

The software design process

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High Performance
Real Time **Lab**

**"Weeks of coding can save you
hours of planning." - Unknown**



Why do we do this?

For the present

- › Enable collaborative development (collaborative tools)
- › In > months of dev, the team might change! (documentation, both internal and external)
- › Automate testing and releasing

Ultimately, every team member should focus on few tasks, the ones that fit him/her better!

For the future

- › Make the maintenance process easier
- › Enable future extensions/development

The Apollo 13

"We need find a way to put this, in the hole for this, using these"

> https://www.youtube.com/watch?v=ry55--J4_VQ





Software engineering

The discipline of building big, complex systems

- › Applies methodologies from the engineering world, to software development process
- › The only way of dealing with complex software systems and teams
- › A systematic approach to design, development, testing, deploy and maintenance (IEEE 1990)



...don't worry... ☺

- › This won't make of you an engineer
- › It will help you engineering software



Think today, for tomorrow

Engineering:

- › Have a strong focus on the process
- › Treat everything as “a resource”, either physical (a brick for a wall, a chip for a server farm) or non-physical (software artifacts, licenses, etc)
- › In years, they (..we... 😊) developed an common methodology for multiple application areas

Software, on the contrary, is (correctly) treated as a non-physical entity, “a product of the mind”

- › During the development, you care less of physical assets (mostly, computers, desks...)
- › *“Sul mio computer funziona”*
- › When you design SW, you care more of people and their skills

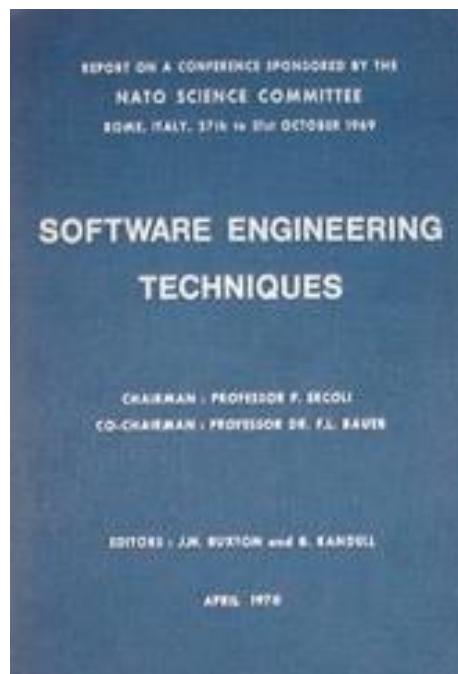
Adapt this for future complex SW!

- › Future systems will be distributed CPSs, made with different computers (high-performance, energy efficient, ect..) with tight(est) interaction with the world
- › Will be large-scale 24/7 distributed systems, updated over-the-air
- › Designed today, thought for tomorrow (e.g., Software-Defined Vehicles)

A bit of history...

SW engineering was born in 1968, at the NATO conference, focusing on

- › software crisis
- › software reuse
- › software engineering





In the nineties...

- › ...the era of object oriented programming
- › Design tools (UML), and patterns





In the last decade(s)

Internet-of-Things

- › Large scale cloud projects
- › Ubiquity, pervasiveness, CPSs
- › Massively parallel computers (GPGPUs)

The era of machine learning

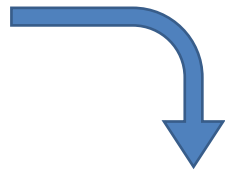
- › How can you structure a probabilistic-based SW component?
- › Design of the training process
- › Data engineering!



Example - The Waterfall model

(aka: where do we all come from)

