Thesis Opportunities AA20/21

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Research topics for a MSc Thesis

Image Processing and Deep Learning
- Anomaly/Change Detection
- Image restoration and registration

Computer Vision
- Object detection / template matching
- Robust Model Fitting Methods

Unconventional Imaging Modalities
- Deep Learning for unconventional data
- Shape registration

Machine learning for Health
- Machine Learning for diagnosing nasal pathologies through CFD
- ML for Seismocardiogram and ECG signal analysis in wearable devices

Change/Anomaly Detection in Datastreams
- Data-driven models for high-dimensional and heterogeneous streams
- Histograms for change/anomaly detection
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
You’ll be supervised by myself and by an experienced colleague of mine. Here we are:

Giacomo Boracchi
Diego Carrera (STM)
Luca Frittoli
Filippo Leveni
Nicolò Folloni
Luca Magri
Simone Melzi (La Sapienza)
Andrea Schillaci
Diego Stucchi
For any enquiry

Just drop me an email and we can arrange a short meeting to discuss...

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Image Processing and Deep Learning
Anomaly Detection

Anomaly Detection is the process of identifying unexpected items or events in data sets, which differ from the norm.

Anomalies are also referred to as outliers, novelties, noise, deviations and exceptions.

Anomaly detection is a very general problem with applications ranging from: quality inspection to health and industrial monitoring.

It is typically treated as an unsupervised problem, being anomalies unknown.
Anomaly Detection for automatic quality control

https://www.mvtec.com/company/research(datasets/mvtec-ad/)
Anomaly Detection in Point Clouds

In 3D point clouds, anomalous items typically translate to some kind of problem such as a **structural defect**.

Detecting anomalous points in 3D clouds is a challenging problem, since normal data in 3D are typically scattered (rather than lying on a regular grid like images) and more difficult to **describe by many local primitives**.
Anomaly Detection

Goals:

- Design efficient algorithms to detect anomalies in images and point clouds.
- Study state-of-the-art anomaly detection techniques in point clouds and multi-model fitting.
- Design data-driven embeddings of input that are optimized for anomaly detection.
- Formulate effective locality consistency principles.

Materials and Methods:

- Access to a server mounting GPUs.
- Multi-model fitting algorithm code.
- Dataset from our industrial partner.
Multimodal Image Analysis

Different imaging modalities offer a rich view on the subject to be analyzed.

For example, different modalities are used in medical imaging (MRI and PET scans provide different diagnosing hints), remote sensing, (hyperspectral and aerial images offer different information at different resolutions) and in thermal imaging (IR and RGB images can be combined to improve image understanding and resolution).
Challenges in Multimodal Imaging

**Image Registration:** estimate transformation that registers misaligned images coming from different modalities.

**Anomaly Detection:** identify anomalous regions which do not conform to a reference from a different modality. This is often the case in industrial monitoring where sensors (IR / RGB-d) measurements have to be compared with expected outputs from simulations (CFD, CAD).

These are **challenging problems**, since the different modalities make pixel-by-pixel comparison meaningless (differences can be arbitrarily large even in case of perfect registration), preventing the use of standard algorithms.
Thesis on Multimodal Images

Research goals:

• Design an adaptive intensity transformations to match images from very different modalities (PET – MRI, IR – RGB, IR – Temperature from CFD, RGB-D and CAD models)

• Design efficient registration algorithms to be interleaved with intensity transformations in iterative schemes

• Design anomaly detection algorithms comparing different modalities from different views

Materials and Methods:

• Reference codes for iterative multiscale registration

• Public datasets and datasets from our industrial partner
Image Restoration

Denoising (or noise suppression) is a cornerstone problem in image processing, and a fundamental ingredient of image-processing pipelines.

One of the most effective priors in images is self-similarity, namely that a patch in an image has many similar patches exhibiting the same content, by different noise realization. Similar patches can be jointly filtered to suppress noise and clean the image.

