

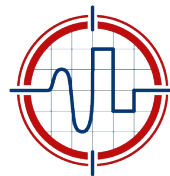
# Programming for today's physicist and engineers

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D. Rabady, CERN

ISOTDAQ 2022: 12<sup>th</sup> International School of Trigger and Data Acquisition

University of Catania, Catania, 22 June 2022



**ISOTDAQ**

International School of Trigger  
and Data Acquisition



# Opening words

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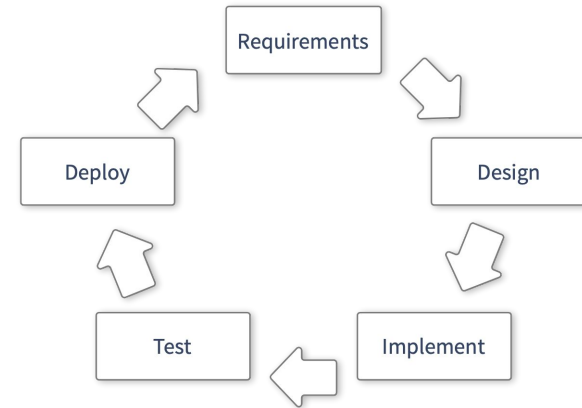
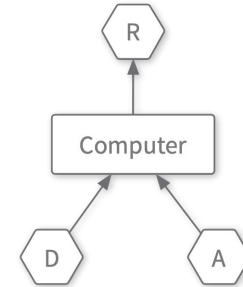
**Disclaimer:** This is more a collection of pointers\* than a tutorial, it's a starting point...  
(Almost) no code but a bias towards C++ and Python

**Note:** While the lecture focus is software, most of the content equally applies to firmware programming.

**Acknowledgment:** Slides are based on previous lectures by Alessandro Thea, Joschka Poettgen (Lingemann) and Erkcan Ozcan

\*further reading and tips in  
these boxes

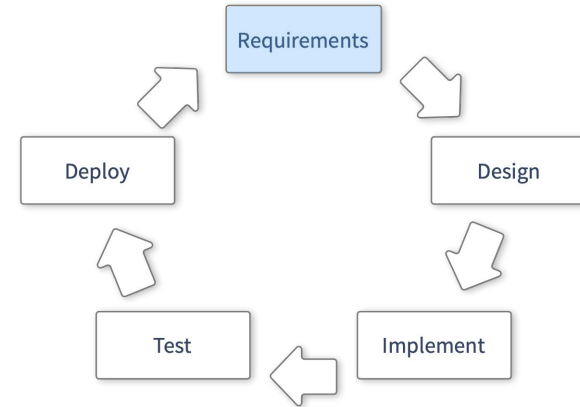
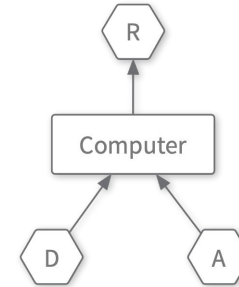
# What is programming?



[https://en.m.wikipedia.org/wiki/Systems\\_development\\_life\\_cycle](https://en.m.wikipedia.org/wiki/Systems_development_life_cycle)

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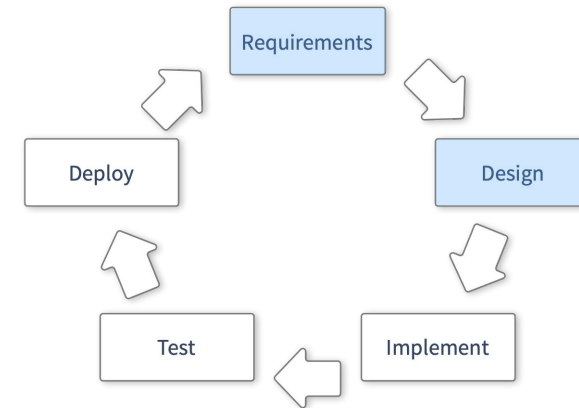
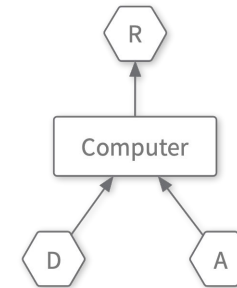
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  - Define the requirements for your software
  - Choose the language



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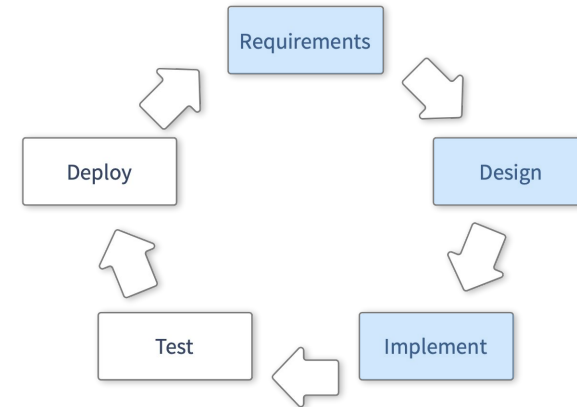
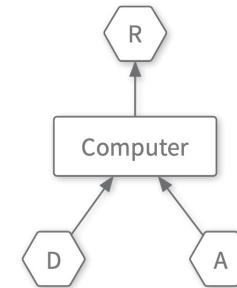
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  - Identify key functionalities and features



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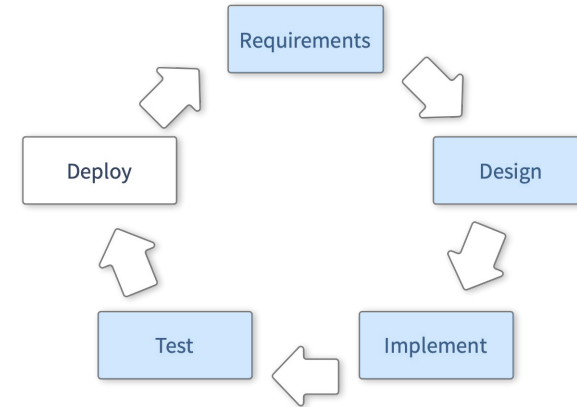
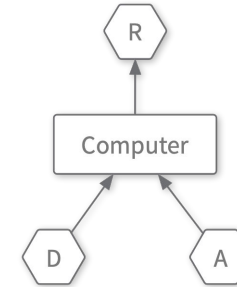
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  - Write code, debug it
  - Prepare documentation



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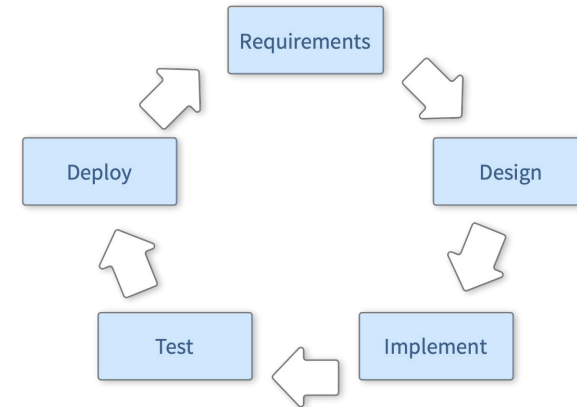
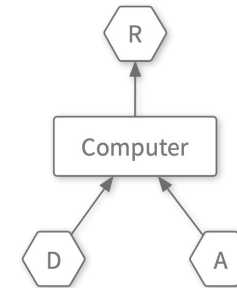
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- Validate the code
  - Perform thorough verification
  - Execute unit and system tests



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  - Execute unit and system tests
- Deliver the code
  - Collect feedback
  - Ensure portability to different platforms?
- Go back to square 1

