Introduction to Advanced Programming Concepts

Stefan Kluth
MPI für Physik
skluth@mpp.mpg.de

Who are we?

- Introduce ourselves
- Why are we here?
- What do we expect?
- What is our background?
- What do we know already?

APC topics

Principles of object oriented design

Advanced C++ concepts

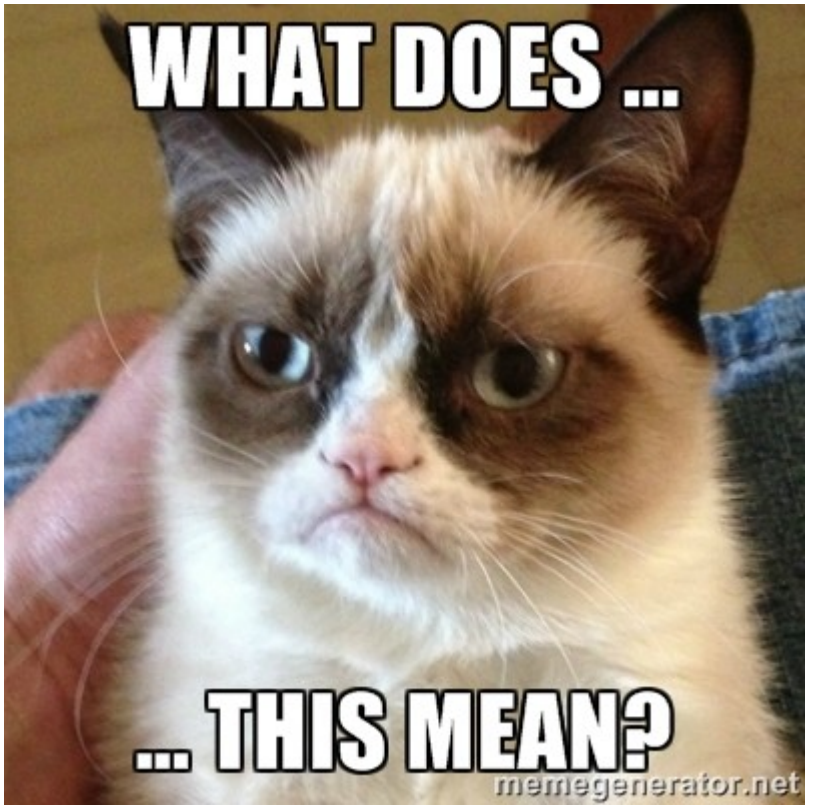
Unified modeling language

Refactoring

Unit testing

Performance, design and parallelization

Julia language



Languages

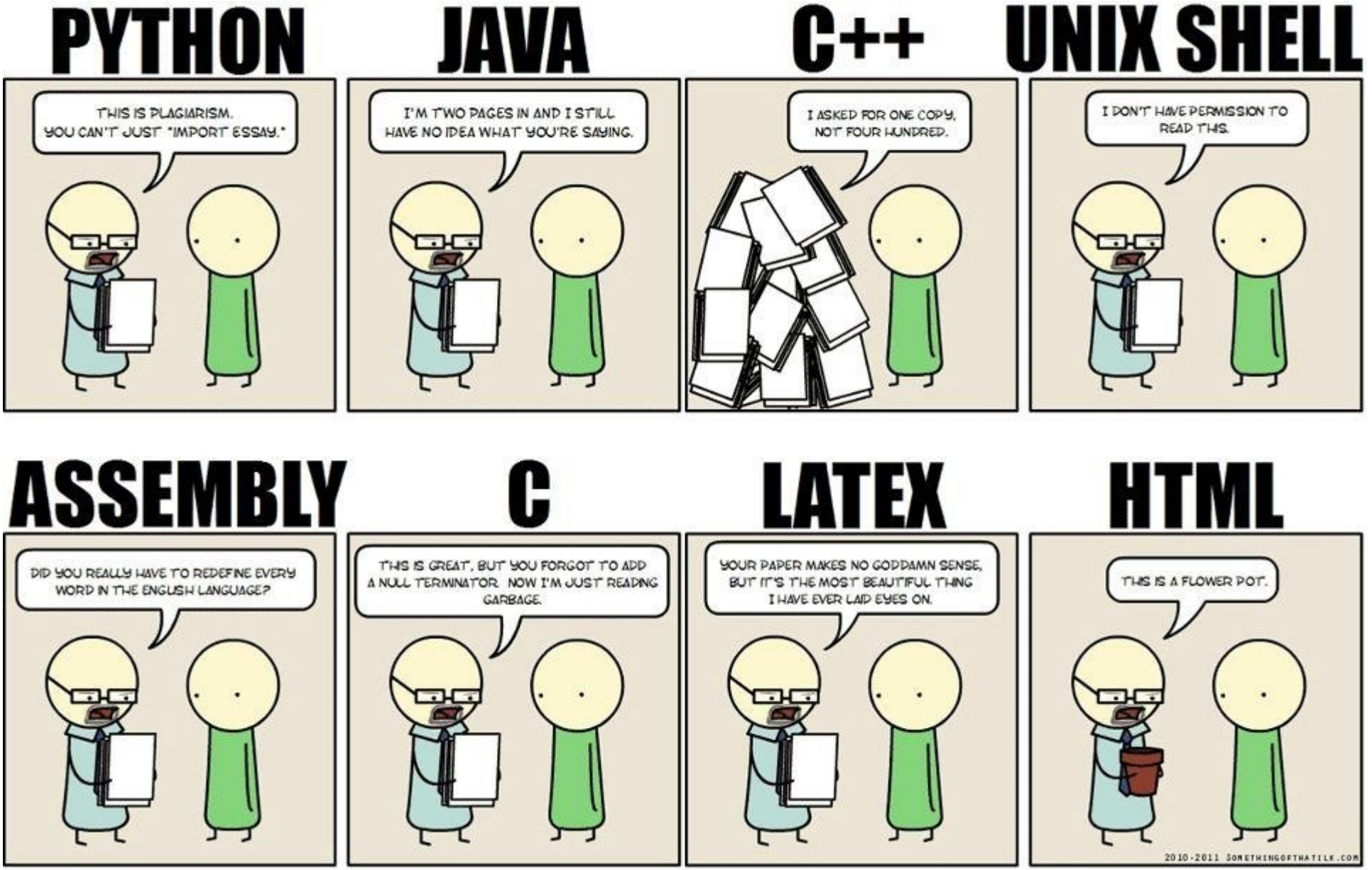
Wikipedia on Programming Language:

“A programming language is a formal constructed language designed to communicate instructions to a machine, particularly a computer.”

Imperative: execution instructions for explicit algorithm
(for most people this is all)

Declarative: express logic w/o fixing control flow
(Db query, regexp, configuration management, Functional, …)

Languages


PYTHON
THIS IS PLAGIARISM. YOU CAN'T JUST "IMPORT ESSAY."
JAVA
I'M TWO PAGES IN AND I STILL HAVE NO IDEA WHAT YOU'RE SAYING.
C++
I ASKED FOR ONE COPY, NOT FOUR HUNDRED.
UNIX SHELL
