Programming

for Today's Physicists and Engineers

ISOTDAQ 2018
Vienna

February 16, 2018

Alessandro Thea
Rutherford Appleton Laboratory - PPD
Science & Technology Facilities Council

How to Survive

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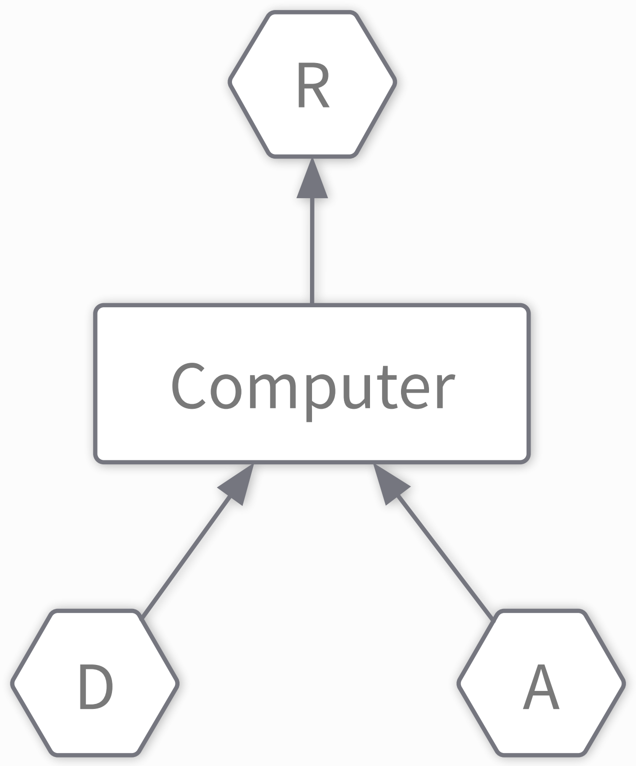
Opening words

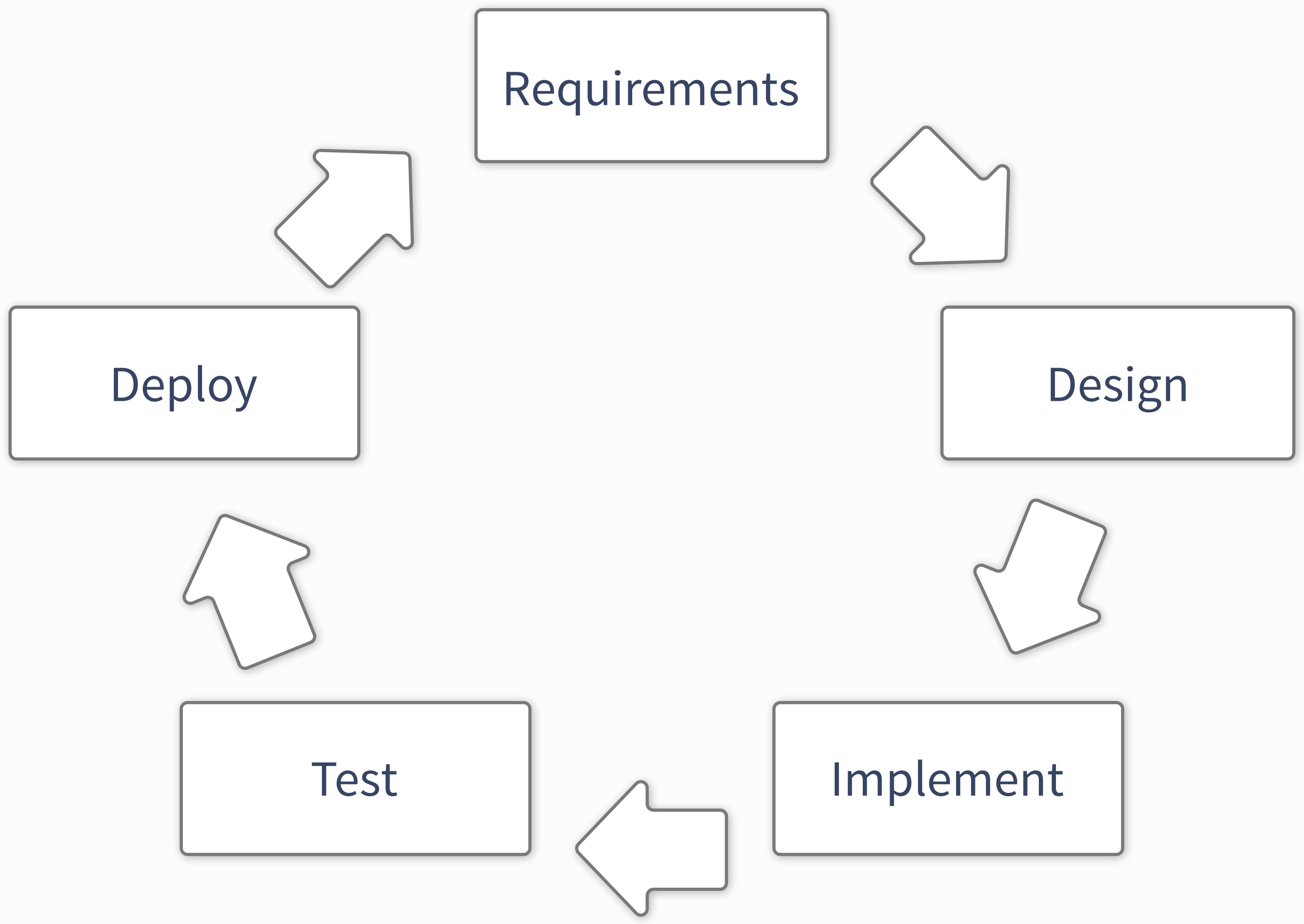
- **Disclaimer:** This is more a collection of pointers* than a tutorial, it's a starting point…
- **(Almost) no code** but a bias towards C++ and Python

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

*further reading and tips in these boxes

What is programming?





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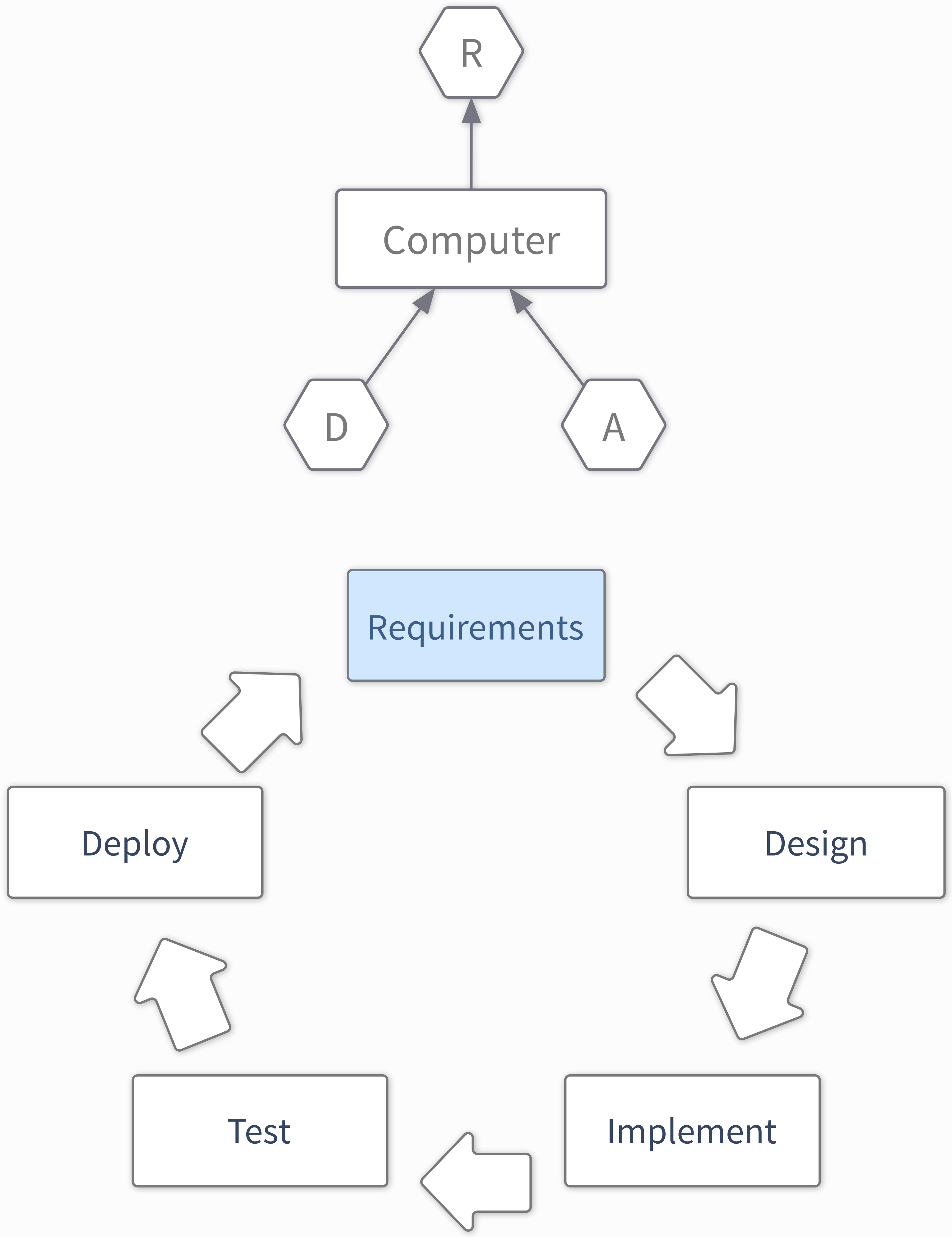
- **Understand** & define what you want to solve
  - Define the **requirements** for your software



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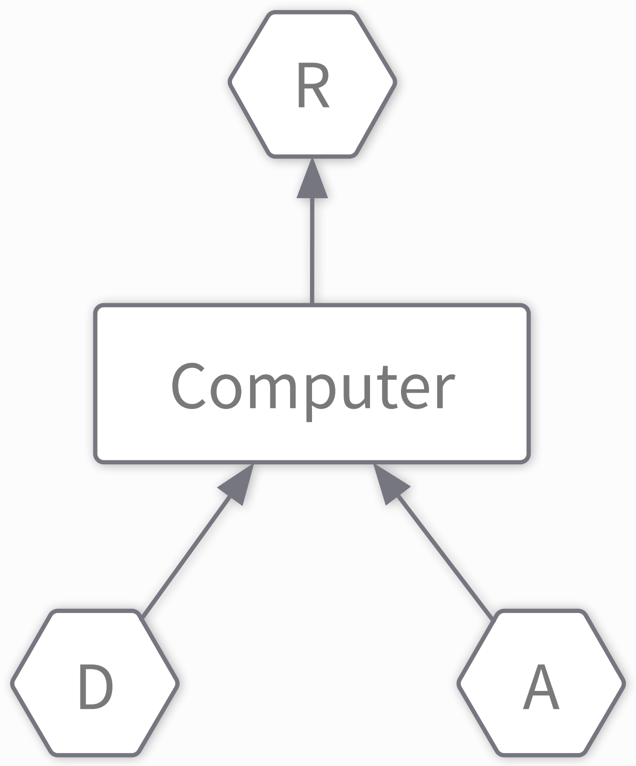

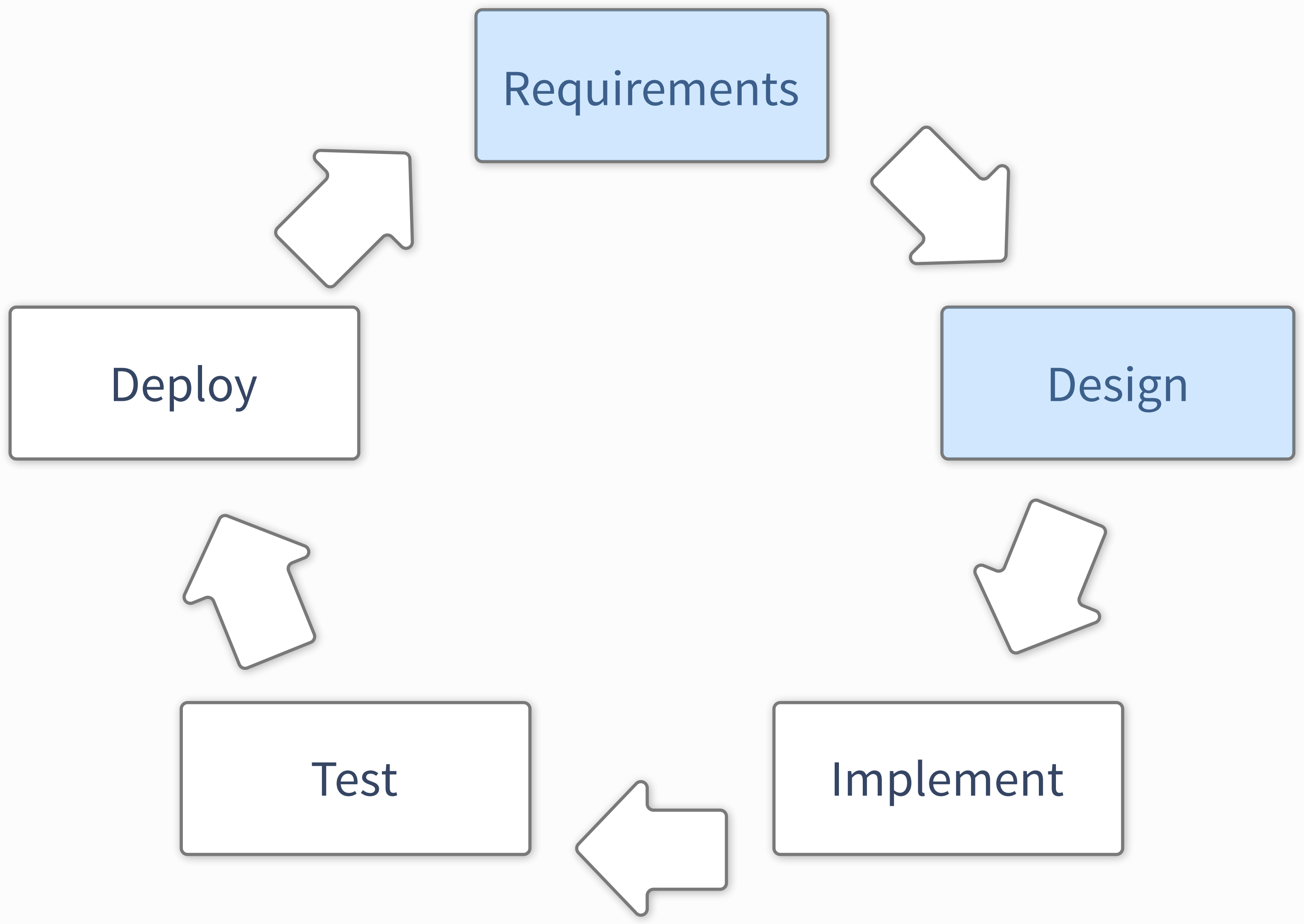

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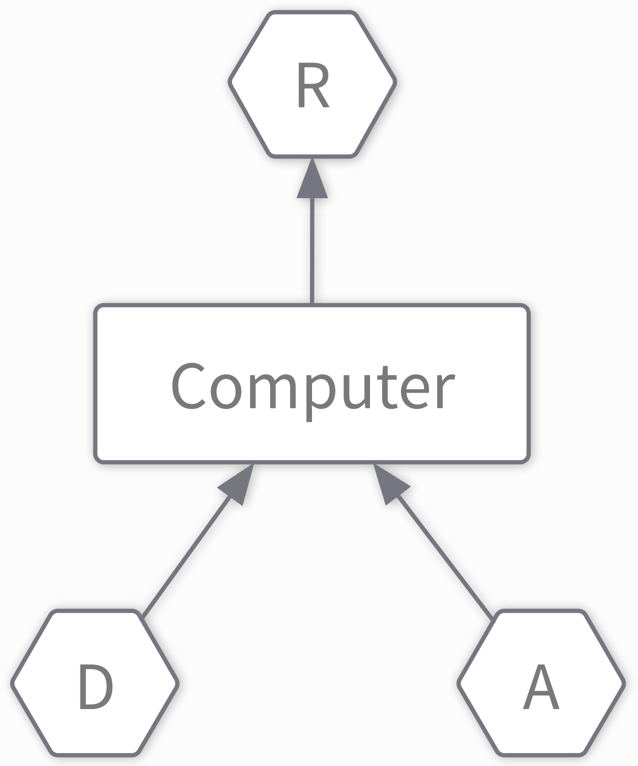
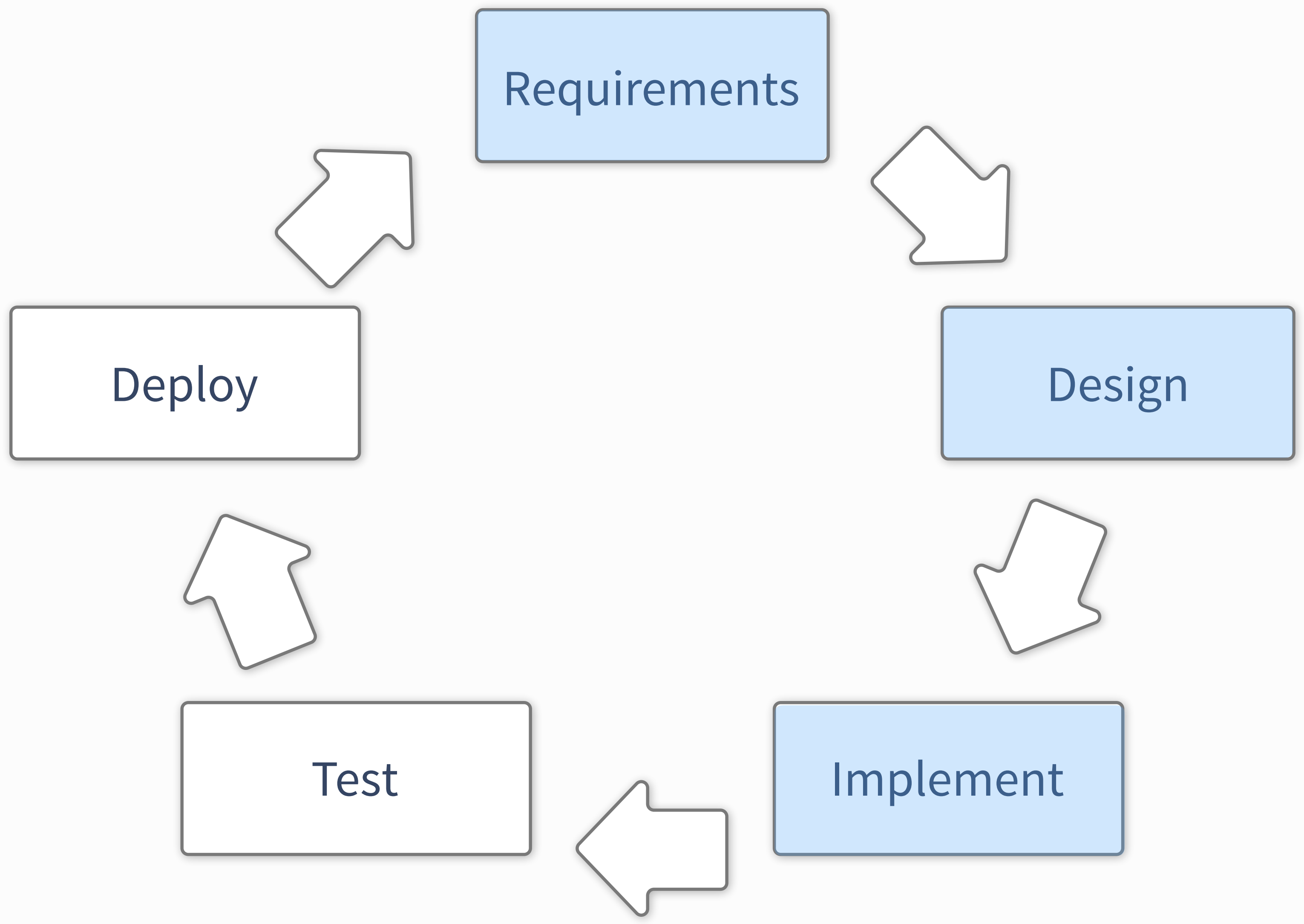
  - Which language?
  - Documentation
  - Debugging
  - Implement tests





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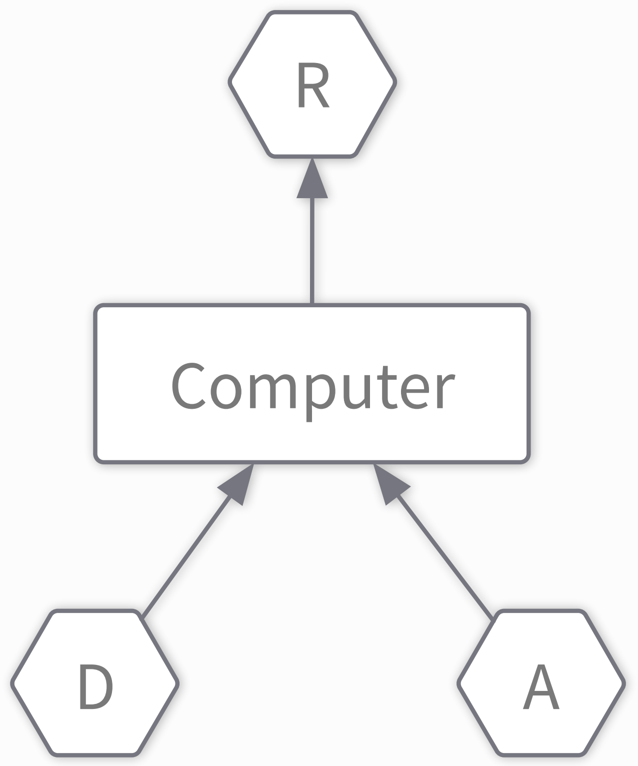