Similar patches are identified based on some distance measure. The better the distance measure, the most effective the denoising algorithm. Typically, patch-similarity is assessed through Euclidean distance (possibly spatially-weighted).

Thesis on Image Restoration by data-driven distances

Research goals: Design new data-driven distance measures for patch-similarity to the purpose of image denoising. These include:

• Isolation kernel, to assess similarity in an unsupervised manner
• Deep Learning, and in particular siamese networks (supervised)
• Test will be performed over Non Local Means algorithms, which is the most straightforward way to assess the impact of a better distance measure.

Materials and Methods:

• Reference codes for NLMeans denoising
• Datasets for performance assessment
Class-activation Maps (CAM)

Heatmaps are one of the most effective ways for extracting an explanation from a deep neural network. These maps highlight which regions in the input image have mostly influenced the network prediction.

Heatmaps are typically computed from the deepest layers of the network and most algorithms resort to some form of upsampling to compare the heatmaps and the input image.

We have proposed Augmented-CAM, a general framework for heatmaps super-resolution!

Augmented CAM for heatmaps super-resolution

Augmented CAM for heatmaps super-resolution

Research goals: adopt augmented CAM to train an image segmentation network by leveraging only image-class labels

• Assess Augmented CAM localization accuracy (over datasets annotated for segmentation)
• Train a simple segmentation model using labels provided by augmented CAM (Pseudo-Label Generation)

Materials and Methods:

• Grad-CAM and Augmented Grad-CAM codes https://github.com/diegocarrera89/AugmentedGradCAM
• Access to a server mounting a GPU for the heaviest simulations
Computer Vision
Our template matching algorithms in action
Our template matching algorithms in action
Our template matching algorithms in action
Object Detection by Advanced Template Matching

Template matching is a very practical technique for finding all the occurrences of a template image in a given query image.

Deep-learning techniques are not very flexible, requiring re-training for new templates.

Traditional computer vision techniques (e.g. SIFT + RANSAC) are more practical but require an underlying model describing the transformation between the template and its occurrences in the query image.
Thesis: Efficient template matching in large scale

Goals: Dynamically identify which template to search first when the number of templates is very large (e.g. a few hundreds):

• Studying state-of-the-art template matching techniques based on image features and content based image retrieval.

• Transfer learning of pre-trained models with very little samples in segmentation.

• Chromatic transformation to improve matching.

• Definition of new templates from a single image.
Thesis: Efficient template matching in large scale (cnt)

Goals: Dynamically identify which template to search first when the number of templates is very large (e.g. a few hundreds):

- Implementation of learning-based criterion to identify the template that will be most likely found in a region of the query image.
  
  - Clustering of template images to speed up the retrieval.
  - Learning a latent representation of templates.

Materials and Methods:

- Access to a server mounting GPUs.
- Annotated grocery dataset
- Annotated Image Retrieval Dataset
Thesis: Template matching for non-rigid distortions

Embedding non-rigid distortions into robust fitting methods (RANSAC).

Goals: Design efficient clustering algorithms for feature matches that identify multiple distorted instances of the template in the query image:

- Study state-of-the-art template matching techniques based on image features.
- Design of learning-based feature matching schemes.
- The design of an innovative technique to group feature matches that refer to the same template instance in the query image.

Materials and Methods:

- Access to a server mounting GPUs.
- Dataset from our industrial partner.
Robust Model Fitting in Computer Vision

Consensus analysis: (e.g. Ransac, Hough transform)

1. represent models (columns of the matrix)
2. number of points explained by each model (consensus)
3. maximize consensus

Preference analysis: (e.g. Residual Histogram Analysis, T-Linkage, Higher Order clustering)

1. represent points (rows of the matrix)
2. each point “votes” for the preferred models
3. clustering of points preferences

For further references see: https://magrilu.github.io/assets/talks/202001Praga.pdf
Multi model fitting: beyond analytical models

Classical multi-model fitting methods leverage on **analytical models with very few parameters**. These can be easily integrated in robust fitting framework to gain resilience against outliers, but, due to their simplicity, they are not able to encode higher level semantic information.