Analysis of the
requirements and
spec, identifying
KPIs



System design



Development
and unit testing



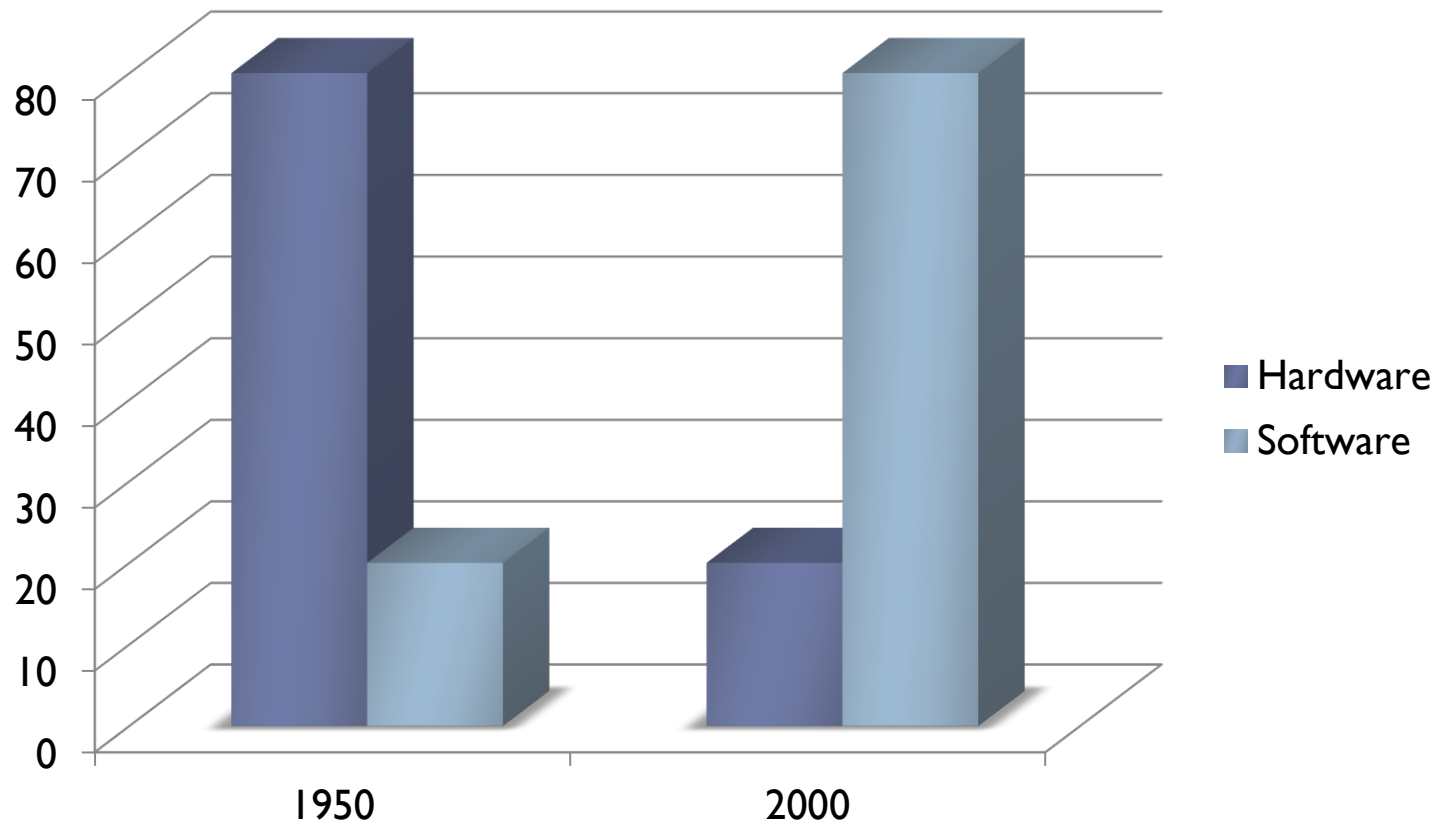
Integration
and system-
wide testing



Delivery and
maintenance



Costs: HW vs SW





Who is our customer?

For whom it is developed?

- › (This includes also open source, and free software)
- › We will generically speak of *customer*, without loss of generality

Custom solutions, tailored for specific customer, or customer segment

- › Time-to-market agreed with the customer
- › Internal R&D projects (e.g., iotty, Hipert “Fire”)
- › Market-wide products (E.g., MS Windows)

General-purpose software, released for the masses

- › For research (e.g., our F1tenth stack, tkDNN)
- › Business models based on open-source (Home Assistant, GNU/Linux, Erika..)



Quality of software, and process

Of product / extrinsics / external

- › Refers to the functionality, it's the main quality against which software is assessed!
- › By the customer / segment / community / domain
- › Has directly reflect on cost pricing
- Assessed by **functional requirements**

Of process / intrinsics / internal

- › Refer to the process, i.e., how the software is developed
- › Relates mainly to the specific domain, or company/team (hence, even more important!)
- › Hard to map onto product pricing
- Reflects into **non-functional requirements**



Assessing the quality / functional properties

Correctness

- › *Does my software do what I want it to do?"*
- › The easy part: captured by functional requirements, which are directly negotiated with the customer

Ease-of-use

- › Involves UX, documentation...

Performance/efficiency

- › *"Is it fast?"*
- › What do "fast" mean? FPS? E2E latency? On which computer?
- › How many resources does it need (e..g, power/Watts? Enery/Joule?, physical space)?

Dependability

- › *"Can I rely on it?"*
- › Definition applies to specific fields...



On dependability

"a measure of a system's availability, reliability, maintainability, and in some cases, other characteristics such as durability, safety and security. In real-time computing, dependability is the ability to provide services that can be trusted within a time-period. The service guarantees must hold even when the system is subject to attacks or natural failures."

Specific of application domains (can overlap!!!)

- › Real-Time systems
- › Embedded systems
- › Exascale systems
- › ...

The IFIP working group identified three main elements

- › **Attributes**, i.e., Key Performance Indicators (KPIs) to assess the dependability
- › **Threats** to dependability
- › **Means** to increase dependability



Non-functional properties

A system is

- › **Verifiable** if we can assess its characteristics (what about ML?)
- › **Maintainable**, if we can easily modify it (docs are in order??)
- › **Reusable**, if it's well packed for deployment (docker?)
- › **Portable**, if we get the same functionality on different HW/OS/.... (and also performance!!!! – see GPGPUs)
- › **Interoperable**, if it's open for interaction with other systems...
- › ...



Basic design principles ~~of software engineering~~



Our friends

- › Strictness, formalism
- › Separation of concern
- › Modularity
- › Right level of abstraction
- › Resilency / robustness

SW best practices (we'll see them later)

- › Design patterns (architectural, coding)
- › SOLID principles
- ~~Tools and methodologies~~ Methodologies and tools



Strictness, formalism

Still, we are artists! Software is a piece of art!

- › GPL licenses apply also to books, paintings...

But...we need to systematize the process

- › Typically, we borrow from mathematics / logics / engineering 😊
- › ...to create well-known schemes...
- › ...and leave the artist programmer the freedom to improvise within them

(Like a painter with a frame)



Separation of concern

Divide-et-impera

- › Split the problem onto subproblems

..but, which problem?

- › Lifecycle (Waterfall vs. Agile/Scrum)
- › System architecture (e.g., Microservices)
- › Internal system architecture MVC – MVVM
- › Testing and deployment (CI/CD)



Modularity

Comes directly from the separation of concern principle, affects system design

Two main approaches

Top-down

- › Where we have a complete view of the project, and we split it into components
- › When we typically start from scratch

Bottom-up

- › where we first develop the components, and then integrate them
 - › A typical scenario is when we need to re-use existing modules



Abstraction

Example: how shall we model a user?

- › In a gym club: name, age, weight, height, gender, email
- › In the City Servers: name, age, address, CF, phone nr
- › In a smart city roundabout: Lat, Long, velocity, class (car, bike, pedestrian)



What about costs?

Software costs outperform all other “structural” costs

- › Licensing for libraries
- › Fees for platforms (who has in-house servers anymore??)
- › Electricity/heating/cooling

Maintenance is the main component

- › A bad design is costly on the long term (see Apple's)

Personnel costs

- › Developers (80%)
- › Support/aftermarket

Other costs

- › HR, generic costs (chairs, laptops..)





Maintenance

The need for modifying the system after it has been deployed

- › Bugfixing (typically for free in 12-24 months) – Functional testing with customer is really important to mitigate this – 20%
- › Performance improvement – 60%
- › Changes in the operational domain (e.g., new version of libraries, OS, hardware) – 20%

But most of all..

- › Customer **never** knows what they want
- › ...l'appetito vien mangiando ☺ - customer might ask modifications, even paying them in advance!

Often, more than 50% of the overall costs!