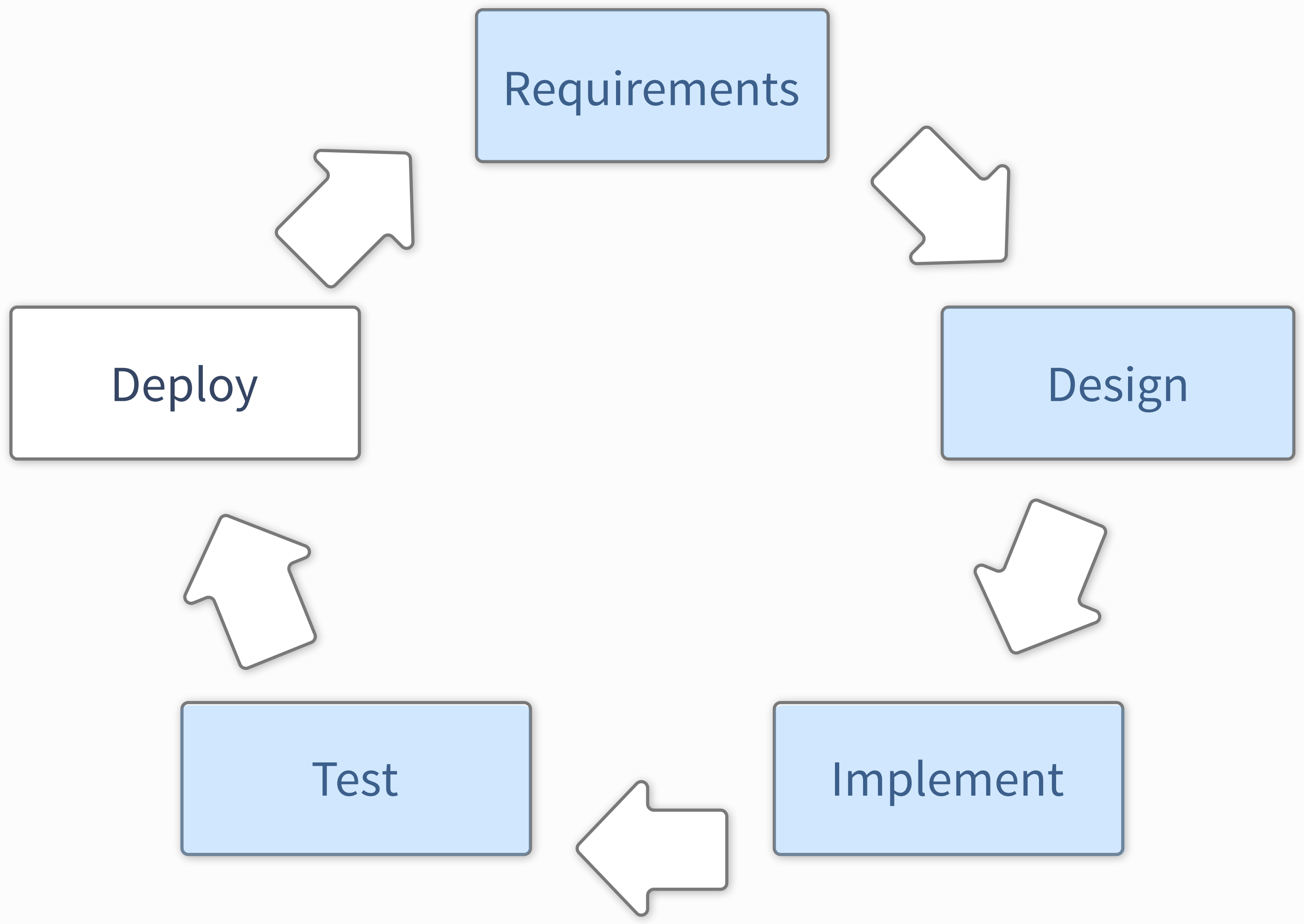

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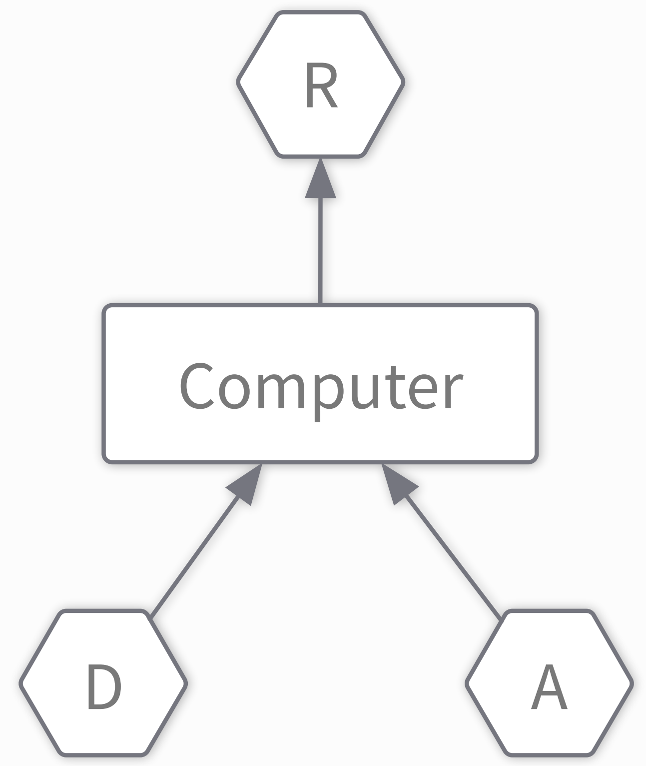

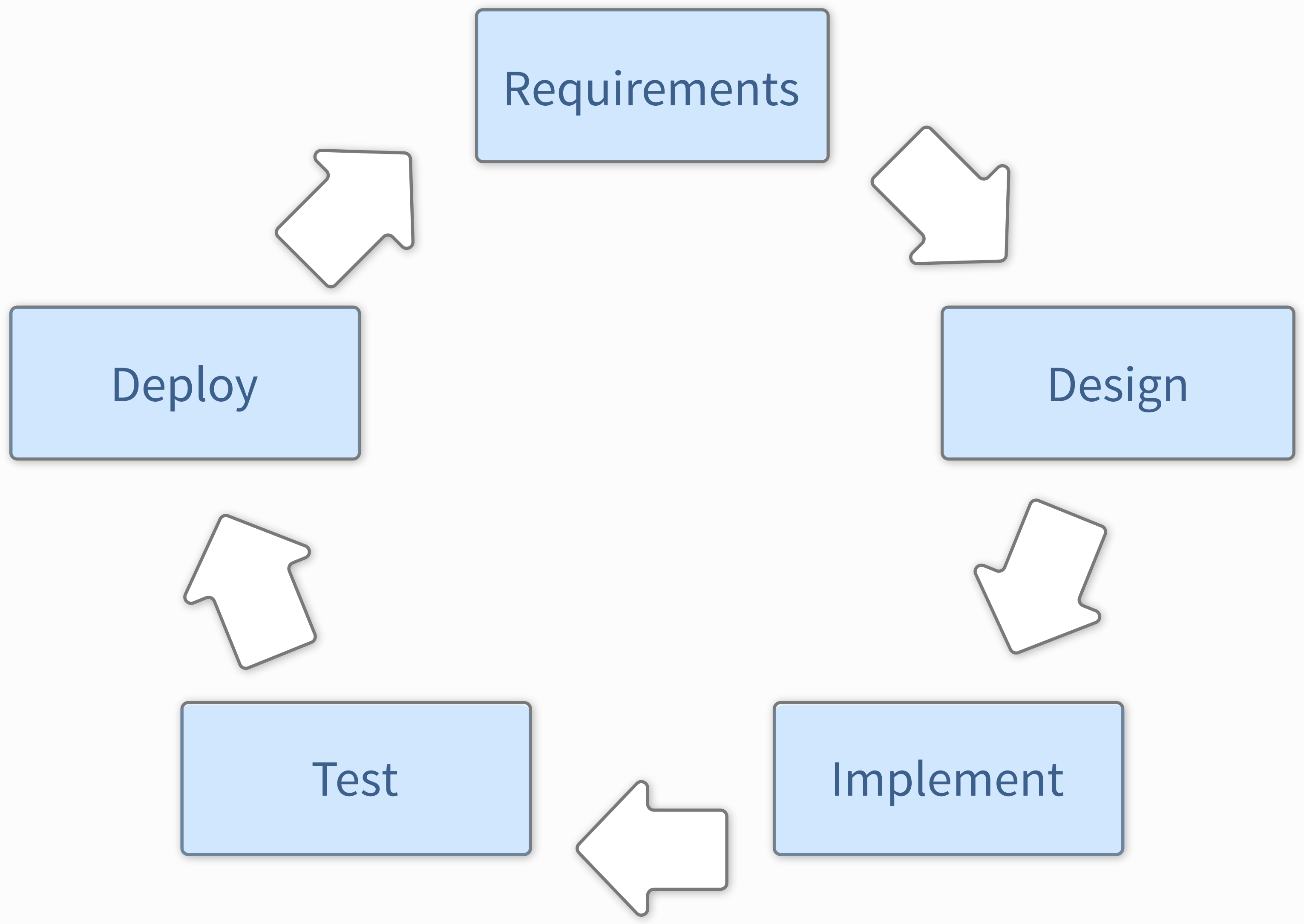

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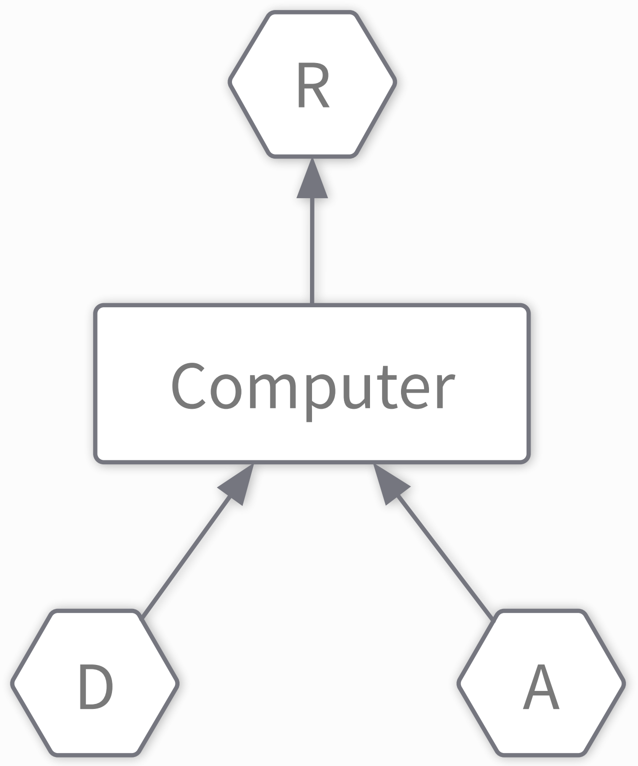

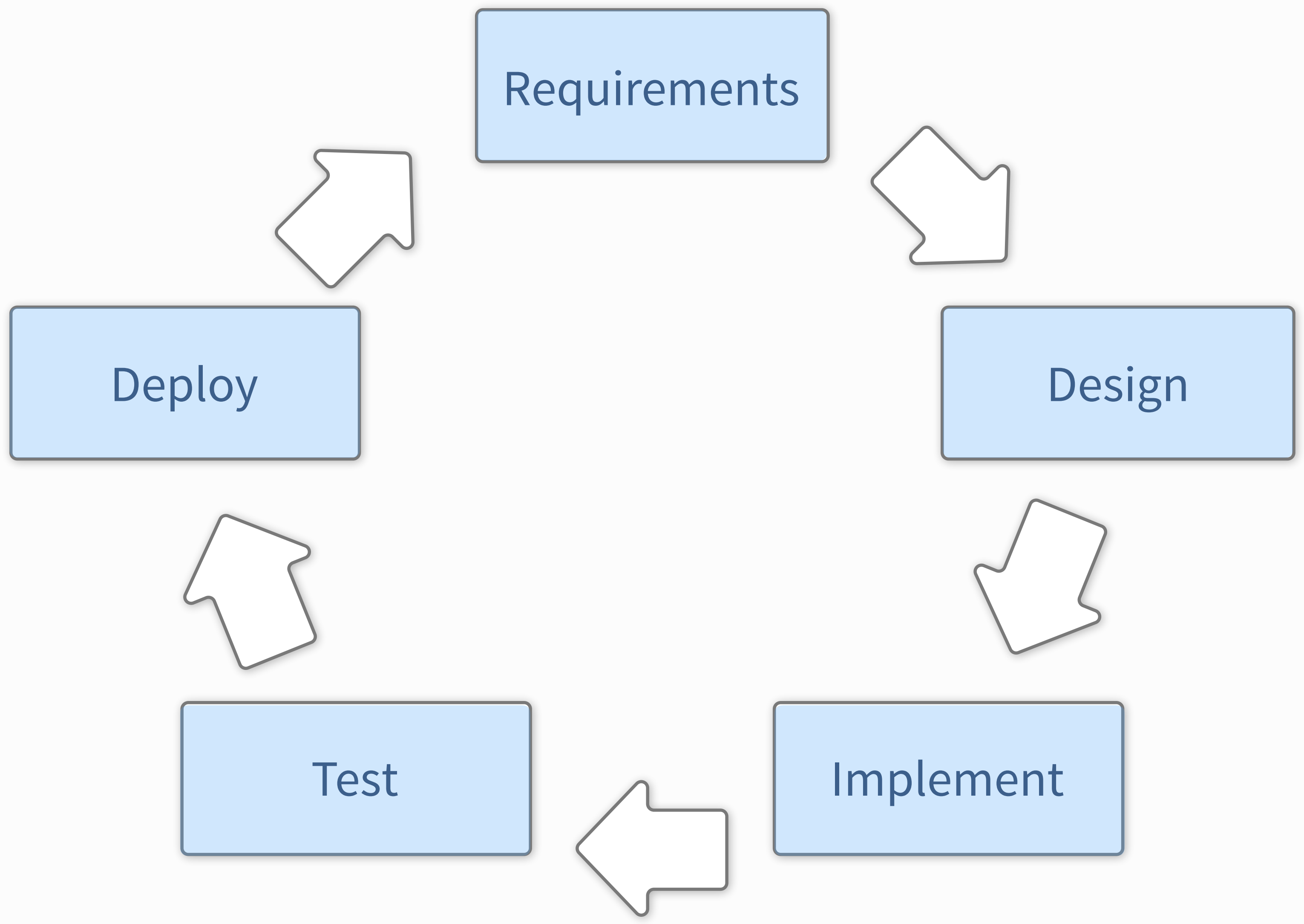

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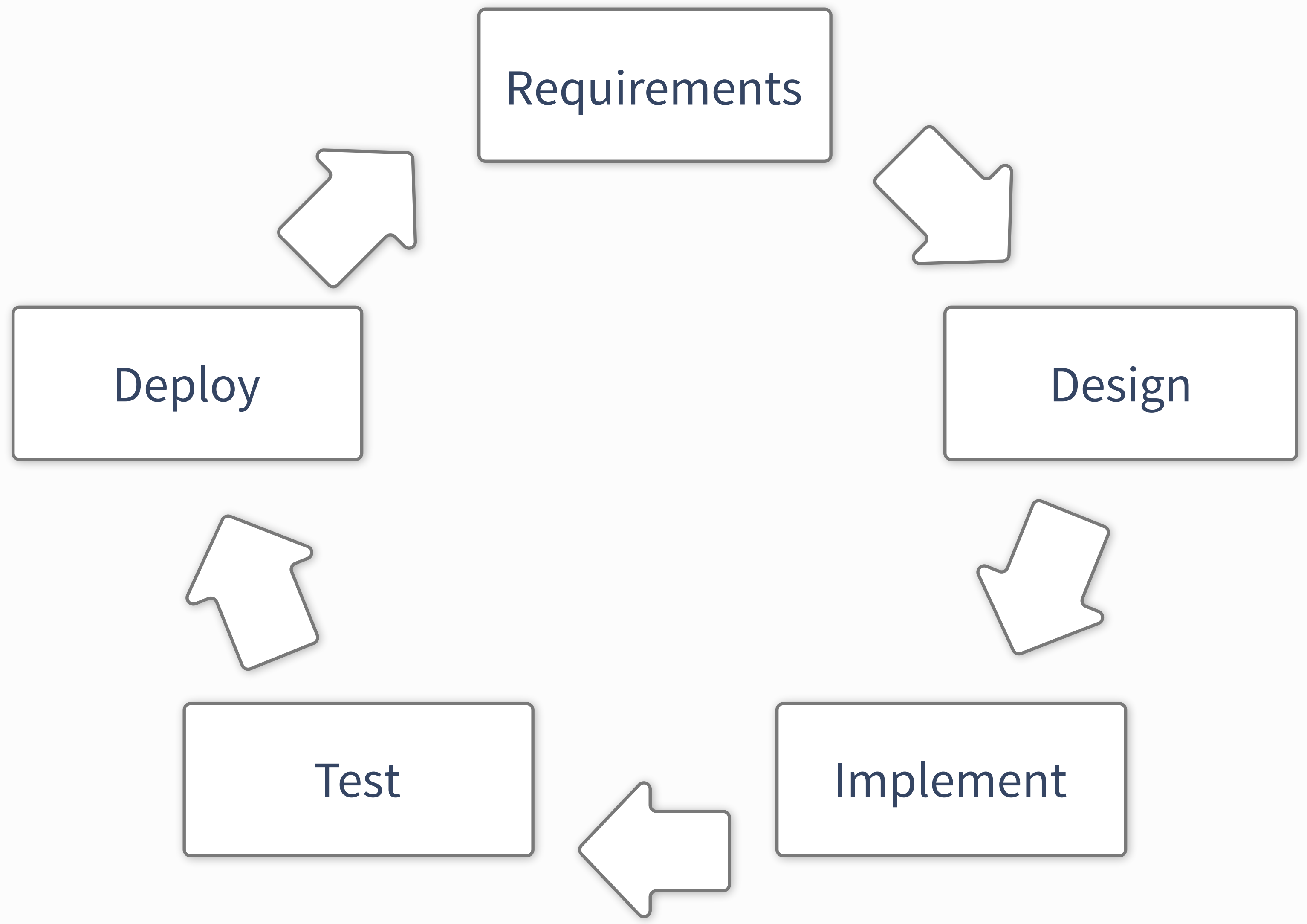

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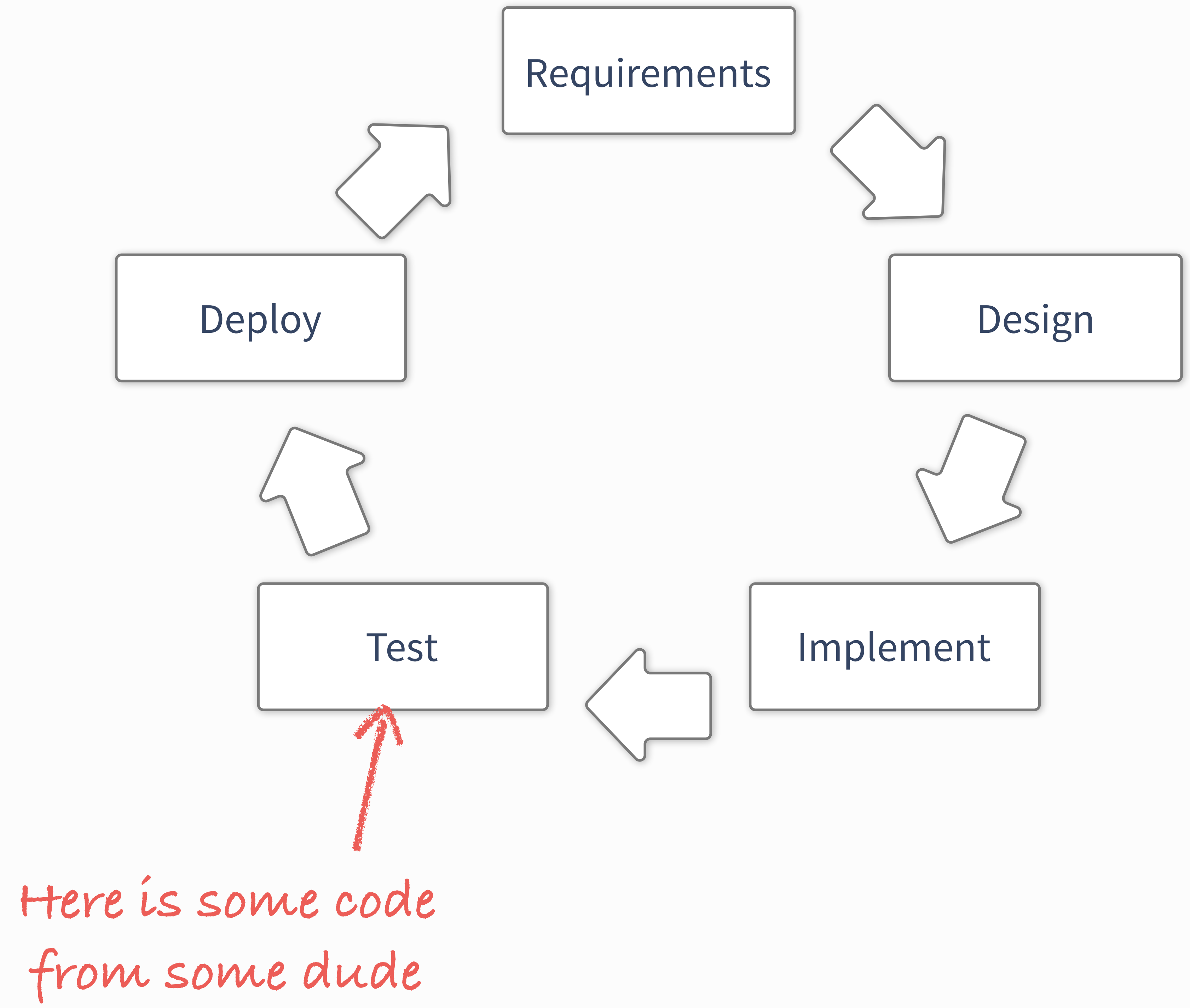

