Thesis and Stage Opportunities AY22/23

Giacomo Boracchi, Politecnico di Milano, DEIB

https://boracchi.faculty.polimi.it/

Updated on February 2022
The Team

Faculties

Giacomo Boracchi
Luca Magri
Federica Arrigoni
Filippo Leveni
Diego Stucchi
Loris Giulivi

PhD Students

Antonino Rizzo
Andrea Porfiri Dal Cin
Riccardo Margheritti
Michele Craighero
Edoardo Peretti
Giuseppe Bertolini

Research Assistants
Research Topics

Deep Learning & Image Processing
- Anomaly Detection
- Explainable CNN
- Neural Networks for 3D vision

Change/Anomaly Detection in Datastreams
- Data-driven models for high-dimensional streams
- Concept Drift Detection

Computer Vision
- Object detection / template matching
- Multi-view geometry
- Robust Model Fitting
- 3D reconstruction & Structure from Motion
- Quantum Computer Vision
These slides...

...provide both:

• A short overview of the research background (Background slides)
• Possible research directions along which to develop a thesis under our supervision (Research directions slides)
• Research institutions / companies involved in these research activities
Thesis Types:

- **Research thesis:** for those of you willing to investigate some new problem, discover something new. *Enthusiasm, talent, sense of initiative, willingness to learn and try.*

- **Thesis on industrial research projects:** for those of you looking for a direct and full involvement in a research project with the industry. You will work under our strict supervision. *Dependability, talent, rigour.*

- **Internships:** for those of you looking for an experience in a R&D company. Still, we regularly collaborate with these companies.
What do we offer

- Our supervision + co-supervision by a PhD student / colleague of ours
- General guidance on «how to address thesis work». Meetings with your colleagues concerning:
  - Thesis management
  - Related work
  - Problem Formulation
  - Thesis / Executive Summary Preparation
  - Thesis Presentation
- Every now and then we organize also meetings to illustrate research activities in the group.
If you feel like a brilliant candidate…

... and you are considering pursuing a PhD related to our research topics…

... and you have a wonderful idea / some special interest for a research topic of ours…

Just drop me an email and we can arrange a short meeting to discuss whether there is room for an additional research thesis

giacomo.boracchi@polimi.it
How to apply for a thesis

Fill in the form by Tuesday February 28th

https://forms.gle/U18g5XibF95m2pwC6

indicating:
- Which thesis are you interested in and if any is a «first option»
- What is your background, which courses you have passed that are inherent to the thesis you selected.
- Mention also
  - any information you deem relevant for working on that specific thesis.
  - successful projects and your programming expertise.
- A short motivation paragraph.
- Please, let us know if you are considering pursuing a PhD.
Deep Learning and Image Processing
DL 1: Heterogeneous Feature Matching

CLIP learns two different embeddings:

- A text embedding
- An image embedding

That maps images and their "paired text" into nearby vectors

It is based on the Contrastive Learning paradigm, to bring embeddings of different natures nearby when semantically related

DL 1: Heterogeneous Feature Matching

Goal
• Learn via contrastive learning a joint embedding to map 2D (image) and 3D (point cloud) descriptors and match them
• Design automated dataset preparation for 2D-3D matching

Requirements: AN2DL, Python programming
Preferable: IACV, ATDL (The rise of Transformers)
Materials and Methods: RGB cameras, access to GPUs
Start: asap Duration: 9 – 12 months.

Boracchi, Magri, Rizzo, Giulivi

State of the art in generative models editing and translation are based on Diffusion Models. As a matter of fact, Denoising Diffusion Probabilistic Models (DDPM) are a powerful way to model probability distributions of very complex data (images).

DL 2: Denoising Diffusion Restoration Models

A pretrained DDPM can be used as a powerful image prior in restoration problems. Denoising Diffusion Restoration Models (DDRM) can solve denoising, deblurring, super-resolution, inpainting and colorization.

**Limitation** DDRM require the complete knowledge of the degradation process.

DL 2: Denoising Diffusion for Image Restoration

Goals:

• Train a restoration network based on DDPM but also realistic noise models (Poissonian, correlated, blurred)

• Extend DDRM to deal with unknown / partially known degradations.

Materials and Resources:

• access to GPU powered machines

Requirements: AN2DL, Python, Basics of Probability

Start: asap, Duration: 9-12 months

Boracchi, Peretti
DL 3: DL for environmental crime detection

Application scenario: Design tools and solutions for detecting environmental crimes based on remote sensing imaging.