**Research challenge:**
- Go beyond analytical models: use more general models to foster the extraction of higher level information from data.
- Non-analytical models can be:
  - **Neural** models (exorbitant numbers of parameters)
  - **Non-rigid** models (piece-wise analytical models)
  - **Parameter-less** (partition of data)
- How non-analytical models can be fitted in a robust way (resampling)?

**Applications:**
- **Instance Segmentation Networks**
- **Non-Rigid models**
- **Ensamble clustering**

*It is possible to use Preference Analysis to deal with non-rigid models?*
Thesis: Robust Instance Segmentation via Preference Analysis

Indoor modeling aims at recovering structural elements such as rooms, doors, and walls, then reconstructs a structured 3D model consisting of such elements. Instance Segmentation architectures can provide higher-level information to enable semantic-aware multi-model fitting.

Research goals:
- Investigate how Instance Segmentation Networks can be integrated into the Preference Analysis
- Enforce robustness through resampling scheme
- Test on 3D datasets for indoor classification

Materials and Methods:
- 3D datasets
- Access to a server mounting GPUs will be provided

Some reference to start:
Thesis: non-rigid model fitting

The rigidity assumption is often violated in real challenging scenarios, as non-rigid Structure from Motions, non-rigid Shape Registration, non-rigid Template Matching. However inliers of non-rigid models typically satisfy local properties that can be profitably exploited.

Research goals:
• Investigate how model-free consensus maximization [1] can be used to formulate non-rigid single model fitting by exploiting local properties of inliers.
• Explore how this approach can be extended to the case of multiple non-rigid objects.
• Explore how these ideas can be integrated in preference analysis.

Materials and Methods:
• Datasets for non-rigid matches.
• Access to a server mounting GPUs will be provided.

Some reference to start:
[1] Probst et Al. Model-Free Consensus Maximization for Non-Rigid Shapes
Thesis: **Ensemble clustering via Preference Analysis**

*Ensemble clustering refers to the problem of combining the output of multiple clustering in an unique partition of the data. If we consider each element of a partition as a tentative model this problem can be neatly translated in the preference analysis framework.*

**Research goals:**
- Investigate how to tailor Preference Analysis to address the case of Ensemble clustering, by considering the partition induced by a clustering as a parameterless model.
- Consider clustering that are robust to outlier (dbscan) to perform Robust Ensemble clustering.
- Implement and test the solution on both clustering and multi-model fitting problems such as motion segmentation.
- This approach can be extended to deal with learned clusters.

**Materials and Methods:**
- Datasets available
- Access to a server mounting **GPUs will be provided**

**Some reference to start:**
1. Topchy et Al. Clustering Ensembles: Models of Consensus and Weak Partitions
3. Schubert, Erich, et al. DBSCAN revisited, revisited: why and how you should (still) use DBSCAN
Research Directions

Thesis: Dealing with outliers in preference space

Research goals for a few thesis:

• Develop methods able to **accurately remove outliers** for geometric computer vision tasks

• Study and compare existing **outlier rejection techniques** (robust statistic, low rank decomposition, NFA)

• Investigate how the **geometry of the preference space** can be exploited to detect outliers. (e.g. Topological Data Analysis with the Jaccard distance)

Materials and Methods:

• Annotated datasets for two-view body segmentation and video segmentation.

Some reference to start with:


Thesis: synchronization on graphs

Synchronization aims at inferring the unknown states of a network of nodes, where only the ratio (or difference) between pairs of states can be measured (e.g., rototranslation between point clouds).

Research is carried on in collaboration with Andrea Fusiello (Università degli Studi di Udine) and Federica Arrigoni (Università degli Studi di Trento).
The hand eye calibration problem (also called the robot-sensor or robot-world calibration problem) is the problem of determining the transformation between a robot arm and a camera.