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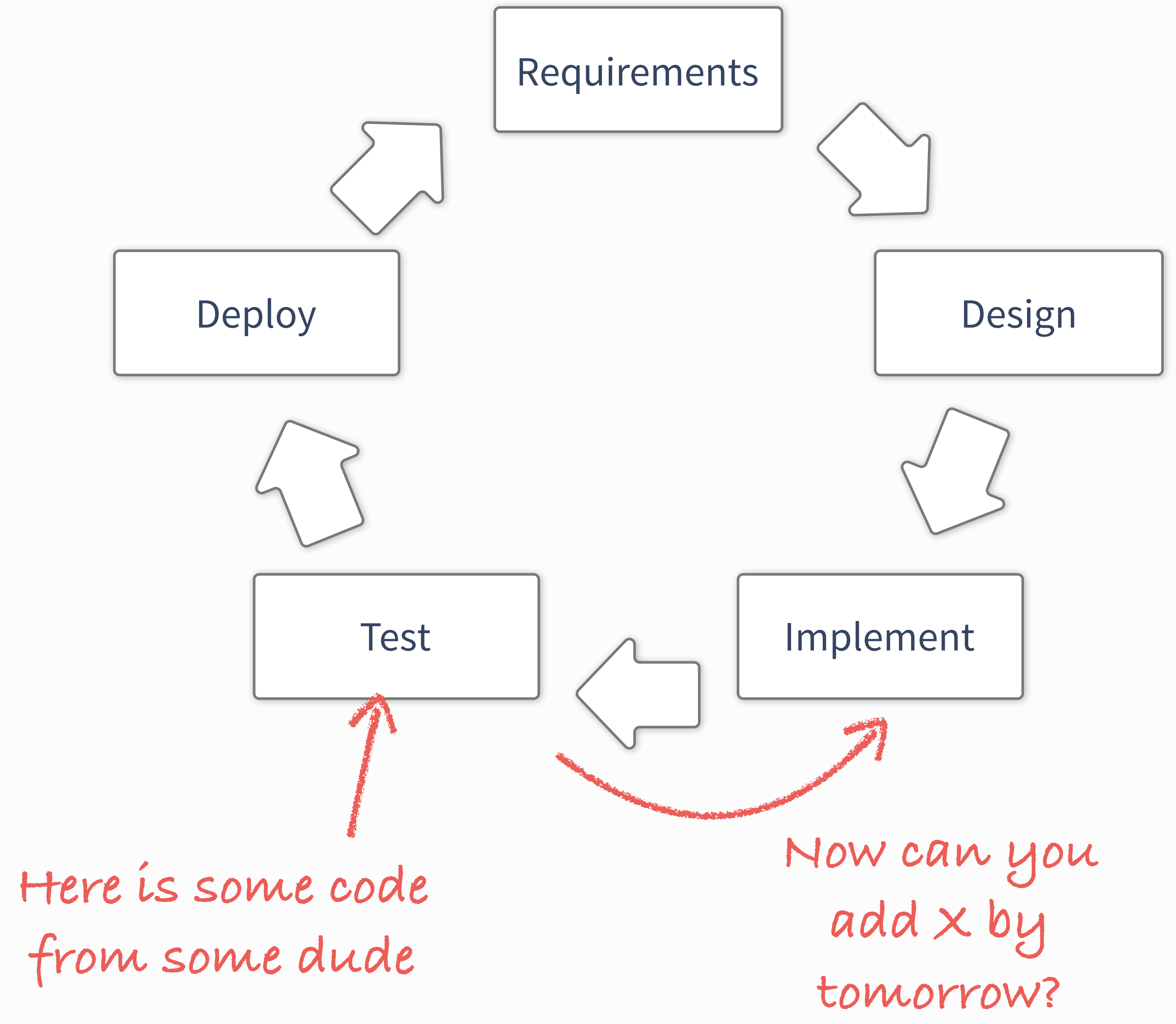
  - by patching some files



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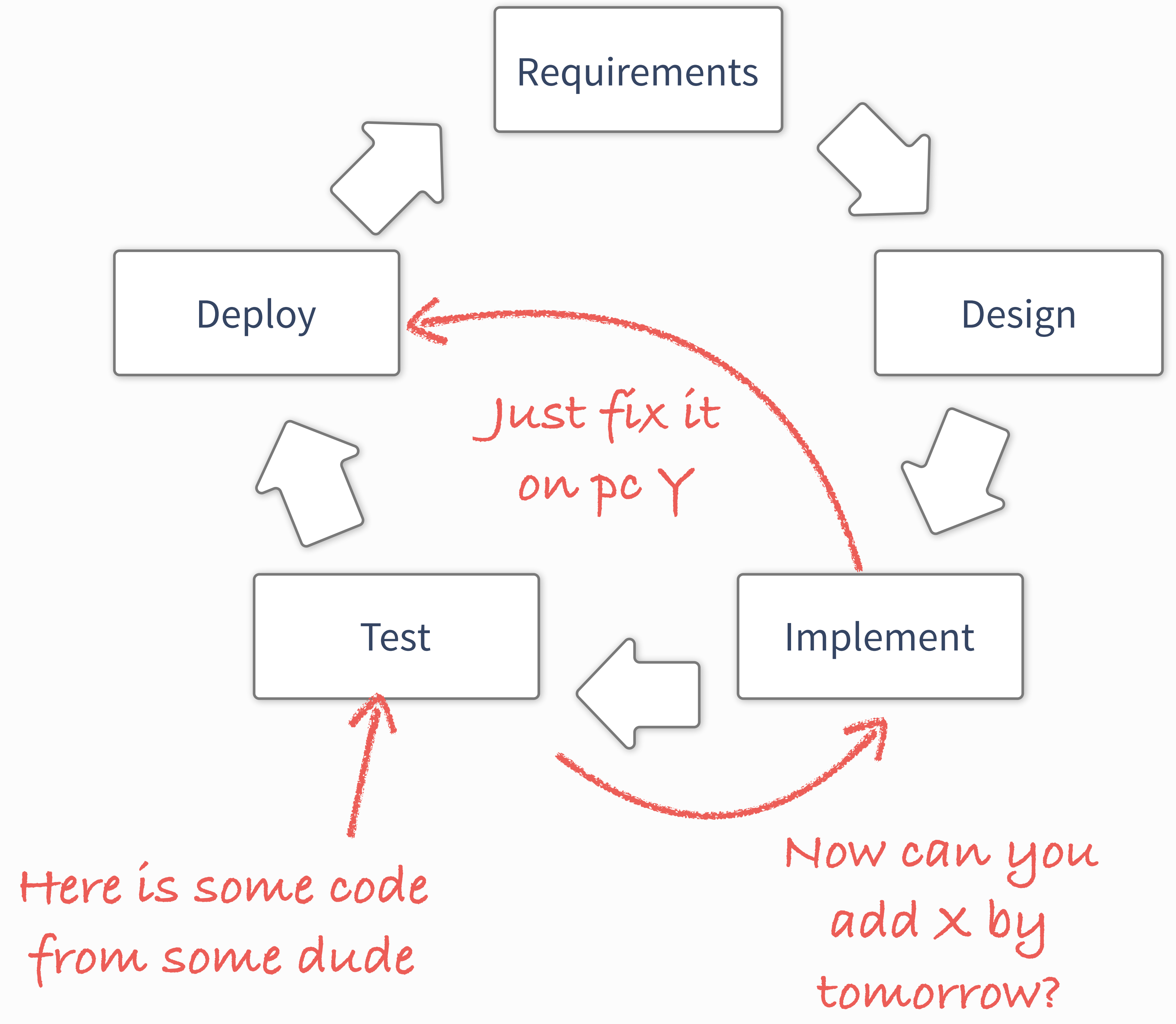

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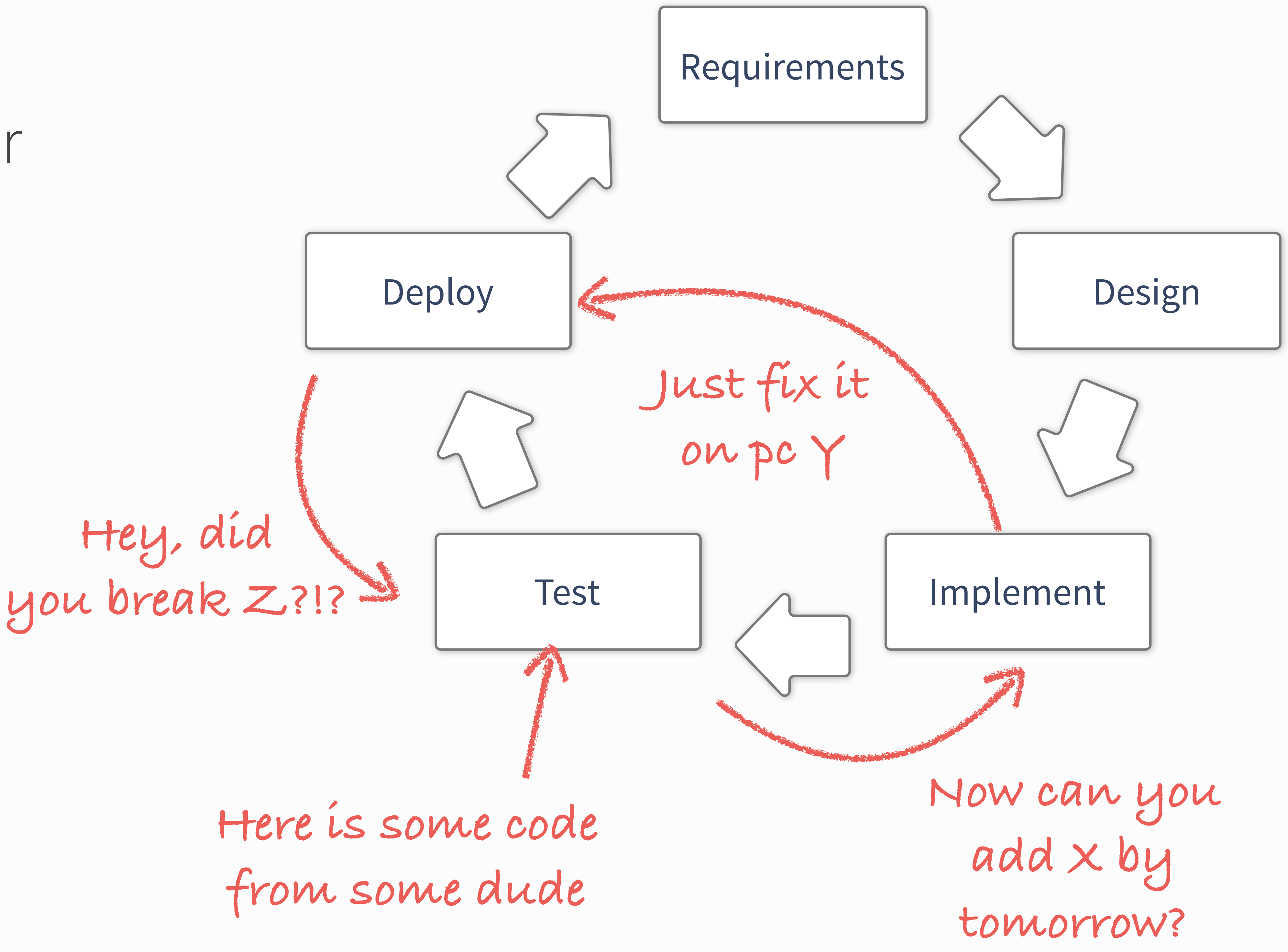

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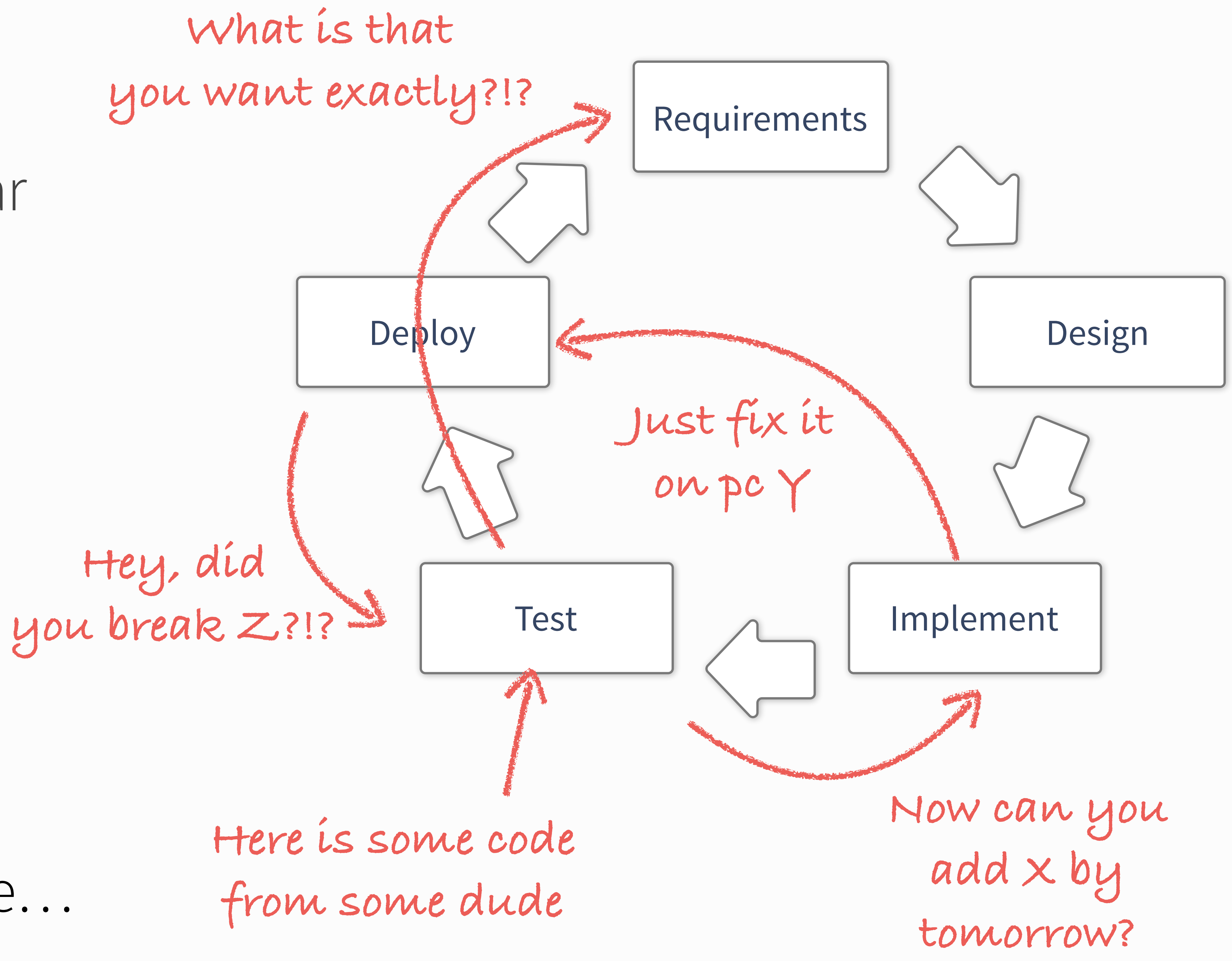

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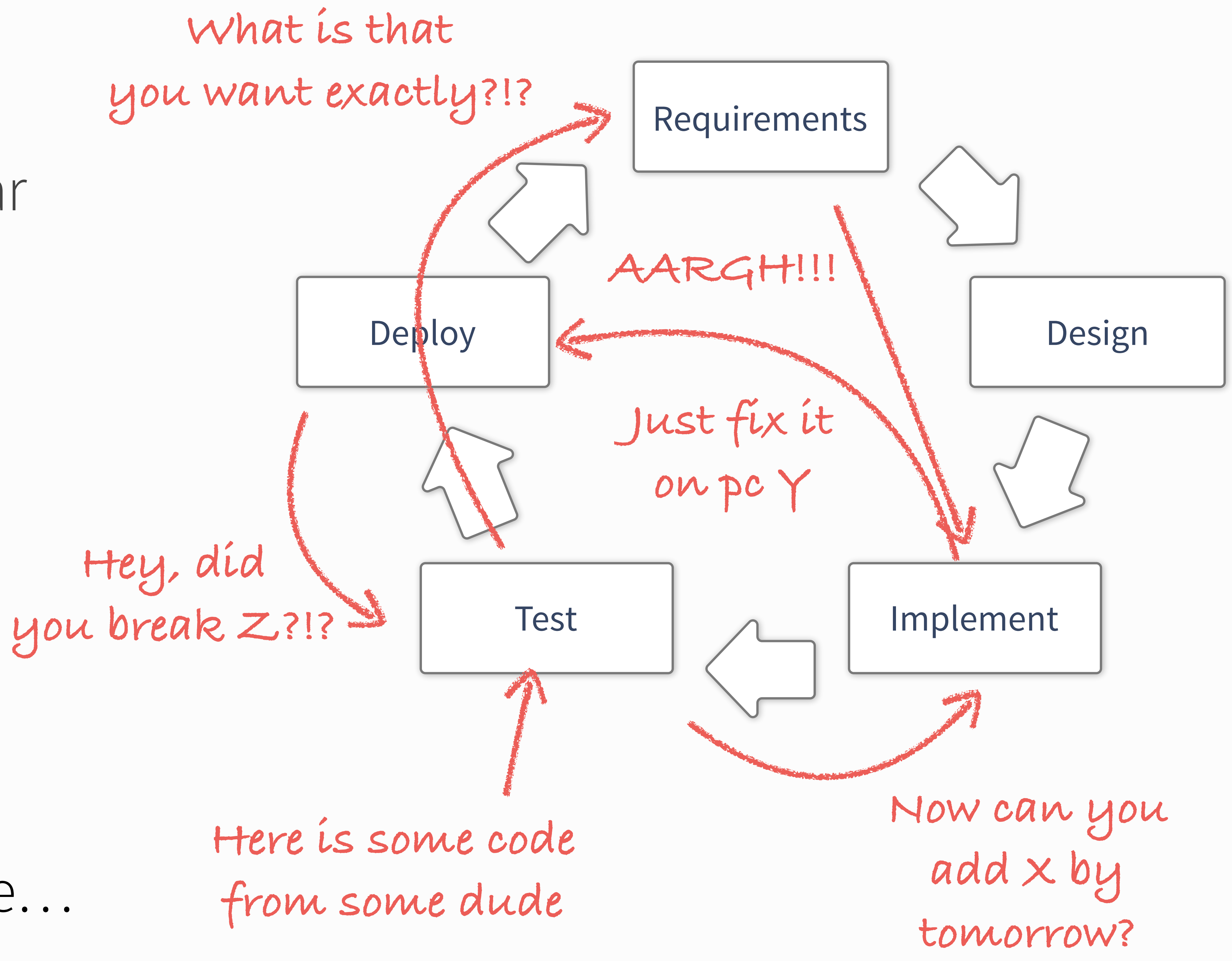
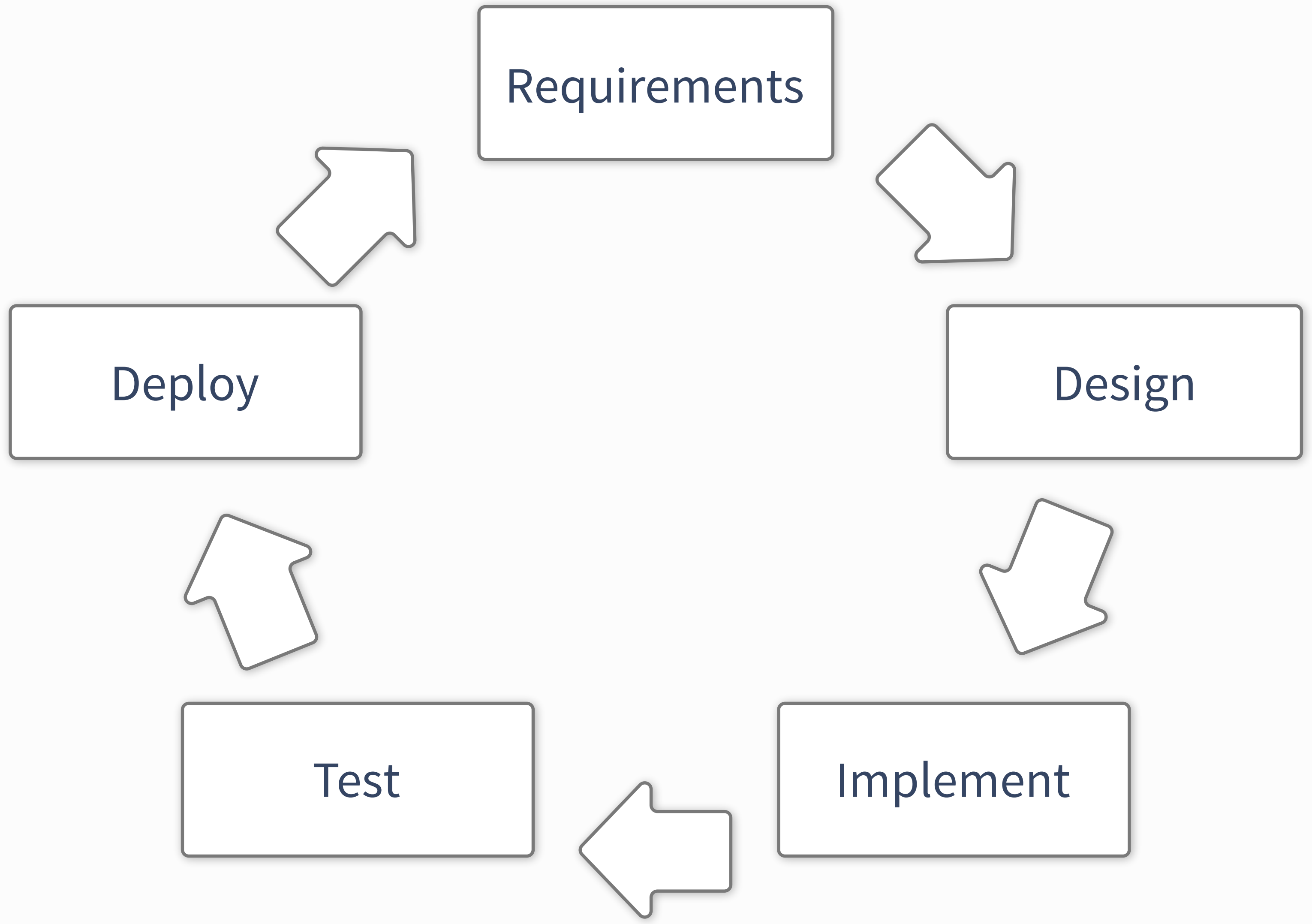


