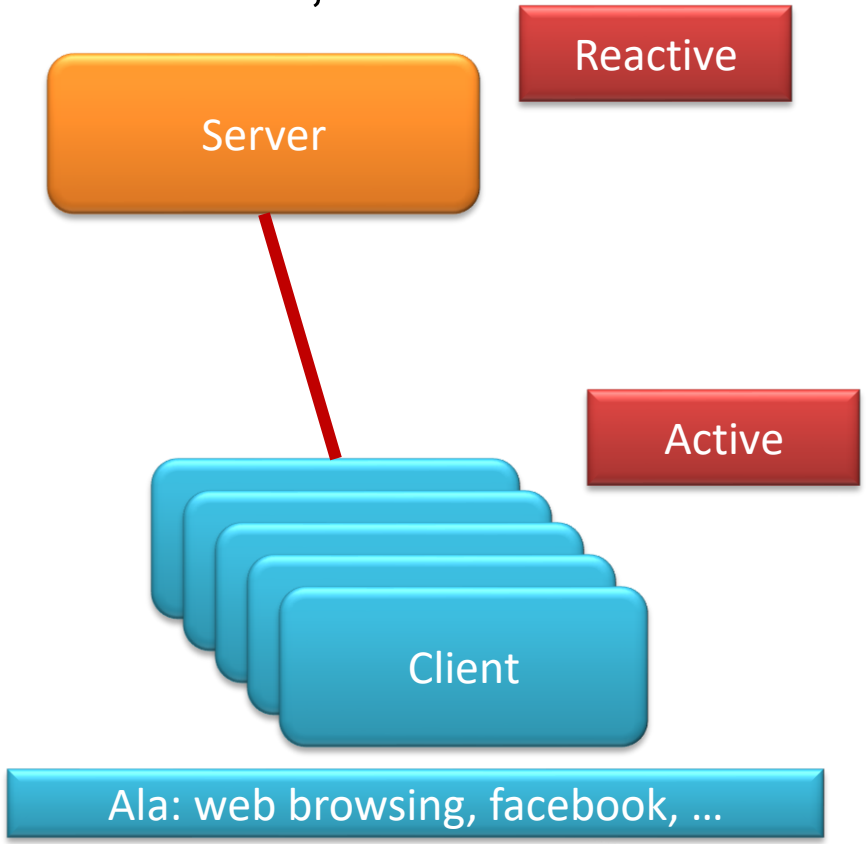
Client-Server

- You all know ‘client-server’ architectures, but…

Client-server architecture Two components need to communicate, and they are independent of each other, even running in different processes or being distributed in different machines. The two components are not equal peers communicating with each other, but one of them is initiating the communication, asking for a service that the other provides. Furthermore, multiple components might request the same service provided by a single component. Thus, the component providing a service must be able to cope with numerous requests at any time, i.e. the component must scale well. On the other hand, the requesting components using one and the same service might deal differently with the results. This asymmetry between the components should be reflected in the architecture for the optimization of quality attributes such as performance, shared use of resources, and memory consumption.

The CLIENT-SERVER pattern distinguishes two kinds of components: clients and servers. The client requests information or services from a server. To do so it needs to know how to access the server, that is, it requires an ID or an address of the server and of course the server’s interface. The server responds to the requests of the client, and processes each client request on its own. It does not know about the ID or address of the client before the interaction takes place. Clients are optimized for their application task, whereas servers are optimized for serving multiple clients[3].



[3]Paris Avgeriou and Uwe Zdun, “Architectural patterns revisited - a pattern language”, In 10th *European Conference on Pattern Languages of Programs* (EuroPlop), Irsee, 2005.

Client-Server

- One big difference from all you have been doing up until now…
  - You have been building “programs” = all behavior in one ‘unit’
- A client-server system consists of **two programs**
- The *client* program: The one the user runs
  - Communicating with…
- The *server* program: Well hidden in some server room
  - The one storing the ‘shared information’

Or Visually

game.playCard(Findus, ff);

Client program

game.playCard(Findus, ff);

Server program

Or Visually

```
game.playCard(Findus, c) {
  result =
    sendToServer("Findus tries to play ff");
  return result;
}
```

Client program

```
Await incoming command, c {
  if (c == "Findus tries to play ff") {
    r = game.playCard(Findus,ff);
    send 'r' back to client;
  } else …
```

Server program

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Or Visually

```
game.playCa
  result =
    sendToSe
  return res
}
```

```
d, c {
play ff") {
dus,ff);
;
```

In the next two Iterations – you will build **both** the client program as well as the server program!

The server is the domain thing, remember!

Client prog

Server program

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One Word of Caution

- We will ***happily disregard security !!!***

- Security is so important that we ignore it!
  - Because the real security techniques is one big set of *hard bindings and strong coupling*
    - You need certificates that tie you to a specific DNS name
      - Certificate stores, key pair generation, trust chains, yaga yaga
    - Quite a lot of extra coding and makes experiments difficult

- ***Morale: Add that stuff for real production usage !***

The History

- Birrell and Nelson, 1984:
  - “allow calling procedure on remote machines”
  - A calls procedure f on B means
    - A suspends, information on f is transmitted to B
    - B executes the f procedure
    - B sends the result back to A
    - A resumes