**Application:** Use synchronization techniques, and specifically conjugate rotation averaging, to handle the hand-eye calibration problem.

**Materials and methods:**

- Research is carried on in collaboration with Federica Arrigoni (Università degli Studi di Trento)
- Access to server mounting GPU will be provided.

**References to start with:**

Thesis: Projective Synchronization

Application: Extend synchronization techniques to deal with projective entities: the main idea is to deal with relative projective transformations $Z_{ij} \in GL(4)$ that are known only up to a scale factor.

Materials and methods:

- Research is carried on in collaboration with Andrea Fusiello (Università degli Studi di Udine) and Federica Arrigoni (Università degli Studi di Trento)
- Access to server mounting GPU will be provided.
- Real word datasets are available

References to start with:

Arrigoni et al. Synchronization Problems in Computer Vision with Closed-Form Solutions, IJCV 2019

\[ \lambda Z_{23} = x_2 \cdot x_3^{-1} \]
Machine Learning for Health
ML and CFD for diagnosing nasal pathologies

These thesis will be part of an established research collaboration with the aerospace department.

Goal: Design new machine learning methods that

- analyze CFD simulation of the human upper airways
- help surgeon to make the most informed choices

Why ML and CFD?

- Large failure rate of surgical corrections
- Lack of reliable diagnostic tools
- CT scan only gives information about shape of the nasal apparatus
- CFD can give information about the functional properties during breathing
ML and CFD for diagnosing nasal pathologies

Challenges:

- **Dimensionality**, CFD’s output is an **high dimensional 3d (or 6d) -vector field**, it has to be **suitably transformed** to be handled by ML models. On a disk it might take a few GB!

- **Registration**, CT scan provides very different shapes from different subjects which needs to be registered.

- **Very little supervision**, compared to the input dimension. Many different pathologies to diagnose.
ML and CFD for diagnosing nasal pathologies

CT - SCAN

ML for Flow Inference

Regional /Streamlines Feature Extraction

CFD Simulation

3D Surface Reconstruction

Nose with sinuses

Reference w/o sinuses

Clutter-robust registration (f-maps)

Sinuses Removal via registration

Deformations

Deformation transfer via f-maps

Background

Flow Regions

Feat. Computation

Feature vector

Flow Inference

Septoplasty

Turbinoplasty

Classification Network

Surgery Taxonomy
Example of Registration via functional maps

Noses from two subjects that are matched through functional maps. Colors encode estimated correspondences.

A reference section extracted from the first subject

A nasal section extracted from the second subject, estimated through the correspondences

Thesis Opportunities in ML and CFD

Very Multidisciplinary environment:
This project brings together doctors, CFD expert, Data scientist, experts of geometric computer vision

Methods and Materials:
• Features inspired to image analysis techniques.
• State-of-the-art feature selection methods from ML literature
• Many CFD simulations of patients provided with the medical diagnosis
Online and long-term ECG monitoring in wearables

We have been designing algorithms to enable online and long-term ECG monitoring on low-power wearable devices. Our algorithms are based on data-driven models to automatically detect anomalies (e.g., arrhythmias), these models undergo a domain adaptation procedure to track heart rate variations. The model is based on a learned and user-specific model of heartbeats.

IJCAI Demo webpage: http://home.deib.polimi.it/carrerad/IJCAI_2018_Demo.html
Machine Learning for Seismocardiogram analysis

- Seismocardiogram (SCG), records micro-accelerations of the chest wall due to the heart movements, and it’s a very informative signal since, w.r.t. traditional ECG:
  - SCG provides a direct measure of the heart mechanical activity, and not just the heart electrical triggers (assessed by the ECG).
  - The analysis of SCG is a quite new research, and efficient automatic algorithms for segmenting, classifying and identifying anomalies in this signal have still to be investigated.

- Recently, Fondazione Don Gnocchi developed a wearable system for SCG monitoring, which have been used to monitor patients in clinics, and also in the International Space Station to monitor astronauts during their sleep.