(some) Typical programming contexts



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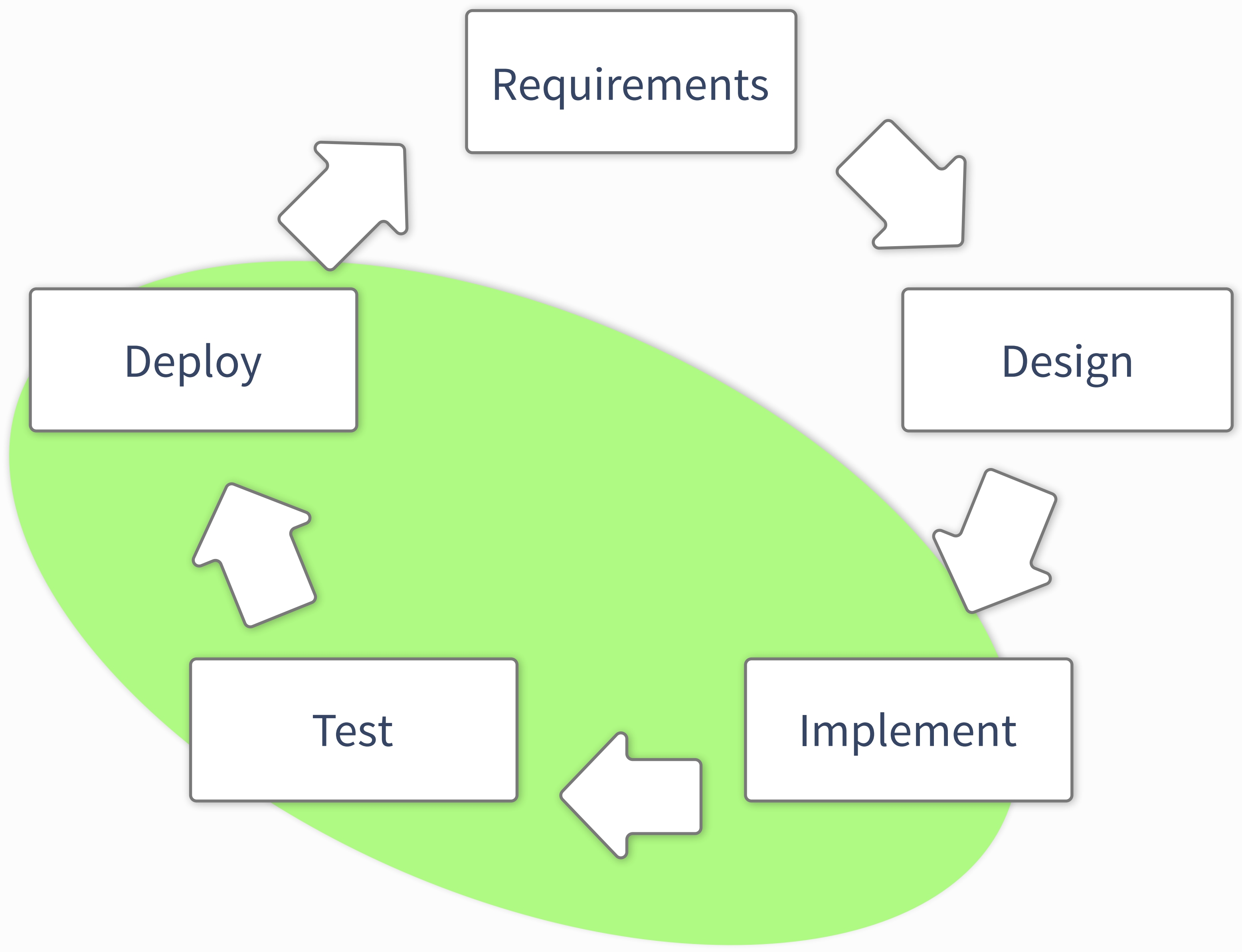
Small projects

- Shortened dev-cycle: Implement, Test, Deploy
  - Requirements and design already defined
- Mostly self contained
  - no /few external interfaces and dependencies
- Few developers (typically 1)



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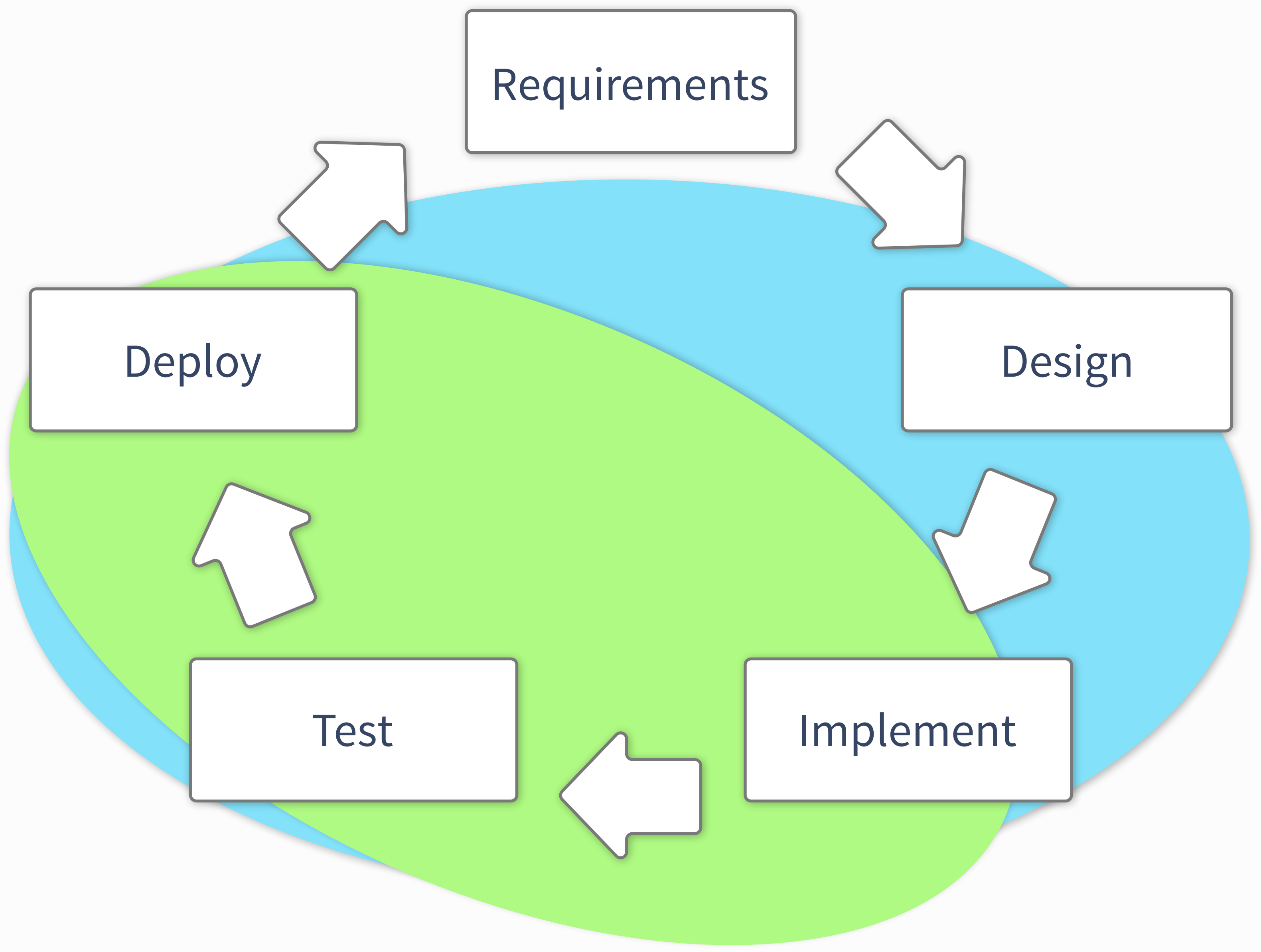
Medium projects

- Design becomes unavoidable
- Well defined interfaces and dependencies
  - e.g. external frameworks
- Many developers
- Maintenance issues make their appearance



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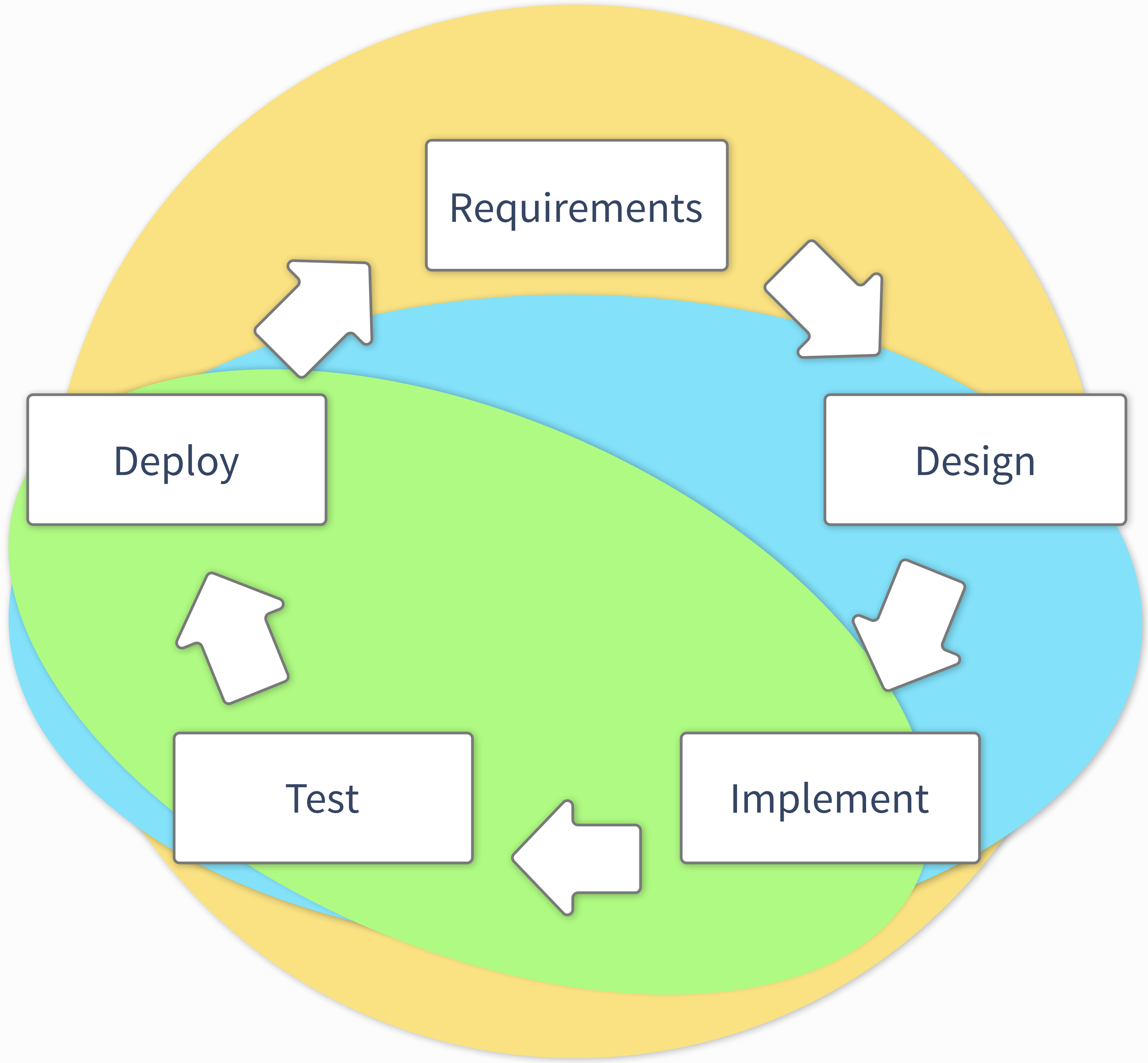
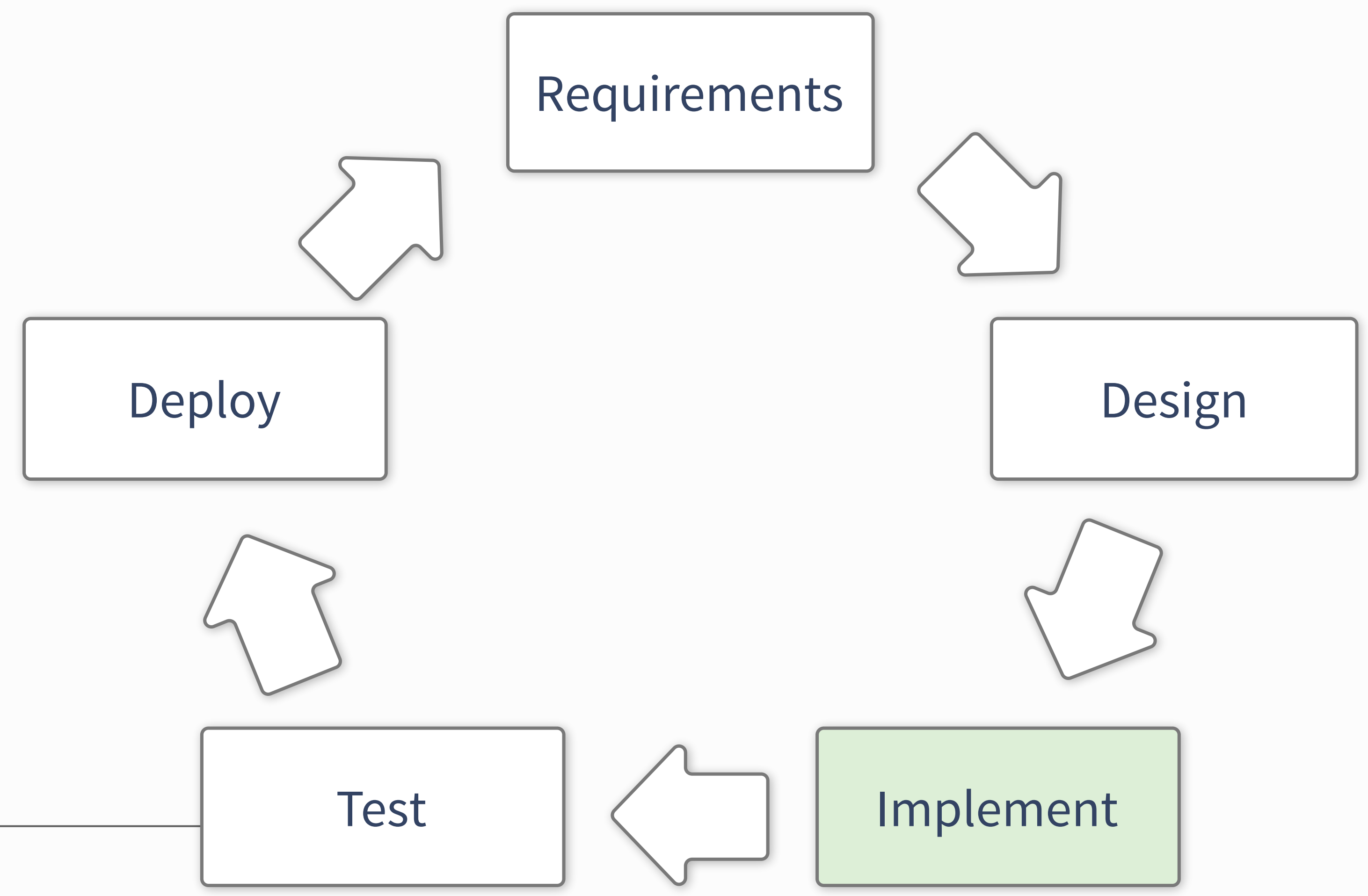
Large projects (TDAQ)

- Requirements become crucial
- Many interfaces, complex dependencies
- Sizeable userbase
  - Support becomes your worst nightmare



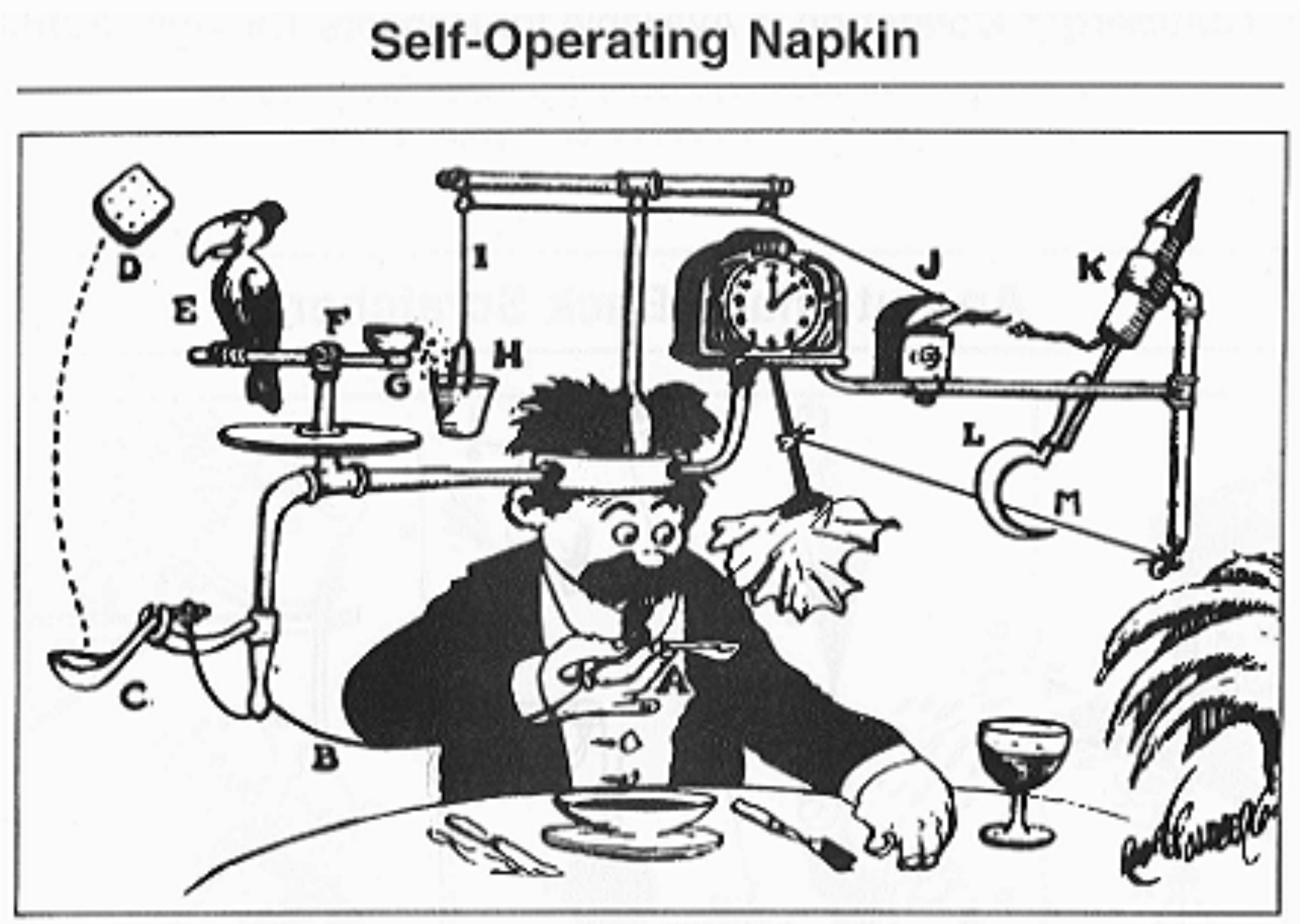
Implementation



Check for existing solutions

Do not reinvent the wheel

- Many problems have already been solved
- (Sometimes necessary — avoid dependencies)
  - Do not reject a library because of too many features
- Look for libraries where:
  - Active community? Well maintained? Tested?
  - Rule of thumb: Last commit a few days ago, most over a year old



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

Getting to know new frameworks:

- Before asking for advice: Try the simple tools
  - Read the docs (RTFM)
    - Investing time in the beginning will pay off
  - Are there wikis? Has it been asked on StackOverflow?
  - python packages: try the ipython “help”

- Start with a simple test
  (existing examples -> what you want to do)
  - Does the code do what you expect?

before looking at external libraries:
Look at the STL / python standard library

Avoid feature bloating

If you try to do everything at once:

- You'll probably end up doing nothing right
- Generalising a problem before solving it: Probably not a good idea
  - Only do it when you have a use case
- **Write dedicated tools / libraries**

Define features by writing a test that needs to be passed

- Do not implement more than you need to pass that test.

