Computing Methods for Experimental Physics and Data Analysis

Introduction

L. Baldini, G. Lamanna, A. Manfreda, A. Retico, A. Rizzi

luca.baldini@pi.infn.it

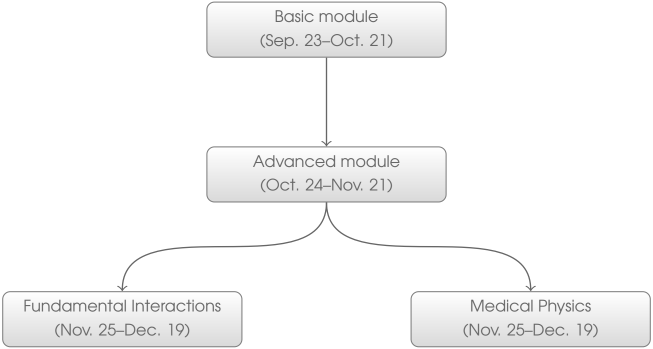
Università and INFN–Pisa

September 28, 2019

Goals and prerequisites

- What is this all about?
  - Automating repetitive tasks
  - Python basics, standard library and scientific ecosystem
  - Collaborative code development and best practices
  - Algorithms and data structures
  - Machine learning
  - Specific tools for high-energy physics or medical physics
- This is not so much about Python or C++—it is about how to write code for effective data analysis
- Will I be a professional data scientist at the end of the semester?
  - No, but hopefully you'll be able to poke around and find the right tool for the job at hand
- What do I need to know in advance?
  - Have a vague idea of how a computer operates
  - If you have ever programmed before that would be great!
- This is our first round: we will adjust along the way

Basic structure of the course



- Modularity and standard paths:
  - Each module is worth 3 credits
  - 6 credits: basic + advanced
  - 9 credits: basic + advanced + fundamental interactions
  - 9 credits: basic + advanced + medical physics

- Collaborative tools
  - Version control, development workflow, development platforms
- Python basics
  - Coding conventions, structuring a package
  - Variables, native types, functions
  - The Python standard library
- Algorithms and data structures
  - Complexity and asymptotic running time
  - Python data structures and native algorithms
- Object-Oriented Programming (OOP)
  - Classes, inheritance, composition
  - Operator overload and emulation of Python builtin types
- The Python computing ecosystem
  - numpy: arrays, functions, broadasting
  - Vectorization
  - Scipy: plotting and fitting
  - Pandas

Advanced module

L. Baldini, G. Lamanna, A. Manfreda, A. Rizzi

- Advanced code development
  - Unit testing, continuous integration, static analysis, documentation
- Advanced Python
  - Errors, exceptions, iterators and generators, decorators
  - Profiling and optimization
- Parallel computing
  - Computer architectures, memory, scaling laws, CPUs and GPUs
  - Parallel programming: concurrency and parallelism, threading in Python
- Machine learning
  - Classification and regression: boosted decision trees and multilayer perceptrons
  - Deep learning: neural networks, the keras library
  - Supervised and unsupervised training, reinforcement learning
  - Tensorflow

- Introduction to C++
  - Coding style and organization, declaration of interfaces
  - Classes: constructors, virtual functions, private and public, abstract classes, inheritance
  - References, pointers, dynamic memory allocation, memory ownership, smart pointers
  - Templates, standard template library
  - C++11 and C++14: lambda functions, auto variables
- More parallel computing
  - Cuda and OpenCL
  - Examples of algorithms for HEP
  - GPU in HEP Data Analysis
- The ROOT data analysis framework
  - ROOT toolkit
  - PyROOT, root-numpy, RDataFrame

- ▷ Medical data processing and feature extraction (python/MATLAB)
  - ▷ Tools for handling standard-format medical data (DICOM)
  - ▷ Data anonymization and visualization
  - ▷ Deriving features form images, image segmentation
  - ▷ Data quality control pipelines: outlier removal, dimensionality reduction
- ▷ Data analysis and classification (python/MATLAB)
  - ▷ Performance evaluations: figures of merit, cross-validation schemes, permutation test
  - ▷ Machine-learning and deep-learning tools for segmentation and classification
  - ▷ Data augmentation, transfer learning, retrieving localization information.

Logistics

Timetable and final exam

- Timetable
  - Monday, 09:00–11:00 (room G1)
  - Monday, 16:00–18:00 (room H)
  - Thursday, 09:00–11:00 (room M)
- Lectures on Monday morning and Thursday morning (2×2 hours)
  - Tentative idea: 1 hour with slides and 1 hour at the computer
  - (Actual mileage might vary)
- "Lab" on Monday afternoon
  - Attack a small project each week in a 2–3 hour session
  - (Bring your own laptop!)
- And, of course, the final exam
  - Development of a specific, reasonable-size software project (related to the topics covered in the course)
  - Two-page description of the project and source code made available in advance
  - Oral exam (starting from the discussion of the project)