Grounding Example

TeleMed

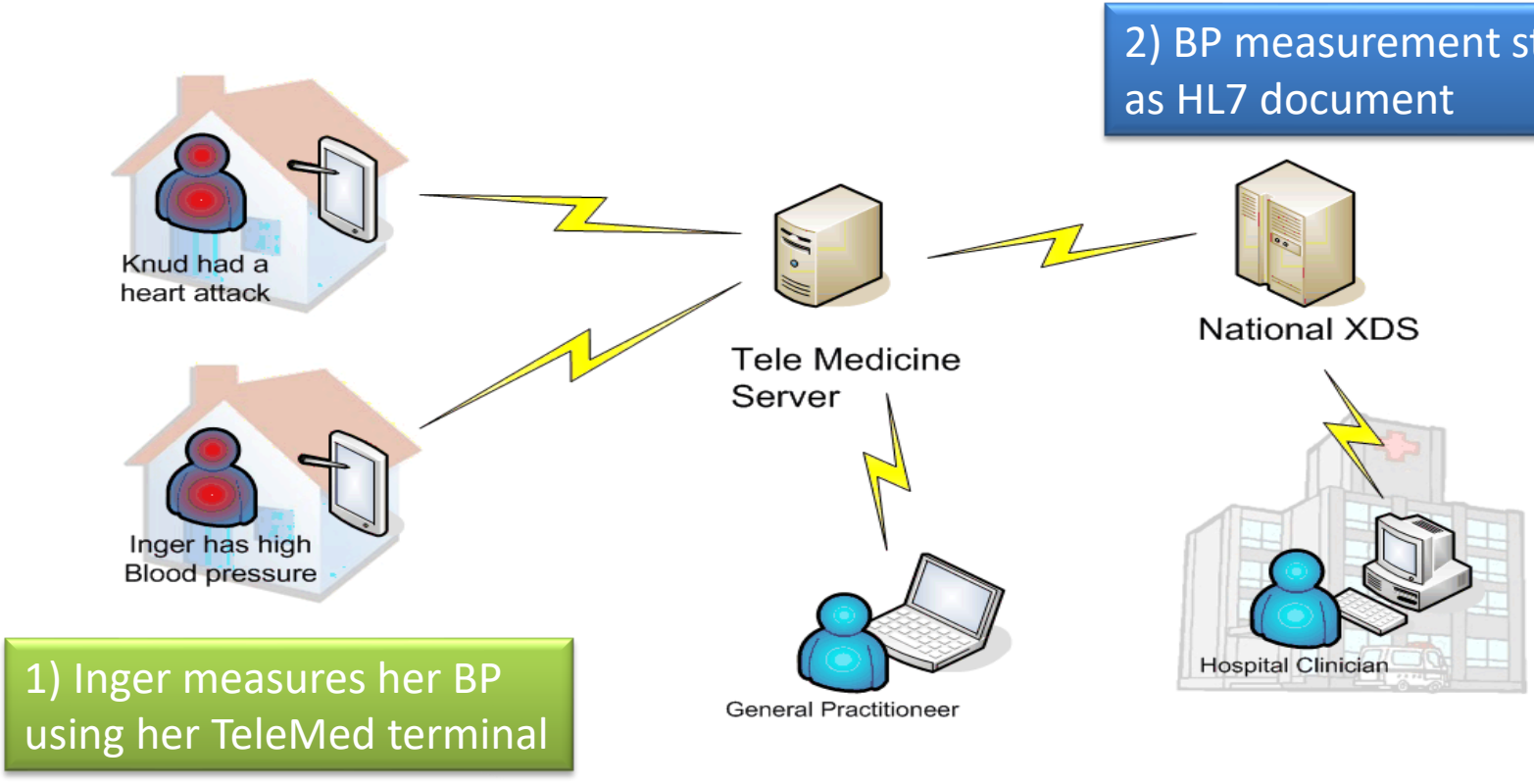
Inspired by Net4Care:

https://baerbak.cs.au.dk/net4care/

Vision

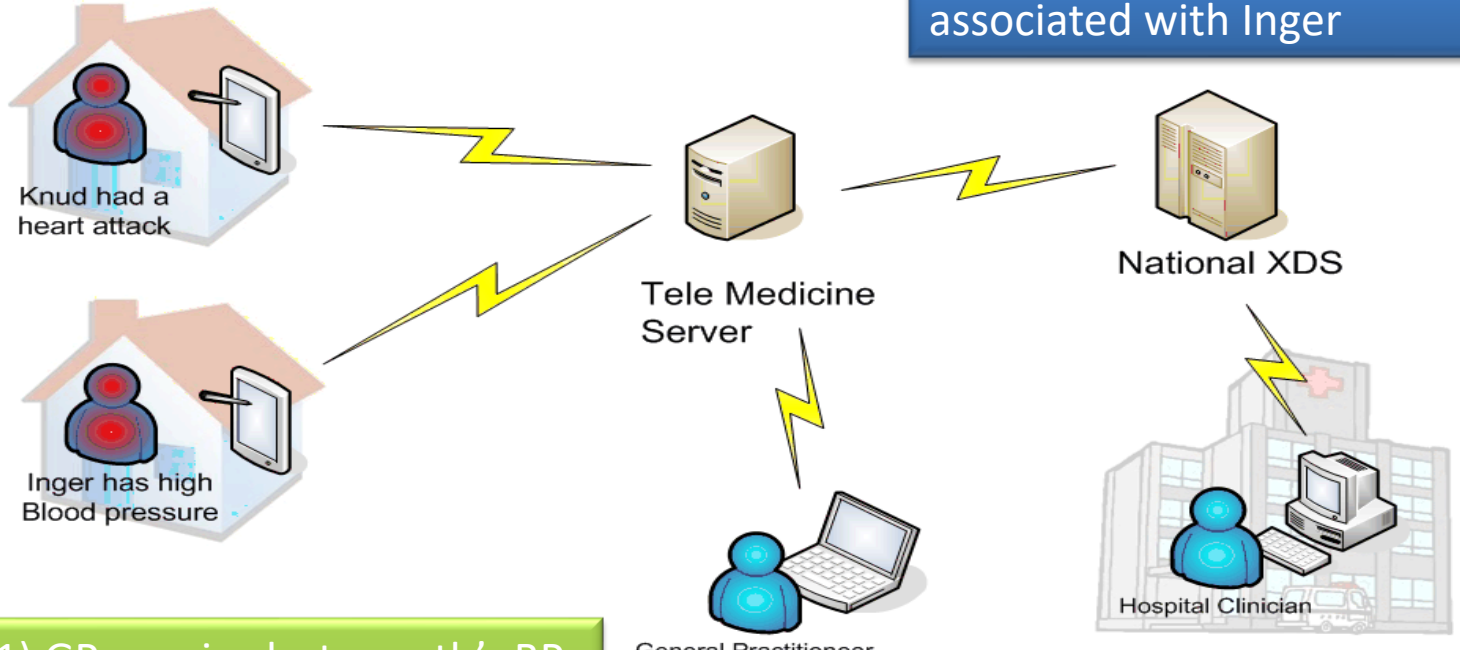
- Vision
  - Replace out-patient visits by measurements made by patients in their home
  - *Move data from home to regional/national storage so all health care personal can view them...*
- Motivation
  - Reduce out-patient visits
    - Better quality of life
    - Cost savings
    - Better traceability and visibility

Story 1


2) BP measurement stored as HL7 document
Knud had a heart attack
Inger has high Blood pressure
Tele Medicine Server
National XDS
General Practitioneer
Hospital Clinician
1) Inger measures her BP using her TeleMed terminal

Story 2

2) Query for all BP documents associated with Inger



1) GP queries last month's BP measurements for Inger using web browser

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(What is XDS)

- Cross-Enterprise Document Sharing
  - One Registry + Multiple Repositories
  - Repository: Stores *clinical documents*
    - (id,document) pairs
  - Registry: Stores *metadata* with document *id*
    - Metadata (cpr, timeinterval, physician, measurement type,...)
    - Id of associate document and its repository

- Think
  - Registry = Google (index but no data)
  - Repository = Webserver (data but no index)