Be pragmatic

- Only do the abstract cases when it is likely that they will be used
- Try to make everything as concise as possible (maintain readability)
- **Keep it simple!**

Don't reinvent an existing wheel

Tools of the Trade: Editor, Terminal and IDEs

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

- Editor
  - Know* at least one "always" present editor: **`nano`**, **`vi(m)`**, **`emacs`**, etc.
  - More modern solutions: May have some benefits
  - Depending on the language / platform (e.g. Java): IDEs are a better choice **Eclipse**, **Netbeans**
- 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 know how to save and exit :)
for the more daring: try **`ed`**

A few words on editors: Choose what suits you and be effective

The choice of editor is yours…

- 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

However: Alternatives exist that have a less steep learning-curve

- Most of them are commercial solutions (Sublime Text, TextMate,…)
- Open alternatives: github's Atom & Microsoft's VSCode
  - Plugins, git integration, active communities, more plugins…

Once you decided which one is best for you:

- Spend some time learning about it's features and keybindings
- Many things that might require dozens of keystrokes can be done with 2 (5 in emacs ;))
- Learn about: Linters, extensibility — look at existing plugins

vs

* from http://en.wikipedia.org/wiki/Editor_war

Use what is comfortable and learn to be efficient

The Terminal - Get used to it

At the beginning might think: Quicker with GUI, don’t need terminal

- After learning about some command line tools… probably not
- What if you don’t have a GUI?

Searching files: grep, find — example:

```
$ find . -name "*.cc" -exec grep -A 3 "foo" {} +
```

- Displays all matches of “foo” (+3 lines below) in all .cc files from the current work dir

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 just be dumped in a script
- Alternative: Can solve most things more conveniently with an interpreted language
  - Con: interpreters / bindings might not always be available

* dump the last 100 steps:

```
$ history | tail -n 100 > steps.txt
```

log the terminal “responses”:

```
$ script # press ctrl+d to stop
```

tune your bashrc / bash-profile
see additional material

Interlude: Working on the go — SSH

SSH — might be more versatile than you think:

- Tunneling
  - Secure connections to other machines
  - Use with VNC to avoid man-in-the-middle vulnerability
- Generate keys for authentication
- Working around bad latency / shaky connection
  - Always use **`tmux`**/**`screen`** or similar
  - Alternative: mosh (https://mosh.mit.edu/)
    - allows intermittent connectivity, roaming and more…

SSHFS (AFS)

- Work locally but have files on remote host

SSH tunnel for VNC connection:

```
ssh -L 5902:<VNCServerIP>5902 <user>@<remote>\
   vncserver :<session> -geometry\
   <width>x<height> -localhost -nolisten tcp
```

SSH authentication via kerberos token. In ~/.ssh/config:

```
GSSAPIAuthentication yes
GSSAPIDelegateCredentials yes
HOST lxplus*
    GSSAPITrustDns yes
```

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

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

The right tool for many jobs - interpreted languages

Make your code as short as possible

while maintaining readability

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

```python
from __future__ import print_function
from argparse import ArgumentParser

parser = ArgumentParser(description="Get number of days")
parser.add_argument("month", type=str, nargs='+', help="Name of month")
args = parser.parse_args()

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}

for usermonth in args.month:
    if usermonth in months:
        print("{0} has {1} days.".format(usermonth, months[usermonth]))
    else:
        print("sorry. month '{0}' not known.".format(usermonth))
```

Easy to read

Easier to maintain; Easy to re-use

Interlude: iPython

```
> ipython
 In [1]: import array
 In [2]: help (array)
```

Interlude: iPython

```
ArrayType = class array(__builtin__.object)
 |  array(typecode [, initializer]) -> array
 |
 |  Return a new array whose items are restricted by typecode, and
 |  initialized from the optional initializer value, which must be a list,
 |  string or iterable over elements of the appropriate type.
 |
 |  Arrays represent basic values and behave very much like lists, except
 |  the type of objects stored in them is constrained.
 |
 |  Methods:
 |
 |  append() -- append a new item to the end of the array
 |  buffer_info() -- return information giving the current memory info
 |  byteswap() -- byteswap all the items of the array
 |  count() -- return number of occurrences of an object
 |  extend() -- extend array by appending multiple elements from an iterable
 |  fromfile() -- read items from a file object
 |  fromlist() -- append items from the list
```

Interlude: iPython

```
> ipython
 In [1]: import array
 In [2]: help (array)
 In [3]: import ROOT
 In [4]: help (ROOT.TH1D)
```

Interlude: iPython

```
class TH1D(TH1, TArrayD)
 |  Method resolution order:
 |      TH1D
 |      TH1
 |      TNamed
 |      TObject
 |      TAttLine
 |      TAttFill
 |      TAttMarker
 |      TArrayD
 |      TArray
 |      ObjectProxy
 |      __builtin__.object
 |
 |  Methods defined here:
 |
 |  AddBinContent(self, *args)
 |      void TH1D::AddBinContent(int bin)
 |      void TH1D::AddBinContent(int bin, double w)
```

Interlude: iPython

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> ipython
 In [1]: import array
 In [2]: help (array)
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 In [4]: help (ROOT.TH1D)
 In [4]: run myscript.py
```

Documentation: Do it while it's fresh

Two sides of the same coin: Internal and external documentation

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

Internal 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"
- Clean code: You write it once and you read it many times

External documentation:

- Again: Explain your interfaces (can be derived from internal, e.g. doxygen.org)
- For large projects: Explain the big picture
  - Wiki pages with use-cases and examples
  - Consider using UML (unified modelling language)

```
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...
```

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```

Document while coding

You write it once, read it many times

Write build scripts to ease your life

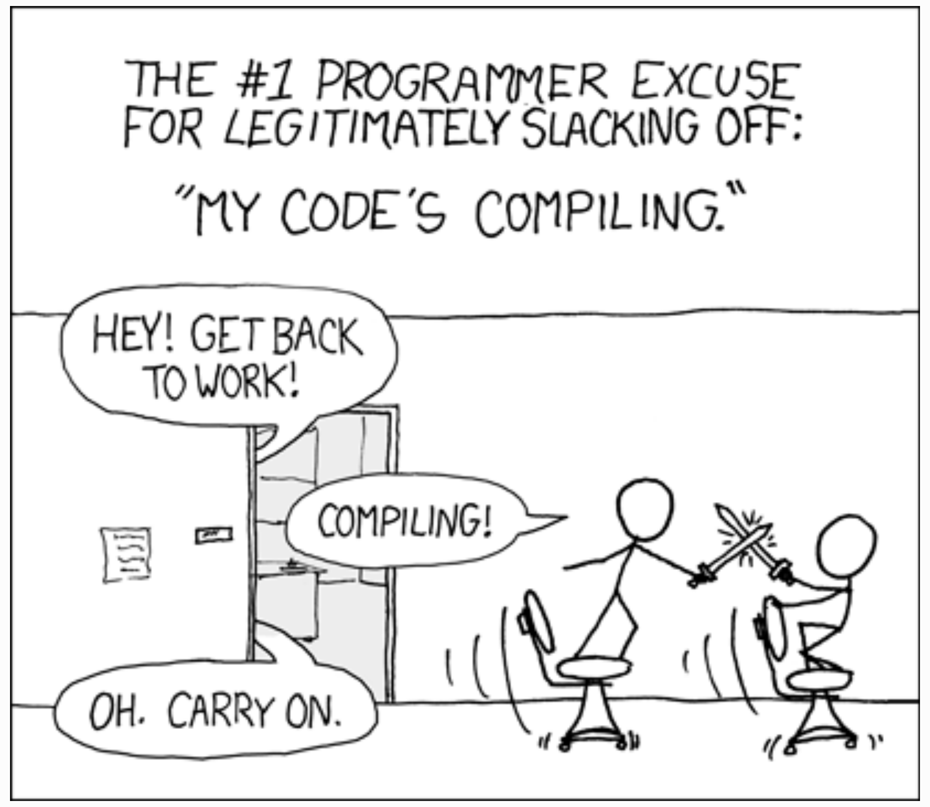
Makefiles — makes compilation **easier and faster**

- Makefiles might look complex
- More than one source file: Useful!
  - Again: Think about yourself in 2 years
- Write your own for a small project
- Automatically allows parallel compilation (option -j)

```
CC=clang++
CCFLAGS=-Wall -pedantic -std=c++14
SOURCES=src/howmanydays.cc
OBJECTS=$(SOURCES:.cc=.o)
EXE=howmanydays

all: $(SOURCES) $(EXE)

$(EXE): $(OBJECTS)
	$(CC) $(CCFLAGS) $(OBJECTS) -o bin/$@

%.o: %.cc
	$(CC) $(CCFLAGS) -c -o $@ $<

.PHONY: clean all
clean:
	rm -f $(OBJECTS) bin/$(EXE)
```

Abstraction layer on top: CMake and others

- Might look like overkill; Makes things easier in the long run
  - CMake is easier to read and better documented
  - Improved **portability**
  - Support different build-systems: ninja, GNU make, ...
- At least you should learn how to compile with it



"Compiling" by Randall Munroe
xkcd.com

Debugging with the right tools

While running your code:

- printing to console: only suitable for (very) small code base
- Sooner or later have to use a debugger: gdb (GNU debugger) — get a stack-trace
  - basic commands: **`run`**, **`bt`**, **`info <*>`**, **`help`**
- Python debugger (**`pdb`***):

