Curriculum Vitae et Studiorum of Nunzio Alberto Borghese - August 2017

Personal Data

Place and date of birth, Pavia, Italy, 30.October.1960. Residence: Milano, Italy.
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Positions hold:

- 2015-Present. Full Professor in Computer Science (INF/01), at the Department of Computer Science Università degli Studi di Milano, Milan, Italy.
- 2001-2015. Associated Professor in Computer Science (INF/01), at the Faculty of Science, Università degli Studi di Milano.
- 1988-2001. Research fellow at CNR at "Istituto di Fisiologia dei Centri Nervosi (later renamed "Istituto di Neuroscienze e Bioimmagini").
- 1987-1988. Post-doc at CNR at "Istituto di Fisiologia dei Centri Nervosi".

Professional experience:

- 2000 –Visiting Scientist at the Department of Motion Capture of Electronic Arts, Vancouver, Canada (with a project on algorithms and software for tracking of complex movements with passive markers motion capture)
- 1992 Visiting Scientist at the Department of Electrical Engineering, Californian Institute of Technology, Pasadena, USA (with a project on autocalibration of cameras networks for motion capture).
- 1991-1992 Visiting Scientist at the Centre for Neural Engineering, University of Southern California, LosAngeles, USA (with a project on modelling the control of human motion through artificial neural networks).
- 1983-1990 Expert in Computer Science in High schools and translation from English of computer science texts.

Education

- 1991 Ohlstadt (D). EEC Summer School on "Cognitive Aspects on Motor Behaviour".
- 1989 Trieste (I). Encounters on Cognitive Sciences at SISSA. Summer course on: "Theoretical Issues in Motor Control".
- 1986-1987 CNR Followship at "Istituto di Fisiologia dei Centri Nervosi" of Milano.
- 1984/1985 (Academic Year). Politecnic of Milano, Laurea in Electrical Engineering with full marks and honors (100/100 cum laude).
- 1979 Maturità Classica, liceo Alessandro Volta, Como (52/60).

Awards

2017 Premio Innova S@lute 2017
2016 Premio Mercks Neurologia 2016
2010 "Runner-up" (second best paper) prize at IJCNN2010, Barcelona (Spain).
2008 "Outstanding reviewer" in 2008 for IEEE Trans. Instr. & Meas.
1992 CNR fellowship for visiting scientists
1991 Fullbright fellowship.
1987 CNR fellowship.

- Member of the PhD program in Computer Science (Membro del collegio dei docenti del Dottorato in Informatica).
- Member of the steering body of the Department of Computer Science (Membro della Giunta del Dipatimento di Informatica).

Research Activity of N.A. Borghese

- **2002-Today. Established and directed the laboratory AIS-LAB** (Applied Intelligent Systems Laboratory), at the Department of Computer Science of the Università degli Studi di Milano. Home page: http://ais-lab.di.unimi.it. **AIS-Lab supports also the teaching activity** of the courses of Intelligent Systems, Digital Architectures and Statistical signal and image processing.
- 1997-2001. Established and directed the laboratory MAVR (Motion Analysis and Virtual Reality) of the "Istituto di Neuroscienze e Bioimmagini CNR".

Research carried out at AIS-Lab covers a wide spectrum, focusing on developing and applying methods and algorithms based on computational intelligence with particular attention to limited processing time. The application areas cover both industrial and clinical domains. Main areas of application are: modeling Human motion control and cognitive processes, and rehabilitation; machine learning and neural networks, medical image processing; computer vision and 3D scanners. Strong ties with industry, that has financed AIS-Lab research significantly, has provided a pathway towards real application that has been both challenging and rewarding for the group. Research has also been funded also by National and European grants, and in particular by the FITREHAB (Fitness and rehabilitation at home under expert planning, http://www.innovation4welfare.eu/287/subprojects/fitrehab.html), the REWIRE (Rehabilitative Wayout In Responsive home Environments, https://sites.google.com/site/projectrewire/) and MOVECARE (Multiple-actOrs Virtual Empathic CARegiver for the Elder, http://www.movecare-project.eu/) coordinated by myself.

A complete list of the main financed project can be found at the WEB page: *http://borghese.di.unimi.it/Research/Projects/Projects.html*. N.A. Borghese holds 18 patents (2 national and 16 international, some industrially exploited), whose updated list can be found at: *http://borghese.di.unimi.it/References/Patents.html*. He has published more than 70 refereed journal papers (*http://borghese.di.unimi.it/References/References.html*), and more than 100 refereed conference papers, 10 book chapters and 1 book (*http://borghese.di.unimi.it/References/Conferences.html*).

The results of the research activity have been disseminated through several invited talks.