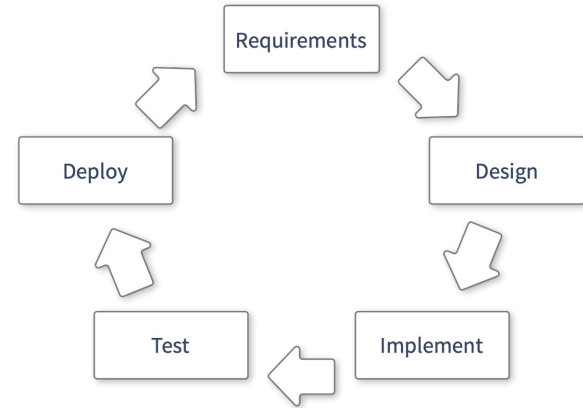


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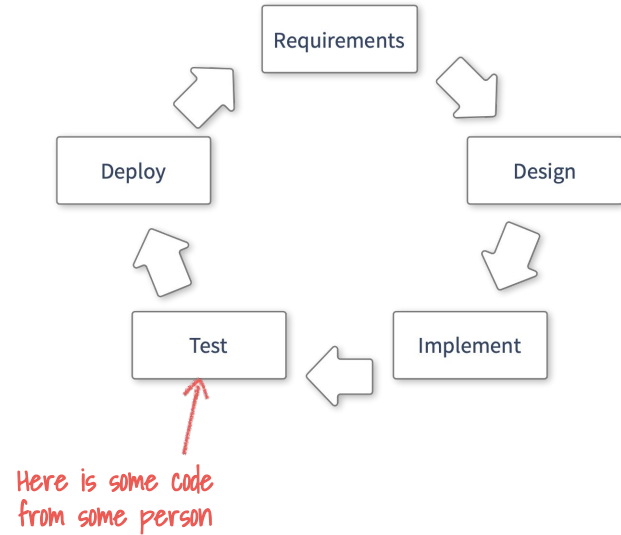
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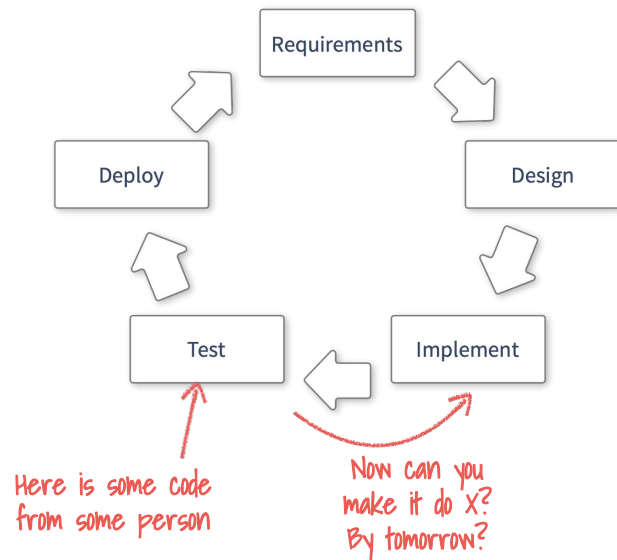
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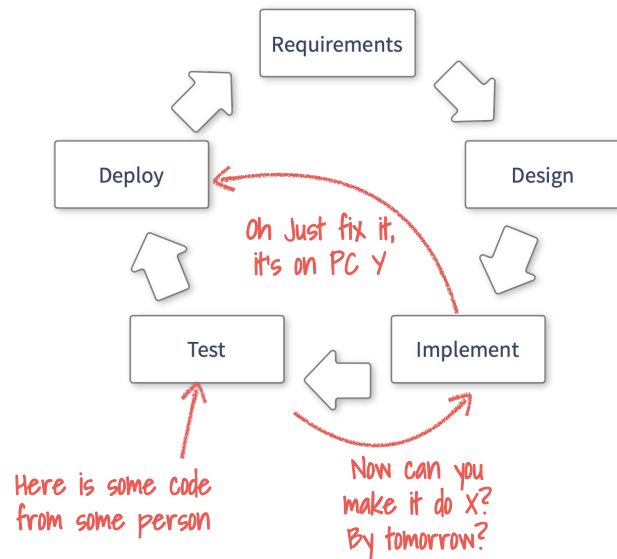
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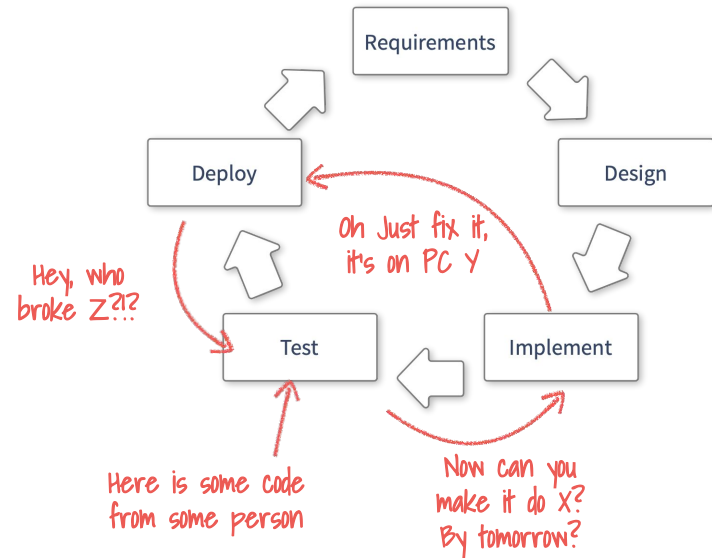
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  - Well, it's the only place where the code runs, isn't it?



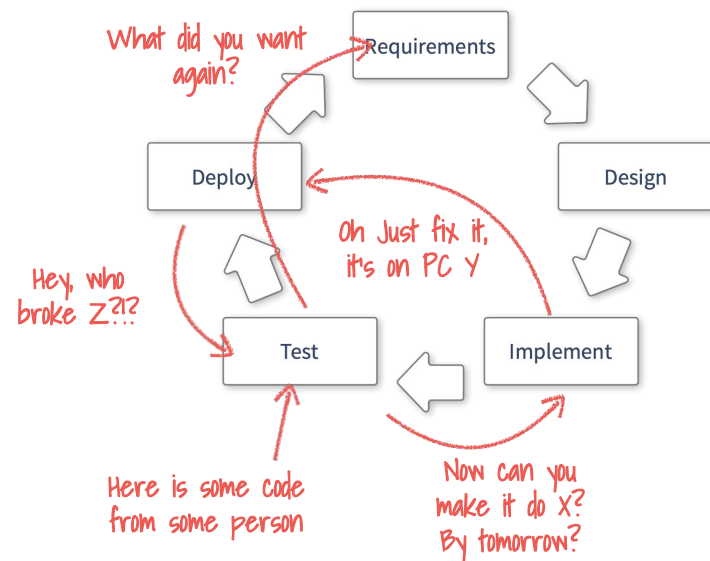
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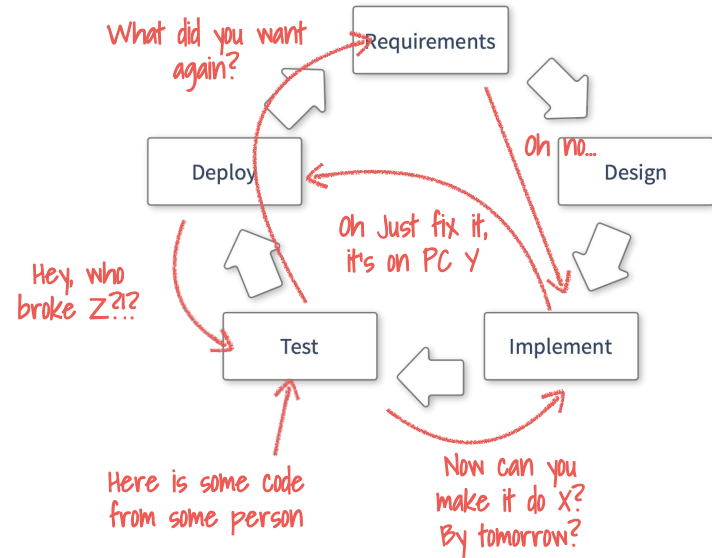
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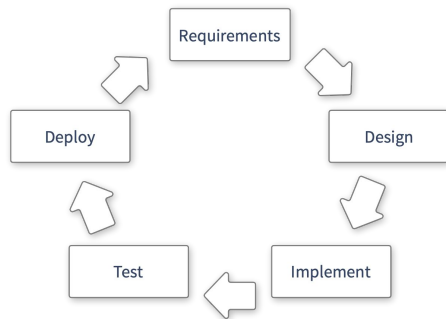
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- Just to finally realise you got it wrong in the first place...
  - And so on and so on...



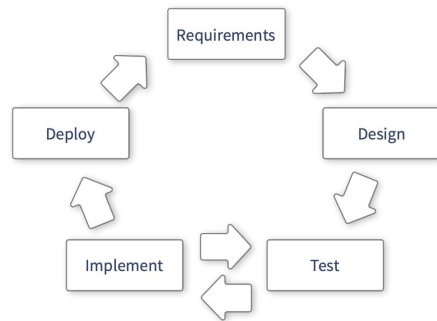
# But it doesn't have to be...

- General guidelines
  - Avoid duplication of work
  - Avoid feature bloating
  - Ensure code quality
  - Keep in mind: Software engineering relies heavily on communication!
    - Communication with the computer
    - Communication with your peers
- Many ways to do this right
  - Agile/waterfall project management
  - Extreme programming
    - Test driven development
    - Pair programming
  - ...
  - Some of these have ideas/techniques that are even useful in isolation