- › 75% (Hewlett-Packard)
- › 70% (US Defense)



Main issues with SW, today

Aka: “the generational debt”

- › Old, legacy systems, developed with obsolete technologies, which cannot be replaced due to bad engineering practices
- › The “Comune di XXX” example
- › “Big bang” migrations/updates vs (take longer) step-by-step migrations

Systems are increasingly complex and heterogeneous

- › The rise of micro-services architectural pattern

Time-to-Market

- › Rush, rush rush!
- › Tackled with agile methodologies



Professionalism, and ethics

Sw developers shall always keep an ethic and professional conduct of work

- › What does "ethic" mean?
- › E.g., Hipert srl doesn't, and will never do, produce weapons

Confidentiality

- › Often, you need to sign an NDA – Non disclosure agreement, before working
- › After resigning a contract, some pros might not be hired by other competitor companies for 1-2 years!!!
- › Example: Maserati SpA

Intellectual Property and licensing

- › How much do you know about licenses/patents?



Structuring ethics

- › Personal ethics
- › Company rules (see Hipert)
- › Professional
 - see “Ordine degli ingegneri”
 - Association for Computer Machinery (ACM) ed Institute of Electrical and Electronics Engineers (IEEE) - <http://www.acm.org/about/se-code>



Structuring the process



Modeling the process

We need to structure the entire development flow

There are multiple chances, depending on

- › Type of technologies - *Might fit or not fit a methodology*
- › The time we have for producing it - *Agile vs. more "traditional" methodologies*
- › Legacy codebase - *Migrating/updating, or re-implement from scratch?*
- › Company processes - *Use the right tool for the right processes*
- › Standard processes for specific domains – *The V process in automotive*



A typical pattern

1. Specs
2. Design
3. Implement (SW and HW)
4. Integration
5. Test
6. Deploy
7. Maintenance/Aftermarket (AM)

Methodologies mainly differ in

- › *How much time we dedicate in every phase?*
- › *How early do we want to test/integrate?*
- › *Shall we iterate on the main process? Or provide sub-processes?*
- › *How early/late do we involve the customer? (e.g. graphic interfaces L&F)*
- › *Do we need to standardize?*
- › *Do we have legacy codebase/constraints on the tech to use?*



Typical choices / mistakes

1. Specs
 2. Design
 3. Implement (SW and HW)
 4. Integration
 5. Test
 6. Deploy
 7. Maintenance/Aftermarket (AM)
- MISTAKE:** mixing them
- BEST PRACTICE:** tight overlapping
- MISTAKE:** underestimating documentation
- BEST PRACTICE:** can automate this!!!
- MISTAKE:** underestimate its cost



1) Requirements and specifications

Involve the commitments, and flood them with questions

- › On what the system should do (functional) / how it interacts with user (non-functional)
- › On the environment / ecosystem (hardware vs. software)
- › Any legacy codebase? Any legacy process? Any legacy vendor?
- › Try to imagine possible issues (for maintenance) and possible future steps (for aftermarket)

Yearly expertise on this / on specific application domains help

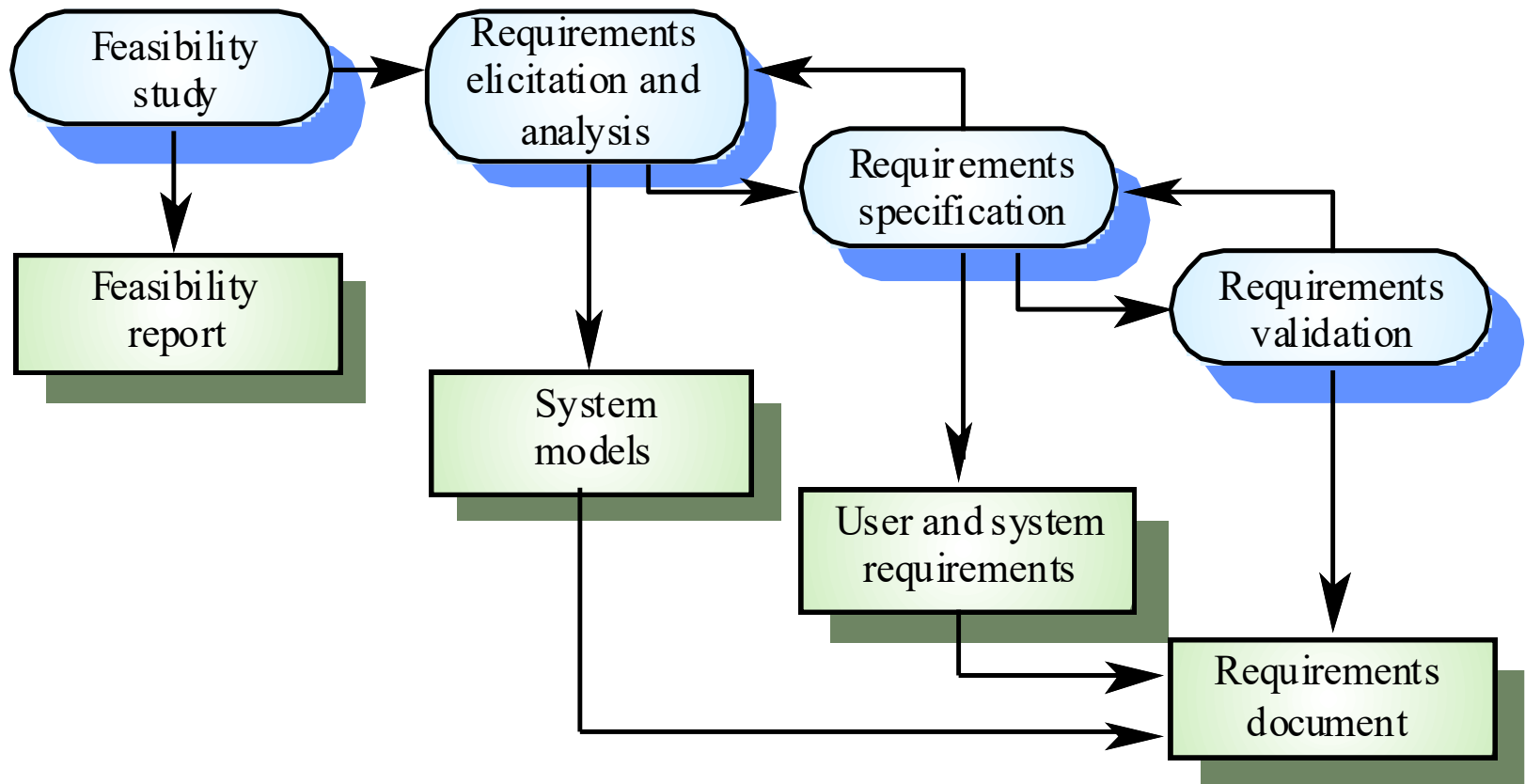
- › Often, specific non-dev people: *Business analysts, Performance engineers, Requirements engineers*

The output: a (set of) document(s) that clearly cover all of these topics

- › Identifying measurable identifiers (KPIs) to assess whether the system is working properly
- › Directly affects testing phase!!!
- › This is what defines the value for our customer



Reqs and specs – cont'd





Wait another minute...

