Course Title (in English)
High Performance Python Lab

Course Title (in Russian)
Лабораторный курс "Высокопроизводительный Python"

Lead Instructor(s)
Rykovanov, Sergey

Is this syllabus complete, or do you plan to edit it again before sending it to the Education Office?
The syllabus is a final draft waiting for form approval

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1. Annotation

Course Description
This course is devoted to learning how to use Python for High Performance Computing on different architectures – multi-core CPUs and general purpose GPUs.

The course is oriented on practical knowledge, where the students will get a hands-on experience with Python code profiling, modern Python frameworks, such as Python MultiProcessing, Numba, Cython, mpi4py, PyCuda and others.

Wide range of problem sets from linear algebra, image processing, deep learning, physics and engineering makes this course interesting and suitable for all levels of students from all CREIs. Students will also get the possibility to work on modern supercomputers.

Course Prerequisites
Laptop with Linux or Linux based Virtual Machine, basic knowledge of Python

2. Structure and Content
### Course Academic Level

Master-level course suitable for PhD students

### Number of ECTS credits

3

<table>
<thead>
<tr>
<th>Topic</th>
<th>Summary of Topic</th>
<th>Lectures (# of hours)</th>
<th>Seminars (# of hours)</th>
<th>Labs (# of hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HPC basic theory and terminology</td>
<td>Moore’s law. Amdahl’s law. Gustafson’s law. Strong and weak scalability. Parallelism. Flynn’s taxonomy.</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Computing systems architecture</td>
<td>CPU. GPU. Threads. Cores. Computation node. Supercomputing clusters. Memory hierarchy.</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Profiling python programs</td>
<td>Python performance particularities. Approaches to profiling: print() and time module, decorator, UNIX time command. Built-in tools and external libraries: cProfile, line_profiler, memory_profiler. Profiling CPU+GPU python code.</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Matrix and vector calculations using python</td>
<td>Numpy vs. pure python lists. Cache-misses and page-faults. Cache-friendly programming.</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>FFT using python</td>
<td>Fast Fourier Transform: numpy.fft vs. scipy.fftpack vs. pyFFTW vs. pyFFT vs. scikit-cuda.</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Compiling python to C</td>
<td>JIT compiler vs. AOT compilers. Cython. Numba.</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Asynchronous programming and multiprocessing with python</td>
<td>Concurrency. Threads, processes and tasks. Python concurrency introducing modules: threading, asyncio, multiprocessing.</td>
<td>0</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>MPI on python</td>
<td>Message Passing Interface. Mpi4py.</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>CUDA on python</td>
<td>Numba and @cudajit. Pycuda, SourceModule. Using cudaStreams with python. Global memory loads and stores. Coalescing and alignment.</td>
<td>0</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Running python on supercomputing clusters</td>
<td>Parallel Python module (pp). Ipcluster. Running python programs on supercomputers: slurm, pbs, jupyter notebook.</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

### 3. Assignments

<table>
<thead>
<tr>
<th>Assignment Type</th>
<th>Assignment Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final Project</td>
<td>Implement a selected topic (preferable related to your research) in Python, use High Performance Python ideas from the course, present the final project</td>
</tr>
<tr>
<td>Computer Labs</td>
<td>Solve 2D Laplace equation using PyCuda and similar tasks. Write a simple image filter using PyCuda, etc</td>
</tr>
<tr>
<td>Homework</td>
<td>Implement Monte-Carlo PI calculation using Python and MPI and similar tasks</td>
</tr>
<tr>
<td>Homework</td>
<td>Find a maximum value of a large matrix using PyCuda.</td>
</tr>
</tbody>
</table>
4. Grading

| Type of Assessment | Graded |

<table>
<thead>
<tr>
<th>Grade Structure</th>
<th>Activity Type</th>
<th>Activity weight, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Class participation</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Homework Assignments</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>Computer Labs</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>Final Project</td>
<td>30</td>
</tr>
</tbody>
</table>

Grading Scale

<table>
<thead>
<tr>
<th>Letter</th>
<th>Grade</th>
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<tbody>
<tr>
<td>A:</td>
<td>86</td>
</tr>
<tr>
<td>B:</td>
<td>76</td>
</tr>
<tr>
<td>C:</td>
<td>66</td>
</tr>
<tr>
<td>D:</td>
<td>56</td>
</tr>
<tr>
<td>E:</td>
<td>46</td>
</tr>
<tr>
<td>F:</td>
<td>0</td>
</tr>
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</table>

Attendance Requirements

Mandatory with Exceptions

5. Basic Information

<table>
<thead>
<tr>
<th>Maximum Number of Students</th>
</tr>
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<tbody>
<tr>
<td>Overall:</td>
</tr>
<tr>
<td>Per Group (for seminars and labs):</td>
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</table>

Course Stream

Science, Technology and Engineering (STE)

Course Delivery Frequency

Every year

Students of Which Programs do You Recommend to Consider this Course as an Elective?
6. Textbooks and Internet Resources

<table>
<thead>
<tr>
<th>Recommended Textbooks</th>
<th>ISBN-13 (or ISBN-10)</th>
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</table>

7. Facilities

<table>
<thead>
<tr>
<th>Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>laptop with Linux</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Software</th>
</tr>
</thead>
<tbody>
<tr>
<td>python3, jupyter notebook</td>
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</table>

8. Learning Outcomes

<table>
<thead>
<tr>
<th>Knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td>High performance computations, supercomputer architecture, Parallelization of algorithms.</td>
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</table>

<table>
<thead>
<tr>
<th>Skill</th>
</tr>
</thead>
<tbody>
<tr>
<td>high performance python, supercomputer programming, hybrid programming on python, mpi4py, pycuda, numba, multithreading.</td>
</tr>
<tr>
<td>Experience</td>
</tr>
<tr>
<td>------------</td>
</tr>
<tr>
<td>Experience parallelizing programs, Python programming, parallel programming, accelerating the Python programs, experience working on modern supercomputers</td>
</tr>
</tbody>
</table>

### 9. Assessment Criteria

Input or Upload Example(s) of Assignment 1:

Input or Upload Example(s) of Assignment 2:

Input or Upload Example(s) of Assignment 3:

Input or Upload Example(s) of Assignment 4:

Input or Upload Example(s) of Assignment 5:

### 10. Additional Notes