PhD in Information Technology and Electrical Engineering
Università degli Studi di Napoli Federico II

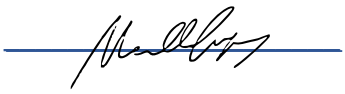
PhD Student: Marco Barletta

Cycle: XXXVII

Training and Research Activities Report

Academic year: 2022-2023 -Year: Second

Tutor: prof. Marcello Cinque



Date: October 21, 2023

1. Information:

- **PhD student: Marco Barletta**
- **DR number: DR995851**
- **Date of birth: 24/04/1998**
- **Master Science degree: Computer Engineering**
- **University: Università degli Studi di Napoli Federico II**
- **Doctoral Cycle: XXXVII**
- **Scholarship type: UNINA**
- **Tutor: Marcello Cinque**
- **Co-tutor: N/A**

2. Study and training activities:

Activity	Type[1]	Hours	Credits	Dates	Organizer	Certificate[2]
IoT Data Analysis	**Course**	12	4	**09/01/2023 to 27/01/2023**	**Dr. Raffaele Della Corte**	**Y**
How to boost your PhD	**Course**	16	4	**11/01/2023 to 01/03/2023**	**Prof. Antigone Marino**	**Y**
Connecting the dots: Investigating an APT campaign using Splunk.	**Seminar**	**2**	**0.4**	**11/11/2022**	**Proff. S.P. Romano and R. Natella**	**Y**
Crash course on data excellence - Part I	**Seminar**	**1**	**0.2**	**14/11/2022**	**Physics Dept.**	**N**
How to manage up	**Seminar**	**1**	**0.2**	**15/11/2022**	**IEEE**	**N**
Publishing Open Access IEEE Journal Articles under the Care Crui Agreement in Italy.	**Seminar**	**1**	**0.2**	**09/11/2022**	**IEEE**	**N**
Privacy and Data Protection	**Seminar**	**2**	**0.4**	**22/11/2022**	**Proff. S.P. Romano and R. Natella**	**Y**
Automated Offensive Security: Intelligence is all you need.	**Seminar**	**1**	**0.2**	**28/11/2022**	**Physics Dept.**	**N**
Digital Forensics. Lecturer: Group-IB.	**Seminar**	**1**	**0.2**	**6/12/2022**	**Proff. S.P. Romano and R. Natella**	**Y**
Game Theory for Information Engineering	**Seminar**	**3**	**0.6**	**13/12/2022**	**Prof. Marcello Caleffi**	**Y**
From Cyber Situational Awareness to Adaptive CyberDefense: Leveling	**Seminar**	**2**	**0.4**	**13/12/2022**	**Dr. Giancarlo Sperlì**	**Y**

the Cyber Playing Field.						
Tutorship for bachelor course "Sistemi Operativi"	**Tutorship**	**10**	**1**	**October to December 2022**		**Y**
Industry 4.0 Fundamentals in Bosch Applications	**Seminar**	**10**	**2**	**23/01/2023 to 26/01/2023**	**Prof. Ing. Mariagrazia Dotoli.**	**Y**
How to Publish Under the CARE-CRUI Open Access Agreement with IEEE	**Seminar**	**1.5**	**0.3**	**05/04/2023**	**IEEE**	**N**

1) Courses, Seminar, Doctoral School, Research, Tutorship
2) Choose: Y or N

2.1. Study and training activities - credits earned

	Courses	Seminars	Research	Tutorship	Total
Bimonth 1	**0**	**3**	**5**	**1**	**9**
Bimonth 2	**4**	**2**	**3.5**	**0**	**9.5**
Bimonth 3	**4**	**0.3**	**5.1**	**0**	**9.4**
Bimonth 4	**0**	**0**	**9**	**0**	**9**
Bimonth 5	**0**	**0**	**9.5**	**0**	**9.5**
Bimonth 6	**0**	**0**	**9.5**	**0**	**9.5**
Total	**8**	**5.3**	**41.6**	**1**	**55.9**
Expected	**30 - 70**	**10 - 30**	**80 - 140**	**0 – 4.8**	

3. Research activity:

My research activity is about Orchestration strategies for dependable mixed-criticality software containers in mission critical environments like IIoT, Industry 4.0, and next generation wireless networks (5G and beyond).
Mission critical environments like the ones mentioned require more and more flexibility to keep up the pace with mutating environments and business requests.
This brings the need for continuous and automatic reconfiguration of the networks, the computing infrastructure, and the devices, while respecting strict non-functional requirements.
For example, in the Industry 4.0 vision factory floors and production lines are automatically adapted and re-programmed to meet any new business goal without the need for manual intervention.
The current problem is that the required level of flexibility, programmability, and elasticity cannot be satisfied by the current state of practice implementation. One promising way is to take advantage of recent computing paradigms like fog and edge computing, heirs of the cloud computing, which leverage the same ideas of containerization, and their automatic orchestration, in order to consolidate computing resources and allot them in a flexible and elastic way. Orchestration systems are distributed systems in