An agreement shall be signed with our customer

- › The, we set up / deal the price of our service / sw
- › Clearly state what we will do and don't
- › ...also what the customer shall do
- › E.g., who's in charge of maintaining the server infrastructure? Who's paying the possible licenses (yearly)?

At this stage, the customer will still be nice, and lovely...

- › ...but they will start to get anxious, because they want the product done

DON'T RUSH! (yet, try to be as fast as possible)

- › Remember, we're in Italy: 95% of companies are PMI/SMEs, and Project Manager have limited expertise/culture of sw design
- › They think that *"They have a friend that might also do that"*

This phase is the most important!!! Here, you are making promises!

- › Typical scenario: in 6-12 months the customer says: *"Well, the system doesn't work, unless you also do this, this, and also this. If the system doesn't work, of course I won't pay you"*



2) System design

Let's sketch a working system

- › How quick do we want a working prototype?
- › Are we starting from legacy code, or from scratch?
- › Shall we also design functional tests, from KPIs?

At this point you must take some decisions

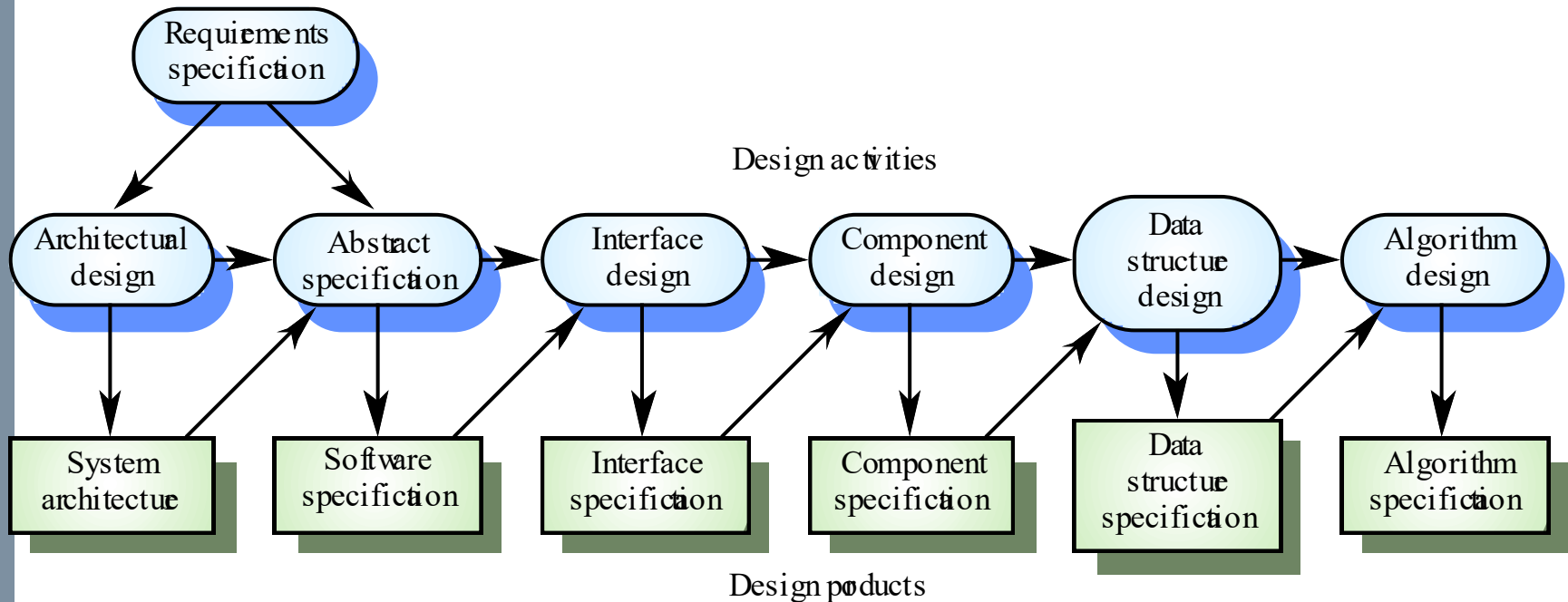
- › Architectural design
- › Choose the most appropriate language(s), framework(s)
- › Choose the hardware
- › Plan the integration / define protocols and comm infrastructure

What about the team?

- › Which tools shall we use? Which methodology?
- › Git (of course..?), Agile, Waterfall?

2) System design

- › A typical high-level design





2) System design

At this point, we can start drawing how our system is actually made, not only what it does

- › And the technology it uses

There are several tools / graphical models

- › Unified Modeling Language / UML (a family of models)
 - For describing the behavior, and the way classes are done in OOP
- › Data-Flow Diagrams / DFD
 - If data representation is our main concern
 - Pipeline-like architectures if we cannot store data / have too many data
- › Entity-Relation (E-R) diagrams
 - Streamlines the development of DB models, and the main operations
 - E.g., Relational DBs are good



3) Implementation

After a good (even sub-optimal) design phase, implementation is streamlined!

Most of the applications we design today follow a very well-known paradigm

1. We need to store some data – aka: “CRUD”
 - Create, Read, Update, Delete
 - See HTTP(s) verbs
2. Process it somehow
3. And make it available to customers via an interface
 - Web? UX? REST service?

This means there are tons of tools and frameworks, to do so!