Iterative Development

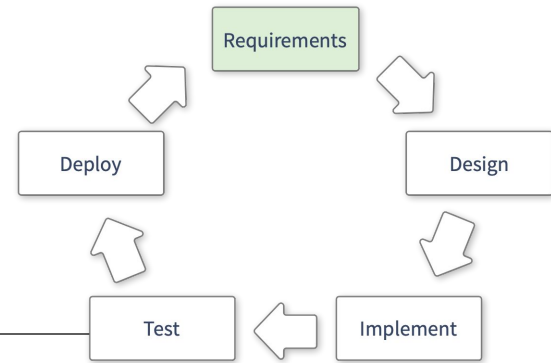


Test-Driven Development



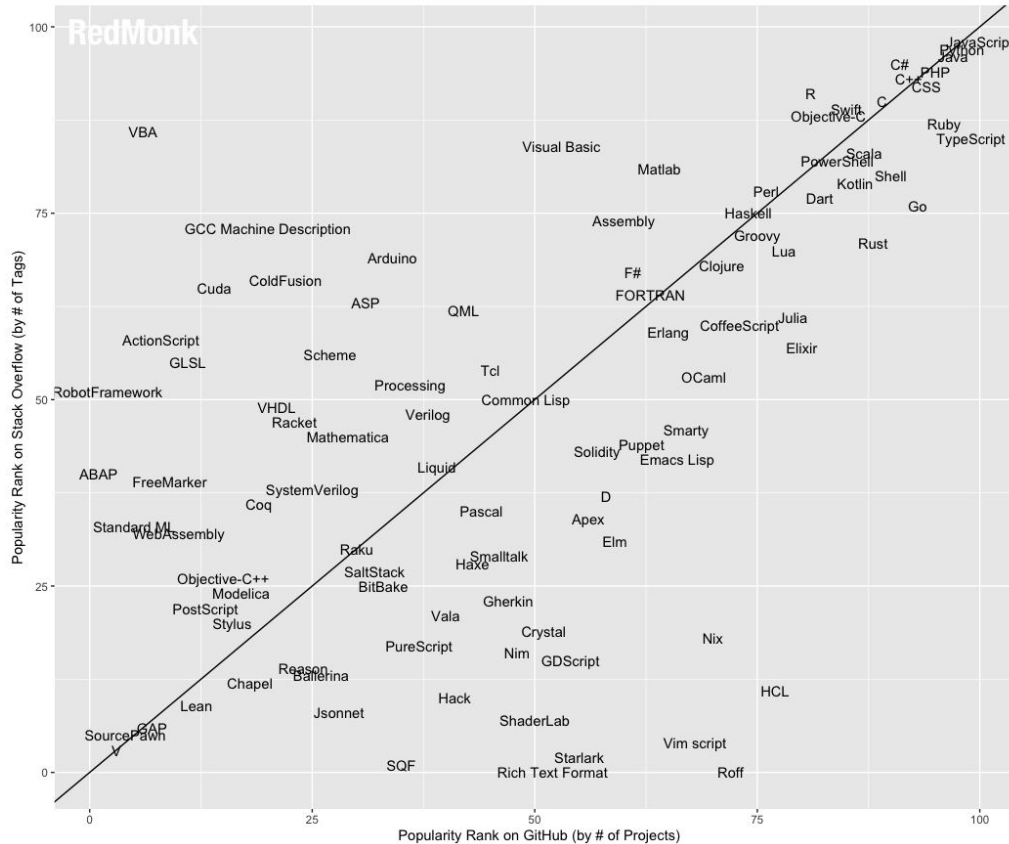


# Requirements



# Choosing the programming language

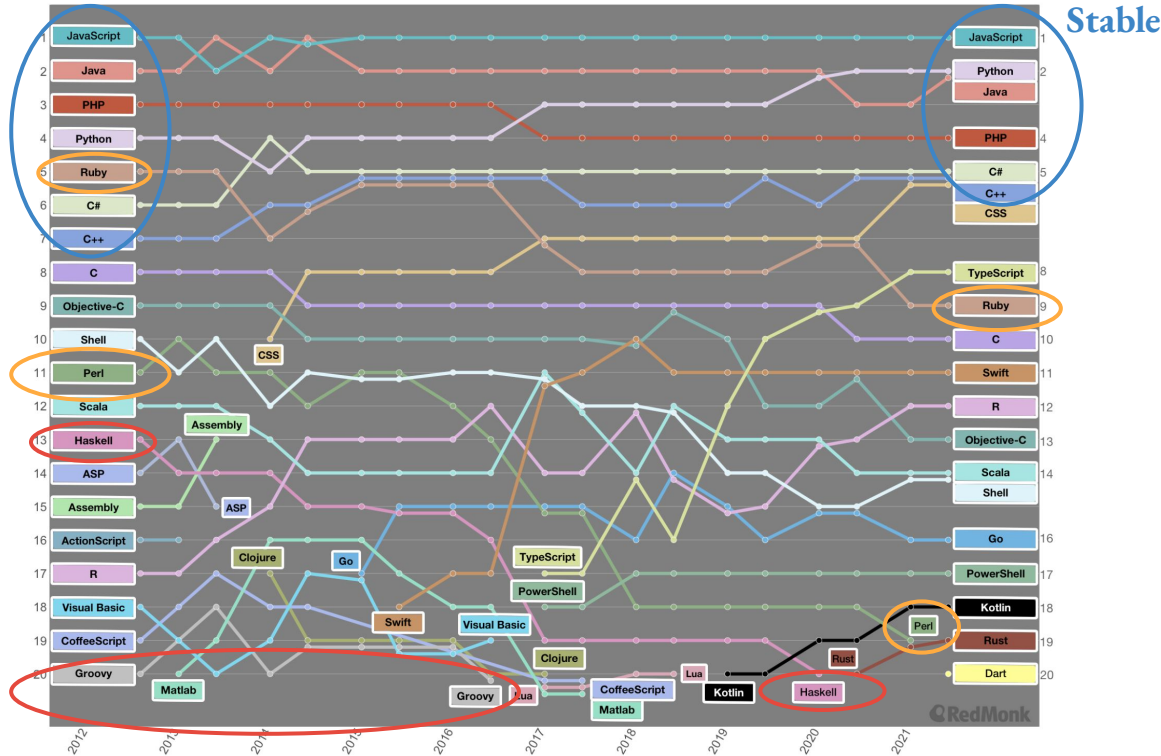
RedMonk Q122 Programming Language Rankings



# Choosing the programming language

## RedMonk Language Rankings

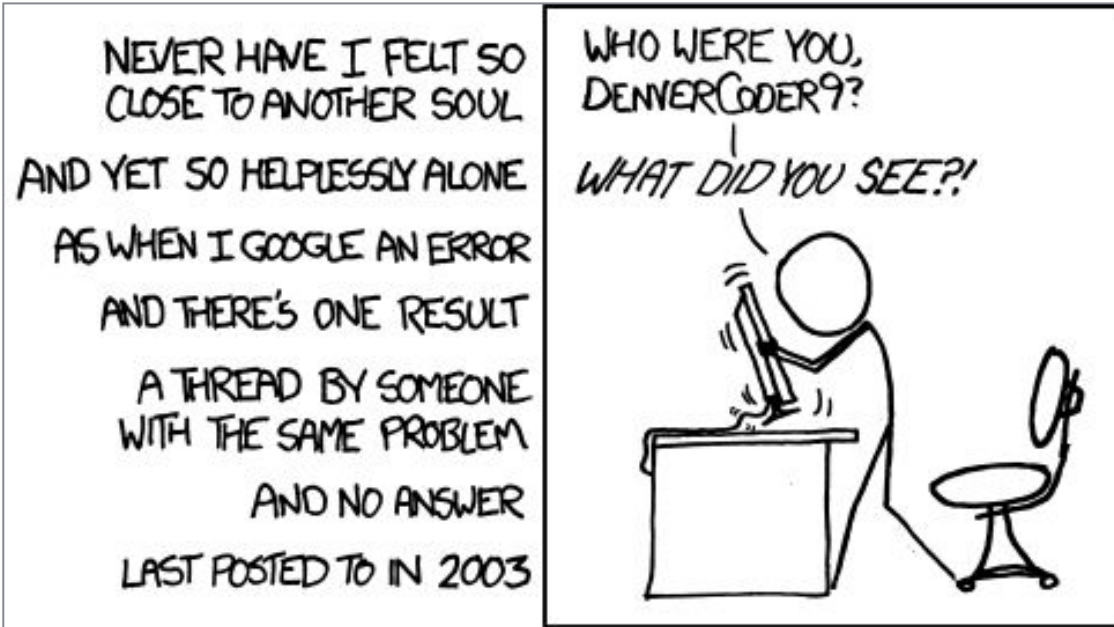
September 2012 - June 2021



## Things to consider:

- Problem domain
  - Analysis?
  - Physics?
- Popularity
  - The more people using the language the more questions already asked (and hopefully answered)
  - But it shouldn't be short lived...

# Choosing the programming language



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  - But it shouldn't be short lived...
- Documentation and support
  - Don't underestimate the utility of useful official docs

# Choosing the programming language

```
; g++ -std=c++17  
g++: error: unrecognized command line option '-std=c++17'
```

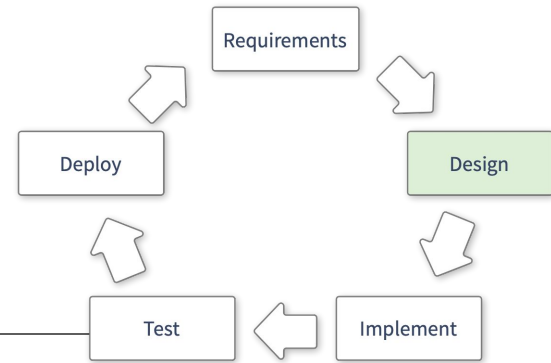
```
; python3.9  
zsh: command not found: python3.9
```

## Things to consider:

- Problem domain
  - Analysis?
  - Physics?
- Popularity
  - The more people using the language the more questions already asked (and hopefully answered)
  - But it shouldn't be short lived...
- Documentation and support
  - Don't underestimate the utility of useful official docs
- **Can you choose?**
  - **Existing expertise in group**
  - Language support at workplace
- ...

Do you really  
have to  
program?  
*Or has somebody already done it for you?*

# Design



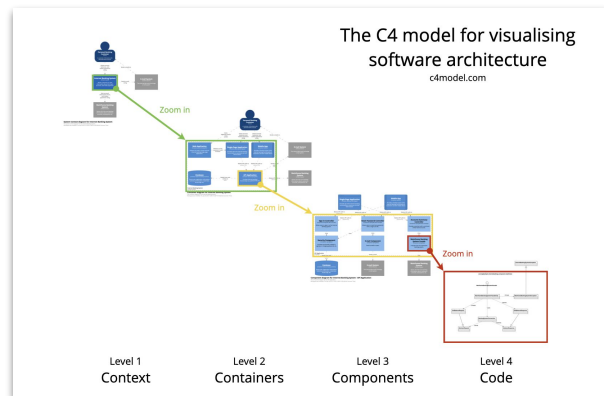
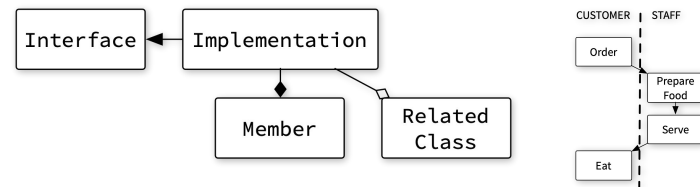
# Plan ahead

## Sketch out what you want to design

- Unified modeling language (**UML**) diagrams
  - Very powerful
    - Not very widespread nowadays, though...
  - Support for many types of diagrams
    - Structural, behaviour, interaction diagrams,...
- **C4 model**
  - Rather new arrival, but gaining popularity
  - Four levels of diagrams from "birds eye view" to "code level" diagram
    - UML used for lowest level code description

## Write your first ideas out in **pseudo-code**

- Don't need to think about scope, initialisation, etc.
- Allows you to quickly put your thoughts to paper
  - Can be useful e.g., for algorithm design, when you want to spend your brain cycles on the problem, not on the tools



```
function find_local_optimum()
    while solution is not locally optimal do
        find s with f(s) < f(solution)
    return s
```



# Things to keep in mind when designing

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## Goal

- Are you still building what was required?
- Are you adding unneeded features?

## Maintainability

- Is it easy to adapt to changed environment?
- Can you cope with (slightly) changed requirements?

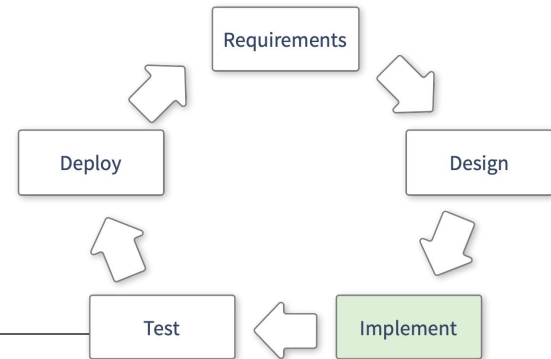
## Scalability

- Large data volumes
  - Think about data-flow and data layout
  - Try to avoid complicated data structures

## Re-usability

- Identify parts of the design that could be used elsewhere
- Could these be extracted in a dedicated library?