Goals:
- Design DL models to detect landfills from aerial and satellite images
- Combine models analyzing satellite images and drone surveys
- Volume estimation of landfills from drone images / point clouds

Materials and Methods: Access to machine with dedicated GPUs. Datasets. Thesis work will be done within an EU-funded project

Requirements: AN2DL, Python programming.

Start: asap, Duration: 9 – 12 months.

DL 4: Risk prediction in TAVI patients

**Context:** severe aortic stenosis can be treated with transcatheter aortic valve implantation (TAVI). Implanted devices are mainly of two types: self-expandable and balloon expandable.

**Problem:** depending on the type of device and patient characteristics, patients can undergo complications after treatment, including device migration and paravalvular leakage.

**Current state of research:**

Preliminary statistical analysis revealed significant correlations between pre-op geometrical features and device migration.

All attempts at training deep models ended in overfitting.

DL 4: Risk prediction in TAVI patients

Goals:

• Training a DL model on such a large-dimensional to predict the risk of post-operative complications from pre-operative imaging.

• Design models and augmentation procedures for such high-variability data, given a small sample size.

Materials and Methods:

• 3D CT scans of 220 patients, 50% treated with self-expandable devices and 50% treated with balloon expandable devices.

• Access to servers mounting GPUs

Requirements: AN2DL, Python Programming, Preferred: Understanding of cardiovascular pathologies, 3D Geometry fundamentals

Start: asap, Duration: 9 – 12 months

Boracchi, Prof. Vesentini, Ing Saitta (DEIB)
In collaboration with
DL 5: Augmented Semantic Segmentation

Context: semantic segmentation is the task of assigning a class to each pixel in an image.

Problem: current state-of-the-art semantic segmentation models [1] develop segmentation maps at a lower resolution than needed, and resort to simple interpolation for upsampling. This has detrimental effects on performance.

[1] Rethinking Atrous Convolution for Semantic Image Segmentation

Architecture of the SOTA model DeepLabV3. The output is upsampled to obtain a segmentation map of the desired resolution.

Boracchi, Giulivi
**DL 5: Augmented Semantic Segmentation**

**Goal:** Improve the performance of semantic segmentation models by using test-time augmentation and multi-frame super-resolution.

**Current state of research:** We have already developed a python experimental framework to test the methodology, which is inspired by Augmented Grad-CAM [2].

**Materials and resources:** You will have access to GPU powered machines and to our experimental framework.

**Requirements:** AN2DL, Python

**Start:** asap, **Duration:** approx. 6 months


The developed methodology involves obtaining semantic segmentation maps from many augmented copies of the images and then merging them in a single high-resolution map.
Computer Vision
CV 1: Geometric Augmented Reality

Traditional 3D reconstruction techniques focus on point-wise features but falls short in presence of:

- repeated structures,
- moving objects,
- occlusions and clutter.

They provide only a sparse description of the scene.
CV 1: Geometric Augmented Reality
Supervisor: Magri, Boracchi

Goals:

- Design camera pose algorithms that leverage the use of Geometric Features (lines, planes, conic)
- Implement reconstruction algorithms that yield a simplified reconstruction of the 3D scene for augmented reality applications.

Requirements: Linear algebra, preferred: IACV, robust fitting, multi-view geometry

Start: asap – duration: 9-12 months

"TRPLP: Trifocal Relative Pose from Lines at Points " CVPR 2020.
Recent developments in AR require smartphones or head visors to accurately estimate depth from video sources. Accurate depth estimation enables the correct placement of objects in the 3D scene and realistic results.
CV 2: Video Depth Estimation for AR
Supervisor: Magri, Porfiri Dal Cin, Boracchi

Goals:
• Explore how to leverage multi-view information to improve the accuracy of depth estimation and, possibly, improve training and inference times w.r.t. state-of-the-art solutions

Materials and Methods:
• Video datasets of indoor and outdoor scenarios
• Access to the GPU to train custom DL models

Requirements: AN2DL, basics of linear algebra, Python programming
Start: asap
Duration: 9-12 months

CV 3: Learning to fit Multiple models

\[ \hat{\theta} = \arg \min_{\theta} \ell(x, \theta) \]

**Stereo matching**
\[ \theta = \text{fundamental matrix} \]

**Circle fitting**
\[ \theta = \text{(center, radius)} \]

**Primitive fitting**
\[ \theta = \text{rototranslation} \]
\[ \theta = \text{camera parameters} \]
Deep Learning methods are gaining momentum also to solve robust fitting problems. Currently, the State-of-the-Art in stereo-matching is reached by $\nabla$-RANSAC, which is based on a NN architecture.