- See the video at [http://ow.ly/7z7Q30mgI1K](http://ow.ly/7z7Q30mgI1K)
Thesis proposal: ML methods for Seismocariogram analysis

Goals:

- Develop data-driven algorithms for the automatic localization of patterns (associated with salient moments of the cardiac cycle) within the SCG waveform
- Develop patient-specific ML models to detect anomalies in the SCG signal
- Design a data-driven model to propagate annotated positions of fiducial points over the time series (as per optical flow in video frames)

Materials and Methods:

- The activity will be carried out in collaboration with the Wearable Sensor and Telemedicine Laboratory coordinated by Ing. Marco Di Rienzo, of the IRCCS Fondazione Don Carlo Gnocchi Hospital in Milano.
- The SCG recording device (SeisMote)
- Annotated datasets and tools
Change/Anomaly Detection in Datastreams
Anomaly detection in datastreams

Usually anomaly detection is carried out modeling the density of normal data and identifying anomalies as samples that fall in low density regions.

Non-parametric density models are much more flexible, but extremely inefficient (e.g. KDE). This is particularly evident when the data dimensionality and the number of samples increases.
Anomalty detection in datastreams

**Isolation Forest (IFOR):** introduced a new paradigm in anomaly detection. Instead of learning the density of normal data, IFOR models how **difficult is to isolate** each sample $x$ from the others.

Fei Tony Liu, Kai Ming Ting and Zhi-Hua Zhou, “Isolation Forest”, Proceedings of the 2008 Eighth IEEE International Conference on Data Mining
Thesis: Beyond IFOR

Goal: investigate improvements for IFOR:

• Discover the properties of the isolation space.

Then:

• Design adaptation mechanisms for IFOR to handle evolving data-streams.
• Perform unsupervised features selection/elimination.
• Define interpretability criteria for anomalies.

Materials and Methods:

• Access to a server mounting GPUs will be provided.
• Dataset from our industrial partner.
Preference Isolation Forest

**Preference Isolation Forest (PIF):** exploit the preference embedding to discover non-structured anomalies.

Instead of working directly in the euclidean space, PIF embed points in the preference space, where samples that deviate from unknown structures can be recognized as isolated points in a framework similar to IFOR.

Filippo Leveni et al, PIF: Anomaly detection via Preference Embedding, ICPR 2020
Thesis: Forest for metric and non metric spaces

PIF [1] uses Voronoi tessellation to derive an anomaly score in the preference space, but this technique is general enough to cope with general metric space.

Goal: investigate tessellations to deal with:
- Categorical data using different distances (e.g. hamming distance)
- Non-metric space exploring tessellation/partition that do not require a metric (e.g. by using spectral clustering on affinity matrix)

Materials and Methods:
- Access to a server mounting GPUs will be provided.
- Dataset available.

Some reference to start:
[3] Qin et Al, Nearest-Neighbour-Induced Isolation Similarity and Its Impact on Density-Based Clustering
Thesis: PIF & clustering

The Voronoi tessellation presented in PIF [1], can be used to derive an isolation kernel, that can be fed to clustering algorithms to robustly detect clusters of non-anomalous samples.

Goal:
- Combine the framework of PIF with a density-based clustering algorithm to robustly recover clusters of structured points.
- Study the connections with non-rigid multi model fitting.

Materials and Methods:
- Access to a server mounting GPUs will be provided.
- Dataset available.

Some reference to start:
[2] Qin et Al, Nearest-Neighbour-Induced Isolation Similarity and Its Impact on Density-Based Clustering
[3] Kai Ming Ting et Al., Isolation Kernel and Its Effect on SVM
Thesis: PIF with local models

*When nominal data are described by a complex unknown model, we can use simple local approximation to build the preference embedding, where anomalies are identified by PIF.*

**Goal:** Detect **wrong predictions** of a complex as **anomalies w.r.t. simple models** fitting training samples locally
- Approximate the regressor locally using piece-wise linear regressors
- Embed the samples in the corresponding preference space
- Detect anomalous prediction using PIF or similar techniques.