```
import pdb; pdb.set_trace()   # set a breakpoint
```

especially with ipython

General hints for debugging

- Segmentation violations due to memory management
  - Life-time vs. scope
  - Only use raw pointers when you have to!
    (I.e. when you know what you're doing and you need the performance)
  - Look at smart pointers (part of C++11/14 standards, alternative: boost)
- Even if you don't have crashes: Memory Leaks. Try **`valgrind`** (valgrind.org)

* or rather its civilised counterpart **`ipdb`**

Static Code Checking

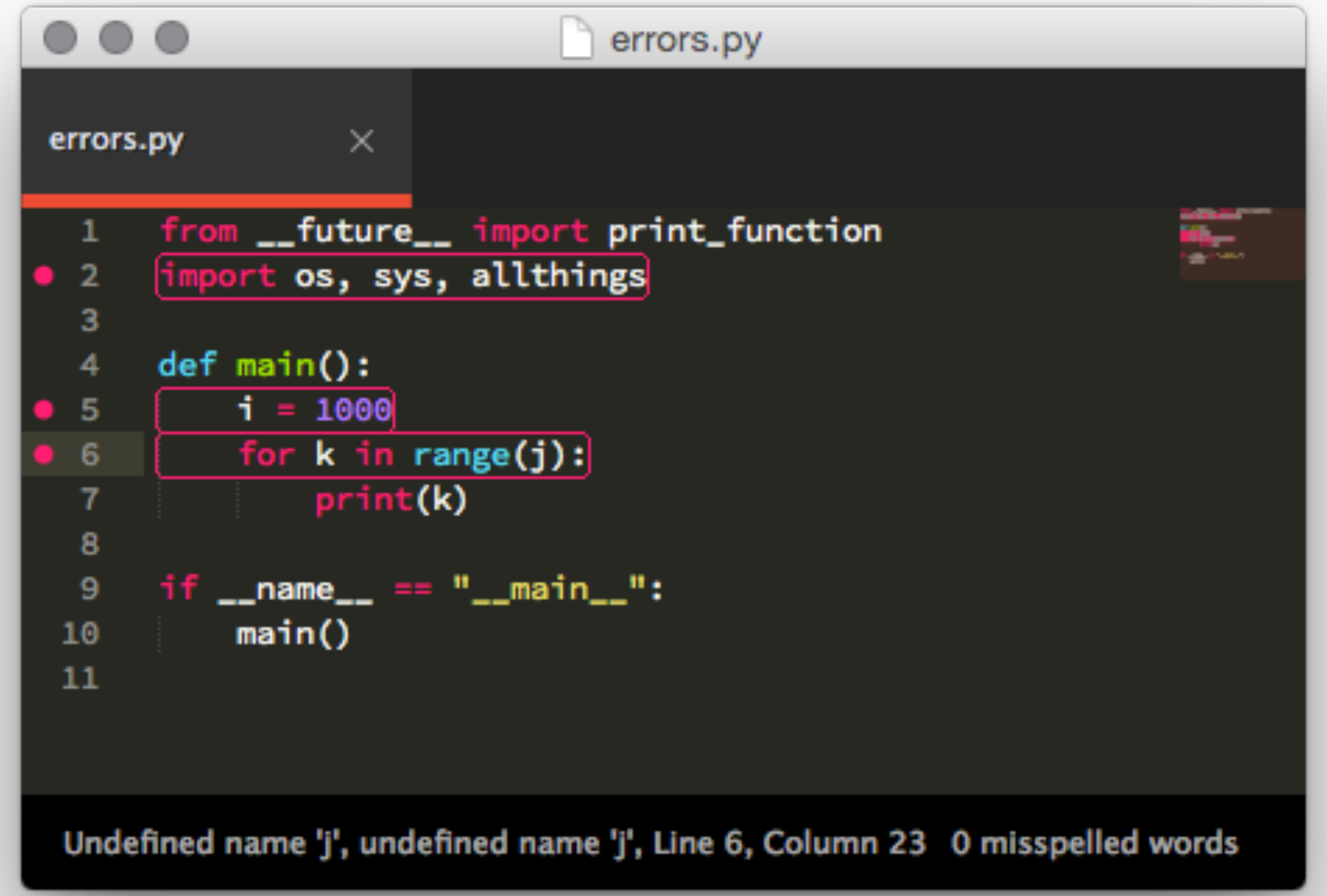
While writing your code:

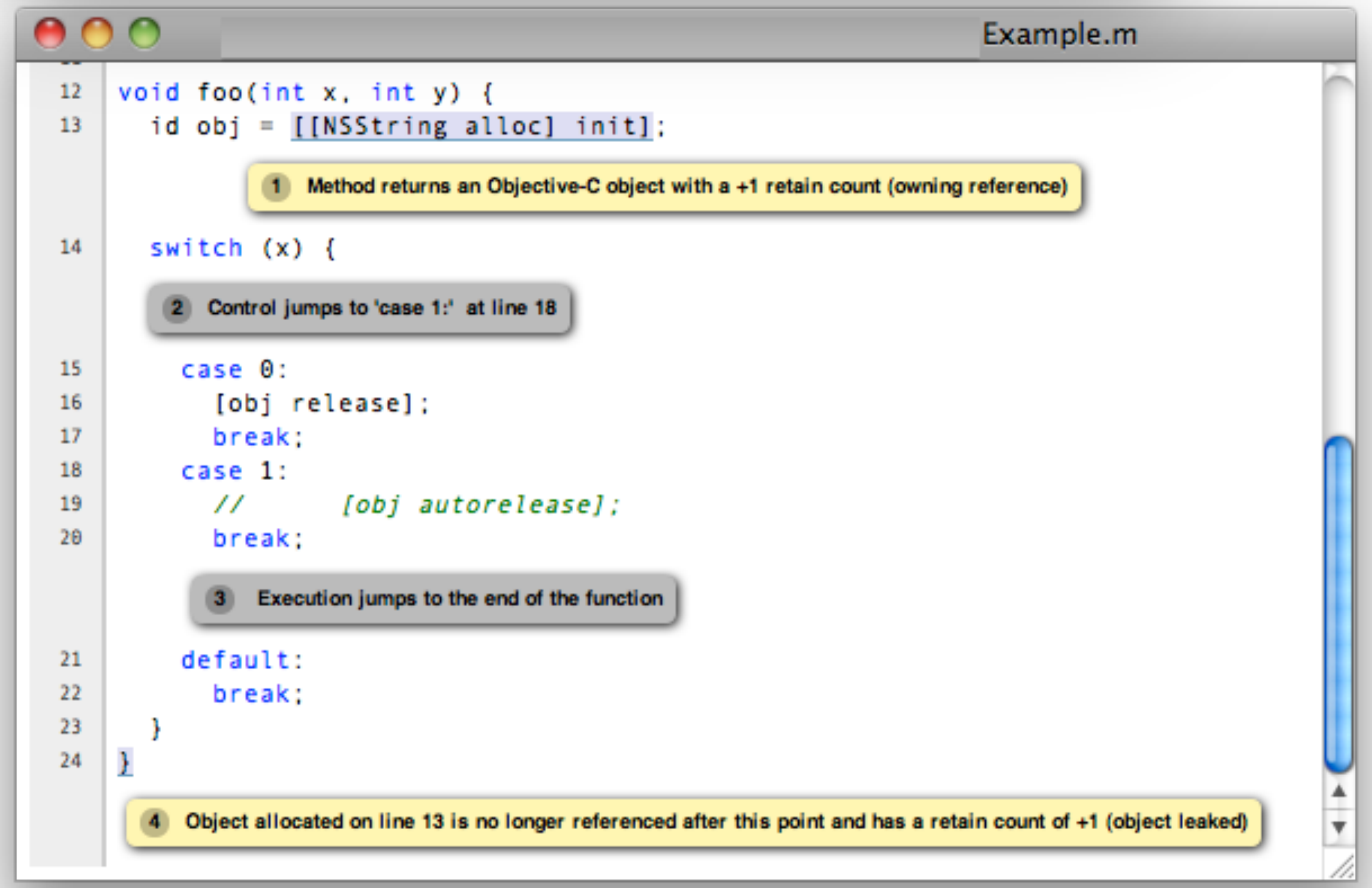
- There are static code analysis tools that can help you
- Try out a linter for your preferred editor (e.g. atom: https://atom.io/packages/linter)
  - Highlights potentially problematic code
  - Your code will be more reliable

Static checking at compile time:

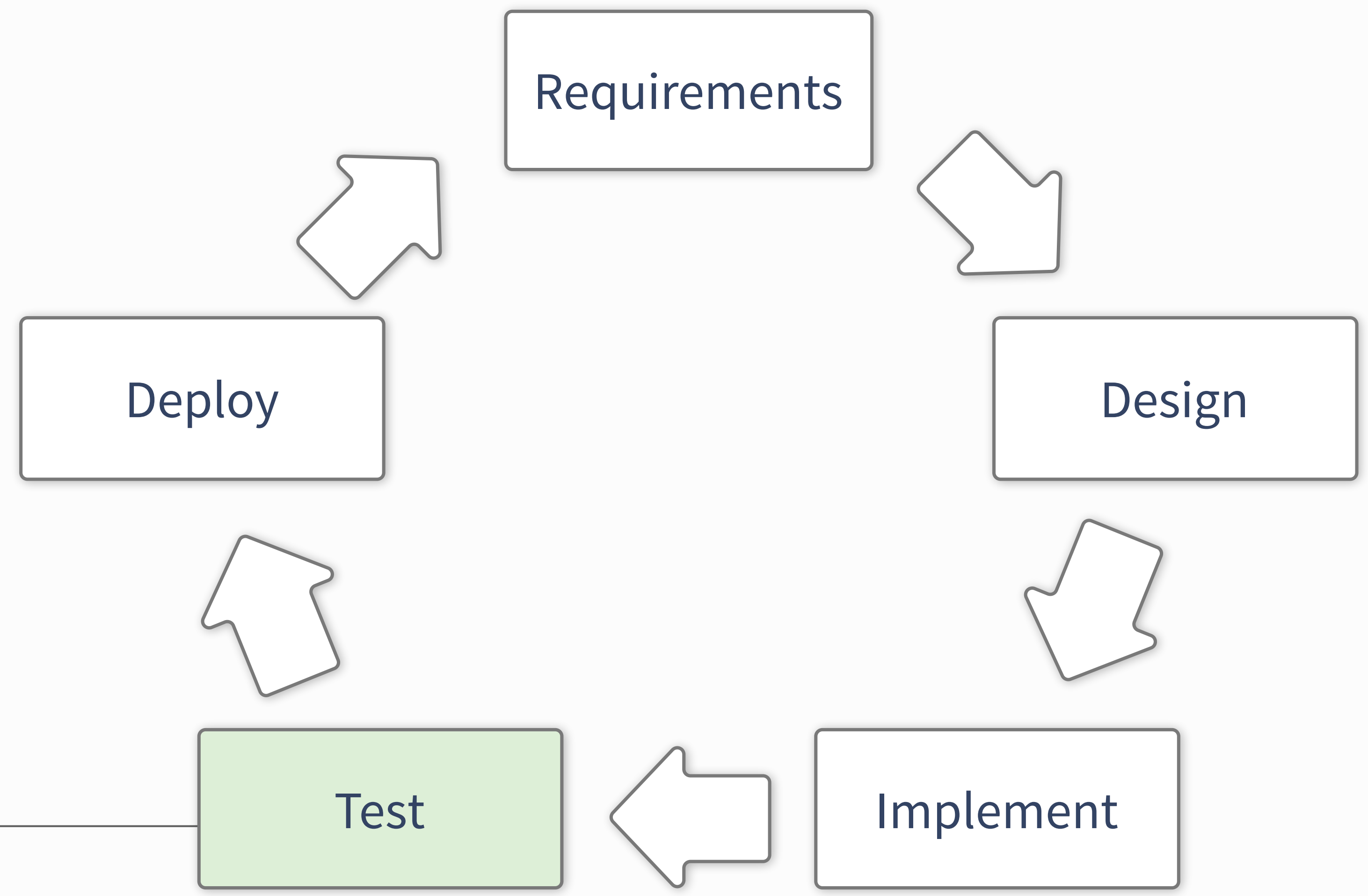
- Clang has a nice suite of static checks implemented http://clang-analyzer.llvm.org
  - Can also enforce coding styles
- Takes longer than compiling; HTML reports with possible bugs
- Might flag some false-positives

Static code checking helps you avoid problems!





Testing



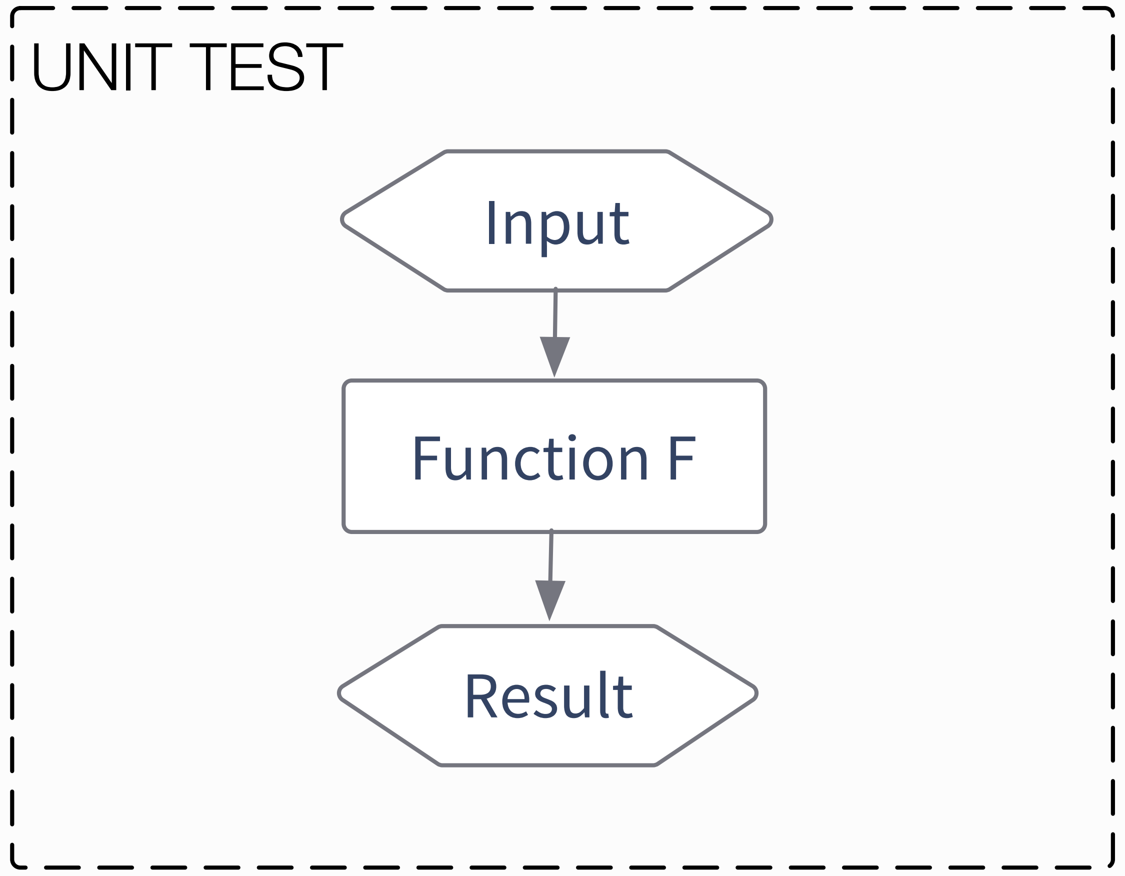
What do we mean with tests?

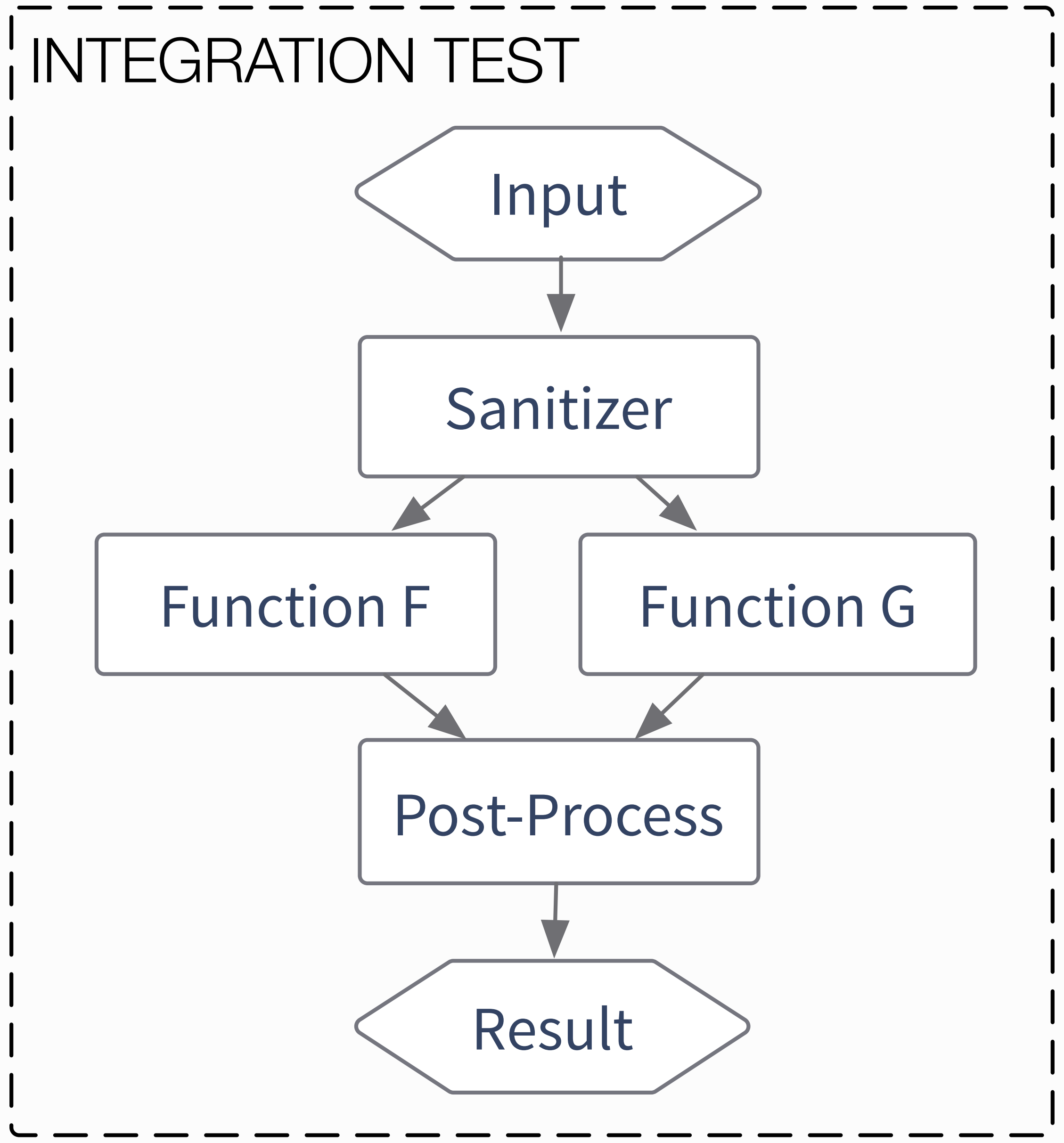
Different tests, different purposes:

- 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

Do not mix it up with verification

- Checking if specifications are met





Writing good tests is hard

How to come up with tests?

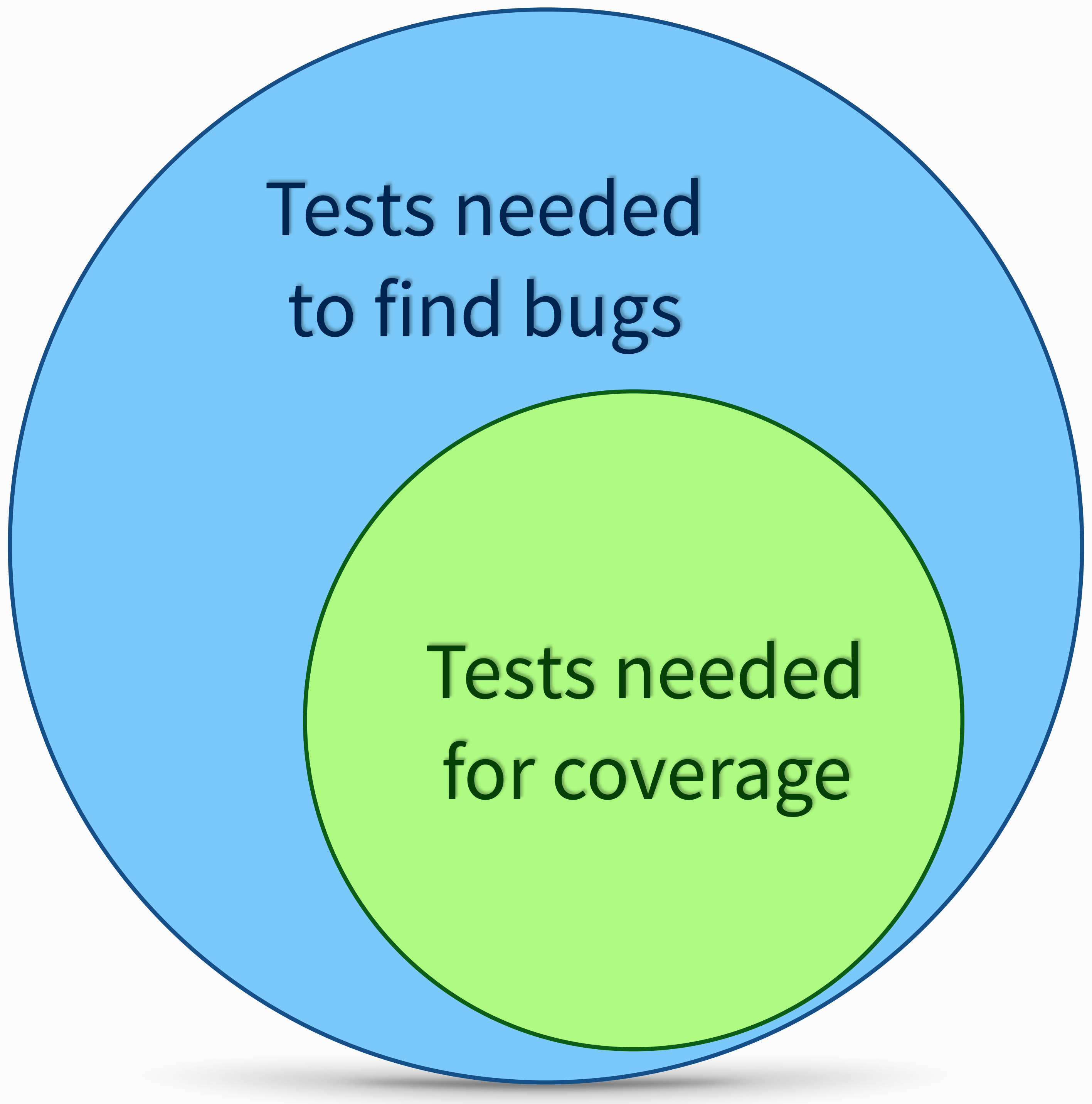
- What should the algorithm do?
  - Check if well defined input produces correct result
- How should the algorithm fail?
  - Check if wrong input fails in the way you want

You'll ~~probably~~ miss corner cases:

- Once you discover them, implement a test!
  - Only let a bug hit you once
- Have beta-testers / 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

```python
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
>
```

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def fib(n):
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Interlude: doctest

> python testfib.py -v

```python
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
```

```python
def fib(n):
    """ Returns the fibonacci series at n
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    a, b = 1, 1
    for i in range(n-1):
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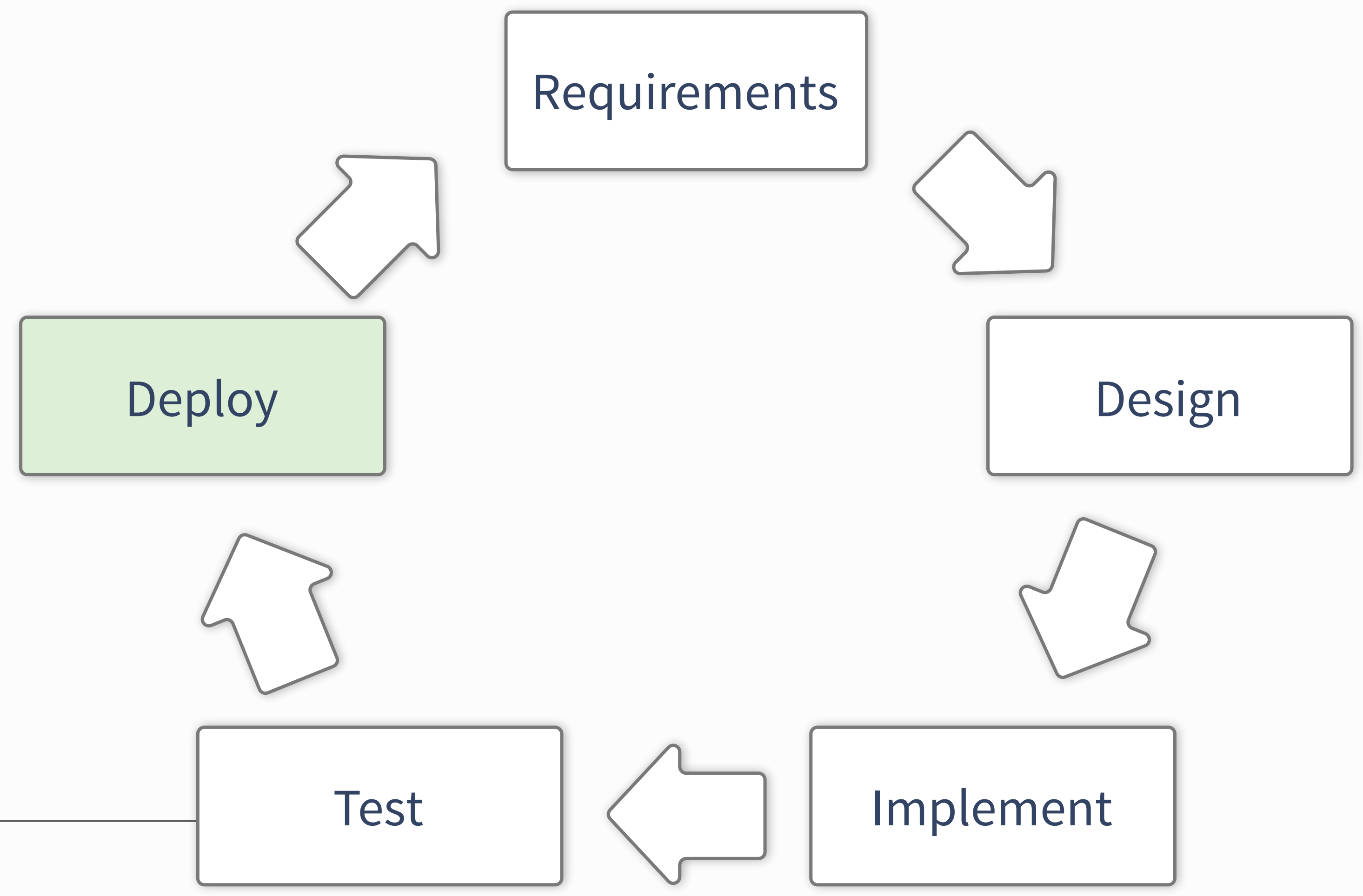
    return a