CV 3: Learning to fit multiple models
Supervisor: Magri, Rizzo, Boracchi

Goals:
• Enhance $\nabla$-RANSAC to fit multiple models in the same input set
• Test on Computer Vision benchmarks (plane / motion segmentation)

Requirements: Deep Learning, Python programming (TensorFlow/PyTorch)

Preferrable: Robust Fitting

Start: asap  Duration: 9-12 months

CV 4: Autocalibration of variable focal length cameras

[Thesis on an Industrial Project]

Inspection machines for Quality Assurance (QA) require very accurate visual feedback from camera arrays. Variable focal length cameras enable more accurate inspection when objects move closer or farther from the camera point of view.
CV 4: Autocalibration of variable focal length cameras
Supervisor: Magri, Porfiri Dal Cin, Boracchi

[Thesis on an Industrial Project]

Goals
• Work in our research team and in collaboration with Antares Vision s.p.a. to develop novel autocalibration algorithms to improve the reliability of variable focal length cameras in QA machines.

Materials and Methods
• Access to the camera hardware and software provided by Antares Vision
• Access to servers with CPU and GPU access

Requirements: IACV, basics of linear algebra, Python/MATLAB programming

Start: asap Duration: 9-12 months
CV 5: Exploring Three-view Constraints

The **trifocal tensor** can be viewed as a generalization of the fundamental matrix to three views.

It can be used to determine the exact position of a point in a third image (given its position in the other two images), hence there are fewer mismatches over three images than there are over two.

CV 5: Exploring Three-view Constraints
Supervisors: Federica Arrigoni & Luca Magri

The goal of the thesis is to establish whether in practical applications (pose estimation, motion segmentation) it is better to use a solver based on 2 views or 3 views.

Requirements:
• Basics of Computer Vision
• Basics of Python/Matlab programming

Materials & Methods
• Multiple view geometry
• NO DEEP LEARNING

Start: asap Duration: 9-12 months

In collaboration with Czech Technical University in Prague
A quantum computer is as an **accelerator** for specific tasks. Among the existing paradigms, Adiabatic Quantum Computers (AQC) are the most mature. They can solve **NP-hard** optimization problems expressed as a QUBO (quadratic unconstrained binary optimization):

$$\min_{y \in \mathbb{B}^k} y^T Q y + s^T y$$

Related Computer Vision problems:

- Multi-image matching
- Robust Fitting
- Motion segmentation

CV 6: Quantum Computer Vision
Supervisors: Federica Arrigoni & Luca Magri

The goal of the thesis is to bring new Computer Vision problems into a form that is manageable by quantum computers, analyzing the advantages.

Requirements:
• Computer Vision
• Python/Matlab programming

Materials & Methods
• Online access to DWave quantum annealer https://docs.ocean.dwavesys.com/en/stable/
• NO DEEP LEARNING

Start: asap Duration: 9-12 months

In collaboration with Max-Planck Institute for Informatics
CV 7: Viewing Graph Solvability

When is 3D reconstruction well-posed (i.e., unique solution)?
It is very important to classify unsolvable cases in advance.
This theoretical question can be addressed by analyzing the viewing graph:

- Nodes = images
- Edges = fundamental matrices

This is a hard problem:
- Polynomial system of equations

CV 7: Viewing Graph Solvability
Supervisor: Federica Arrigoni

The main challenge is how to derive a more efficient algorithm.

Requirements:
Computer Vision (mandatory)
• Mathematical background (preferred)

Materials & Methods
• NO DEEP LEARNING
• Symbolic computation: https://faculty.math.illinois.edu/Macaulay2/

Start: asap Duration: 9-12 months

In collaboration with: University of Udine & Czech Technical University in Prague
CV 8: Synchronization
Supervisor: Federica Arrigoni

Synchronization refers to the problem of computing absolute/global quantities starting from pairwise/relative measures, given as a graph.

The main idea is to exploit a matrix representation of the problem and enforce global consistency.