# Implementation



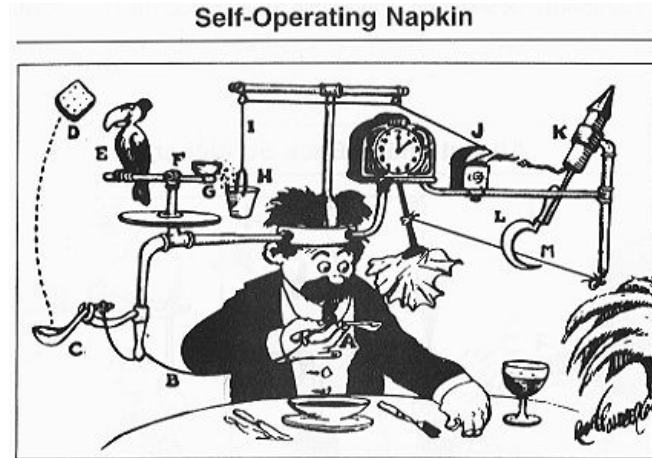
# Do not reinvent the wheel

## Look around for existing solutions

- Many problems have already been solved
- Look for libraries where:
  - Active community? Well maintained? Tested?
  - Rule of thumb: Last commit a few days ago, at most a year old
- Be wary of libraries with many features
  - Often come with lots of dependencies, increasing your attack surface, overall complexity, might slow down your code, ...
- Caveat: **Don't pull in external code for trivialities**
  - Almost no reason to use e.g., <https://pypi.org/project/isEven/>

## Getting to know new frameworks:

- Read the docs
  - Investing time in the beginning will pay off
- python packages: try the ipython "help"
- Start with a simple test
  - Modify existing examples to what you want to do
  - Does the code do what you expect?



"Prof. Lucifer Butts and his Self-Operating Napkin",  
by Rube Goldberg

Before searching for external libraries: Check out e.g., STL and Python standard library!

# When coding: Avoid feature bloat

**If you squeeze every conceivable feature in one place:**

- You'll probably end up doing nothing right
- Write specialised toolkits/libraries

**Define features by writing a test that needs to be passed**

- Only implement what is strictly needed to pass that test

**Be pragmatic**

- Generalising a problem before solving it:
  - Probably not a good idea
  - Only do it when you have a use case
- Keep everything as concise as possible (increased readability)
  - Introduce abstraction only when likely to be actually used
- **Keep it as simple as possible!**



# Tools of the Trade: Editor, Terminal and IDEs

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Whatever you do, you'll end up using (at least)

- Editor
  - Know\* at least one ubiquitous editor: [nano](#), [vi\(m\)](#), [emacs](#), etc.
  - More modern solutions: Can make your life a lot easier..
  - Depending on the language/platform (e.g., Java): IDEs are a better choice (Eclipse, Netbeans, etc.)
- Terminal
  - Learn about shortcuts (minimal set: [Tab](#), [Ctrl+r](#), [Ctrl+e](#), [Ctrl+a](#),... have a look\*\*)
  - Knowing about some basic command line-tools can come in handy

\*at least how to exit them :-)

\*\*<https://ostechnix.com/list-useful-bash-keyboard-shortcuts/>  
or <https://gist.github.com/tuxfight3r/60051ac67c5f0445efee>

# Some words on editors: Choose what suits you

The choice of editor is yours to make...

- Do you want
  - “a great operating system, lacking only a decent editor”
  - Or one with two modes: “beep constantly” and “break everything”\*
- **Both are versatile and learning them is worthwhile**



vs



However: **Modern alternatives have a less-steep learning-curve**

- Some are commercial (Sublime Text, TextMate,...)
- Some are (reasonably) open: e.g., Microsoft VSCode, Adobe Brackets,...
  - Plugins, git integration, active communities, more plugins...



Once you decided which one is best for you:

- Spend some time learning about features and keybindings
- Many things that might require dozens of keystrokes can be done with 2
- Learn about: Linters, version control system integrations, and other plugins

\*from [The Editor War](#)

# The terminal

**Initially: Clicking is faster than typing, no need for the terminal.**

After learning about some command line tools... probably not.

- What if you don't have a GUI?
- Searching files: `grep`, `find` — example:
  - `$ grep -R -A 3 "foo" *`
    - Displays all matches of “foo” (+3 lines below) in all files in the current directory and its subfolders
  - Can be extended to only search files with certain ending
    - `$ find . -name "*.cc" -exec grep -A 3 "foo" {} +`
- Once you learn some tools it becomes very versatile:
  - **sed, head, tail, sort... awk** (a turing-complete interpreted language)
  - At the beginning: Note down often used commands...
  - After a tutorial dump your history\* (increase cache size for max usage)

## Shell scripting:

- **Anything you do with the shell can be put into a script**
- **Alternative:** Can solve most things more conveniently with an interpreted language
  - **Con:** Might not always be available where you need it

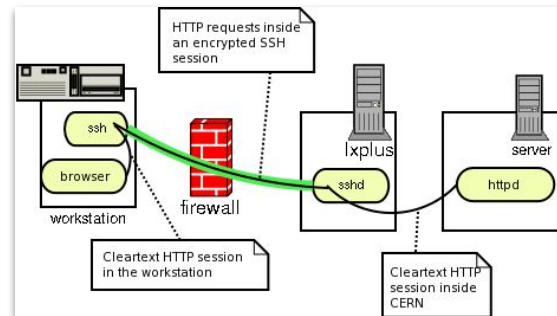
\*to dump e.g., the last 100 commands:  
`$ history | tail -n 100 > history.txt`

Bite size bash (few dollars, but quite useful):  
<https://wizardzines.com/zines/bite-size-bash/>

# Interlude: Working on the road — SSH

SSH — very, very versatile:

- **Tunneling**
  - Secure connections to other machines
  - Can e.g., establish secure connections to machines behind firewalls
- Keys for authentication instead of passwords
  - Makes life a bit more comfortable
  - **Alternative:** Login via Kerberos token if available\*
- To work around shaky connections
  - Always use tmux/screen or a similar terminal multiplexer
- **SSHFS**
  - Files on remote host but "pretend" to be local



Lots of things possible with the ssh-config:

```
HOST <host>
USER <remote-user>
ProxyCommand ssh <tunnel> nc <host> <port>
```

More on (auto-)tunnelling:

[https://security.web.cern.ch/security/recommendations/en/ssh\\_tunneling.shtml](https://security.web.cern.ch/security/recommendations/en/ssh_tunneling.shtml)

tmux guides and courses:

<https://robots.thoughtbot.com/a-tmux-crash-course>  
<http://www.hamvocke.com/blog/a-quick-and-easy-guide-to-tmux/>

\* see e.g., <https://linux.web.cern.ch/docs/kerberos-access/>



# The right tool for many jobs: Interpreted languages

Keep your code as short as possible while **maintaining readability**

- Sometimes means to use the right language
- Often these are interpreted languages
  - python, perl, ruby, tcl, lua
- Used as binding languages:
  - Performance critical code in C/C++
  - Instantiated within python  
(e.g. in CMS, ATLAS & LHCb offline software)
  - Best of both worlds
- Python: large standard library & very expressive!

```
import click

months = {"january": 31, "february": 28, "march": 31,
          "april": 30, "may": 31, "june": 30,
          "july": 31, "august": 31, "september": 30,
          "october": 31, "november": 30, "december": 31}

@click.command()
@click.option('--month', prompt='Which month are you interested in?',
              help='Print the number of days this month has.')
def print_days_in_month(month):
    """Simple program that states how many days MONTH has."""
    if month in months:
        print(f"{month} has {months[month]} days.")
    else:
        print(f"Sorry. Month {month} not known.")

if __name__ == '__main__':
    print_days_in_month()
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Usage: month_script.py [OPTIONS]

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Options:
  --month TEXT  Print the number of days this month has.
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Options:
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$ python month_script.py --month november
november has 30 days.
$ python month_script.py
Which month are you interested in?: november
november has 30 days.
```

# Static Code Checking

## While writing your code:

- There are static code analysis tools that can help you
  - Like spell-check for your code
- Try out a linter for your preferred editor\*
  - Highlights potentially problematic code
  - Your code will be more reliable

## Static checking at compile time:

- Clang has a nice suite of static checks implemented\*\*
  - Can also enforce coding styles
  - Takes longer than compiling; HTML reports with possible bugs
- Might flag some false-positives

Static code checking helps you avoid problems early on!

```
1  #!/usr/bin/env bash
2
3  set -e # Exit on error
4
5  if [ $# -lt 4 ]; then
6      echo "#### Usage:"
7      echo "## " $Q "[CERN username] [bitfile version] [scouting_board_type] [input_system]"
8      echo "# Example " $Q "dinyar vx.y.z kcu1500 ugmt"
9      echo "## Exiting.."
10     exit 1
11 fi
12
13 if [ "$(command -v vivado_lab)" ]; then
14     echo "Found Xilinx Vivado Lab Edition at" $(command -v vivado_lab)
15 else
16     echo "vivado_lab could not be found in your path. Exiting."
17     exit 1
18 fi
19
```

Quote this to prevent word splitting. shellcheck(SC2046)  
View Problem Quick Fix... (Ctrl+.)  
You, 2 months ago • Fix bug stopping

```
19
20 public void addConfigSetting(String id, String val) {
21     configSettings.put(id, val);
22 }
23
24 public String getHost() {
25     return host_;
26 }
27
28 public int
29     return "some_string";
30 }
31
32 public Map<String, String> getConfigSettings() {
33     return configSettings;
34 }
35
```

Type mismatch: cannot convert from String to int Java(16777235)  
View Problem Quick Fix... (Ctrl+.)  
You, 1 second ago • Uncommitted changes

\* Examples for VSCode:

Python: <https://code.visualstudio.com/docs/python/linting>

Shell: <https://github.com/vscode-shellcheck/vscode-shellcheck>

\*\* see <http://clang-analyzer.llvm.org>

# Documentation: Do it while it's fresh

Two sides of the same coin: embedded and standalone documentation

- Both necessary to make your programs easy to use
- They have different purpose!

## Embedded documentation:

- Explain interfaces i.e., function signatures
- Make note of possible future problems (better: prevent them)
- Sometimes might be good to document your reasoning
- Do not “over comment”
  - Can at worst lead to “comment bugs”
- Clean code (almost) documents itself: **You write it once but you read it many times**

```
class TheClass(object):  
    """ Documentation of this class. """  
    def __init__(self, var):  
        self.var_ = var  
        ## @var var_  
        # my member variable  
  
        ## Documentation of this function.  
        # More on what this function does.  
        ## @param arg1 an integer argument  
        ## @param arg2 a string argument  
        ## @returns a list of ...  
    def some_function(self, arg1, arg2):  
        pass
```

```
if a > b: # when a is greater than b, do...
```

# Documentation: Do it while it's fresh

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# Documentation: Do it while it's fresh

Two sides of the same coin: embedded and standalone documentation

- Both necessary to make your programs easy to use
- They have different purpose!