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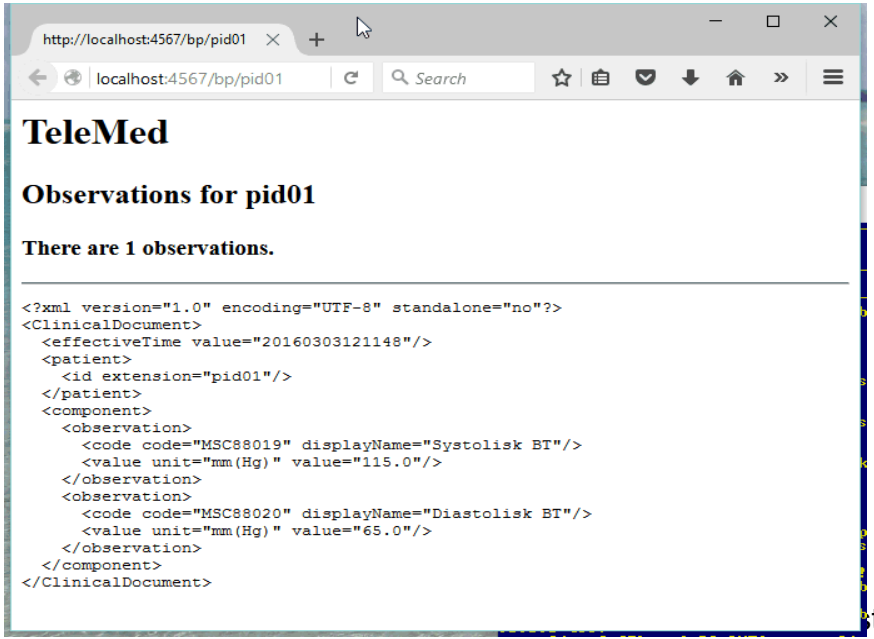
(What is HL7)

- HL7 is a standard (complex!) for clinical information storage and exchange.
  - Version 3 loves XML!
- Our version:

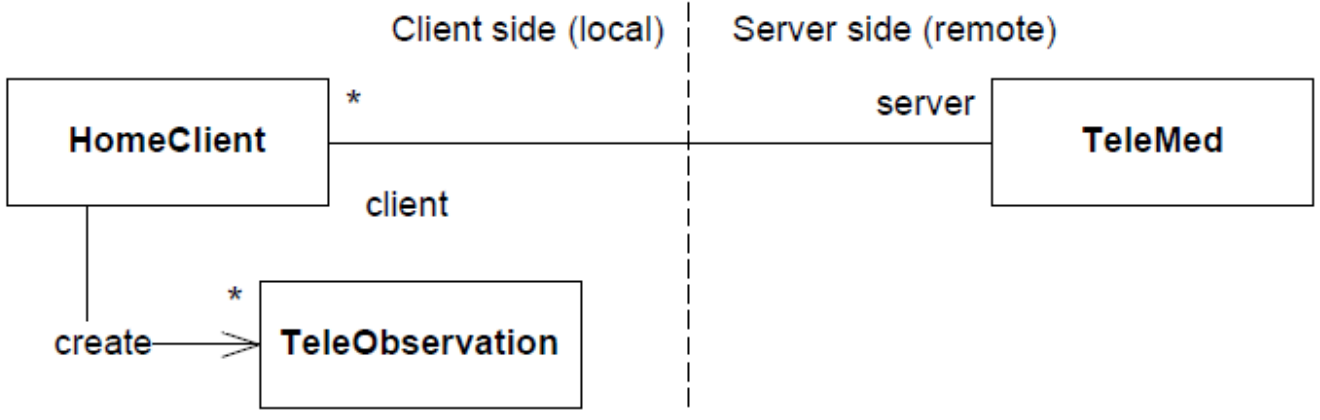


Real version:

tensen

TeleMed Design

- Roles involved



- TeleObservation: Represents a measurement
- HomeClient: Responsible for measuring + uploading
- TeleMed: Responsible for storage and queries

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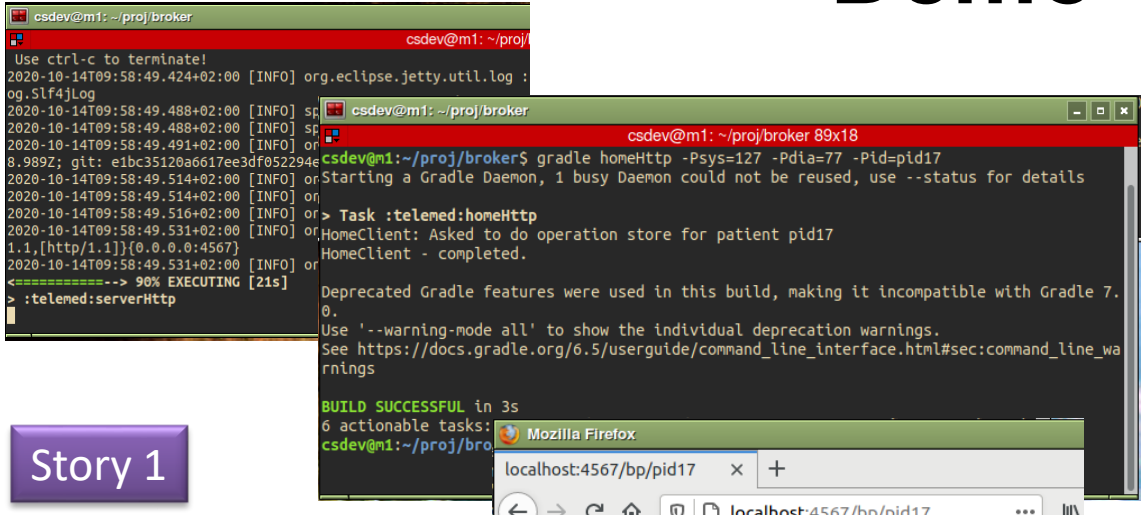
Demo

- Start a server
  - gradle serverHttp
- Send an obs.
  - gradle homeHttp
  - … -Psys=126 -Pdia=70 -Pid=pid17
- GP review in browser
  - http://localhost:4567/bp/pid17