I DON'T HAVE PERMISSION TO READ THIS.
ASSEMBLY
DID YOU REALLY HAVE TO REDEFINE EVERY WORD IN THE ENGLISH LANGUAGE?
C
THIS IS GREAT, BUT YOU FORGOT TO ADD A NULL TERMINATOR. NOW I'M JUST READING GARBAGE.
LATEX
YOUR PAPER MAKES NO GODDAMN SENSE, BUT IT'S THE MOST BEAUTIFUL THING I HAVE EVER LAID EYES ON.
HTML
THIS IS A FLOWER POT.
2010-2011 SOMETHINGOFTHATILK.COM

The right tool for the job

- Scripting
  - Interpreted “line-by-line”, high-level only
  - Short “throw-away” programs (mostly)
  - Availability of libraries
- Compiled
  - Down to machine code, many optimisations possible
  - Structure your program → functions, subroutines, data structures, classes, packages
  - Long-term projects

In HEP

- Dominant languages
  - C++
    - Frameworks, DAQ, reconstruction, simulation, data reduction, analysis
  - Python
    - Analysis, data handling, workflows, system services
  - Unix shell (bash)
    - Workflows, system services
  - Julia
    - Many of the above, high or low level, fast
  - Fortran
    - Legacy, numerically intensive
- Many more for special purposes

