The Doctoral Program Form contains, year by year, the description of the PhD program of each Doctoral student. This form must be submitted to the PhD coordinator with roughly the following timing:

- by the end of February of the first year for first year students
- before the admission to the second year by perspective second year students
- before the admission to the third year by perspective third year students

The Doctoral Program Proposal is approved by the PhD board shortly after submission.

The Doctoral Program requirements place formalized emphasis on methodology and mastery of fundamental and applied engineering systems concepts. A Doctoral Program Proposal should be constructed in agreement with the Faculty mentor, that is the supervisor or tutor, by complying to the requirements, described in the Tables below.

### ADVANCED COURSES: 0 CREDIT FORMATION UNITS (CFU)

Only courses/schools providing a final verification test with pass/fail outcome certified by instructor can be included here.

<table>
<thead>
<tr>
<th>Title</th>
<th>Type</th>
<th>Duration / period</th>
<th>CFU (^3)</th>
<th>Motivation for selection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insert here course /school title, etc..</td>
<td>Insert here course type, e.g. Master Degree course, PhD course, summer/winter school</td>
<td>Insert duration (measured in hours or days) and period of year</td>
<td>Insert here a detailed explanation of why the course/school was selected and how it connects with the research area of the PhD student.</td>
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<td>Summer / winter school</td>
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<tr>
<td>Other (specify)</td>
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<tr>
<td><strong>Total CFU</strong></td>
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</tbody>
</table>

### SEMINARS AND LABORATORY ACTIVITIES: 6 CFU

<table>
<thead>
<tr>
<th>Activity</th>
<th>Type</th>
<th>Duration / period</th>
<th>CFU (^5)</th>
<th>Motivation for selection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Development of the model of the ExaNeST Tier-1 n-dimensional Torus network interconnect in the OMNeT++ simulation framework.</td>
<td>Laboratory Attended at INFN APE Lab – Department of Physics, “Sapienza”</td>
<td>Nov. 2017 – Sept. 2018 120 hours</td>
<td>6</td>
<td>The topic of the thesis is the development of a novel adaptive routing algorithm for n-dimensional Torus network interconnects. The implementation of this simulation model will enable the validation and the benchmarking of the novel adaptive routing algorithm with the traffic patterns generated from a set of reference applications including Human Brain Project simulations codes of Spiking Neural Networks.</td>
</tr>
<tr>
<td><strong>Total CFU</strong></td>
<td></td>
<td></td>
<td></td>
<td>6</td>
</tr>
</tbody>
</table>

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1. Please insert lines as required/appropriate, and for each line complete each column of the Table.
2. During the second year, the doctoral student may complete the credits corresponding to advanced courses that were not completed in the first year.
3. Indicate here the CFUs that can be accounted for as a result of the successful completion of the activity; for Master Degree courses, assume 1 CFU = 8 teaching hours + 12 homework/study hours, for a total of 20 hours. This rule can be slightly adjusted for other types of courses/activities (e.g., PhD courses may require slightly less hours per CFU).
4. Please insert lines as required/appropriate, and for each line complete each column of the Table.
5. Indicate here the CFUs that can be accounted for as a result of the successful completion of the activity; as a rule of thumb, assume 1 CFU = 20 working hours.
### ADDITIONAL INDEPENDENT FORMATION AND RESEARCH ACTIVITIES: 6 CFU

Indicate activities that extend and complement the mandatory activities listed above.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Type</th>
<th>Duration / period</th>
<th>CFU</th>
<th>Motivation for selection</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONTROL OF AUTONOMOUS MULTI-AGENT SYSTEMS</td>
<td>Sapienza Univ. Master Degree course, code 1041427</td>
<td>Feb. – Apr. 2018 24 hours</td>
<td>1</td>
<td>The first part of this course covers several reinforcement learning techniques in multi-agent systems that could be effectively applied to my research.</td>
</tr>
<tr>
<td>Design and Implementation of a deep neural network for the real-time classification of the events generated in the RICH detector in the NA62 experiment at CERN</td>
<td>Laboratory Attended at INFN APE Lab – Department of Physics, &quot;Sapienza&quot;</td>
<td>Mar. – Jul. 2018 120 hours</td>
<td>6</td>
<td>One of the research lines I plan to explore to develop a novel adaptive routing algorithm involves the usage of deep neural networks in a reinforcement learning framework (Deep Reinforcement Learning). With this activity I will gain knowledge on how to tackle a time-constrained task, as routing is, using deep neural networks techniques.</td>
</tr>
</tbody>
</table>

**Total CFU**: 7

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### RESEARCH ACTIVITY: 42 CFU

**Research area**

Interconnection Network Architectures for High-Performance Computing.

**Research topic**

Adaptive Routing Techniques for $n$-dimensional Torus Networks.

**Framework of the proposed research topic**

With the current VLSI technology, about $10^5$ high end processor nodes have to be assembled in order to build a High Performance Computing (HPC) system capable of at least one exaFLOPS ($10^{18}$ floating point operations per second) and to enter the domain of Exascale computing. This is considered as a fundamental milestone in computing achievement that will have a great impact on many scientific and technological fields.

It is well known that the sustained computing power of HPC systems depends dramatically on the efficiency of their interconnection network when scaling to high number of processor nodes.

The EU H2020 ExaNeSt project aims at designing the system architecture for Exascale class HPC parallel machines characterized by a highly scalable three-tier interconnection architecture: intra-node tree network, inter-node torus direct network and an optional top tier indirect network.

During the architectural exploration phase of the project, 2D/3D/4D torus network interconnecting up to thousands of computing nodes will be considered for the tier-1 level.