- › In theory, no need to re-invent the wheel...
- › ...unless the customer wants so



4) Integration

The process of re-uniting the different parts of our software

- › Call them component/modules/services/etc...depending on your actual architecture
- › Streamlined by the *divide-et-impera* principles
- › Following adequate architectural patterns during the design phase enables us using specific tools and methodologies

Example:

1. Reqs & Specs (summarized)

- we need a web server, with a lot of Eps, and possibly making it work with other existing services
- there are licenses for MS azure and AWS we can exploit
- a lot of read/write in our business flow, but we might not modify the data

2. Design

- we follow the micro-services arch pattern
- will deploy on Azure FAAS and AWS Lambdas, hence use c#/dotNet and Python
- MongoDB (or in general, no-SQL) are our man



4) Integration (cont'd)

From Design phase

- › We decided use dotNet to build the system, we can quite easily streamling testing, CI and CD

As a consequence:

- › Integration can happen using MS tools and methodologies
- › We can test it using the in-house testing framework
- › CI/CD is integrated both in VS, but also in Vscode, but also in github, or devOps



5) Testing & validation

Verify that we meet the specifications and requirements

- › Both functional, and not functional
- › It is based on the concept of test cases / scenarios
- › At different abstraction levels

Examples

- › “I can store and modify information on user accounts” – high level, less details
- › *“I can store the birth date, but only if it's > 1800 and $< today$ ”* – lower level, more details
- › *“If I insert Feb 30th as birth date, I get an error”* – lower level, specify a constraint on a number



5) Different levels of testing

"Testing can find errors in your code, but they cannot prove its correctness" (E. Dijkstra)

How do we proceed?

- › We need to isolate a number (high number) of test cases that streamline directly by the functional specifications, which enable us to have the customer saying "Yes, it's working properly"

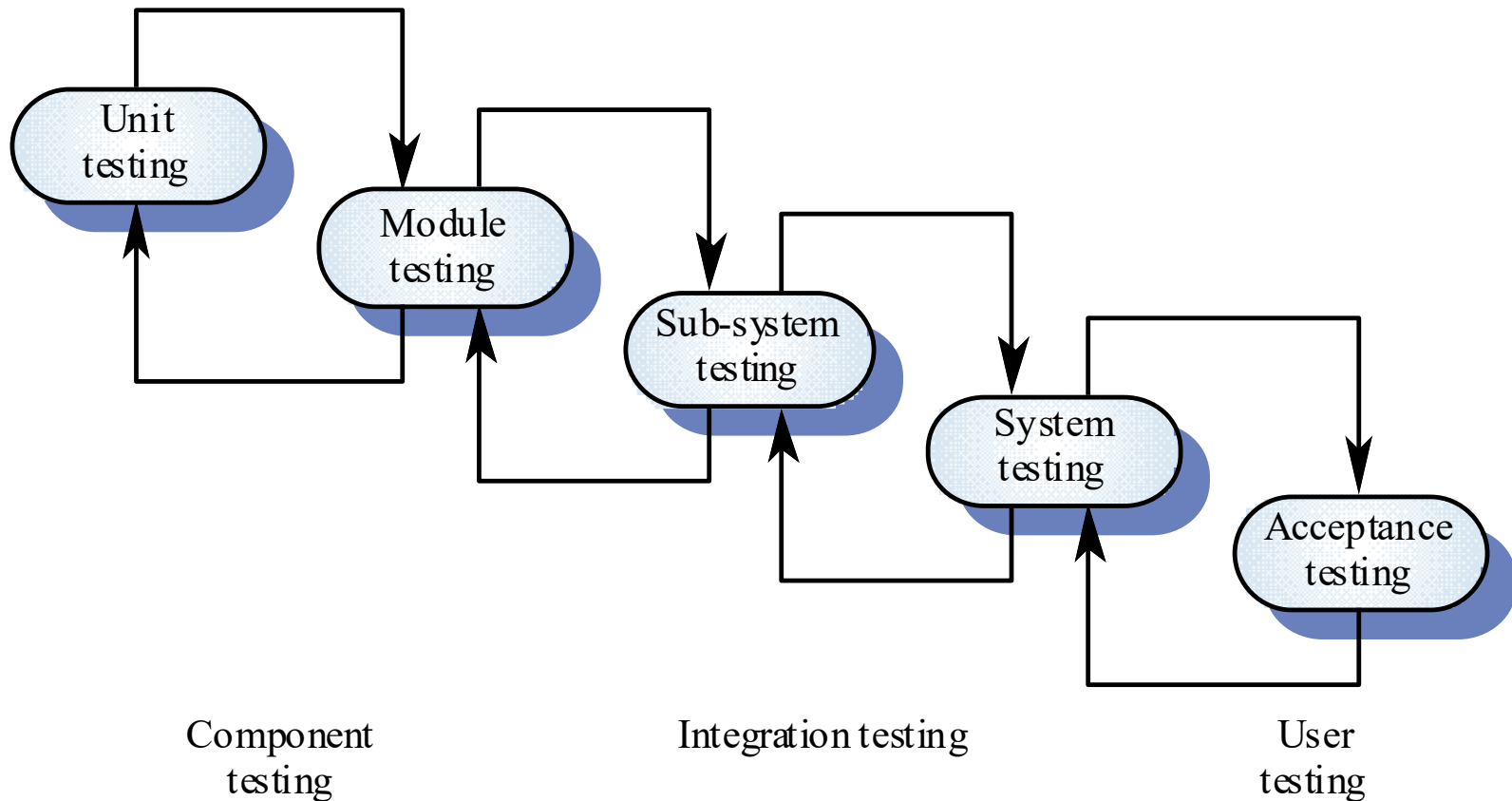
This is called **testing in the large**

- › Then, we isolate smaller test-cases for specific components, or blocks of components, to assess that they do the functionality that they are supposed to do
 - E.g., store a number (age) in a DB depending on the FK (Codice Fiscale?)
 - Directly streamline by the system partitioning (*divide-et-impera*) in the system design phase

This is called **testing in the small**



5) Testing & validation – how it was





5) From the small to the large

Unit testing

- › Testing a single component (es: a class) in isolation
- › Es: store in my age in a table in a DB, calc the area of a rectangle

SMALL

Module testing

- › Testing more components that constitute a “functional block”
- › Es: store my age in a table, and log this action, in another table (*transactional*)

Integration testing

- › Test that different components can work together
- › Webservice can work with DB, for instance (see next slide for an example)

LARGE

Functional testing / user acceptance testing

- › Involve the customer / end user – always remember, this is what **gives value** to your SW, and, ultimately, to you!
- › It is also the boring part...
- › Match what's written in the requirements document



5) Testing in the small

- › Check single code portions / functionalities, inside a single module/component

In OOP, we partition code within classes and functions

- › So, this typically boils down to testing single functions, then single classes

Unit testing

- › ..or aggregations of classes (which indeed are other classes)

Module testing

We shall test every single line of code – **coverage test**

- › We can test private functions – get deep inside the class – **white-box testing**, or we can “use” the class – **black-box testing**
- › We shall test branches and conditions – **branch and condition tests**
- › Of course, the #test easily explodes, so we might omit some test, or even understand that some lines of code are unnecessary!!!!