## Standalone documentation:

- Again: Explain your interfaces (can be derived from internal, e.g. doxygen.org)
- For large projects: **Explain the big picture**
  - Give use-cases and examples
  - Consider using UML (unified modelling language) or other graphical notation techniques (e.g., the C4 model)

## Introduction

SWATCH is a C++ bibliothèque designed to provide a generic interface for controlling and monitoring the 2016 Level-1 trigger upgrade hardware.

The generic interface is based on the following classes:

- Processor ( `swatch::processor::Processor` ): Represents the uTCA cards that process trigger primitive data
- DaqTTCManager ( `swatch::dtm::DaqTTCManager` ): Represents the connection to the central TCDS and DAQ networks (i.e. the AMC13)
- System ( `swatch::system::System` ): Represents a trigger subsystem composed of one or more processors and DaqTTCManagers (e.g. calo layer-1, calo layer-2, uGT, etc)

Each processor contains the following interfaces:

- TTC interface ( `swatch::processor::TTCInterface` )
- Readout interface ( `swatch::processor::ReadoutInterface` )
- Input optical port ( `swatch::processor::InputPort` )
- Output optical port ( `swatch::processor::OutputPort` )
- Algorithm interface ( `swatch::processor::AlgoInterface` )

These generic interface classes contain a built-in common monitoring and control framework. There are three concepts of actions for controlling hardware in SWATCH:

- Commands: One shot action - e.g. reset board, configure links
- Command sequences: Multiple commands executed in succession
- Operations: FSMs (Finite State Machines); each transition is typically a single command or command sequence

# Documentation: Do it while it's fresh

Two sides of the same coin: embedded and standalone documentation

- Both necessary to make your programs easy to use
- They have different purpose!

## Standalone documentation:

- Again: Explain your interfaces (can be derived from internal, e.g. doxygen.org)
- For large projects: **Explain the big picture**
  - Give **use-cases and examples**
  - Consider using UML (unified modelling language) or other graphical notation techniques (e.g., the C4 model)

### Step 2: Register subsystem-specific metrics

In the subsystem classes for processors and processor component interfaces (TTC, readout, input port, output port, and algorithm), you can add subsystem-specific metrics, which will then be accessible from the generic SWATCH API, and updated along with that object's common metrics. The new metrics are registered in the constructor of the subsystem-specific class, by calling one of the `registerMetric` methods, and their values must be set in the subsystem class' implementation of the `retrieveMetricValues()` method (in the same way as the values of the common metrics are set).

For example, a `uint16_t` counter for an input port - with "good" status for value of zero, error if the value is above 8, and warning otherwise - could be registered in the `MyInputPortClass` as follows:

- Add a reference to that type of metric as member data:

```
class MyInputPort {  
    // ...  
    // ...  
    // ...  
  
    swatch::core::Metric<uint16_t> mMetricMySpecialCounter;  
};
```

- Register that metric in the constructor:

```
MyInputPort::MyInputPort ( ... ) :  
    swatch::processor::InputPort(stub),  
    // ...  
    mMetricMySpecialCounter( registerMetric<uint16_t>("specialCounter", swatch::core::GreaterThan  
{  
    // ...  
}
```



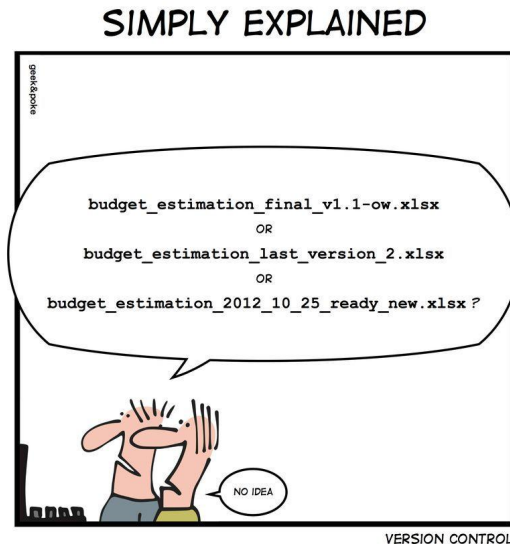
# Always track code changes - Revision Control

## Don't underestimate the challenge of tracking your code

- Deceitfully simple at the beginning...
  - e.g.: zip/tar-based backups, versioning and distribution
- But the illusion is shattered soon enough
  - Upgrading tools or library, refactoring, rushing-in a patch
  - “Long-range” bugs are a thing, not always immediate to catch

## Get familiar with Revision Control early

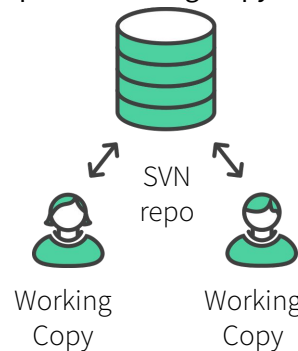
- Learn to track (and comment) every code change
- RCS Essential (and unavoidable) for collaboration



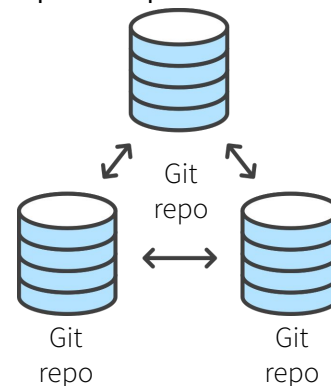
# Revision Control Software

- Once upon a time: CVS and Subversion
- **Nowadays:** Distributed revision control – Great for personal use
  - Easy to work on the go
  - Your local copy has everything (including history)
- The most popular nowadays git: [git-scm.com](https://git-scm.com)
  - Other distributed solutions are: Mercurial, bazaar...
  - Easy to get started...

Central-Repo-To-Working-Copy Collaboration



Repo-To-Repo Collaboration



## *Interlude:* git basics

```
$ git init
```

```
Initialized empty Git repository in /TestDirectory/.git/
```

## *Interlude:* git basics

```
$ git init
```

```
Initialized empty Git repository in /TestDirectory/.git/
```

```
$ touch README.md # Create a readme file
```

```
$ # Edit the file...
```

## *Interlude: git basics*

```
$ git init
```

Initialized empty Git repository in /TestDirectory/.git/

```
$ touch README.md # Create a readme file
```

```
$ # Edit the file...
```

```
$ git add README.md # Add the file to the index
```

## *Interlude: git basics*

```
$ git init
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Initialized empty Git repository in /TestDirectory/.git/

```
$ touch README.md # Create a readme file
```

```
$ # Edit the file...
```

```
$ git add README.md # Add the file to the index
```

```
$ git commit -m "Initial commit to my new repo"
```

## *Interlude: git basics*