My research activity will be focused on the development of a novel adaptive routing algorithm based on reinforcement learning techniques for the tier-1 network of the ExaNeSt architecture.

With the objective of minimizing the workload completion time, this novel algorithm should allow to adapt routing decisions at runtime according to the network traffic pattern generated by the specific computational task under execution. Furthermore, interacting with a pre-existent fault-awareness system, it should provide a fault-reaction mechanism for failures in the network (channels and routers).

The performance of the novel adaptive algorithm will be benchmarked executing Human Brain Project simulation codes of Spiking Neural Networks and other selected scientific codes both on a simulator and on parallel machines based on ExaNet computing nodes interconnected by 2D/3D/4D torus networks.

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Please insert lines as required/appropriate, and for each line complete each column of the Table.

* CFU = 20 working hours.
The research activities will be carried out in the context of ExaNeSt (2015-2018), EuroEXA (2017-2021) and Human Brain Project-SP3 WaveScales (2016-2023) projects.

The ExaNeSt project, started on December 2015 and funded in EU H2020 research framework (call H2020-FETHPC-2014, n. 671553), is a European initiative aiming to develop the system-level interconnect, a fully-distributed NVM (Non-Volatile Memory) storage and the cooling infrastructure for an ARM-based Exascale-class supercomputer. The ExaNeSt Consortium combines industrial and academic research expertise, in the areas of system cooling and packaging, storage, interconnects, and the HPC applications that drive all of the above: Istituto Nazionale di Fisica Nucleare (INFN), Istituto Nazionale di Astrofisica (INAF), EgingSoft S.p.A. and eXact lab srl for Italy, Foundation for Research and Technology - Hellas (FORTH) for Greece, Universitat Politècnica de València for Spain, Virtual Open Systems for France, Fraunhofer Institute for Mathematics (ITWM) for Germany, MoneiDB Solutions for the Netherlands, University of Manchester, Iceotope Technologies Ltd and Allinea Software Ltd for the UK.

The ExaNeSt project, started on December 2015 and funded in EU H2020 research framework (call H2020-FETHPC-2014, n. 671553), is a European initiative aiming to develop the system-level interconnect, a fully-distributed NVM (Non-Volatile Memory) storage and the cooling infrastructure for an ARM-based Exascale-class supercomputer. The ExaNeSt Consortium combines industrial and academic research expertise, in the areas of system cooling and packaging, storage, interconnects, and the HPC applications that drive all of the above: Istituto Nazionale di Fisica Nucleare (INFN), Istituto Nazionale di Astrofisica (INAF), EgingSoft S.p.A. and eXact lab srl for Italy, Foundation for Research and Technology - Hellas (FORTH) for Greece, Universitat Politècnica de València for Spain, Virtual Open Systems for France, Fraunhofer Institute for Mathematics (ITWM) for Germany, MoneiDB Solutions for the Netherlands, University of Manchester, Iceotope Technologies Ltd and Allinea Software Ltd for the UK.

The EuroEXA project started on September 2017 picks up the banner of a triad of partner projects — ExaNeSt, EcoScale and ExaNoDe — building on their work to develop a complete HPC system based on ARM Cortex processors and Xilinx Ultrascale FPGAs. The goal is to deploy an energy-efficient petaFLOPS system by 2020 and lay a path to achieve exascale capability in the 2022-23 timeframe. The project is coordinated at the Institute of Communication and Computer Systems in Greece and has 15 project partners across eight countries:

- Spain — Barcelona Supercomputing Center
- United Kingdom — ARM-UK, Iceotope, Maxeler Technologies, The University Of Manchester, The Hartree Centre of STFC, ECMWF (European Centre For Medium-Range Weather Forecasts)
- Greece — FORTH (Foundation For Research And Technology Hellas), Synelixis Solutions Ltd
- Belgium — IMEC
- Sweden — ZeroPoint Technologies
- Netherlands — Neurasmus
- Italy — INFN (Istituto Nazionale Di Fisica Nucleare), INAF (Istituto Nazionale Di Astrofisica)
- Germany — Fraunhofer-Gesellschaft

The WaveScalES experiment, led by the INFN, is performed by a team of five research institutes. Three of the partners are specialised in experiments on the human brain and the brains of rodents, the other two will concentrate on developing theoretical models and computer simulations. The INFN’s APE lab will combine its DPSNN simulation engine and the HBP platforms to develop the large scale neural WaveScalES simulator, which will mimic the behaviour generated by several tens of billions of nerve cell connections, or synapses. The partners in the experiment will measure the slow cerebral waves propagated in the cortex during deep sleep and the waking state, and observe the cortical response to localised spatio-temporal perturbations. The experimental techniques used will include non-invasive observations in humans, such as high resolution electroencephalographic response to transcranial magnetic stimulation, performed by the team led by Marcello Massi mini at the University of Milan, and electrophysiological measurements on rodents in response to opto-pharmacological stimulations, conducted by teams led by Maria Victoria Sanchez-Vives, from the Institut D’Investigacions Biomèdiques August Pi i Sunyer (IDIBAPS) in Barcelona, and by Pau Gorostiza, from the Institut de BioEnginyeria de Catalunya (IBEC), also in Barcelona. The theoretical models will be developed by the Italian Institute of Health (ISS - Istituto Superiore di Sanità), under the direction of Maurizio Mattia and Paolo Del Giudice.

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**PHD SPECIFIC TOPIC**

**PhD dissertation title**

Adaptive Routing for n-dimensional Torus Interconnects.

**FACULTY MENTOR (TUTOR OR SUPERVISOR)**

**Prof. Dr.** Luca De Nardis

**Supervisor signature for approval**

Signature of Doctoral student: 

Date: October 19th, 2017