5) In the small – Detect unnecessary code

Example: we null-check for a parameter in a ctor that is only called in a single point of the application!

- › If this class were released into a library, we need to re-add the check – *why?*

homeassistant/components/iotty/switch.py Outdated Hide resolved

Comment on lines 96 to 98

```
96 + if iotty is None:
97 +     _LOGGER.error("Cannot retrieve iotty MW component")
98 +     raise ValueError("iotty")
```

edenhaus on Jan 5 Contributor

Suggested change

```
- if iotty is None:
-     _LOGGER.error("Cannot retrieve iotty MW component")
-     raise ValueError("iotty")
```

Commit suggestion Add suggestion to batch

Can never happen as you set it in the init file

pburgio on Jan 18 Author

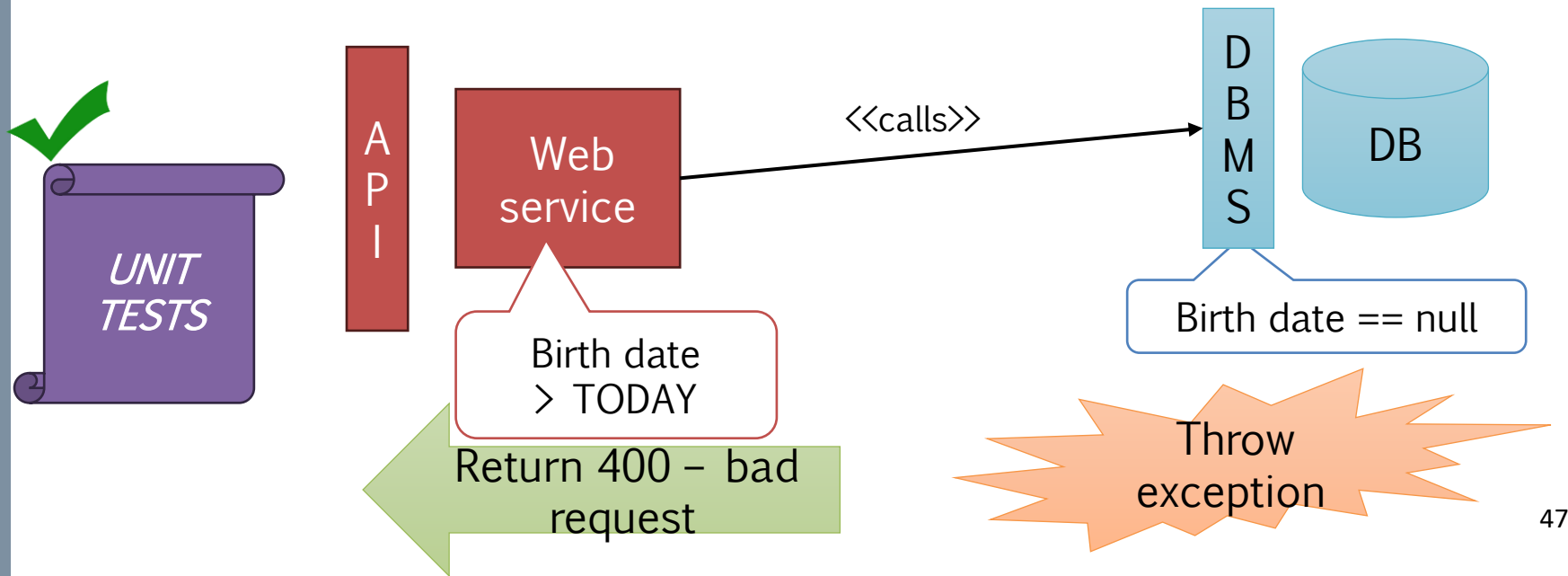
Ack



5) Integration test - example

Often, people are confused, as the multiple definitions can be misleading

- › Example
- › We want to store our age in a DB, and we have a Web service; the birth date 1) cannot be *> today*, nor 2) it cannot be null
- › Design: check 1) performed by the Web frontend, check 2) performed by the DB
- › They both do their work, in isolation (i.e., they throw an exception, or raise some error)