```
$ git init
```

```
Initialized empty Git repository in /TestDirectory/.git/
```

```
$ touch README.md # Create a readme file
```

```
$ # Edit the file..
```

```
$ git add README.md # Add the file to the index
```

```
$ git commit -m "Initial commit to my new repo"
```

```
$ # Create more files and edit them..
```

```
$ git add firstFile.txt sourceFile.cc headerFile.h
```

```
$ git commit -m "Short descriptive summary
```

```
dquote>
```

```
dquote> More expansive explanation of the commit,
```

```
dquote> if necessary."
```

How-to write good commit messages:  
<https://chea.ms/git-commit/>

Random github commit messages:  
<http://whatthecommit.com/>

## Interlude: git basics, avoid this:

	COMMENT	DATE
○	CREATED MAIN LOOP & TIMING CONTROL	14 HOURS AGO
○	ENABLED CONFIG FILE PARSING	9 HOURS AGO
○	MISC BUGFIXES	5 HOURS AGO
○	CODE ADDITIONS/EDITS	4 HOURS AGO
○	MORE CODE	4 HOURS AGO
○	HERE HAVE CODE	4 HOURS AGO
○	AAAAAAAAA	3 HOURS AGO
○	ADKFJSLKDFJSDKLFJ	3 HOURS AGO
○	MY HANDS ARE TYPING WORDS	2 HOURS AGO
○	HAAAAAAAAAANDS	2 HOURS AGO

AS A PROJECT DRAGS ON, MY GIT COMMIT MESSAGES GET LESS AND LESS INFORMATIVE.



# Git in a nutshell

## Learn basic concepts and commands

- Create repository, add file, commit new versions: `git (init, add, commit)`

## Familiarise yourself with parallel development concepts

- Switch to branches or create new ones: `git (switch [-c]/checkout [-b])`
- Merging and rebasing: `git (merge, rebase)`

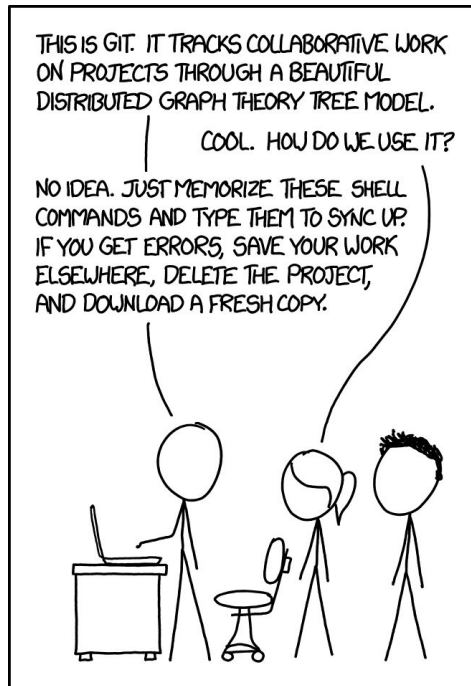
## Learn how to interact with remote repositories and users

- Retrieve and share code: `git (clone, pull, push, fetch)`

Very powerful system means there is inherent complexity

- It is entirely possible to use restricted feature set and be very productive!

Still worth spending some time reading about it!\*

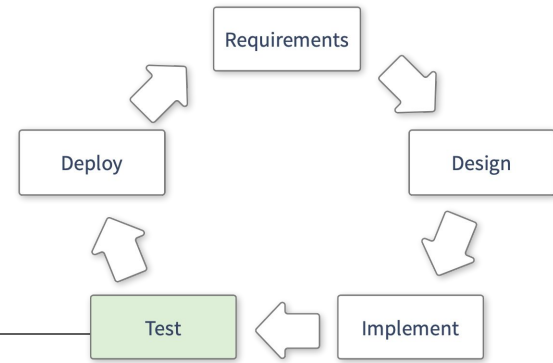


Git tutorials:

<http://git-scm.com/book/en/v2/Getting-Started-About-Version-Control>  
<http://pcottle.github.io/learnGitBranching/>

\*Ultimate git guide: <https://jwiegley.github.io/git-from-the-bottom-up/>

# Testing



# What do we mean with tests?

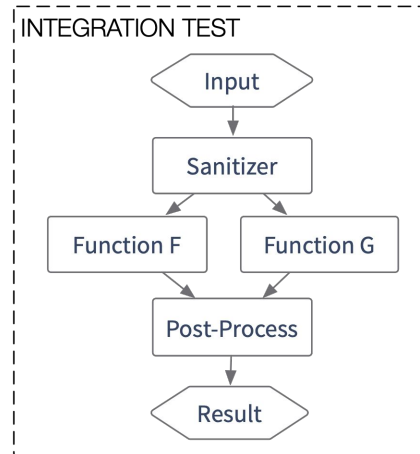
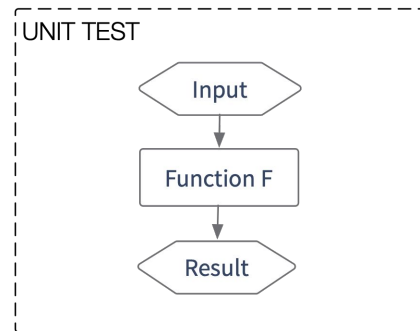
## Different tests, different purposes:

- Unit test
  - Testing “units of code”, e.g. a function or class
  - Given a defined input → expected output?
- Integration test
  - Testing a larger part of your software
  - For example running an example and checking output

**Modifying code base that is well-covered by tests is infinitely more fun than one that is almost untested!**

**Do not confuse it with verification**

Checks if specifications are met



# Writing good tests is hard

---

How to come up with tests?

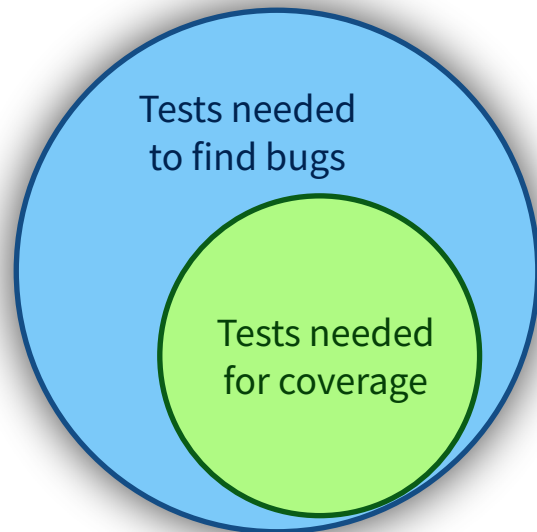
- What should the algorithm do?
  - Check if well defined input produces correct result
- How should the algorithm fail?
  - Check if wrong input fails in the way you want

You'll ~~probably~~ miss corner cases

- Once you discover them, implement a test!
  - **Only let a bug hit you once**
- Have users help you
  - Use issue tracker
  - Be responsive!

Look at existing solutions to implement tests

- Python: [doctest](#) and [unittest](#) packages
- C++: [CTest](#) (integrated with cmake) & [Catch](#)



# *Interlude:* doctest

\$ python testfib.py

```
def fib(n):
    """ Returns the fibonacci series at n
    >>> [fib(n) for n in range(6)]
    [0, 1, 1, 2, 3, 5]
    >>> fib(-1)
    Traceback (most recent call last):
      ...
    ValueError: n should be >= 0
    """
    if n < 0: raise ValueError("n should be >= 0")
    if n == 0: return 0
    a, b = 1, 1
    for i in range(n-1):
        a, b = b, a+b
    return a

import doctest
doctest.testmod()
```

# *Interlude:* doctest

```
$ python testfib.py
```

```
$ # No error → All tests passed!
```

```
def fib(n):
    """ Returns the fibonacci series at n
    >>> [fib(n) for n in range(6)]
    [0, 1, 1, 2, 3, 5]
    >>> fib(-1)
    Traceback (most recent call last):
      ...
    ValueError: n should be >= 0
    """
    if n < 0: raise ValueError("n should be >= 0")
    if n == 0: return 0
    a, b = 1, 1
    for i in range(n-1):
        a, b = b, a+b
    return a

import doctest
doctest.testmod()
```

# *Interlude:* doctest

```
$ python testfib.py -v
```

```
def fib(n):
    """ Returns the fibonacci series at n
    >>> [fib(n) for n in range(6)]
    [0, 1, 1, 2, 3, 5]
    >>> fib(-1)
    Traceback (most recent call last):
      ...
    ValueError: n should be >= 0
    """
    if n < 0: raise ValueError("n should be >= 0")
    if n == 0: return 0
    a, b = 1, 1
    for i in range(n-1):
        a, b = b, a+b
    return a

import doctest
doctest.testmod()
```

# Interlude: doctest

```
$ python testfib.py -v
```

Trying:

```
[fib(n) for n in range(6)]
```

Expecting:

```
[0, 1, 1, 2, 3, 5]
```

ok

Trying:

```
fib(-1)
```

Expecting:

```
Traceback (most recent call last):
```

```
...
```

```
ValueError: n should be >= 0
```

ok

1 items had no tests:

```
__main__
```

1 items passed all tests:

```
2 tests in __main__.fib
```

2 tests in 2 items.

2 passed and 0 failed.

Test passed.

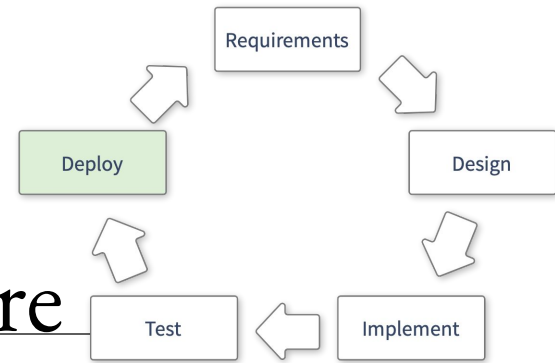
```
def fib(n):
    """ Returns the fibonacci series at n
    >>> [fib(n) for n in range(6)]
    [0, 1, 1, 2, 3, 5]
    >>> fib(-1)
    Traceback (most recent call last):
        ...
    ValueError: n should be >= 0
    """
    if n < 0: raise ValueError("n should be >= 0")
    if n == 0: return 0
    a, b = 1, 1
    for i in range(n-1):
        a, b = b, a+b
    return a