In this workshop

- Concepts, methods, tools for “large” tasks
  - Experiment frameworks and their components
  - Analysis code
- Object oriented programming (OOP)
  - Established method in large systems
  - Code structuring and modularisation
  - Prepare for extensions and maintenance
  - Working in teams
- Enables unit tests and refactoring
- Julia
  - supports and extends OOP
  - multiple dispatch functions for more flexibility

The C++ language

- Since the 80ies as C with classes
  - B Stroustrup et al
  - ISO standards 1998, 03, 11, 14, 17, 20, 23, ...
  - OOP, generic programming (templates), system and applications, from low to high level
- Derived from C with OO contructs
  - Classes, public, private, const, inheritance, polymorphism
  - Low level efficiency with high level structures
- Best match for HEP when transition from Fortran was needed in the 90s / noughties

C++ highlights: classes

A C++ class is a type description, default visibility is *private*

```
class Complex {
   double real;
   double imaginary;
public:
  Complex( double, double );
   ~Complex();
  Complex& operator+( const Complex & );
   ...
};

Complex a(1,2); Complex b(3,4);
Complex c= a+b;
```

Define your own types matching your problem
C++ struct: class with default visibility public members

C++ highlights: operators

Implement +, -, *, /, (), [], … for your class

```
#include “Result.hh”

Class MyClass {
  public:
  Result operator();
};

MyClass mc; Result res= mc();
```

Not directly related to OOP
More flexibility for domain-specific-languages constructed using classes with well chosen methods and operators
Can lead to compact and powerful “C++ scripts”
Need to consider carefully expectations of users

C++ highlights: visibility

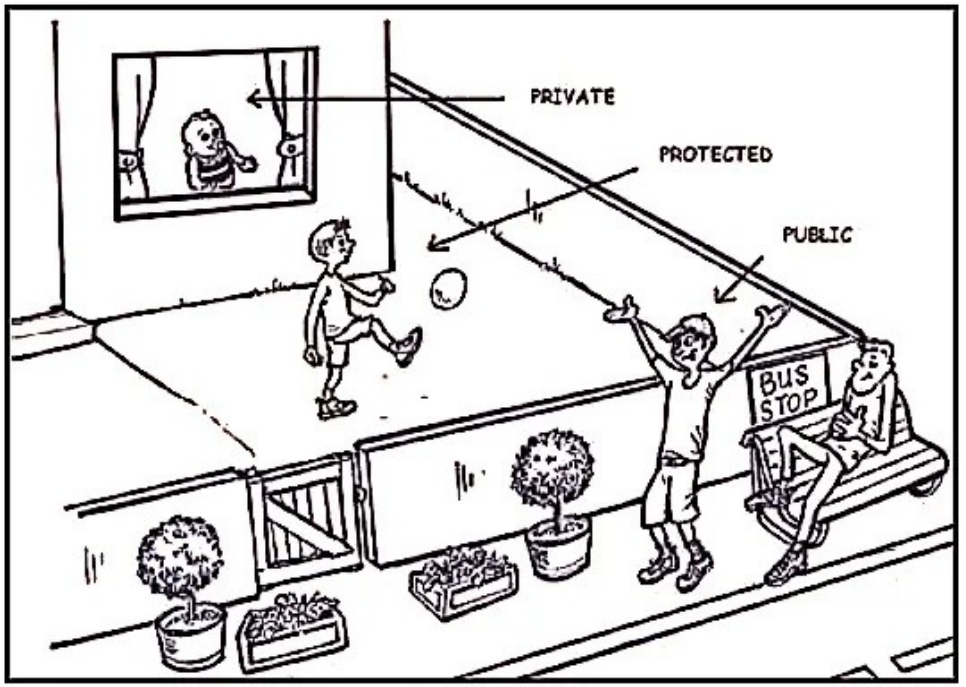
Visibility refers to the concept of private, public, protected data members or methods

public: free access via (pointer to) object (a la C struct)

private: no access except from within class code (data hiding)

protected: no access except private, and from subclasses

Key concept of OOP, hide concrete data structure, access only via methods (interface)



[conservativememes.com]

C++ highlights: class inheritance

Must implement “pure virtual” method signatures
Can re-implement (override) “virtual” methods
Can re-implement non-virtual methods, but w/o upcast!

```
class IFace {
  public:
  virtual Result doSomething( int ) = 0;
  virtual Blob getBlob();
};

class MyClass : public IFace {
  public:
  virtual Result doSomething( int );
};

IFace* mc= new MyClass(); // type upcast
Result res= mc->doSomething();
Blob blob= mc->getBlob();
```