Main results of research activity

Human Motion analysis, Modeling and Rehabilitation

My research activity started with studying and modeling Human motion control in the laboratory of Prof. F. Lacquanti at "Istituto Fisiologia Centri Nervosi" of CNR. Techniques based on statistics and on system identification have been extensively used. The analysis of the impulse response to pseudo-random input sequences has allowed highlighting an innovative characteristic of the peripheral nervous system: the programmability of the spinal stretch reflex, that was previous considered stereotyped and described as a reciprocal inhibition reflex modality of co-agonistic muscles. Under particular conditions, such reflex can reverse the sign up to producing a reciprocal contraction as a response of an external stimulus. [B5, B6, B7, B8, B9]. Moreover, through statistical analysis, the regularity of kinematics patterns and a compact description has been derived for some basic movements [B11, B12, B13, B20].

Connectionist models have been developed to describe possible mechanisms of motor control [B10, B14, B38]; reinforcement learning applied to up-right posture learning has allowed stressing the possible role of biomechanical constraints in shaping control synergies [B30]. Recently, stochastic finite state machines have been used to model emotional interaction between agents or between a human and a robot [B43]. This model has allowed on one side creating a richer repertoire of interaction, on the other side deriving a robust estimate of the time between two visits of the same state [F67]. This work was presented also at NIPS and in an invited seminar at Electronic Arts, Canada.

In the end of the 90s I have started analyzing the possible role of motion capture and Virtual Reality in rehabilitation [B25] and, with the new real-time tracking technology made available for the game industry, I started developing exer-game based platform to support rehabilitation. We first developed a platform targeted to neglect rehabilitation in which a web-cam was used as a tracking device and image subtraction techniques allowed to create an augmented reality scenario in which exer-games, targeted to visual scanning, were played [B55, B57, B58]. The possibility to have rehabilitation at home under control from a hospital and guided by

Virtual Reality has been further explored with the use of inertial tracking inside the EU funded project FITREHAB that has terminated in October 2011. This experience has lead to the REWIRE project, funded under FP7 framework, that has started the 1st October 2011 and will end the 31st December 2014. Both projects are coordinated by myself. REWIRE, in particular, develops, integrates and field tests an innovative virtual reality based rehabilitation platform, which allows patients, discharged from the hospital, to continue intensive rehabilitation at home under remote monitoring by the hospital itself. The main idea is to assemble off the shelf components in a robust and reliable way to get a system that can be deployed massively at the patients' homes. Our role in REWIRE, besides coordination, is to develop the Patient Station (PS). This is based on video-based tracking (Kinect 3D camera + Balance board or Falcon haptic device) and adequate exer-games to guide the patient through **autonomous** rehabilitation. We have soon recognized that actual exer-games come short in providing the functionalities required by rehabilitation: adaptation, monitoring the correct execution of the exercises, feed-back, data storage and the possibility of interfacing different tracking devices. For these reasons, we have designed and realized an innovative game engine, termed IGER (Intelligent Game Engine for Rehabilitation), that integrates a virtual therapist to provide as much as possible the functions of the real therapist, at patient's home. IGER is based on different forms of computational intelligence: Bayesian on-line estimate to adapt the level of difficulty of the game and fuzzy systems for monitoring [F87, B61, B64]. IGER has been patented [A18]. Moreover, a framework to map exercises into games has also been developed [B58, B63]. Starting from this approach a new platform is being developed, inside the H2020 funded MOVECARE project (http://www.movecare-project.eu) to support elders living at home independently. It provides monitoring, suggestion of activities and assistance along three main dimensions: physical, cognitive and social. The approach is completely unobtrusive and on the analysis of the data provided by a constellation of devices: a service robot, domotic sensors, smart objects, a virtual community and an activity center localized in a tablet / PC and/or smart TV. In particular AIS-Lab is strongly exploring the possibility offered by social interaction between peers, through audio/video interaction, while performing activities.

In parallel, we have also explored, through specifically designed experiments, the circuits involved in reading in humans with the aim of modeling the different components. [B31, B56, B59].

Learning from data and models

Predictive learning has been studied as the estimate of a multi-variate surface from a data set of noisy points. In particular a novel neural network model, named Hierarchical Radial Basis Functions Network (HRBF), has been developed. Its main characteristics are a uniform approximation error over the entire definition domain, the adaptation of the local scale to the local scale of the data, and an incremental learning mechanism: more units are inserted in the regions were more details are concentrated [B18]. It has been shown that this model is able to reconstruct a large family of functions and it has a better ability to approximate noisy data with respect to classical multi-resolution analysis carried out through Wavelets [B32]. The reconstruction error due to imprecise storing of the parameters has been also evaluated [B27]. An on-line configuration version has been recently realized [F53, B41]. This allows obtaining the same reconstruction error of the batch version, and to visualize, in real-time, the surface while data are acquired. The incremental approximation approach of the HRBF has been recently extended to the Support Vector Regression introducing, inside the configuration algorithm, pruning the support vectors. This allows obtaining a much reduced computational time and resources used [B52, F74]. This work has won the "runner-up" award (second best paper) at the IJCNN2010 conference. The summary of the different multi-scale approaches to the 3D reconstruction has been published in a monography edited by Springer [D1].