import doctest
doctest.testmod()
```

See <https://docs.python.org/3/library/doctest.html> for more examples and explanations!



# Deploying your software

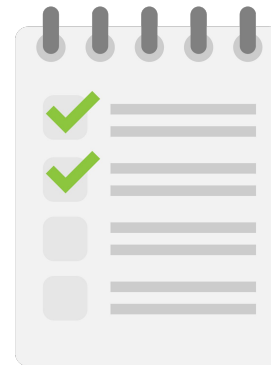


# Releasing the Software

---

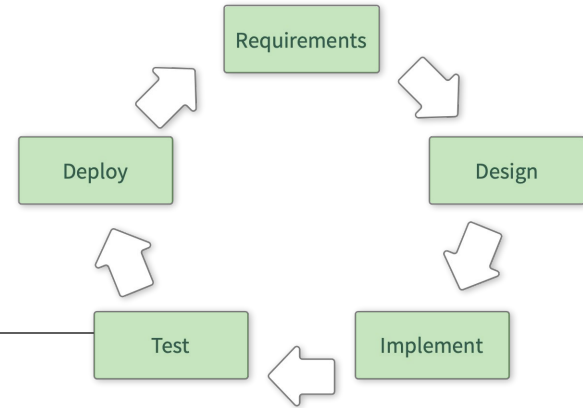
## When you release your software:

- Tag the repository
  - Defines a common "checkpoint"
- Test in the target environment
  - In e.g., fresh virtual machine or docker container
  - If you test locally you might be unknowingly using private files/variables
- Create/release accompanying documentation
  - Produce e.g., Doxygen pages
  - Update wikis or whatever documentation pages you use (tag a new version)
  - Make sure all examples work



**Ideal case: All this is done automatically!**

# Automate

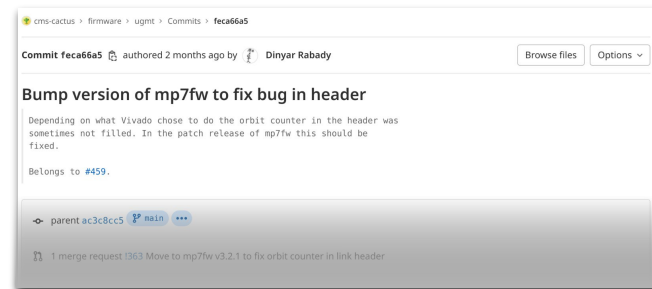


# Goal

We would like to

- Commit some code

and then **automatically** make it ready for deployment.



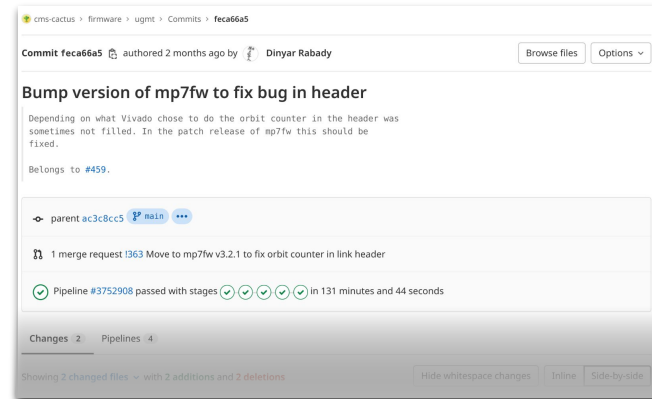
# Goal

We would like to

- Commit some code

and then **automatically** e.g.,

- Test
  - e.g., Unit tests
- Build
- Package the products and name them
  - e.g., RPM, JAR, tar/zip archives, ...
- Test again
  - e.g., Integration tests
- Provide the packages for deployment
  - OR... deploy them immediately



## uGMT firmware

Repository of bitfiles for the upgraded Global Muon Trigger (point 5).

### uGMT bitfiles

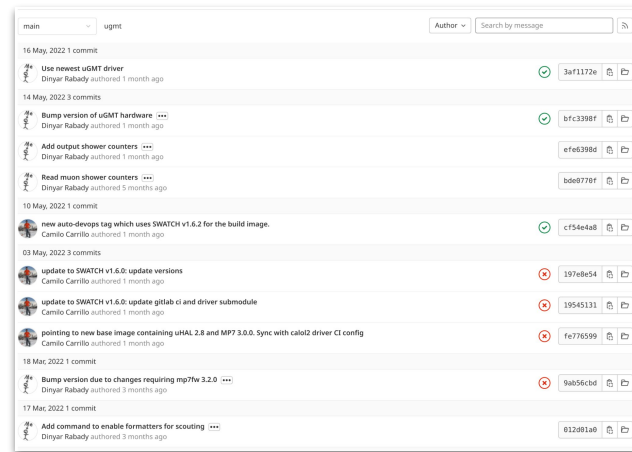
#### Bitfiles for MP7 XE

[uGMT\\_XE\\_v6\\_1\\_0\\_unstableMP7FW](#)  
[uGMT\\_XE\\_v6\\_1\\_0\\_patch2](#)  
[uGMT\\_XE\\_v6\\_1\\_0\\_patch1](#)  
[uGMT\\_XE\\_v6\\_1\\_0](#)  
[uGMT\\_XE\\_v6\\_0\\_1](#)  
[uGMT\\_XE\\_v6\\_0\\_0\\_patch2](#)  
[uGMT\\_XE\\_v6\\_0\\_0\\_patch1](#)  
[uGMT\\_XE\\_v6\\_0\\_0](#)  
[uGMT\\_XE\\_v5\\_0\\_1\\_patch4](#)  
[uGMT\\_XE\\_v5\\_0\\_1\\_patch3](#)  
[uGMT\\_XE\\_v5\\_0\\_1\\_patch2](#)  
[uGMT\\_XE\\_v5\\_0\\_1\\_patch1](#)  
[uGMT\\_XE\\_v5\\_0\\_1](#)  
[uGMT\\_XE\\_v5\\_0\\_0](#)  
[uGMT\\_XE\\_v4\\_1\\_0](#)  
[uGMT\\_XE\\_v4\\_0\\_0\\_patch2](#)

[uGMT\\_XE\\_njshuly](#)  
[uGMT\\_XE\\_branch\\_vivado-2018p3](#)  
[uGMT\\_XE\\_branch\\_timing-experiments](#)  
[uGMT\\_XE\\_branch\\_test-mp7fw-v3p2p0](#)  
[uGMT\\_XE\\_branch\\_speed-up-synth](#)  
[uGMT\\_XE\\_branch\\_scouting-counter-fix](#)  
[uGMT\\_XE\\_branch\\_patterns-from-github](#)  
[uGMT\\_XE\\_branch\\_no-zero-suppression](#)  
[uGMT\\_XE\\_branch\\_no-valid-bits-from-masked-chans](#)  
[uGMT\\_XE\\_branch\\_name-bitfiles-from-branches](#)  
[uGMT\\_XE\\_branch\\_modified-mp7-zero-suppression](#)  
[uGMT\\_XE\\_branch\\_latest-in-ci](#)  
[uGMT\\_XE\\_branch\\_kalman-con](#)  
[uGMT\\_XE\\_branch\\_full-jobs](#)  
[uGMT\\_XE\\_branch\\_fix-use-lagged-patterns](#)  
[uGMT\\_XE\\_branch\\_fix-orbitcounter-for-header](#)  
[uGMT\\_XE\\_branch\\_fix-dsv-position](#)  
[uGMT\\_XE\\_branch\\_fix-counters](#)  
[uGMT\\_XE\\_branch\\_feature-mp7fw-scout-link-header](#)  
[uGMT\\_XE\\_branch\\_feature-hwtest-via-direct-connection](#)  
[uGMT\\_XE\\_branch\\_feature-hadronic-showers](#)  
[uGMT\\_XE\\_branch\\_feature-emt-displ-info](#)  
[uGMT\\_XE\\_branch\\_feature-docker-builds](#)  
[uGMT\\_XE\\_branch\\_environments-for-b40-deployment](#)  
[uGMT\\_XE\\_branch\\_displaced-muons](#)  
[uGMT\\_XE\\_branch\\_chore-uvmiscrpt6p1p1](#)  
[uGMT\\_XE\\_branch\\_chore-jphb-dev2021](#)  
[uGMT\\_XE\\_branch\\_chore-disable-iso-bit-computation](#)

# But why?

- Reduces work
  - **Committing** to repository is enough
    - Tests are run
    - Builds are performed
    - Product provided for download
- Possibility for **non-experts** to **build complex or resource intensive** software or firmware
  - **Added bonus:** Per construction there is a recipe to build your code in the repository!
- **Consistent record** of firmware development
  - With **indication** whether particular **revision is known to be good**
- Gives **confidence**
  - **"Spatial"**: Does my work build correctly on other machines?
    - e.g., Did I commit everything required to my repository?
  - **"Temporal"**: Is this particular commit from two years ago supposed to work?
- Ensures **consistency** of a given package
  - We **know** that this was built with *these* libraries and in *this* environment



# *Interlude:* Gitlab CI

```
$ cat .gitlab-ci.yml
image: gitlab-registry.cern.ch/scouting-demonstrator/scone/rpm-builder:v1_0_0