C++ highlights: const

Declare class methods to not modify data members

Ensure correctness and code readability (“The code is the comment”)

Enables multiple threads (if used consistently), since data members guaranteed to not change

```
class MyClass {
  Data data;
  public:
  void doSomething() const;
  void setData( const Data & );
};

const MyClass mc;
mc.doSomething();
mc.setData( Data ); // error
```

C++ highlights: * & etc pp

C++ does not have built-in memory management
If you are used to java or scripting …

```
#include “Variable.hh”
void func( const Variable& v );
...
{
Variable var; // constructed “on stack”
Variable* varp= new Variable(); // “on heap”
Variable& varr= var; // reference taken
func( var ); // reference to var passed
delete varp; // remove from heap
}
// var and varr out of scope, automatic deletion
```

Memory management via constructor and destructor
Memory leaks, heavy tools (valgrind), ...

C++ memory management

Old style: conventions about “object ownership”, avoid pointers(?), leaks, valgrind, bus error, segmentation violation, !@#$%

E.g. C++11 features:

`shared_ptr<Type>`: manage “reference-count”, create objects, pass around multiple copies, deleted when not used anymore (ref-count=0)

`unique_ptr<Type>`: manage object “uniquely”, no ref-count, pass around unique instance, delete managed object when deleted

Solves most common mem.mgnt errors: no delete (mem-leak), double delete (crash), dangling pointer access (crash)

C++ highlights: templates

C++ templates allow “compile time polymorphism”

```
template<typename T> class Vector {
   T* representation;
   int size;
public:
   Vector() : representation(0) {}
   Vector( int _size ) :
     representation( new T[_size] ),
     size( _size ) {}
   ~Vector() { delete[] representation; }
   // operator+-*/[] etc pp
};

Vector<double> vd(5);
Vd[0]= 0.0;
Vector< unique_ptr<MyClass> > vmc(10);
unique_ptr<MyClass> upmc( new MyClass() );
vmc[5]= upmc;
```

C++ highlights: templates

- Template compile time polymorphism ≠ OOP
- Tension between OOP and “meta-template-programming” (MTP)
  - OOP: abstraction and modularity via inheritance
  - MTP: generic programming, common code around generic type with certain properties
  - After “instantiation” all types are concrete
- In an OOP project use templates with care
  - e.g. templated class methods can't be virtual

C++ highlights: final, override

More detail for class method declarations with inheritance

`final`: class or virtual method can't be overriden in subclasses

`override`: expect to override virtual method in parent class

```
class MyClass : public Iface {
  public:
  virtual Result doSomething( int ) final;
  Blob getBlob() override;
};
```