An alternative approach to the constructing an approximating surface from sparse and noisy data is represented by Vector Quantization, where the Vectors obtained can be used as basis for a surface tessellation. An algorithm for this kind has been developed [B37]. Data are first partitioned into macro-voxel and a set of "reference vectors" are distributed such that the reconstruction error is minimized, using soft- clustering techniques, and "Neural Gas" in particular. This allows not only reducing the dimensionality of the data needed to represent the mesh but also to filter the noise. Moreover, thanks to the position of the data, the complexity of the algorithm is reduced to O(N). Lastly, a method for automatically computing all the parameters has been defined. The work on learning has been carried out mainly with Dr. Stefano Ferrari, who has been my student and is now research fellow at the Department of Information Technology, Crema of our Unviersity.

Hierarchical techniques have also been applied to clustering. Hierarchical clustering has been studied and applied in bioinformatics and in medical imaging. We have highlighted the problem of "ties", that occurs when pairs of input data have the same similarity measure. This problem is largely neglected with the result of obtaining clusters that depend on the order with which data are presented, and as a consequence the same data can lead to different interpretations. In [B50] a solution to this problem is described. It is based on the definition of an equivalence relationship between the dendograms grown, at each iteration of hierarchical clustering.

Medical imaging

The introduction of digital X-ray sensors at affordable prices has revolutionized the world of X-ray imaging in many fields and in the dental field in particular. Several problems are posed and images of different qualities are obtained depending upon processing carried out. For this reason, more reliable and robust algorithms for denoising, image enhancement, structure automatic detection, 3D reconstruction (tomography) are being developed.

In particular, geometrical distortions introduced on the images by the scintillators have been corrected by using local image warping thorugh spline or radial basis functions, competitive with respect other solutions [B26].

One of the main problems in cephalography, mainly the clear visualization of bone soft tissue on the same image, under a wide range of exposures (soft-tissue filtering), has been solved with an innovative procedure [B34], that was later patented [A3, A4]. The procedure is. A different gamma correction is applied to the different tissues identified by the clusters. Down-sampling and up-sampling is used to speed-up the filtering procedure. The filter was able to filter images > di 5 Mpixel @ 12bpp in less than 1s in 2005.

In the raw panoramic images, artifacts due to failure of automatic gain control systems of the X-ray tube, can be observed. These systems modulate the X-ray intensity according to the expected type and thickness of bony and soft tissues. In particular, intensity is increased around the spine. In [B35] an effective algorithm to eliminate these artifacts through a gain equalization pairs with adequate spatial filtering is described.

An additional problem associated to digital sensors is the transient failure of the transducer associated to one pixel. This produces an anomalous gray level on the image that is regarded as a pulse and it is often treated as impulsive noise. This kind of noise is usually treated with switching median filters that first identify the pulses and then filter only the pixels identified as pulses, usually with a median filter. The effectiveness of the filter depends on the accuracy in the identification of anomalous pulses. In [B46, B47] a method based on the accurate estimate of noise through a mixture of Poisson and impulsive noise is described; expectation maximization applied to the resulting log-likelihood function allows solving the resulting optimization problem in a reasonable time.

Another interesting problem related to digital X-ray imaging is the compression of gain and offset maps associated to digital endo-oral sensors. The compression factor is of the order of 1:1,500 and a high quality of the image is required. An innovative algorithm has been developed to this aim, based on quad-tree decomposition of offset and gain maps, that allows to have smaller domains in the regions were gain and offset is more variable, typically close to the corners. The gain and offset maps are then interpolated through radial basis functions to obtain a continuous gain and offset field [B42].

More recently with Dr. Frosio, now at nVidia Santa Clara CA, we have worked with the industry in the design innovative machines for 2D and 3D dental radiography [F55, F80, F83, F97, B65]. Main characteristics of these machines are the ability of auto-positioning and auto-setting, on the single patient basis. [A5, A6, A7, A8, A9], most of the ideas developed have found their way in commercial applications.

Bayesian estimate has been explored as a tool to improve the quality of the 3D images, and in particular the choice of the weight of the a-priori term [F79, B57]. Some of these algorithms have been parallelized and implemented on CUDA architectures [F70].