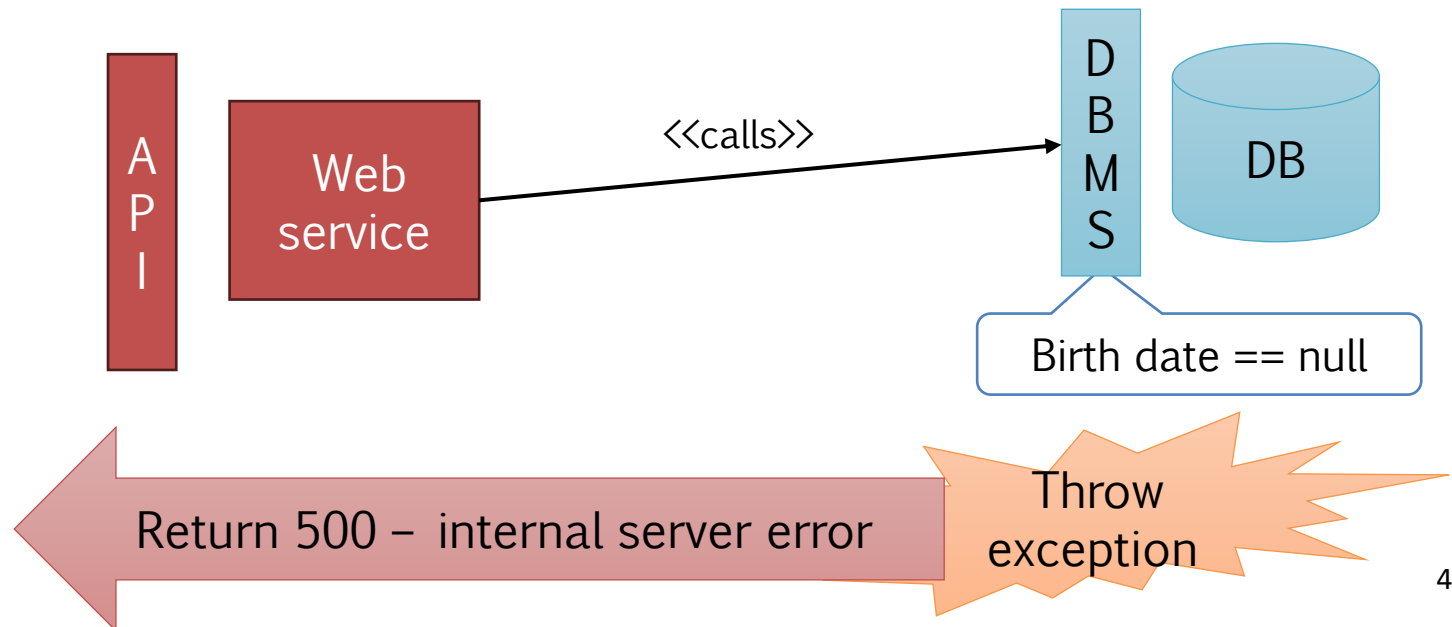




5) Integration test - example

When we glue them together, they might not work properly

- › Typically, a web service **never** returns 5** family errors! Use 4** instead!
- › We need to test the behavior of WS when DBMS throws an exception

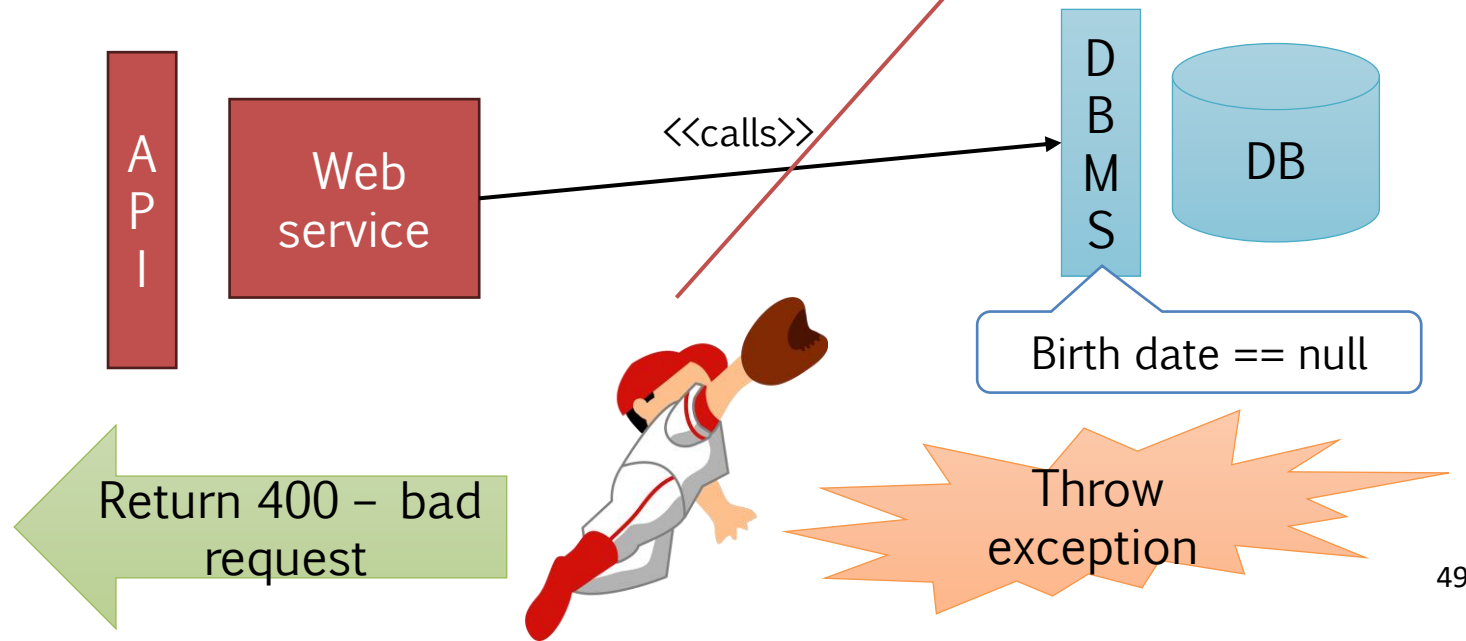




5) Integration test - example

Solution: simply use **try-catch**

```
try
{
    db.save(cf, <ANY>);
}
catch (NullValueException ex)
{
    return Web400Result(
        ex.Msg + " cannot be null");
}
```