Story 1

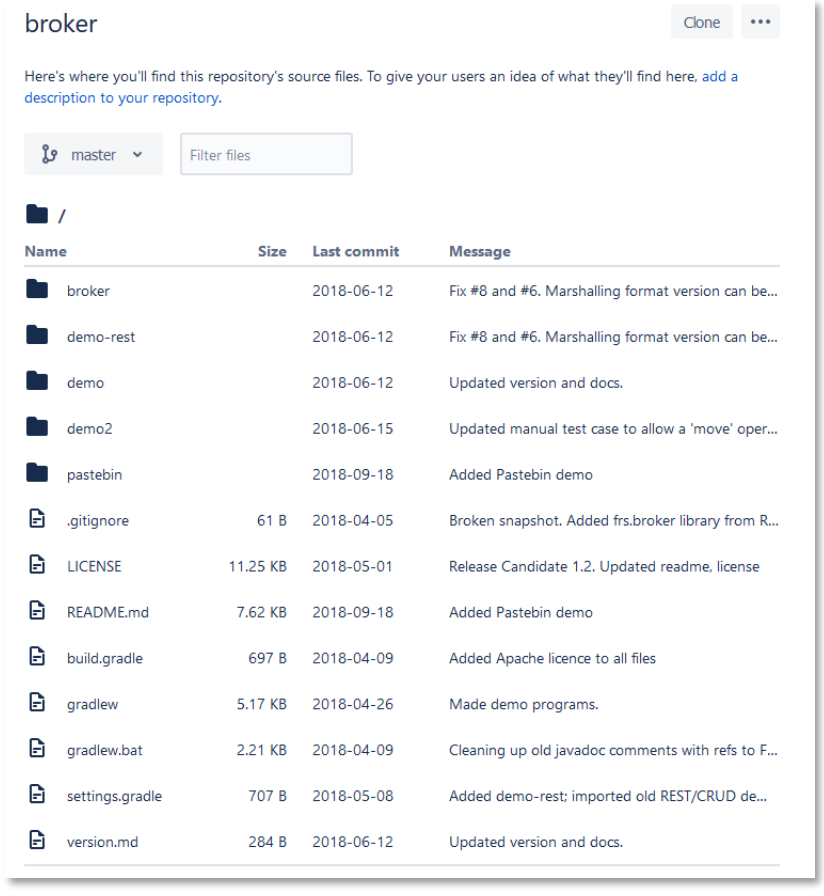
Story 2



Source Code

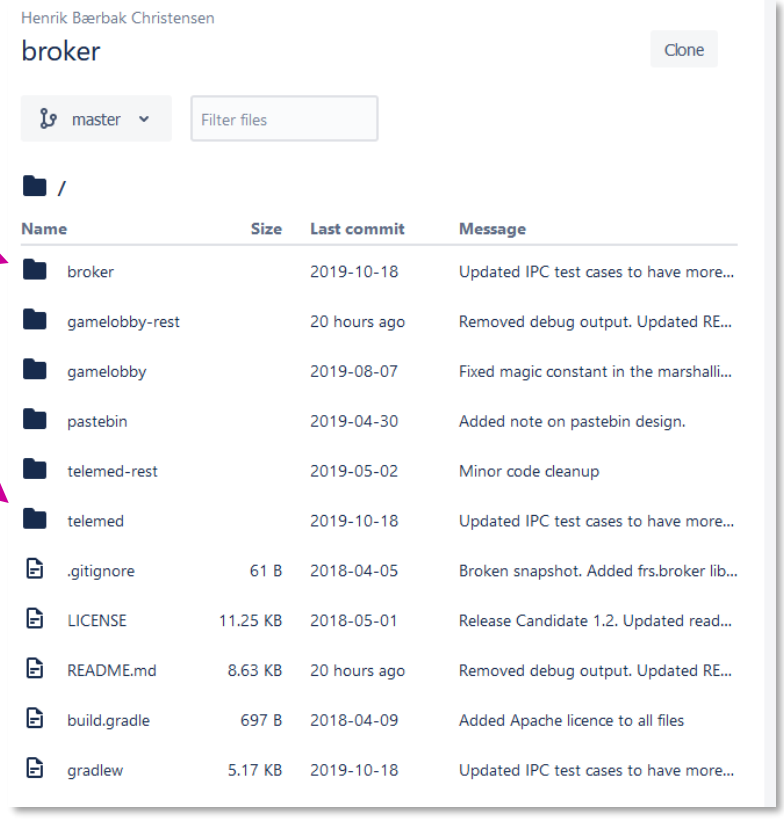
- The source code is open source at
  - https://bitbucket.org/henrikbaerbak/broker/
  - Download or Fork

- ***You will want its code to learn the Broker pattern…***
  - But your HotStone mandatory only needs to fetch the Broker library using gradle…
    - As with the MiniDraw library



Source Code

- Subprojects
  - *Broker*: Core roles + default implementation of *some*
  - *TeleMed:* The TeleMed code including tests of *broker* code
  - *Others:* We will return to these next…



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Issues in Distribution

Why is it hard?

Challenge

- How guys like me like to code:

> **Definition: Object-orientation (Responsibility)**
>
> An object-oriented program is structured as a community of interacting agents called objects. Each object has a role to play. Each object provides a service or performs an action that is used by other members of the community.

- Which is then something like this on the client:

```
public void makeMeasurement() {
  TeleObservation teleObs;
  teleObs = bloodPressureMeterHardware.measure();
  TeleMed server = new RemoteTeleMedOnServer(...);
  String teleObsId = server.processAndStore(teleObs);
}
```

Challenge

- However - networks *only support two asynch functions!*

```
void send(Object serverAddress, byte[] message);
byte[] receive();
```

- Which is *not* exactly the same as

```
public void makeMeasurement() {
  TeleObservation teleObs;
  teleObs = bloodPressureMeterHardware.measure();
  TeleMed server = new RemoteTeleMedOnServer(...);
  String teleObsId = server.processAndStore(teleObs);
}
```

Issues (at least!)

```
public void makeMeasurement() {
  TeleObservation teleObs;
  teleObs = bloodPressureMeterHardware.measure();
  TeleMed server = new RemoteTeleMedOnServer(...);
  String teleObsId = server.processAndStore(teleObs);
}
```

- Send/receive is a too low level programming model
- Send() does not wait for a reply from server (Asynch)
- Reference to object on *my* machine does not make sense on *remote* computer (memory address)
- Networks does not transfer objects, just bits
- Networks are slow
- Networks and remote computers may fail
- Networks are insecure, others may pick up our data

Security QA

Availability QA

Performance QA

Architectural Issues: Not SWEA stuff. (Follow my EVU course once you are in a job ☺)

Performance

- Just how much slower is a network call compared to a local in-JVM memory call?