Motion Capture, Computer Vision and 3D scanning

I started working on Motion Capture at the beginning of the 90s, developing the algorithms for calibration [A1, B1, B2, B3] and tracking [A2] applied to the Elite system™, a commercial Motion Capture system based on passive markers. Calibration was based on surveying a single grid moved parallel to itself following rails on the floor. This allowed to create in a simple and controlled way a 3D distribution of control points inside a large volume. Tracking was based on a model, defined a-priori, on the arrangement of the markers on the human body [A2, F4]. At the end of the 90s I have developed with Dr. Pietro Cerveri, now associate professor at Politecnico of Milano, a calibration method based on moving a rigid wand carrying two markers at its extremity, moved inside the calibration volume [B17]. The calibration problem was recasted as an optimization problem in which a sub-set of the parameters was computed in closed form, using matrix manipulation suggested by projective geometry. The other parameters (the two principal points) were determined through an evolutionary optimization algorithm with parameters adaptation [B22]. More recently I have been working on identifying procedures and calibration algorithms that could work with minimal structures that can be found in real scenes [B36, B45].

During a visiting period of four months at the laboratory of Motion Capture of Electronic Arts I could develop a tracking algorithm, based on matching strings, that turns out to be particularly robust especially when markers are dense on the image [F35].

The experience on motion capture has been applied in a large project financed by industry. Its goal was the construction from scratch of a system for virtual surgery, able to measure in real-time, the simultaneous 3D movement of multiple surgery instruments. The main innovation of the system is the possibility to measure also the axial rotation of the instruments, using only markers placed on the instrument's axis. This last characteristic has allowed greatly reducing the system. For this same system we have also developed an algorithm able to recognize the markers center, based on a statistical framework, also when the marker is partially hidden [B39]. The use of pattern on the marker's surface has allowed measuring also the axial rotation using only markers on the instrument axis [B44]. The method has been patented [A17].

With Dr. Frosio, the new inertial tracking devices have been explored form motion tracking. We have developed algorithms for the autocalibration of tri-axial MEMS accelerometers [B40, B53].

I also participated to the development of one of the first low-cost scanners: Autoscan, based on real-time image processing and a laser pointer [B19]: its main characteristics were easy set-up and flexibility. The system has been later better characterized in [B23], where the HRBF algorithm is used as an engine to create a surface from the sampled points. Quad-tree subdivision of the space has been introduced to speed-up configuration time [B33]. Continuous color fields rendered through Gouraud shading has been explored as an effective alternative to texture mapping. In [B24] it is shown how an adequate re-tiling of the surface, can produce a mesh with a uniform chromatic error, with a better appearance than texture mapping when subtle shadowing is present in the image.

Teaching Activity of N.A. Borghese

Current course taught:

- From A.Y. 2016-2017: Virtual Reality, Laurea Magistrale (Master Level) in Computer Science (6 CFU, 12 hours, frontal teaching, 36 hours of laboratory).
- From A.Y. 2015-2016: Artificial Intelligence. Laurea Magistrale (Master Level) of Cognitive Science and Decisional Processes (9 CFU, 24 hours of frontal lessons, 36 hours of laboratory. Reponsible of the course and administering frontal teaching).
- From A.Y. 2002-2003: Intelligent Systems, Laurea Magistrale (Master Level) in Computer Science. (6 CFU, 48 hours of frontal teaching).
- From A.Y. 2001-2002: Digital Architectures and Networks, Laurea (triennale, undergraduate) in Computer Science. From A.Y. 2009-2010 the course is subdivided into two modules: Digital Architectures I and II (12 CFU: 36 hours of frontal teaching + 24 hours of laboratory for each of the two modules. NA Borghese is responsible of the course and is administering frontal teaching).
- From A.Y. 2012-2013: Statistical signal and image processing. Laurea Magistrale (Master level) in Applied Mathematics (6 CFU. The corse is administered with other two collegues of Mathematics Department and it is organized in 24 hours of frontal lessons and 24 hours of laboratory. I have administered a total of 10 hours of frontal lessons).

Old courses

- From A.Y. 2002-2003 to A.Y. 2008-2009. Robotics and Digital Animation. Laurea Magistrale in Computer Science.

Other courses:

- 2002-2003- Course on Motion Capture. Summer School in Computer Graphics and Visualization at CINECA, Bologna.
- 1999-2000 & 2000-2001. Introductory course on “Computer Vision”. Course of Image Processing, laurea of Computer Science, Università degli Studi di Milano.
- Dall’A.A. 1997-1998 all’A.A. 2000-2001. Course of basics of Computer Science for “operatori radiologi, audio protesisti e logopedisti of Medical School, Università degli Studi di Milano.
- Dall’A.A. 1996-1997 all’A.A. 2001-2002. Course on 3D graphics. Master post-laurea in Advanced Technologies on Computer Science and Communication, Istituto Internazionale per gli Alti Studi Scientifici E. Caianiello, Vietri sul Mare (Salerno).

N.A. Borghese has followed the thesis of more than 140 students (complete list at: *http:/borghese.di.unimi.it/Research/Studenti/index.html*).