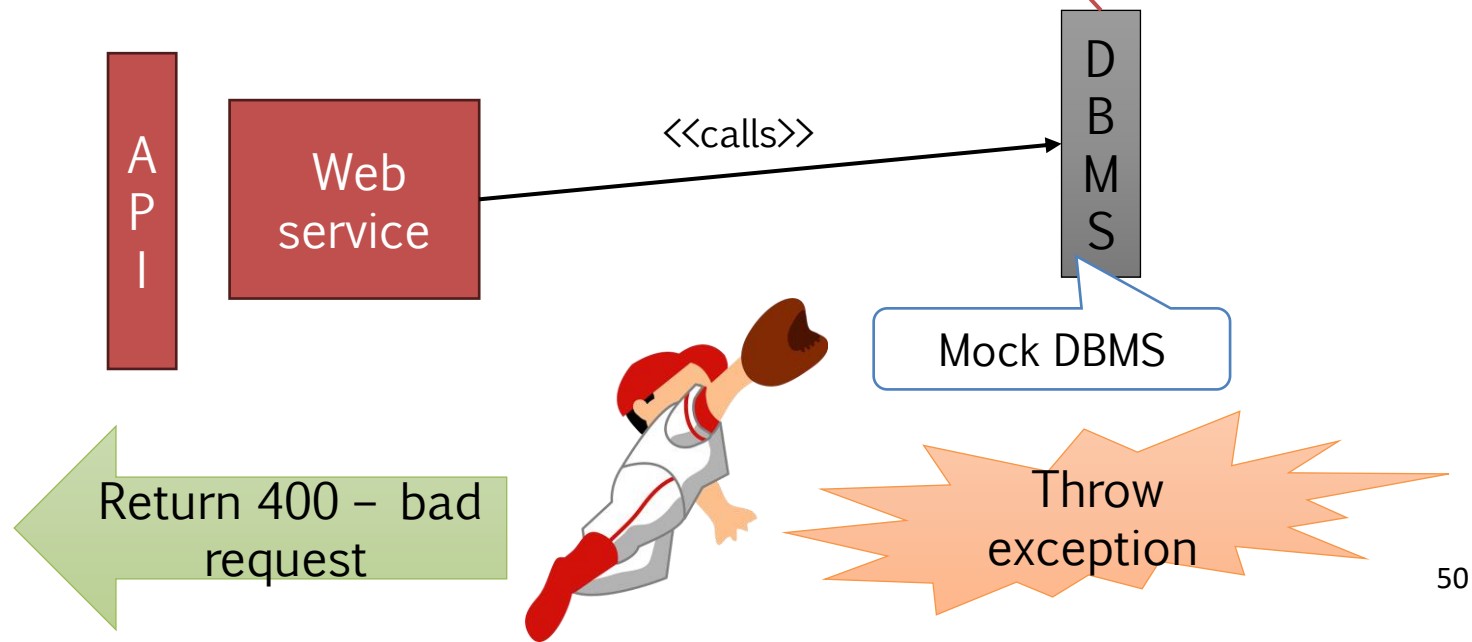


5) Mocking tests

Problem: do we really need a DB to test this?

- › This means, potentially, having the whole system in place for tests
- › Of course not, we can **mock** the DBMS with a fake one

```
void save(int key, int age)
{
    throw new NullPointerException("age");
}
```



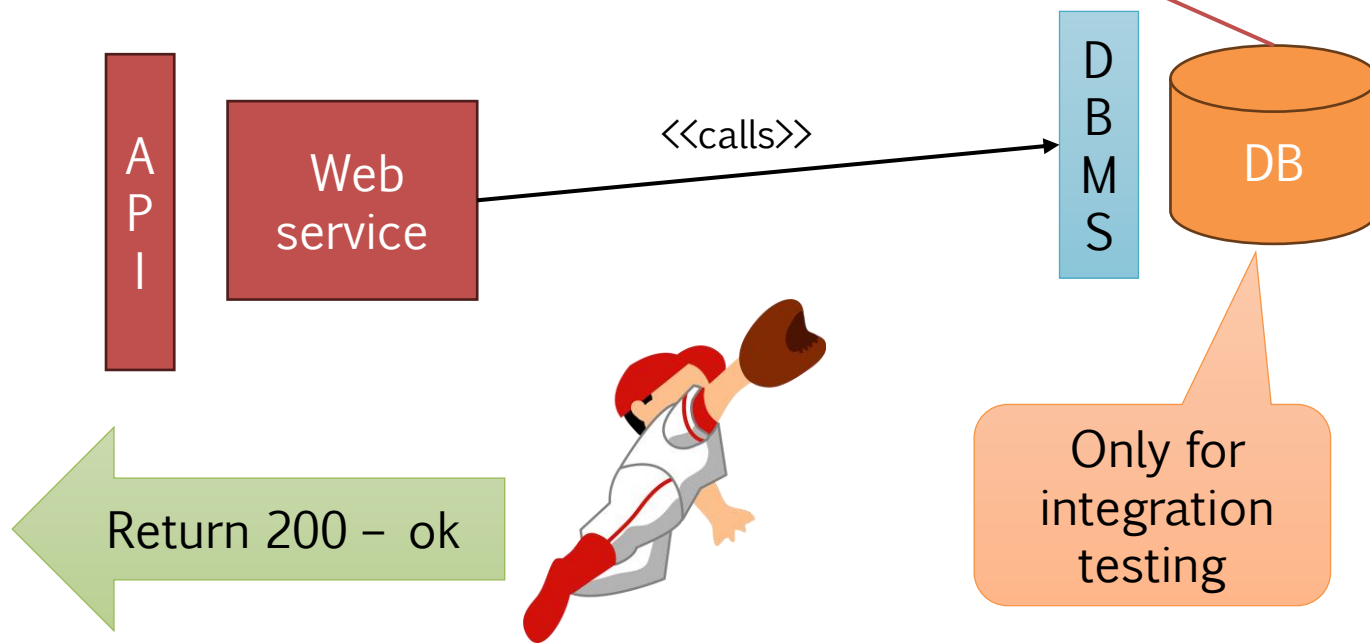


5) Mocking tests

Problem: do we really need a DB to test this?

- › We can also mock an **in memory** DB, with no storage
- › Of course, data is in RAM, hence won't persist

```
Dictionary<int, int> _ages = ...;  
  
void save(int key, int age)  
{  
    this._ages.update(key, age);  
}
```





5) "A manazza"

Code walk-through

- › Run the code with random patterns, to detect problems that we might not have caught in previous phases
- › Limited set of persons: not who develop
- › Few hours

Code inspection

- › More structured
- › Search for well-known problems
 - Non-initialized vars
 - Infinite loops
 - Memory leaks/issues



6) Deploy

Continuous Integration / Continuous Delivery – CI/CD

- › Again, using well-known methodologies and tools that streamline from the framework we want to use
- › Often, integrated with the testing phase
- › “Click, and the framework does everything” – *PARADISE*

Not always the case...

- › Often, projects are smaller and does not require the complexity of a full-fledged framework
- › We might even want to deploy our system on-premise (i.e., on our server room) – like we do @ Hipert Lab
- › These steps can anyhow be automated “simply” at the “repository level”, using GitHub



7) AM / maintenance

The process of modifying/extending the software after the first release, which we agreed with customer

- › Debug is always included, for 6/12/24 months (depending on the contract)
- › You might even agree with the customer to “sell” Man-Month for working on / directly a perk of functionalities – often to be agreed later
- › We will not cover this, as it is really customer/project specific

I can only give you some hints / golden rules

1. Customer **never** know what they want, often neither in the design phase
2. “L'appetito vien mangiando” (for them) – make them hungry! Show the full **potential** of your SW!!
3. This is **not** about your software, this is about **customer mindset!**

Try to enter their mind, speak with them as much as you can, collect as many information on them as you can!



References



Course website

- › <http://hipert.unimore.it/people/paolob/pub/ProgSW/index.html>

Book

- › I. Sommerville, "Introduzione all ingegneria del software moderna", Pearson
- › Chapter 9 for testing

My contacts

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