Configuration	Average time (ms)	Max time (ms)	Factor
Local call	1,796	3,366	1.0
Localhost	9,731	12,806	5.4
Docker	17,091	35,873	9.5
On switch	22,817	29,427	12.7
Frankurt	494,966	513,411	275.6

- Imagine that your next trip to the supermarket for a soda was 275 times slower???
  - 10 minutes walk versus 46,8 hours walking ☺

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Elements of a Solution

- On the ‘happy path’, we need to
  - Make the HomeClient invoke a synchronous method call on a remote TeleMed object using only network send/receive
  - Keep our OO programming model: *telemed.processAndStore(to);*
    - *That is invoke specific method on remote object*
  - Convert TeleObservation object into bits to send it, and convert it back again
  - Locate the remote TeleMed object

Elements Overview

- Solutions are
  - Request/Reply Protocol
    - Simulate synchronous call (solves (partly) concurrency issue)
  - Marshalling
    - Packing objects into bits and back (solves data issue)
  - Proxy Pattern
    - Simulate method call on client (solves programming model issue)
  - Naming Systems
    - Use a registry/name service (solves remote location issue)
- Bundled together these constitute
  - The **Broker** pattern

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Request/Reply

The Protocol

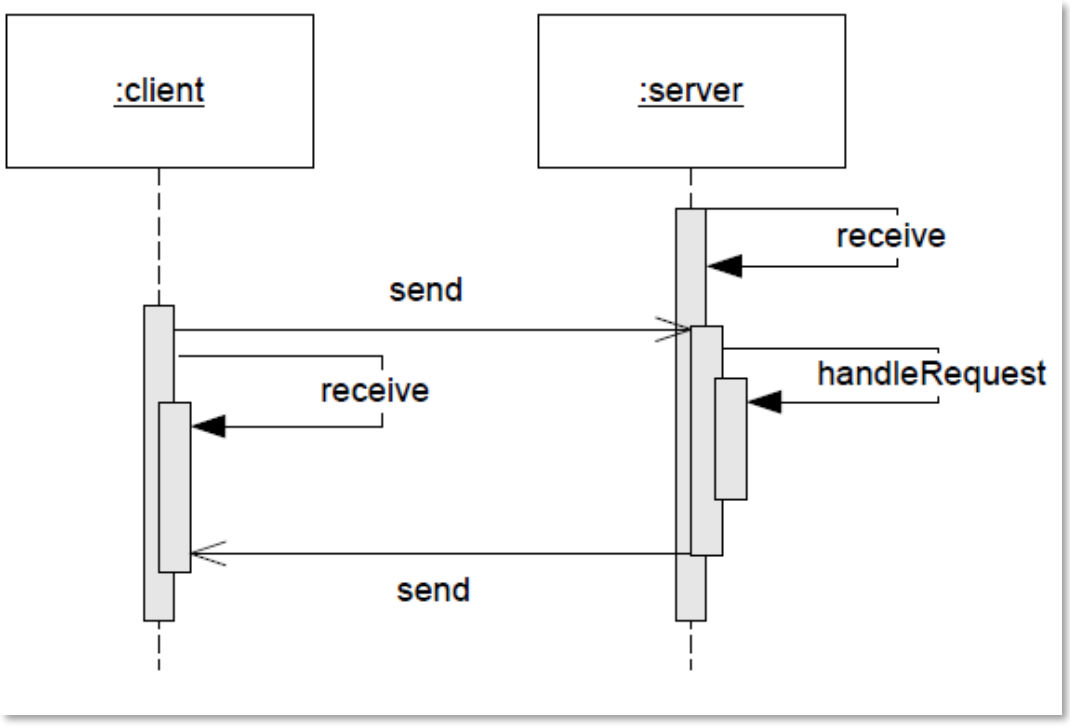
Definition: Request-Reply Protocol

The request-reply protocol simulate a synchroneous call between client and a server objects by a pairwise exchange of messages, one forming the request message from client to server, and the second forming the reply message from the server back to the client. The client sends the request message, and waits/blocks until the reply message has been received.

- Known from every WWW access you have ever made…
  - Firefox will *block* until a web page has been received

Pairing Send/Receives

- Client does
  - Send() and receive
- Server does
  - Receive() and send()
- Roles
  - Client is *active* – initiate action
  - Server is *reactive* – awaits actions and then reacts



Marshalling

Or Serialization

Definitions

Marshalling is the process of taking a collection of structured data items and assembling them into a byte array suitable for transmission in a network message.

Unmarshalling is the process of disassembling a byte array received in a network message to produce the equivalent collection of structured data items.

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Two Basic Approaches

- There are two approaches
  - Binary formats
    - Google ProtoBuf, proprietary
  - Textual formats
    - XML, JSON, proprietary
- Exercise: Costs? Benefits?

JSON blood pressure

```
{
  patientId:   ''251248-1234'',
  systolic:    128.0,
  diastolic:   76.0
}
```

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And we need more

- As we can send only bits, we also need to marshal information about the method and object id!

```
{
  methodName : "processAndStore_method",
  parameters : [
    {
      patientId:  ''251248-1234'',
      systolic:   128.0,
      diastolic:  76.0
    }
  ]
}
```

Note

- Marshalling is fine for primitive datatypes (int, double, char, array, …) but…
- What about *object references?*
  - *inventory.addCustomer(c)* *where c is Customer object?*
  - *Issue: the 'c' is an object reference but how to a use 'c' on the client if the object is located on the server?*
- Actually, it sort of depends on *parameter passing…*

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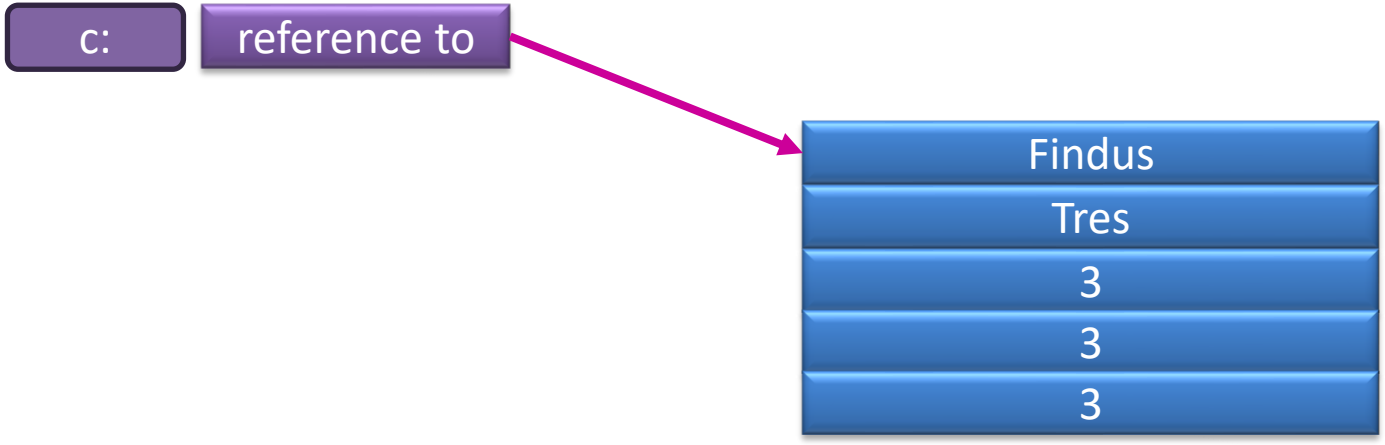
Parameter Passing