import doctest
doctest.testmod()
```

Test your software

and not just in production!

Deploying your software



Releasing the Software

When you release your software:

- Tag the repository
  - Ensure everyone has the same code
- Test in the target environment
  - Fresh virtual machine
- Accompanying documentation
  - Produce Doxygen pages
  - Update wikis (new version)
  - Make sure all examples work

Ideal case: All this is done every single night!

Continuous integration

Working in groups on software can be hard:

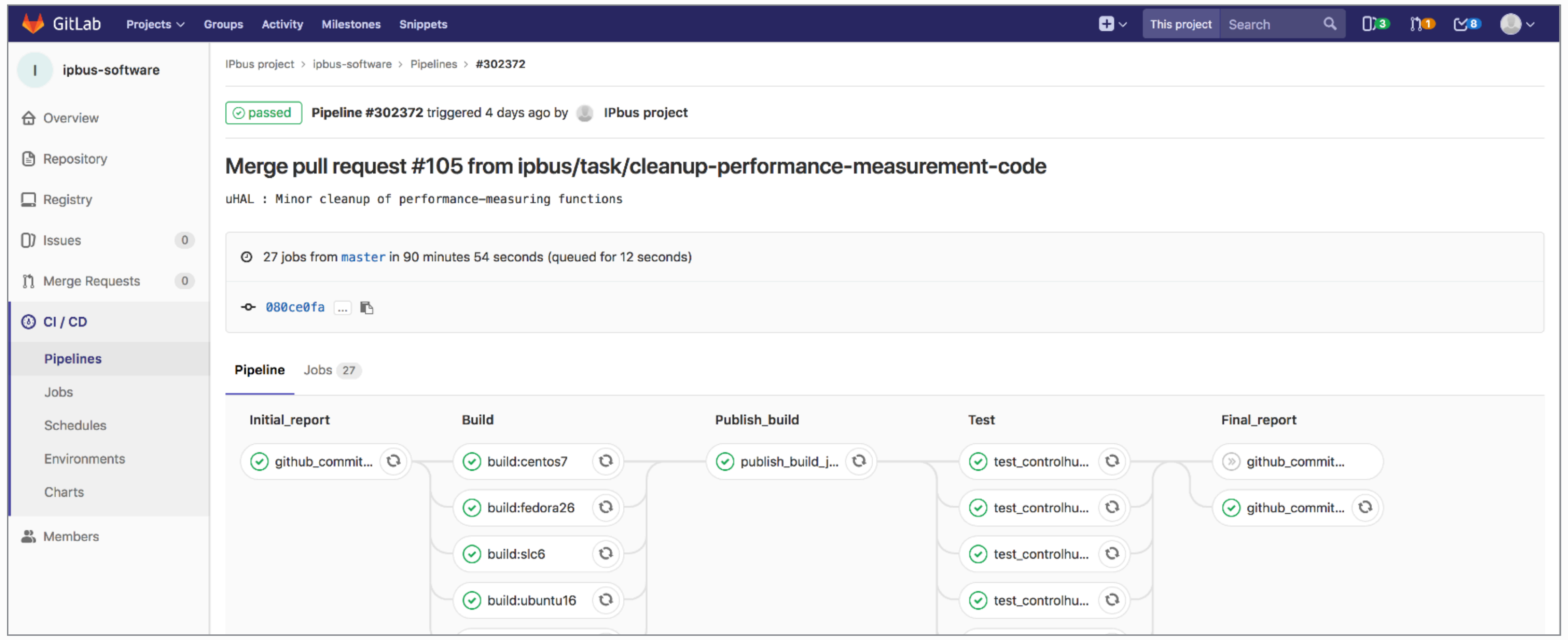
- Somebody changes something: Other code breaks
- **Avoid such nuisances by testing regularly!**

New contribution to the code base:

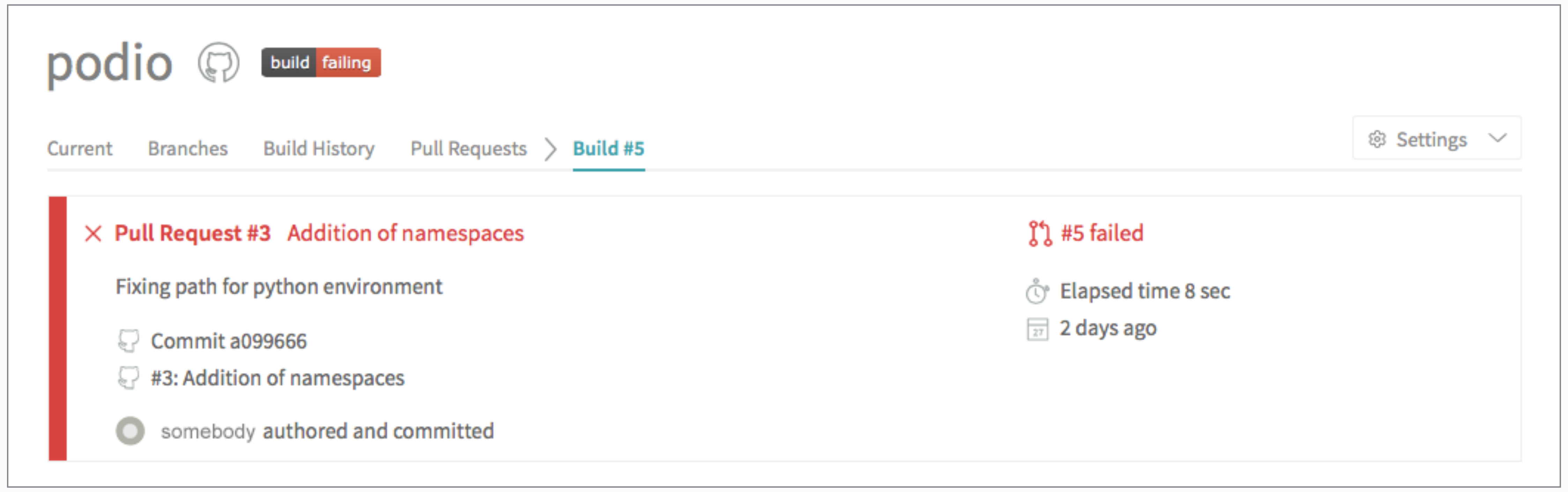
- Check everything works
  - Can do this by hand.. Tedious
  - Better: Automate it.

Many solutions exist that automatically test things:

- Check compilation
- Check all defined test cases
- Write nice summaries

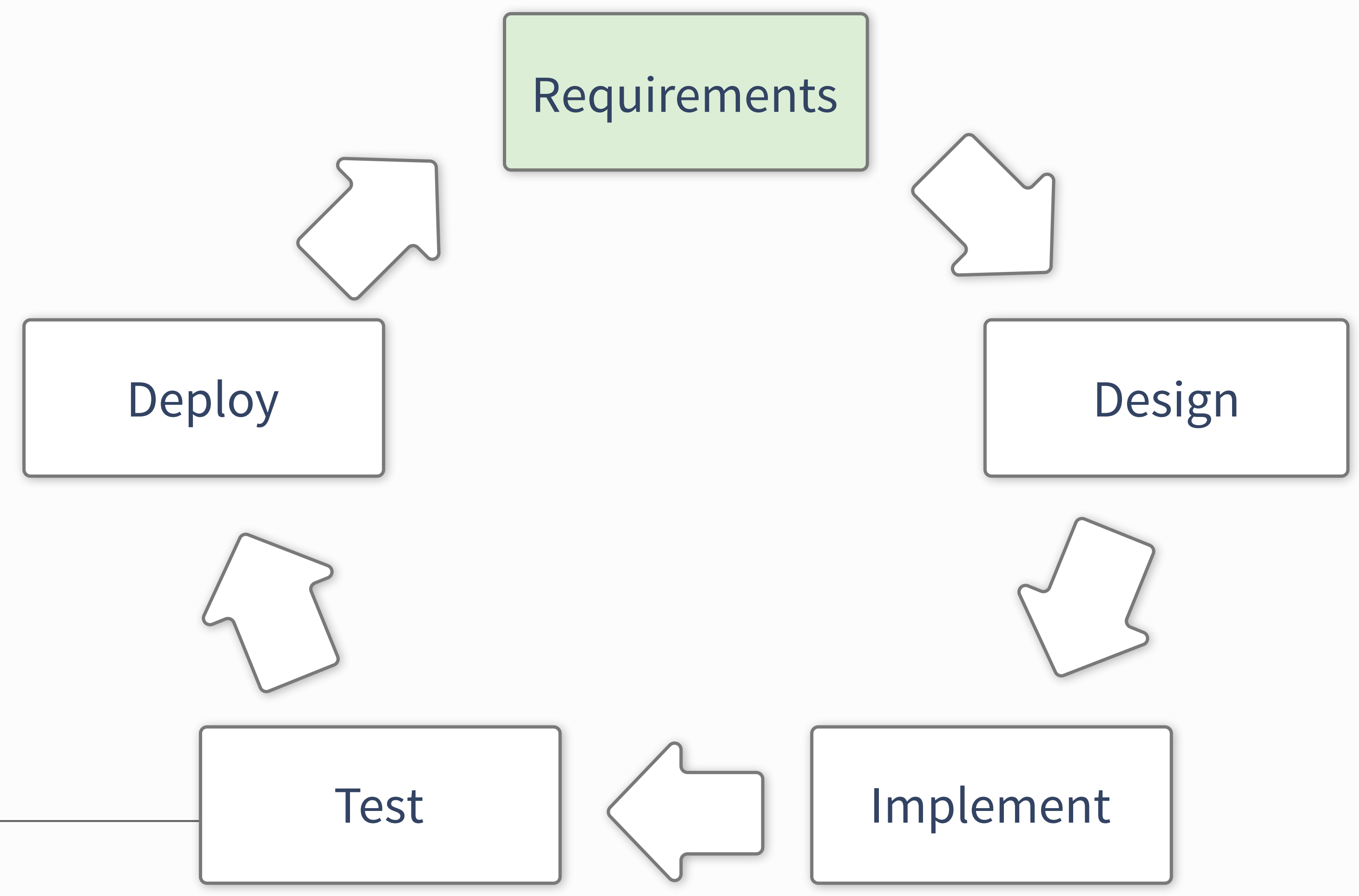


Gitlab CI - https://about.gitlab.com/features/gitlab-ci-cd/



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

Requirements

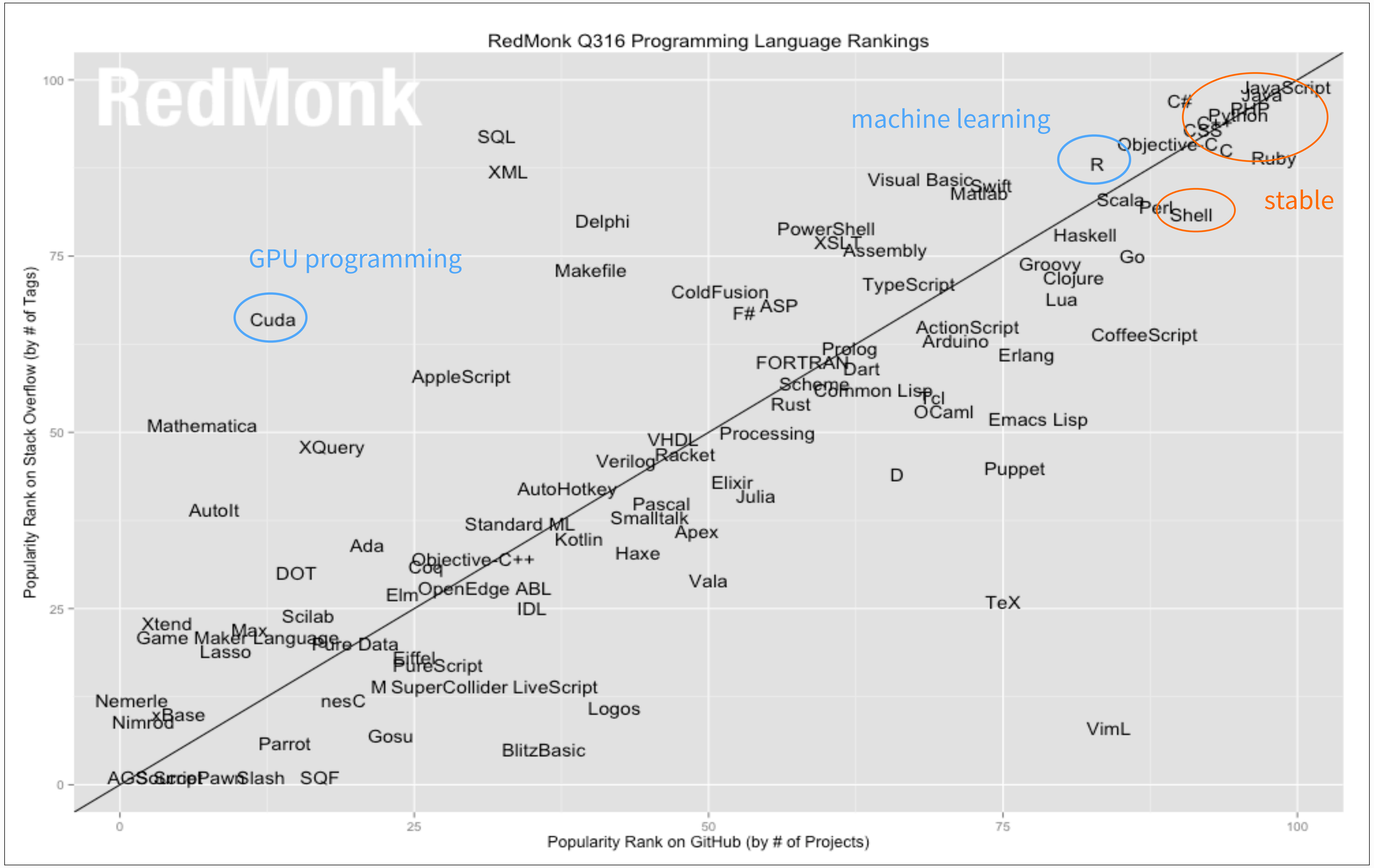


Choosing the programming language

The answer depends:

- Analysis?
- DAQ / Trigger?
- *External conditions?*
  - *Can you choose?*

Choosing the programming language



The answer depends:

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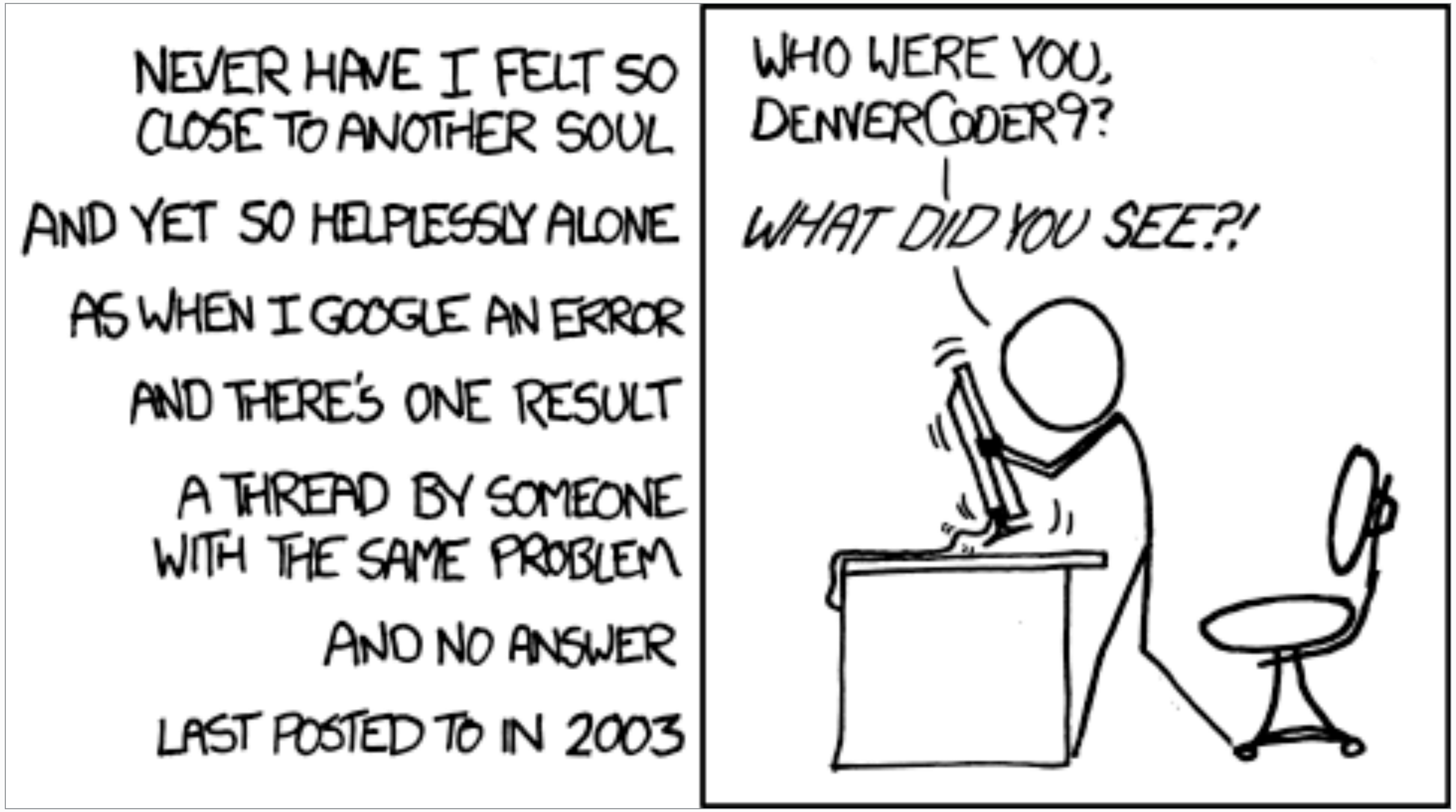
Choosing the programming language



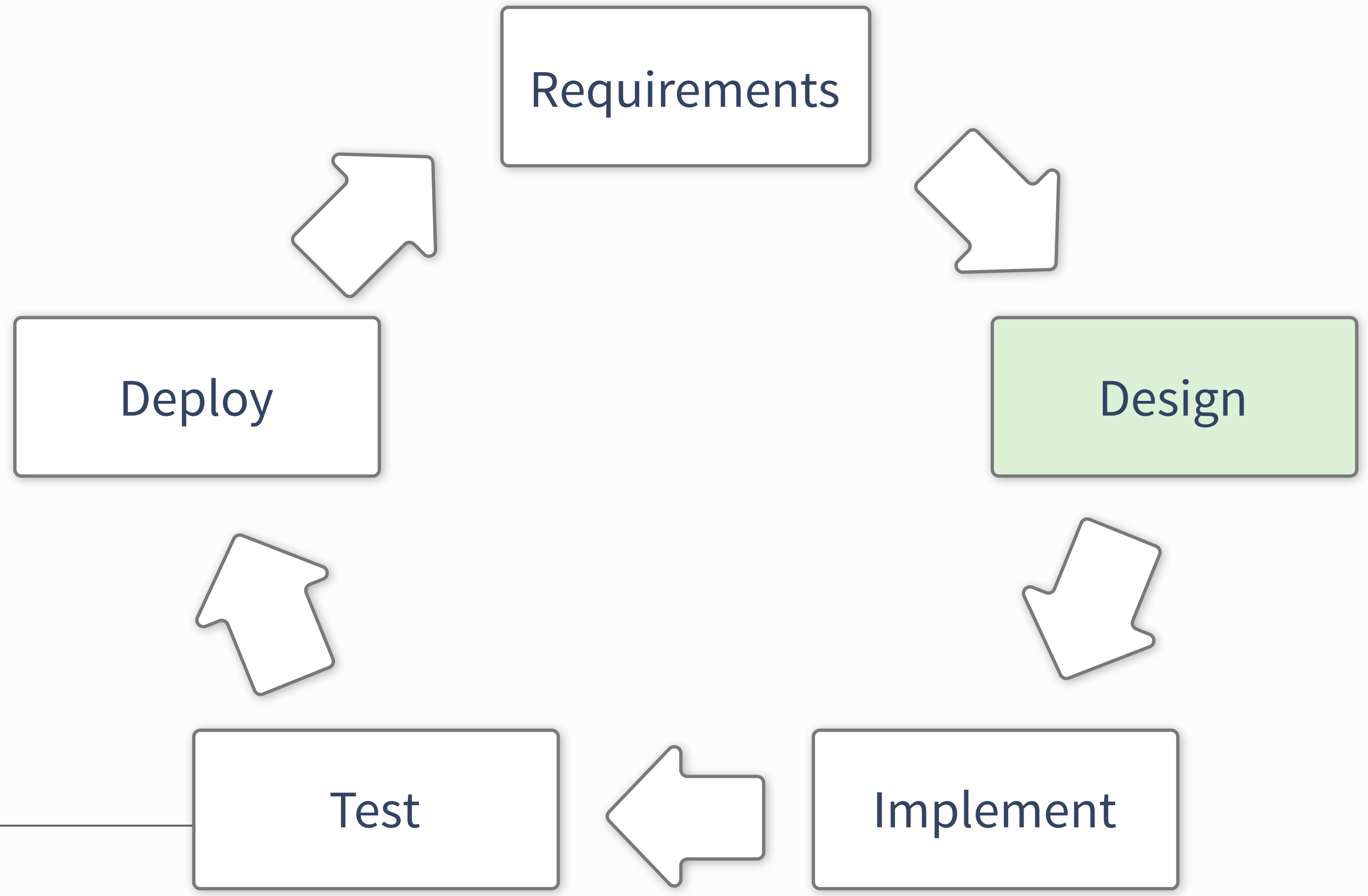
Choose wisely

- Favour documentation and support over features
- Favour large user-bases

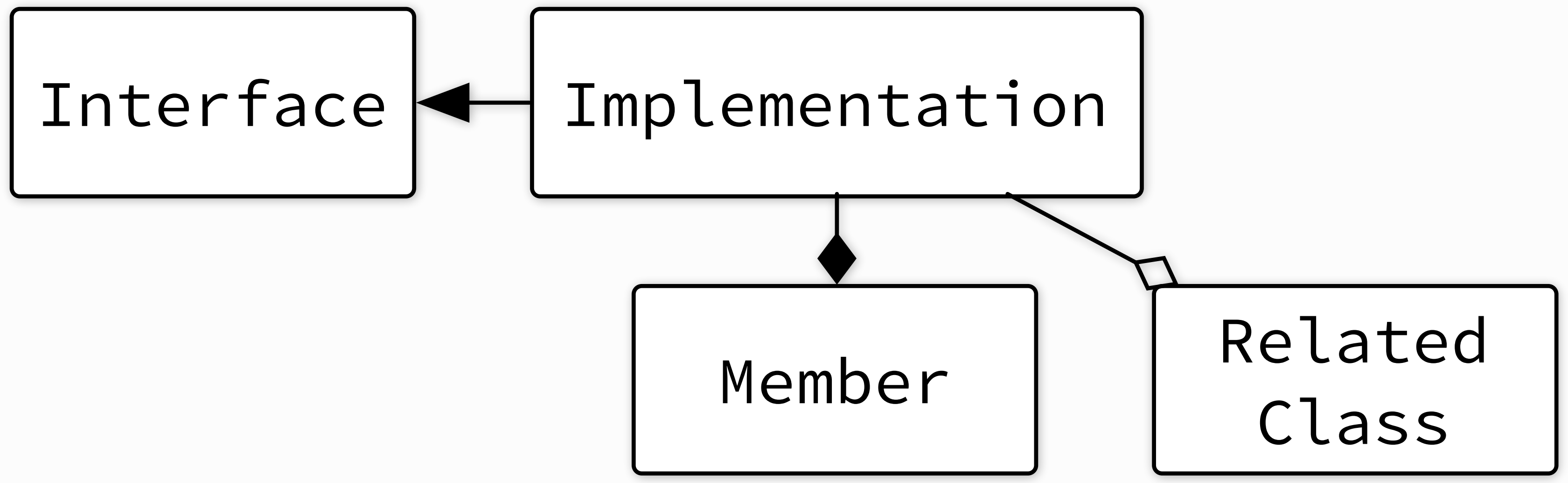
Do you really have to program?

Or did somebody already do it for you?

Design

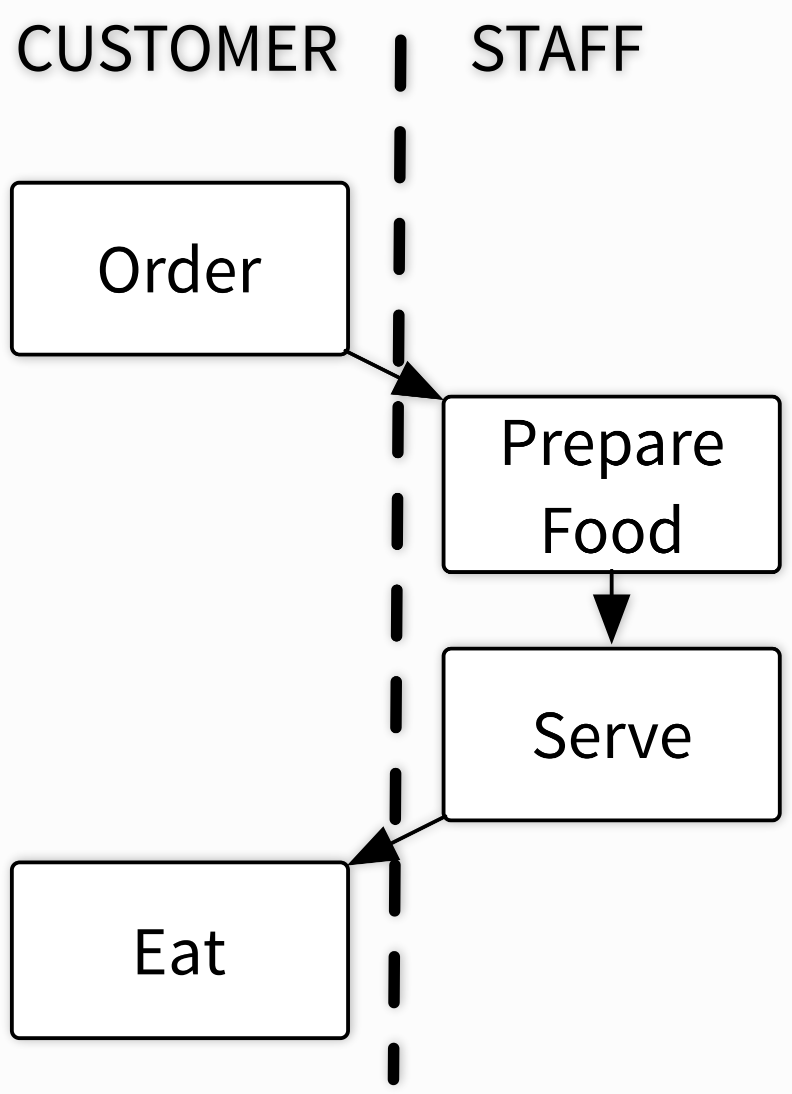


UML Diagrams



Unified Modelling Language: sketch a design

- Probably everyone has seen structure diagrams
  - Relationships of classes (or larger components)
- Behaviour diagrams
  - What does the user do and what should be the result?
- Interaction diagrams
  - How does data and control flow?



Forces you to be concrete!

to make them, look at draw.io

Things to keep in mind when designing

Maintainability

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

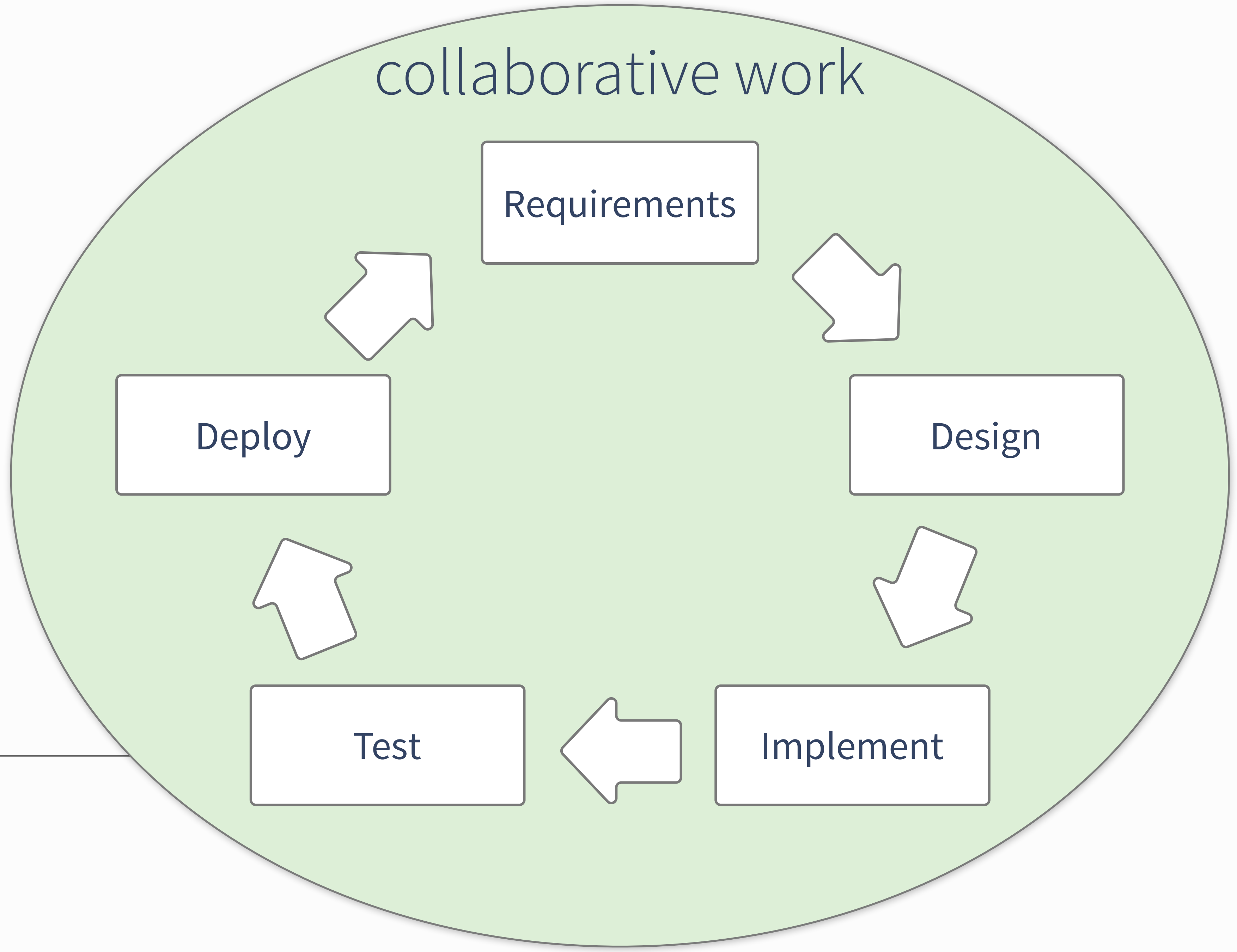
Scalability

- 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?

Collaborative working



Development Cycles

Developing software efficiently:

- Avoid duplication of work
- Avoid feature bloating
- Ensure code quality
- Deliver code timely

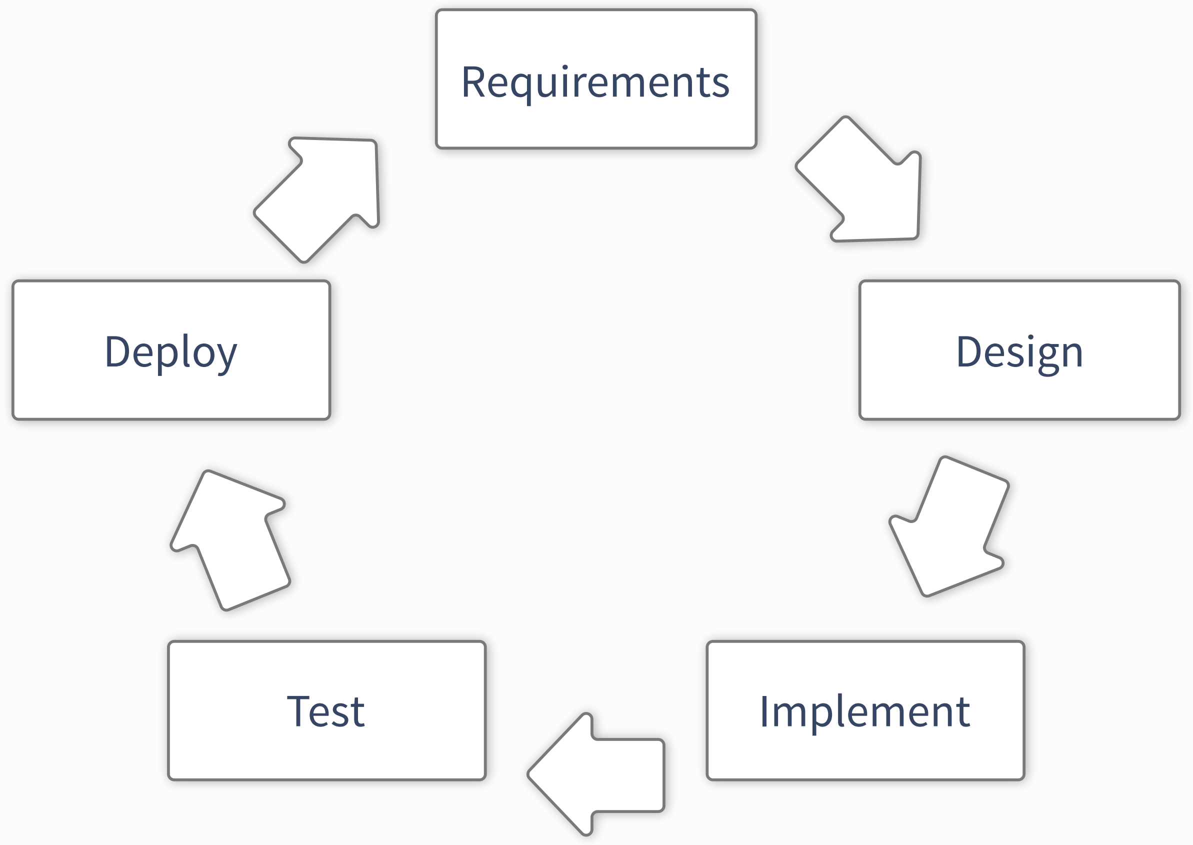
Many approaches to accomplish this:

- Examples: Iterative and Test-Driven Development

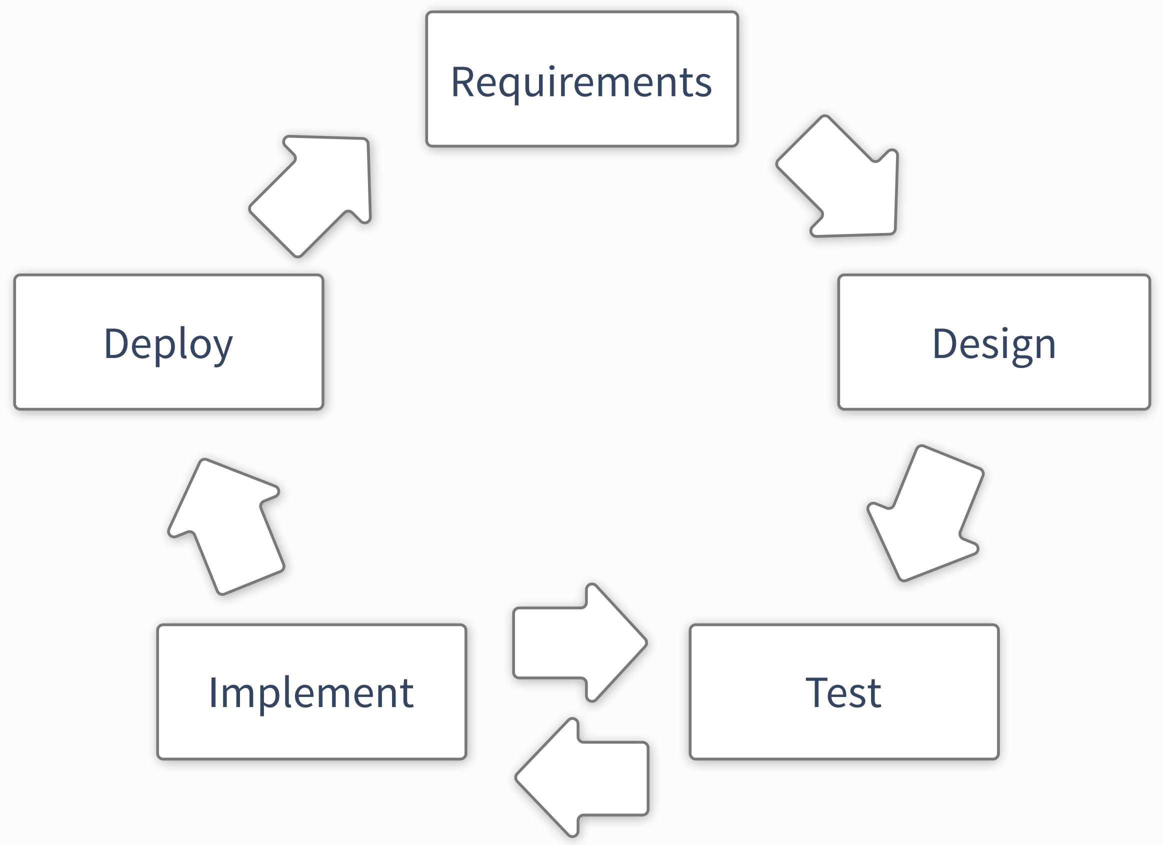
Similar principles, different focus

- on team management (agile development)
- on actual programming style (lean development / TDD)
- broad guidelines to deliver (iterative development)

Iterative Development



Test-Driven Development



Revision control software

Revision control: **Essential for collaboration**… but not only

Basic: CVS and Subversion [“CVS done right”]*

Distributed revision control: Great for personal use

- Easy to work on the go
- Your local copy has everything (including history)

https://jwiegley.github.io/git-from-the-bottom-up/

Gaining ever more popularity **git**: git-scm.com

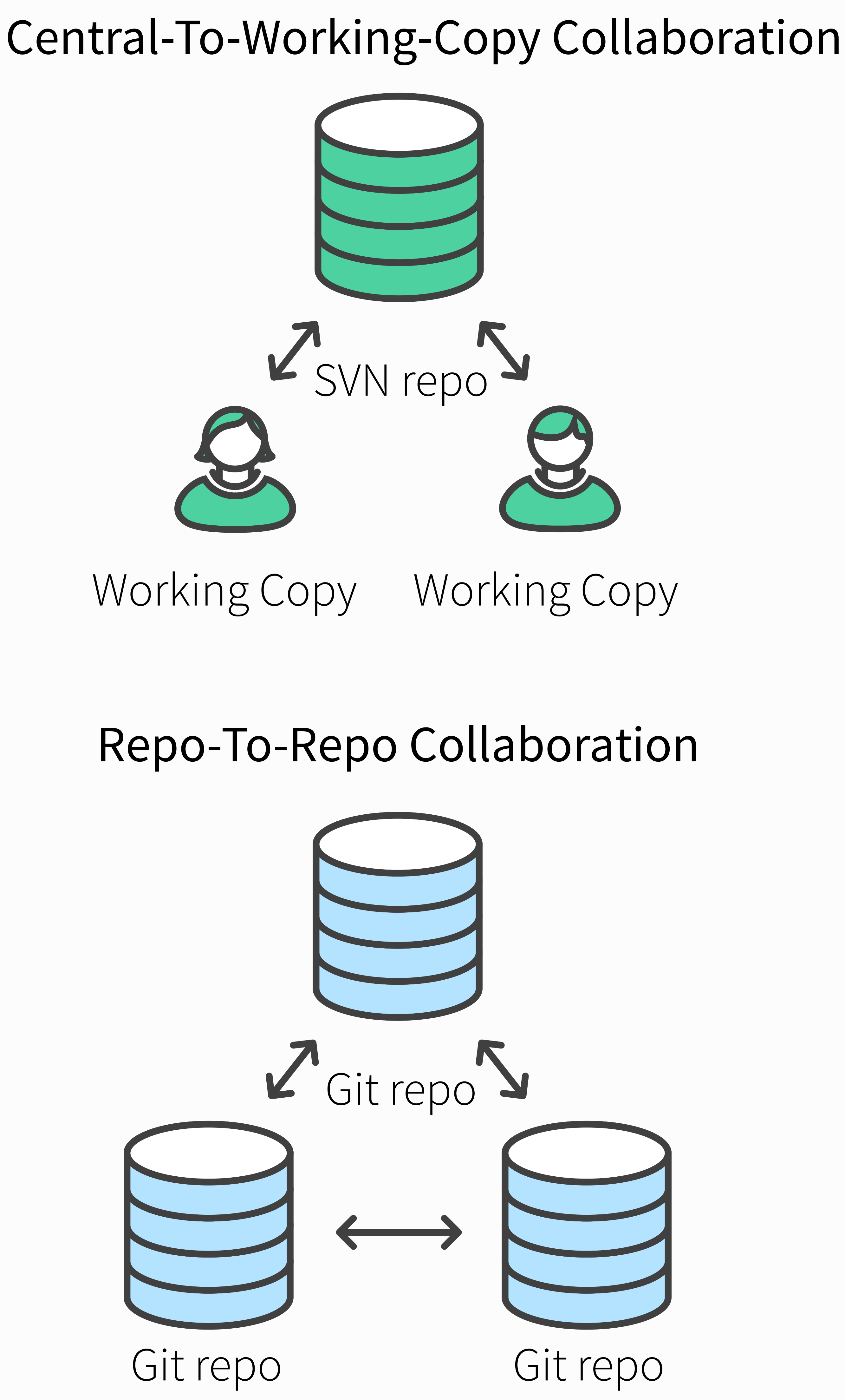
[“there is no way to do CVS right”]*

- Other distributed solutions are: Mercurial, bazaar…
- Easy to learn…

Graphics from: https://www.atlassian.com/git/tutorials/
Ultimate git guide: https://jwiegley.github.io/git-from-the-bottom-up/

* paraphrasing Linus Torvalds

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



Interlude: git basics

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

Interlude: git basics