charge of automatically placing, deploying, monitoring, and migrating the packaged software across the computing infrastructure.
Despite promises, containerization of industrial components and their orchestration are not suited for industrial environments yet, since they were designed for cloud computing. Several challenges and limitations prevent their use in mission critical environments, for example the awareness of criticality, which can be defined as "designation of the level of assurance agains failure needed for a system component" (A.Burns, R. Davis "Mixed-Criticality systems, a review"). Mission-critical environments are indeed generally mixed-criticality systems, i.e. systems that integrate functionalities at different criticality levels into common platforms to reduce the size, weight, power, and cost of hardware.
During the first year of my PhD, I analyzed the state of art and the practice regarding orchestration systems for mixed-criticality environments. Hence, I identified four limitations from a functional point of view in the available orchestration systems that prevent their use in mission-critical environments: i) they support OS-level virtualization and type 2 hypervisor virtualization, but do not support virtualization technologies that can offer proper isolation, ii) the placement, monitoring, and failure recovery strategies do not take into account criticality and non-functional requirements of the applications, iii) networking and computing resources are not jointly managed to guarantee the best use of resources.
Hence, I sketched some design and implementation prototypes to extend current functionalities of currently used orchestration systems.
During the second year of my PhD, I focused instead on non-functional characteristics of orchestration systems, mainly targeting two aspects in particular: i) timing predictability, and ii) fault-tolerance.
Regarding timing predictability, I analyzed the timing of Kubernetes, the most spread out orchestration system, under nominal and increasing loads. I broke down the timing into the single contributions, to understand the contribution with more deviation and the circumstances under which varies, potentially leading to a timing failure (i.e., not performing the required action in time). I found out that the asynchronous management of event can cause resource contention, interference, and activity reordering, that are detrimental to predictability. Thus I designed and implemented some mitigations to reduce the non-determistic effects of the orchestration system, that can be amplified on the devices since they are less powerful devices and the majority of time is spent there to actually start the application.
For what concerns fault-tolerance, I analyzed the Kuberentes behaviour focusing on non-nominal conditions. In particular, high-load conditions and error conditions have been examined through well known techniques like fault-injection. The major fining of the research is that, despite a lot of lessons learned from the previous decade helped to improve the design of the architecture to support fault-tolerance, a few localized errors can propagate and kill an entire cluster of computing resources, causing catastrophic losses (mainly economic) for companies. In particular, despite the tolerance to well known errors like crashes of computing nodes and components, message omission, connection errors, etc., the system is weak with regards to configuration errors, bugs, and human errors, that can easily overload the entire system to the collapse, without any effective mitigation strategy in place to guarantee at least the survival of critical services.
I proposed to integrate my fault injection method in the testing loop phase of the companies, to test the business process used in case of response to failures and train the cluster operators in the task.

4. Research products:

"Criticality-Aware Monitoring and Orchestration for Containerized Industry 4.0 Environments"
M. Barletta, M. Cinque, L. De Simone, R. Della Corte

ACM Transactions on Embedded Computing Systems
Published

"Partitioned Containers: Towards Safe Clouds for Industrial Applications"
M Barletta, M Cinque, L De Simone, R Della Corte, G Farina, D Ottaviano
2023 53rd Annual IEEE/IFIP International Conference on Dependable Systems – Disrupt Track
Published

"SLA-Driven Software Orchestration in Industry 4.0"
M. Barletta, M. Cinque, C. Di Martino
IEEE Internet of Things Magazine (IEEE IoTM)
Published

Patent Application 327300-WO-PCT
M. Barletta, C. Di Martino
Application under review

5. Conferences and seminars attended

The 33rd IEEE International Symposium on Software Reliability Engineering (ISSRE 2022), hybrid mode, Charlotte, USA. I attended the conference online on 01/11/2022 as presenting author of "RunPHI: Enabling Mixed-criticality Containers via Partitioning Hypervisors in Industry 4.0".

6. Activity abroad:

I am currently in Champaign, IL, USA, to spend a research period abroad from 12/04/2023 to 22/12/2023 at University of Illinois at Urbana Champaign as visiting scholar. Here I have been studying resiliency of cloud systems, performing fault-injection campaign targeting spread out cloud technologies, supervised by Prof. Ravishankar K. Iyer and Prof. Zbigniew Kalbarczyk. The research is currently in progess, and the main findings have been summarized in Section 3, in the fault-tolerant section.

7. Tutorship

I earned 1 credit in the tutorship for the bachelor course "Operating Systems", preparing programming exercises assigned to the student to explain the correct usage of POSIX APIs, and explaining them the solutions.

8. Plan for year three

During my third year I will continue researching the issues that prevent the use of orchestration systems in mission-critical domains and I will design countermeasures and possible solutions. In detail, I will focus on how studied fault-tolerance issue can impact the timeliness of orchestration in order to jointly

model the timing and resiliency aspects. I will try to find solutions to the most severe and frequent issues (i.e., failures that can lead to catastrophic failures) and I will design the architecture of an orchestration system suited for mission-critical environments.
I will contribute to the RunPHI project, which involves several members of my research group, regarding partitioned and multi-criticality containers and virtualization to be integrated into orchestration systems.
I will try to implement and measure my solutions on real testbeds with new hardware provided by the research group, also in collaborations with companies involved in the Spoke 1 - PNRR PE 11 project, and Nokia Bell Labs.
Case studies will mainly focus on Industry 4.0 with robotic arms and embedded boards, but will nonetheless regard 5G and beyond networking implementations for edge cloud scenarios, with orchestrated control and virtual network functions.
In detail, the aim is to measure the gain and absolute metrics in terms of timing predictability, and fault-tolerance to errors through well-known dependability metrics.

I am finishing my research period regarding fault tolerance of orchestration systems at UIUC (IL,USA) on December 2023, and no other research period is in plan yet.
I will have tutorship duties for the bachelor course of "Operating Systems" when I will be back on site.

The thesis will discuss about advantages and new issues introduced by orchestration systems in mission critical environments. The thesis will contain an overview of functional and non-functional characteristics of the state of the practice orchestration systems, highlighting the drawbacks for the application in mission-critical environments. Later design solutions will be provided, and measures regarding their implementation in terms of dependability metrics.
Based on the results, I will try to state if orchestration systems can be practically used in critical environments, if there is any scope for improvement, and possible future directions in case of unsolved issues.