- **Pass by reference**
  - The Java style for all *object types*
  - *You do not get the Customer value, you get a **reference** to it!*
  - public void addCustomer(Customer c);
    - ('c' is a *reference* to data, not the data themselves)

- **Pass by value**
  - Java does this for *primitive types*, like int and double
  - You do get the **value** itself
  - public void deposit(double amount);
    - ('amount' *is* the data (a copy of the value passed))

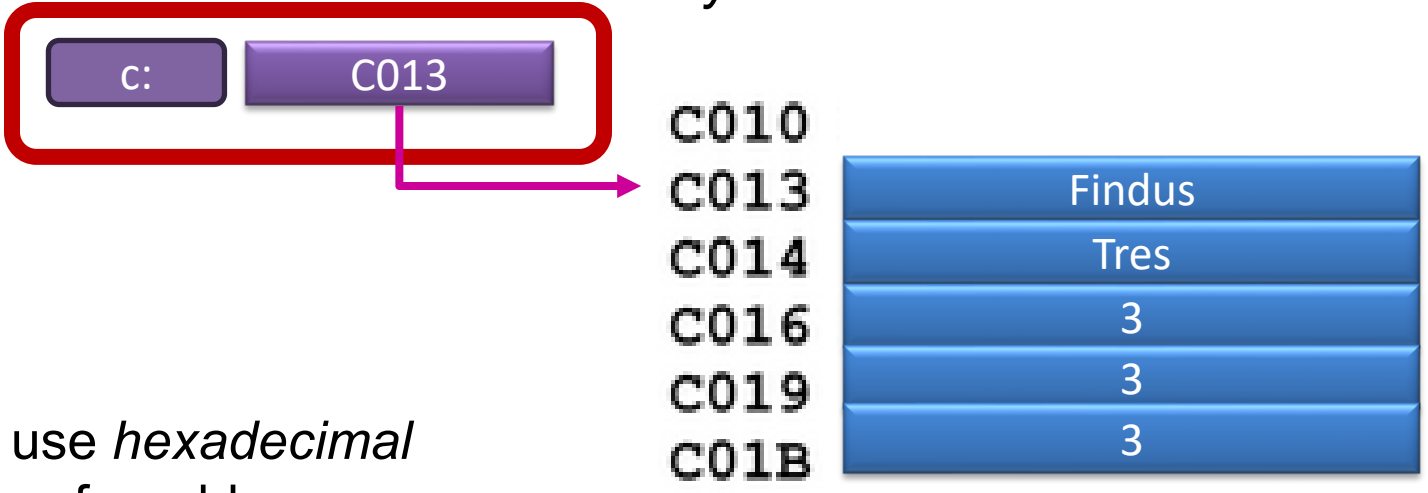
The Difference

- Example: A HotStone Card
  - Card c = new Card(Findus, “Tres”, 3, 3, 3);
  - *Now ‘c’ is a reference (pointer) to some data in memory*



The Difference

- Example: A HotStone Card
  - Card c = new Card(Findus, “Uno”, 1, 1, 1);
  - *At machine code level, c is simply the **address** of that chunk of memory*