```
> git init
 Initialized empty Git repository in /TestDirectory/.git/
> vim README.md
 skipping this part.
```

Interlude: git basics

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> git add README.md
```

Interlude: git basics

```
> git init
 Initialized empty Git repository in /TestDirectory/.git/
> vim README.md
 skipping this part.
> git add README.md
> git commit -m "Initial commit of readme."
```

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

The git ecosystem

Easy to host & share your projects:

- Setting up a shared repo can be done via any cloud service, e.g. dropbox
- Many open-source hosting sites, biggest: github.com
- Not open to public but CERN users: GitLab.cern.ch
  - Both include fairly usable issue-tracking
- The beauty of pull-requests*:
  - Do builds on pull-requests (combine with CI)
  - Review contributed code on pull-requests

Git is widely used — **de-facto community standard**

- Exception: Python uses Mercurial

The more you learn the more you'll like it!

* merge-request in GitLab

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* merge-request in GitLab

General Tips & Pointers

Learning about software development

Coursera — courses by universities (Caltech, Johns Hopkins, Stanford and more)

- https://www.coursera.org/courses
- Large variety of courses
  - Not only technology / programming
  - Also physics, biology, economics… and more
  - Also in different languages

Udacity — courses from industry (Google, Intel, Autodesk)

- https://www.udacity.com/courses#!/all
  - Mixed courses: Some free, recently switched to a payed model with monthly fees

University Homepages — have a gander… many courses available through YouTube etc.

- e.g.: Programming Paradigms, Stanford University

http://ureddit.com/ — University of Reddit

Closing Advice

Before you write trigger / DAQ software, 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

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
  - Bonus: If you know them you'll have an easier time to follow nerd-talk
- Nothing is free
  - You'll have to invest some effort to learn
  - If you do that this week: We'll be here to help!

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
- Tune your .bashrc / .bash_profile to get a more useful prompt
- Try out vim / emacs / atom / 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/

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

Want to try your programming skills?
Google code jam (registration 06.03.18):
https://code.google.com/codejam
Also you can just practice by solving nice problems.

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

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

like the fonts in the presentation?
https://github.com/adobe-fonts/source-code-pro
https://github.com/adobe-fonts/source-sans-pro

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

- 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

SAGE — 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

```
# tune your prompt:
if [ "$PS1" ]; then
          PS1="[\[\033[1;29m\]\[\033[0;34m\] \u\[\033[0;34m\]@\[\033[1;34m\]\h :\[\033[0m\]: \w   \
[\033[0;36m\] \$(git branch 2>/dev/null | grep '^*' | colrm 1 2) \[\033[0m\] ] \n \[\033[0;31m\]\$\
[\033[0m\] "
fi

# do not put duplicate lines into history:
export HISTCONTROL=“ignoredups”

# default to human readable filesizes
alias df=‘df -h’
alias du=‘du -h’

# get some color
alias grep=‘grep --color'

# more file listing:
alias l=‘ls’
alias ll=‘ls -lt -h -G -c -r’

# fool proof cp - asks for each file, use fcp if you’re sure
alias fcp='cp'
alias cp='cp -i -v'

# never remember those..
alias untgz='tar -xvzf'
alias tgz='tar -pczf'

#never install root:
source /path/to/your/working/root/bin/thisroot.sh
alias root=‘root -l’

# Mac OS stuff
alias wget=‘curl -O’
```

resulting prompt

[user@host :: pwd   current git-branch]