Possible applications:
- Point-set alignment (rigid transformations)
- Structure from motion (rotations)
- Multi-image matching (permutations)

CV 8: Synchronization
Supervisor: Federica Arrigoni

There are many challenges related to synchronization problem, that will be explored in this thesis, including the extension to new matrices/applications

Requirements:
• Basics of Computer Vision
• Basics of Python/Matlab programming

Materials&Methods:
• NO DEEP LEARNING
• Multiple view geometry

Start: asap Duration: 9-12 months

In collaboration with University of Udine
Change/Anomaly Detection
Change Detection Tests

Change Detection Tests are statistical tools to detect distribution changes $\phi_0 \rightarrow \phi_1$ by analyzing input data.

Statistical methods can be applied to time series or structured data provided an effective modeling of the temporal dependence by autoregressive or deep models.

Change detection is also related to the detection of changes in data meant for classification (concept drift).
CD1: Concept Drift Detection by learned dimensionality reduction

Goal:

- study dimensionality reduction by leveraging a classifier operating over the stream to boost the detection performance of a CDT (e.g., monitoring logit as in open-set recognition)
- investigate the best way to leverage supervised information provided over the stream
- incremental learning and adaptation strategies (e.g., labeled data to update the classifier/detector).

Materials and Methods: Change Detection libraries for datastreams, annotated datasets.

Requirements: Basic in Statistics and Neural Networks

Start: asap  Duration: 9-12 months
CD2: Change Detection Test for Business Process

Goal:
- investigate and develop an effective description of a business process (e.g. a purchase order in an online shop).
- Design a **CDT to monitor business processes** and their evolution over time.
- Possibly detect changes at intermediate steps of the process, without having to wait the entire process to be accomplished (irregular inputs of different length).

Materials and Methods: Change Detection libraries for datastreams, annotated datasets

Requirements: Basic in Statistics and Neural Networks

Start: asap Duration: 9-12 months

*L. Frittoli, D. Carrera, G. Boracchi "Nonparametric and Online Change Detection in Multivariate Datastreams using QuantTree", IEEE Transactions on Data Knowledge and Engineering 2022*

*C. Alippi, G. Boracchi, M. Roveri, "Just In Time Classifiers for Recurrent Concepts" IEEE TNNLS 2013*

Boracchi in collaboration with UNIST (Korea)
Thesis with Companies and Internship AY 22/23

Research opportunities
Important Disclaimers

• These thesis are activated within existing research collaborations with companies / research institutions and typically lead to a full, research-oriented thesis

• All these companies are sponsoring PhD Scholarship and/or Industrial Research Projects

• You might be collaborating with other MsC/PhD students currently involved in the same research project

• Internship opportunities are often available and not always mandatory. It is also possible to work to a thesis in academia addressing these problem with the project team.
Thesis/Internships @STMicroelectronics

Agrate Brianza
Applied Math Team – Software Platforms
SRA-System Research and Application
ST 1 ML for Battery Management Systems

Most electronic devices are equipped with Battery Management Systems to:

- Detect unsafe operating conditions
- Protect the battery from damage
- Prolong battery life
- Maintain the battery in its optimal state

Nowadays, BMSs have critical importance in several scenarios, from automotive to energy storage
ST 1 ML for Battery Management Systems

There are two relevant variables that measures the state of a battery:

- The **State of Charge** (SoC) measures the amount of charge currently stored by the battery

- The **State of Health** (SoH) measures the maximum charge that a battery can store w.r.t. the factory conditions

Both SoC and SoH have to be estimated during the operations from the measurements of current, voltage and temperature.
ST-1 ML for Battery Management Systems

Goals:
- Design and implement online algorithms for estimating SoC and SoH
- Optimize the algorithms to run on a microcontroller.
- Run exhaustive tests on real data

Materials and Methods:
- public datasets and acquisition from ST sensors will be provided.
- Access to servers mounting GPU

Prerequisites: Machine Learning, Python and C programming, Estimation Theory (e.g., Kalman Filter).

Start: June-September 2023, duration: 9 – 12 months.
Internship info

The research thesis will be carried out under the joint supervision of Giacomo Boracchi and the Applied Math Team in the STMicroelectronics Labs (Agrate Brianza, Centro Direzionale Colleoni + Smart Working).

• Internship lasts 6 months and it’s extended up to other 6 months. Typically, internships last 9 months.
• Start to be agreed between June and September 2023
• The net salary is 800 €/month (graduate students: 1000 €/month)
• Canteen + transportation from Gobba / Lambrate included

Contacts: Pasqualina Fragneto pasqualina.fragneto@st.com