  - Here I use *hexadecimal* numbers for addresses

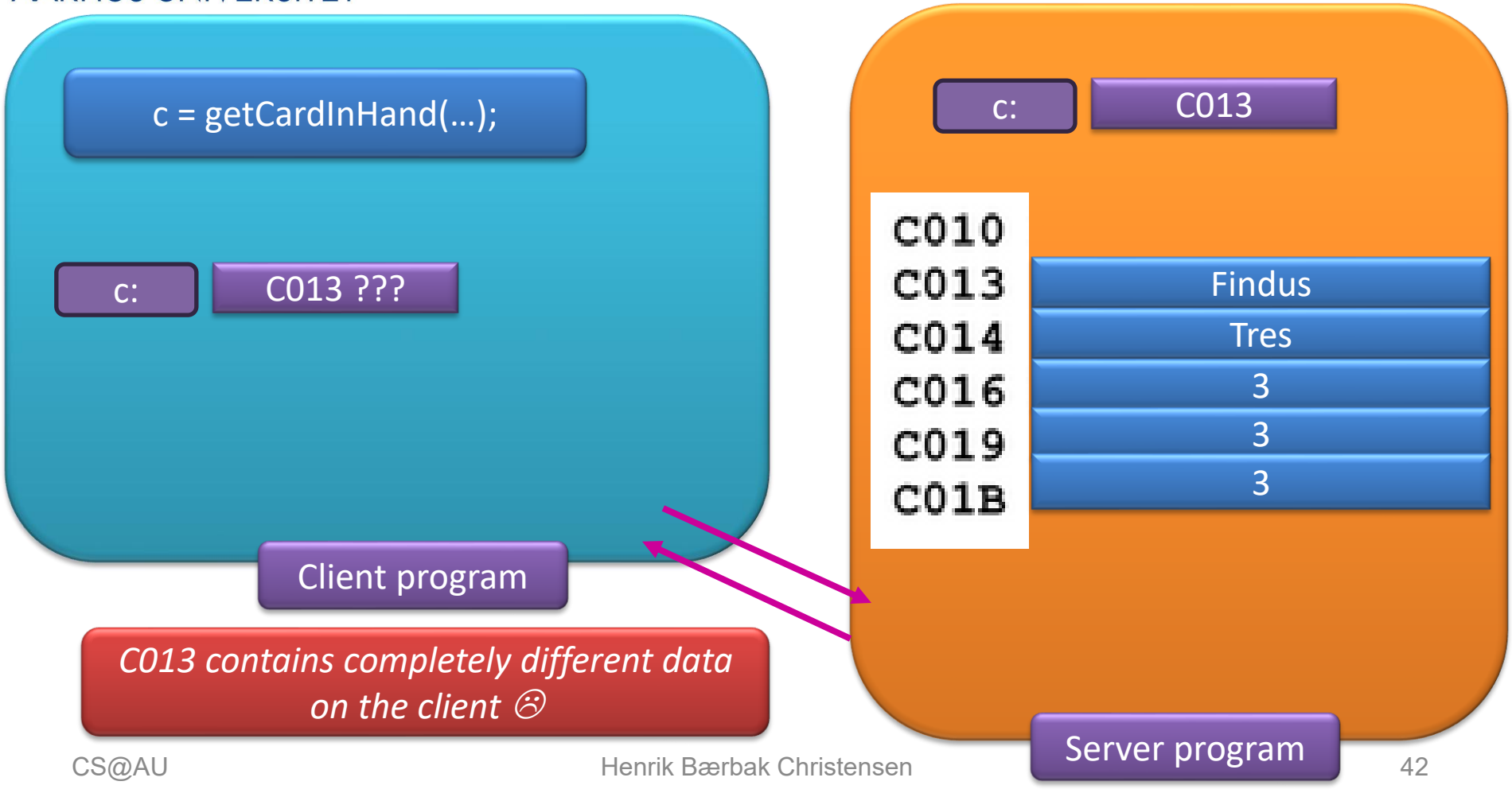
Java References

- If you create a class, and do *not* override ‘toString()’ you get a glimpse of that memory address
  - The JVM does some trickery so it is not a clean/real memory address, but anyway…

```
public class PrintAddr {
  public static void main(String[] args) {
    System.out.println("=== Java References ===");
    Point p = new Point();
    System.out.println("Value of p is: " + p );
  }
  private static class Point { public int x; public int y; }
}
```

```
csdev@m51:~/tmp$ java PrintAddr
=== Java References ===
Value of p is: PrintAddr$Point@372f7a8d
```

… The Problem


c = getCardInHand(…);
c:
C013 ???
Client program
C013 contains completely different data on the client ☹
c:
C013
C010
C013
C014
C016
C019
C01B
Findus
Tres
3
3
3
Server program

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Broker Does Value Passing

- The Key point here

> Broker *only* supports *pass by value!*
>
> (next week we introduce a trick to *simulate* pass by ref)

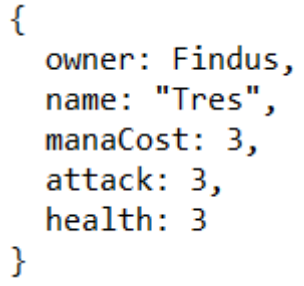
- That is, the server will not send the reference, but a *marshalled copy of the data*
  - *I.e. client receives*

```
{
  owner: Findus,
  name: "Tres",
  manaCost: 3,
  attack: 3,
  health: 3
}
```

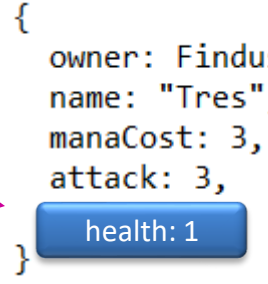
Our Broker is not 'stupid'. **A network can by definition only support *pass-by-value!***

Consequences

- If the *server* sends a card object – **pass-by-value**



- And the *client* receives this object and then change health



- Then what happens in the *server's* card object ???

Quite problematic, right?
We solve it next week…

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JSON Libraries

Libraries

- Every distributed system in the world needs to marshall!
- Thus – lots of marshalling libraries around ☺
  - Do NOT code it yourself!!! You *will* end reimplementing one!
    - ~~String json = ”{ name: ”+ object.name+ ”}…~~

- JSON I have used many libraries
  - Json-simple
  - Jackson JSON
  - Gson

Gson

- Gson is the most compact I have used
  - (But have had trouble with ‘date’ objects that marshall incorrectly!)
- It allows easy marshalling of **record types**
  - Also known as
    - **PODO**: Plain Old Data Objects,
    - **DTO**: Data Transfer Object
- Record type (Pascal) / ‘struct’ (C) / record (java 17+)
  - No complex methods, only set/get methods with no side effects
  - **Must** have a default constructor
- That is: A pure data object, just storing information
  - Akin a ‘resource’ in REST terminology, by the way

Example:

```java
@Test public void shouldMarshallTeleObservation() {
  // This is a learning test, showing Gson marshalling
  Gson gson = new Gson();
  String json = gson.toJson(to);

  assertThat(json, containsString( substring: "\"patientId\":\"251248-0000\""));

  TeleObservation copy = gson.fromJson(json, TeleObservation.class);
  assertThat( copy.getPatientId(), is(HelperMethods.NANCY_ID));
  assertThat( copy.getSystolic().getValue(), is( value: 120.0));
  assertThat( copy.getDiastolic().getValue(), is( value: 70.0));
  assertThat( copy.getSystolic().getUnit(), is( value: "mm(Hg)") );
}
```

- toJson(obj)
  - Marshall
- fromJson(str, type.class)
  - Demarshall, using given type

```json
{
  "patientId": "251248-0000",
  "systolic": {
    "value": 120,
    "unit": "mm(Hg)",
    "code": "MSC88019",
    "displayName": "Systolic BP"
  },
  "diastolic": {
    "value": 70,
    "unit": "mm(Hg)",
    "code": "MSC88020",
    "displayName": "Diastolic BP"
  },
  "time": {
    "date": {
      "year": 2017,
      "month": 6,
      "day": 30
    },
    "time": {
      "hour": 11,
      "minute": 7,
      "second": 26,
      "nano": 0
    }
  }
}
```

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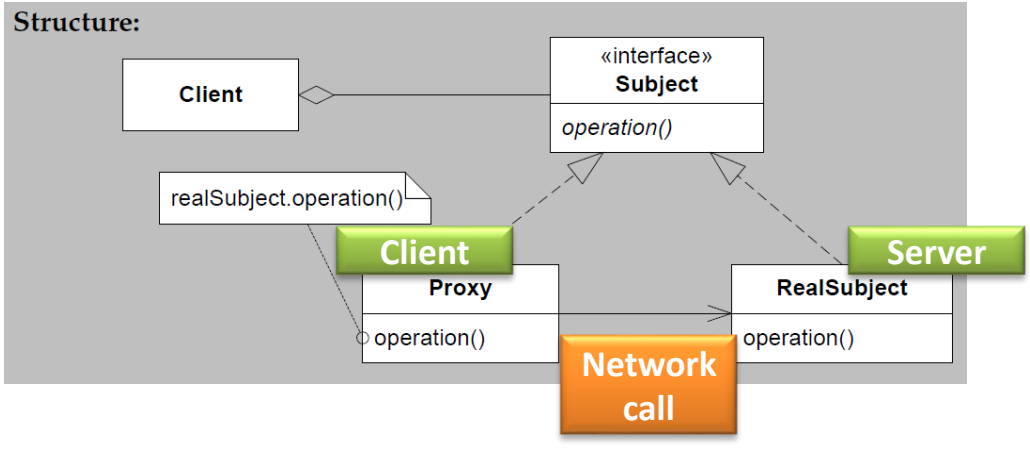
Proxy

You know that one…

Example

- TeleMed**Proxy**

```
public String processAndStore(TeleObservation teleObs) {
  byte[] requestMessage = marshall(teleObs);
  send(server, requestMessage);
  byte[] replyMessage = receive();
  String id = demarshall(replyMessage);
  return id;
}
```