build_rpm_tag:
  stage: build
  only:
    - tags
  script:
    - bash build.sh
    - bash package.sh
  artifacts:
    name: "scone-${CI_JOB_NAME}_${CI_COMMIT_TAG}"
    paths:
      - cms-scone*.rpm
      - info.json
    expire_in: 1 week
```

# Interlude: Gitlab CI

scouting-demonstrator > SCONE > Jobs > #22307454

passed

Job build\_rpm\_tag triggered 2 weeks ago by Dinyar Rabady

1 Running with gitlab-runner 14.10.1 (f761588f)

2 on default-runner-86545f9dd6-zgpcd 8xy--Bqv

3 feature flags: FF\_DISABLE\_UMASK\_FOR\_DOCKER\_EXECUTOR:true

4 Resolving secrets

5

6 Preparing the "docker" executor

7 Using Docker executor with image gitlab-registry.cern.ch/scouting-demonstrator/scone/rpm-builder:v1\_0\_0 ...

8 Authenticating with credentials from job payload (GitLab Registry)

9 Pulling docker image gitlab-registry.cern.ch/scouting-demonstrator/scone/rpm-builder:v1\_0\_0 ...

10 Using docker image sha256:3ffe3f3335dfb435125cb4ab798d0f3555a38660abc382f21ce7ca3b38f9ca4c for gitlab-registry.cern.ch/scouting-demonstrator/scone/rpm-builder@sha256:f488c85e101f16af006fd14a0316560ec95920a85ad5dded55ebd9830f507c51 ...

11 Not using umask - FF\_DISABLE\_UMASK\_FOR\_DOCKER\_EXECUTOR is set!

12

13 Preparing environment

14

15

16 Getting source from Git repository

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23 Executing "step\_script" stage of the job script

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build\_rpm\_tag

Duration: 51 seconds

Finished: 2 weeks ago

Timeout: 1h (from project)

Job artifacts

These artifacts are the latest. They will not be deleted (even if expired) until newer artifacts are available.

Keep Download Browse

Commit e603803d

Make multiple read/write requests possible

Pipeline #4059136 for v1.2.0

build

→ build\_rpm\_tag

For resource intensive builds/tests or other special requirements for the running machine: Can set up specialised runners (i.e., "computers that run your jobs").

See <https://docs.gitlab.com/ee/ci/> for a complete documentation!

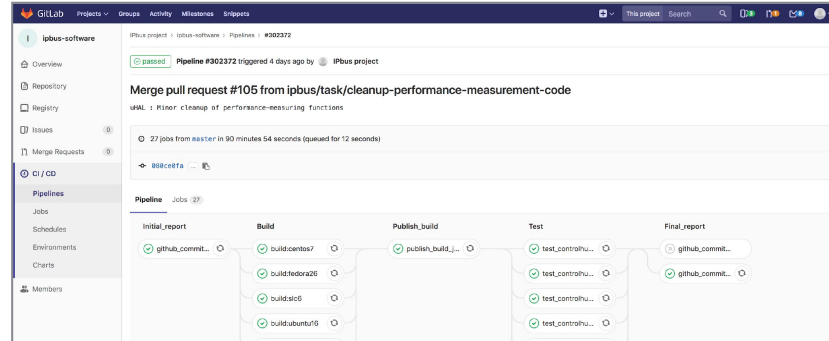
D. Rabady (CERN)

ISOTDAQ 2022. University of Catania, Catania. 22 June 2022

64

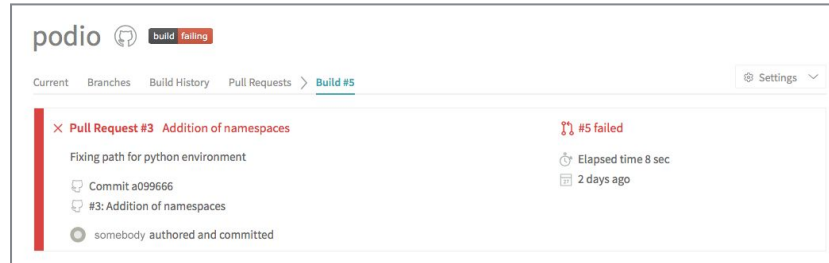


# Many solutions available for this...



CI/CD

Gitlab CI - <https://about.gitlab.com/features/gitlab-ci-cd/>



Travis CI - <https://travis-ci.org>

Also <https://www.jenkins.io/>, <https://circleci.com/>,  
<https://docs.github.com/en/actions/automating-builds-and-tests/about-continuous-integration>, ...

# Words of advice

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- Well designed **build tools are crucial**
  - Invaluable even when not using continuous integration
    - Essential when using it
- Some measure of discipline required to get the most out of this
  - Build system requires some time to set up
    - **Very good investment**, but initially somewhat frustrating
  - Continuous integration most useful if actually used regularly
    - If you put each code change into your repository you can later come back and check what was the breaking change
- Spend time on development process
  - Use of tags?
  - Use of branches?
  - Pull/Merge requests?
  - ...
  - Lots of "standard" processes around (Gitflow, trunk-based,... )
    - Significant experience probably also around your lab (and coffee is cheap)
- Above all: **Don't get overwhelmed by the possibilities!**
  - Start simple!

# General tips & pointers

# Learning about software development

---

## Coursera and Udacity

- <https://www.coursera.org/courses>
  - Large variety of courses
    - Not only technology / programming
    - Also physics, biology, economics... and more
    - Also in different languages
- <https://www.udacity.com/courses/all?price=Free>
  - Mixed courses: Some free, recently switched to a paid model with monthly fees

University Homepages — have a look, many courses available through YouTube etc.

- e.g.: [Programming Paradigms, Stanford University](#)
- <https://www.edx.org/search?tab=course>

# Closing Advice

---

Before you write trigger/DAQ software (and firmware!), you should know the ins and outs:

- What is: compiler, interpreter, linker, terminal, object, class, pointer, reference
- If these concepts are not clear: Excellent material on the web (previous slide)

Before (and while) implementing: **Think**

- Smart solutions can take significant amount of time...  
put it on the back-burner if you have other things to work on

**Read! Ask! Write!** The internet is full of information... Blogs, tutorials, StackOverflow, also Wikipedia can be very useful to get a grasp of new concepts

# Conclusion

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These slides were full of starting points: You have to follow up to get something out of it

- Most of it are tools to make your life easier
- Nothing is free
  - You'll have to invest some effort to learn, but most tools shown here bring benefits very early in the learning curve!
- Many more tools to discover, lots of fun to be had with them!

## Homework:

- Install git, start a repository. Try branching on the web
- Run tmux, kill the connection, reconnect and see if you can continue where you left off
  - **Beware:** If you use a service like lxplus you get a machine from a pool (e.g. lxplus769) → Tmux/screen is running on that one!
- Tune your .bashrc / .bash\_profile to get a more useful prompt
- Try out vim/emacs/vscode and learn what suits you best
  - Download a shortcut summary...
  - Learn how to block-select, indent multiple lines, rename occurrences of text

# Master by doing

Don't forget: Have fun while doing so!

# Random Things

---

## 6 Stages of Debugging:

1. That can't happen.
2. That doesn't happen on my machine.
3. That shouldn't happen.
4. Why does that happen?
5. Oh, I see.
6. How did that ever work?

<http://plasmasturm.org/log/6debug/>

Go-language: Designed with threading in mind  
<http://tour.golang.org/welcome/1>

Want to try your programming skills?  
Google code jam (registration open):  
[codingcompetitions.withgoogle.com/codejam](http://codingcompetitions.withgoogle.com/codejam)

Also you can just practice  
by solving nice problems.

Guru of the Week: (Not any more)  
regular C++ programming problems  
with solutions by Herb Sutter  
<http://www.gotw.ca/gotw/>

“Debugging is like being  
the detective in a crime  
novel where you are also  
the murderer.”

– @fortes

About JavaScript:  
<https://www.destroyallsoftware.com/talks/the-birth-and-death-of-javascript>  
<https://www.destroyallsoftware.com/talks/wat>

2014 lecture has complementary stuff:  
<http://indico.cern.ch/event/274473/session/21/material/0/0.pdf>



More Random Things

---

In HEP probably no way around ROOT / RooFit

- Maintained at CERN, used in LHC experiments

GNU R — [www.r-project.org](http://www.r-project.org)

- Used widely among statisticians (including finance and others)
- Interpreted language + software for analysis and graphical representation
- ROOT bindings now available (use it through TMVA)

SciPy — <http://www.scipy.org/>

- Collection of python libraries for numerical computations, graphical representation and containing additional data structures

Sci-kitlearn: — <http://scikit-learn.org/stable/>

- Python library for machine learning
- ROOT bindings available (usable through TMVA)

---

## Data visualisation:

- Matplotlib (part of SciPy)
  - histograms, power spectra, scatterplots and more.. extensive library for 2D/3D plotting
- ROOT
  - Again, probably no way around it... Sometimes a little unintuitive

## Other:

- JaxoDraw — <http://jaxodraw.sourceforge.net/>
  - Feynman graphs through “axodraw” latex package
- tex2im — <http://www.nought.de/tex2im.php>
  - Need formulas in your favourite WYSIWG presentation tool?
- GraphViz — <http://www.graphviz.org/> or MacOS: <http://www.pixelglow.com/graphviz/>
  - Diagrams / Flowcharts with auto-layout

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SAGE — [www.sagemath.org](http://www.sagemath.org)

- Open source alternative to Matlab, Maple and Mathematica

GNUPlot — <http://www.gnuplot.info/>

- Quick graphing and data visualisation

Wolfram Alpha — <http://www.wolframalpha.com/>

- Wolfram = Makers of Mathematica.. A... ask me anything?:
  - <http://www.wolframalpha.com/input/?i=how+much+does+a+goat+weigh>
  - Answer: Assuming “goat” is a species specification. Result: 61 kg

# Making git (more) fun to use

Create your own `.gitconfig` to get the most out of git

- Colors, aliases, etc.
- Special mention: **graphical history**
  - A lifesaver when working with many branches/developers

Git configuration: <https://git-scm.com/docs/git-config>

```
[user]
  name = Dinyar Rabady
  email = dinyar@cern.ch
[core]
  excludesfile = /home/dinyar/.gitignore_global
  editor = vim
[color]
  status = auto
  branch = auto
[push]
  default = matching
[merge]
  conflictstyle = diff3
[http]
  emptyAuth = true
[init]
  defaultBranch = main
[pull]
  ff = only
```

```
* feca66a - (tag: ugmt_v6_1_0_patch1) Bump
* ac3c8cc - Move hw-test to host connected
| * c09255d - (refs/stash) WIP on hadroni
| \
| | * 5754477 - index on hadronic_showers:
| /
| * d5ce4a1 - Modified opt design directive
| * 23e0151 - Change route design directive
| * cc1944f - Improve artifact handling for
| * 4daf292 - Add counter for output shower
| * ff8f7e3 - Add rate counters for input s
| * 2053ae2 - Extend tesetbench to read sho
| * 9157704 - Implement hadronic showers (3
| /
* eb39fe4 - (origin/feature/mp7fw-scout_lin
```

Magic alias (one of many):

```
[alias]
  lg = log --color --graph --all --pretty=format:'%Cred%h%Creset \
    -%C(yellow)%d%Creset %s %Cgreen(%cr) %C(bold blue)<%an>%Creset' --abbrev-commit
```

Integrate git with your shell

- Tab-completion and git information shell prompt

Git bash shell integration:

<https://git-scm.com/book/en/v2/Appendix-A%3A-Git-in-Other-Environments-Git-in-Bash>

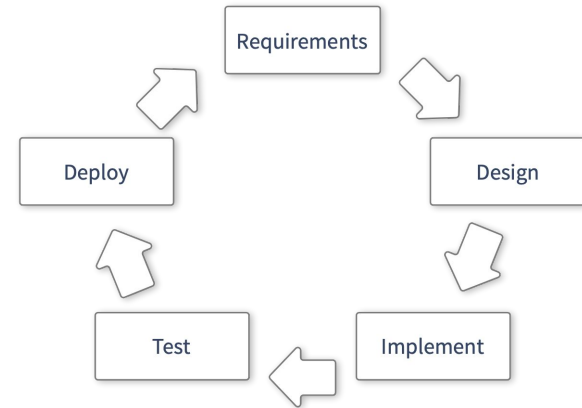
Or try git integration in oh-my-zsh:

<https://github.com/ohmyzsh/ohmyzsh>

```
; █ src/gt-algorithm (feature/vu13p_dc ⚡) lxplus737
```

# (Some) typical programming contexts

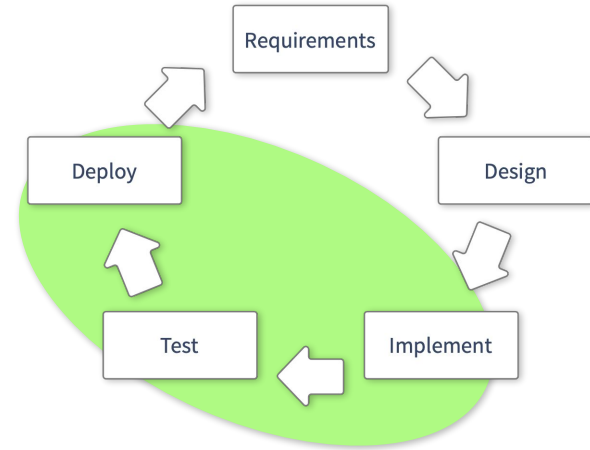
---



# (Some) typical programming contexts

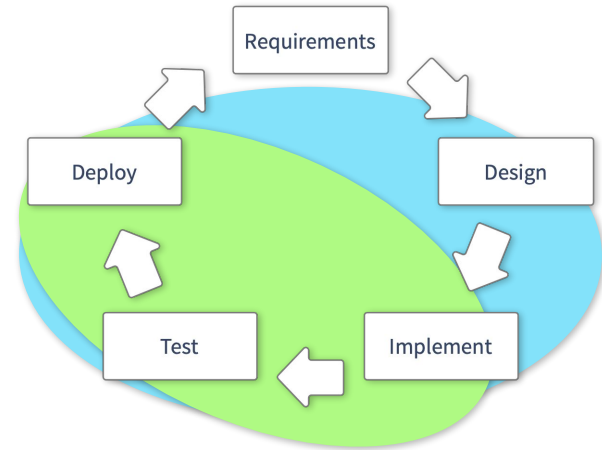
---

- **Small projects**
  - Shortened dev-cycle: Implement, Test, Deploy
    - Requirements and design pre-defined
  - Mostly self-contained
    - Few external interfaces and dependencies
  - Few developers (typically you)



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- **Medium projects**
  - The design effort becomes unavoidable
  - Well defined interfaces and dependencies
    - e.g. external frameworks
  - Multiple developers
    - Human interaction becomes non-trivial
  - Maintenance issues make their appearance





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- **Medium projects**
  - The design effort becomes unavoidable
  - Well defined interfaces and dependencies
    - e.g. external frameworks
  - Multiple developers
    - Human interaction becomes non-trivial
  - Maintenance issues make their appearance
- **Large projects (TDAQ)**
  - Requirements and specifications become crucial
  - Many interfaces, complex dependencies
  - Sizeable user base
    - Support becomes your worst nightmare