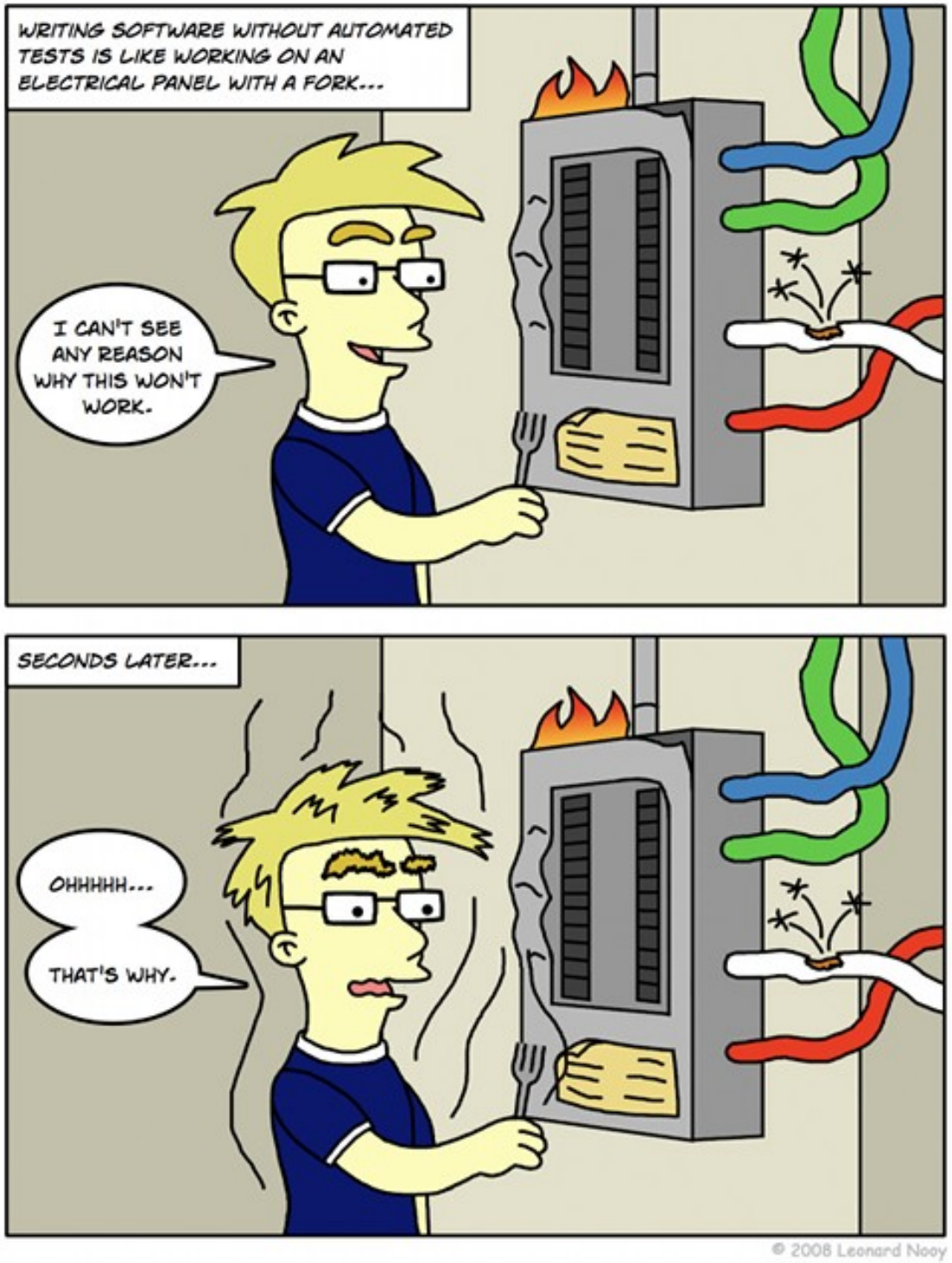
Enforce design choices beyond conventions

final: helps “devirtualisation” compiler optimisation

Refactoring

Change the code without changing its behaviour

The traditional approach: edit (behavior changing!) changes in, meanwhile code is broken, debug, debug, debug, validate
Now: control behavior with unit tests, change code in many small steps until ready for new feature, new tests, new feature



xUnit tests

Test runner

Test case

Test fixture

Test suite

Test execution

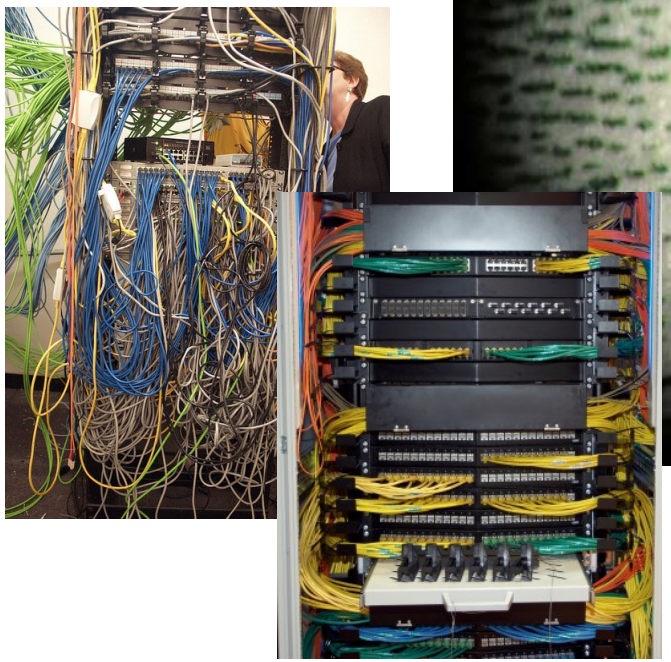
Test result formatting

JUnit, PyUnit, googletest, ...

OOP, unit tests, refactoring

Object-oriented programming

Refactoring, reengineering



Unit tests, Test driven development