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Note

- The algorithm of *all methods in the proxy* will be the same
  - Marshall parameters, send, await reply, demarshall, return
- Can be auto generated – this is what RMI does
- We will *hand-code* it, because
  - … it is the learning goal of this course ☺
  - And it actually makes sense if you want very strict control of architectural attributes like performance and availability
    - *Find more info in*

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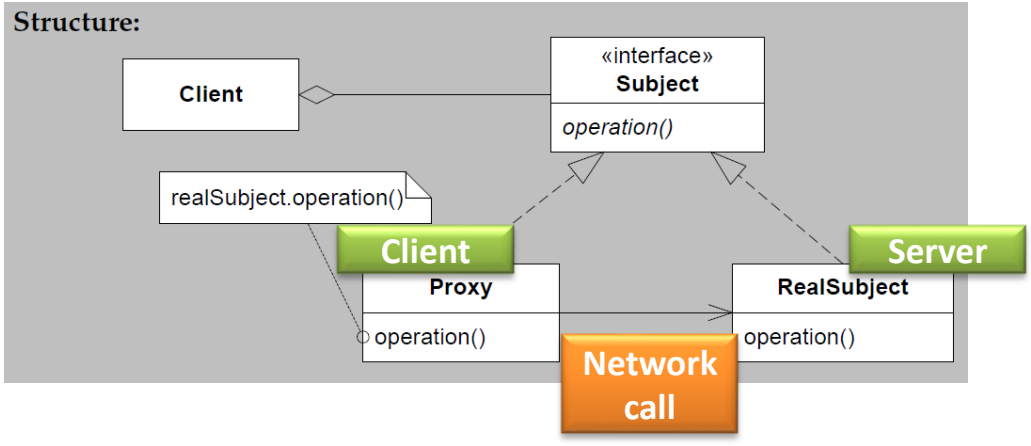
Name Services

Finding the Object to Talk to

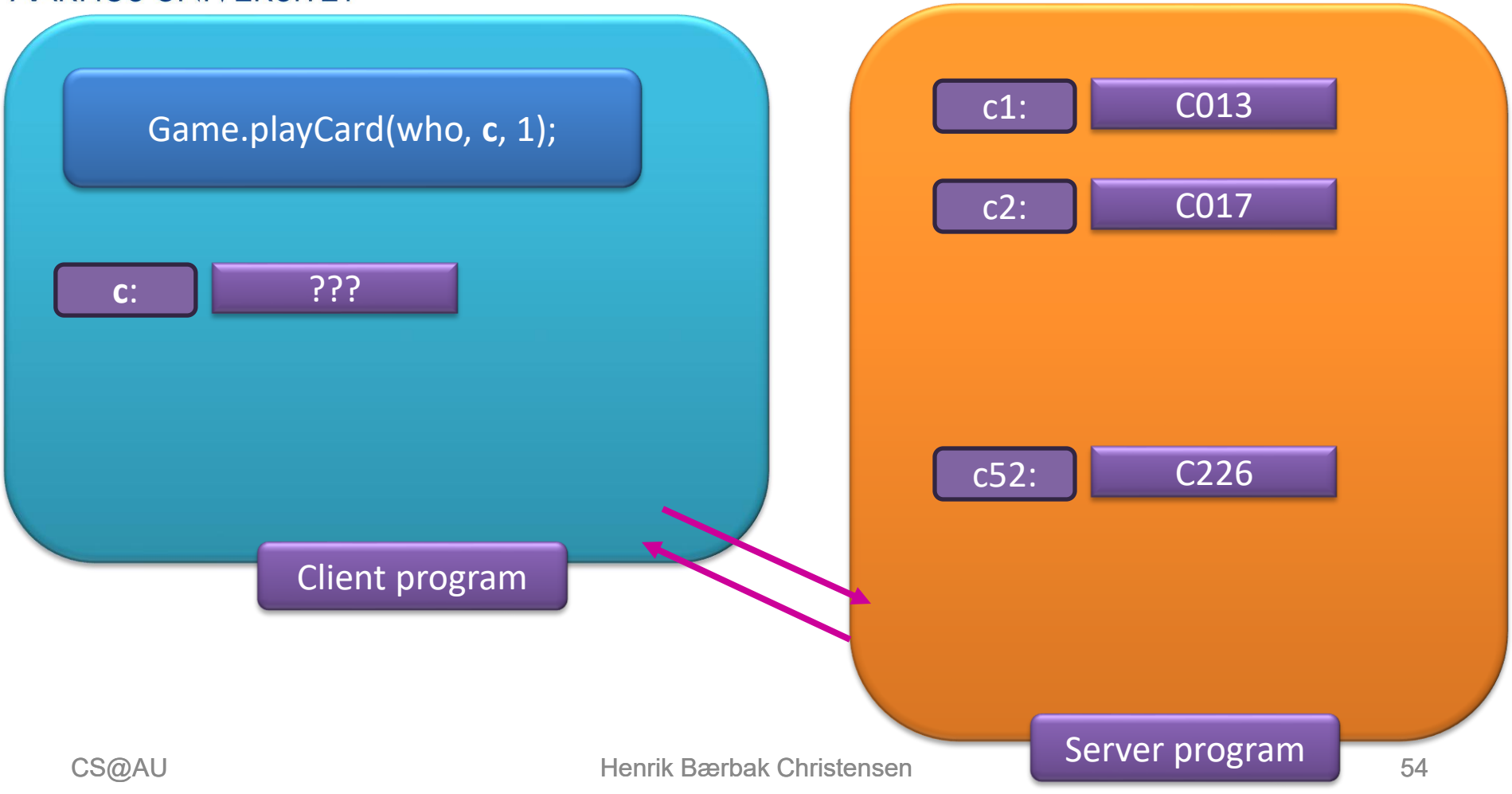
Coupling Proxy and 'server-side'

- OK, a Proxy "plays the client side role" of the real object on the server side…



- But what if there are many 'RealSubjects'?
  - Like 52 instances of 'Card' objects on the server?

The pass-by-reference problem!



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The Solution…

- … is Name Services
  - Which we will talk about next week
    - (Basically just a *mapping* between a UUID and the objects)

- This week we solve it simply by
  - Having only one object!!!
    - Known as a ‘singleton’ only one object like it in the world
  - There is only one “TeleMed” object
  - (And in mandatory, there is only one Game object)

Summary

- The Broker Pattern combines
  - Request/Reply protocol
  - Marshalling
  - Proxy pattern
  - Naming Systems (next week)
- … to produce something that (on happy days)

- Allows an Object-Oriented Programming model to apply to distributed computing