**Materials and Methods:**
- Access to a server mounting GPUs will be provided.
- Dataset available.

**Some reference to start:**
[2] Bicego et Al, Clustering via Binary Embedding
Change Detection in Datastreams

Efficient density models for detecting changes in high-dimensional datatstreams, yet controlling false positives

QuantTree: Boracchi, Carrera, Cervellera, Macciò, “Histograms for Change Detection in Multivariate Data Streams”, ICML 2018
Thesis: Extensions/Applications of QuantTrees

Distribution changes in streams of data and concept drifts can affect classification performance. Change-detection algorithms can be used to adapt classifiers in non-stationary environments.

Goals for different thesis:

• Investigate QuantTree or other monitoring schemes to **handle** categorical data

• Study the applicability of QuantTree for concept drift detection and monitor both distribution changes / drop in classification error

• Design adaptation procedures for the underlying classifier

Luca Frittoli, Nicolò Folloni, Diego Carrera
Thesis with Companies
AA 20/21

Research opportunities and Internship
Important Disclaimers

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

- 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 problems with the project team.
Thesis/Internships @STMicroelectronics

Agrate Brianza
Stage Opportunities in STMicroelectronics
Applied Math Team – Software Platforms
SRA-System Research and Application
Applied Math Team: People and Mission

Collaborate in projects where mathematics is the key to find innovative solutions to industrial problems.

Conceive new mathematical tools to analyze/process data coming from manufacturing and other ST organizations.

Build an open ecosystem involving experts from various disciplines characterized by a synergic working method and a result-focused approach.
Deep Learning for Wafer Monitoring

Semiconductor manufacturing is a long, complex and expensive process involving many specialized steps.

Inspection tools provide a huge amount of data, that can be entirely analyzed only by Deep Learning techniques.

Deep Learning enables the continuous and automatic monitoring of the production lines, increases quality by promptly identifying problems and drives ST’s transformation toward Industry 4.0.
Stage/Thesis: Active Learning

Currently, an automatic solution based on sparse a CNN is employed to classify defective patterns on Wafer Defect Maps.

The **goals** of this thesis are the design of strategies to **identify query samples** that:

- are **maximally informative** for the classifier
- can significantly modify the decision boundaries
- either look at the sample distribution in the latent space (anomaly score) / the classifier performance / the gradient associated to the sample

The development of a solution to **accordingly update the classifier with limited information**

**Requirements:** basics of image/signal analysis/processing, machine learning, statistics, Matlab/Python programming.

**Materials and methods:** annotated WDM dataset, support from ST's engineers, reference algorithm based on sparse convolutions

*Nicolò Folloni*
Stage/Thesis: Adaptation techniques

Currently, an automatic solution based on sparse a CNN is employed to classify defective patterns on Wafer Defect Maps.

The objectives of the stage/thesis are:

• The implementation of concept-drift detection in a datastream of supervised samples

• The development of a solution for handling novel classes, classification in open-set settings rather than traditional closed-set settings

Requirements: basics of image/signal analysis/processing, machine learning, statistics, Matlab/Python programming.

Materials and methods: annotated WDM dataset, support from ST's engineers, reference algorithm based on sparse convolutions

Luca Frittoli
Stage/Thesis: Similarity Search

The problem is to retrieve information from the very large IMAGO dataset containing SEM images of devices to improve the quality inspection systems.

The objectives of the stage/thesis are: The development of a solution to identify the type of malfunctioning and localize the faulty machinery in the production pipeline

- similarity search in quality inspection systems
- perform similarity search in the latent representation of wafers
- combine this with meta-data information (categorical data)

The development of a solution to retrieve the most similar structure of the die to a query picture (SEM images)

Requirements: basics of image/signal analysis/processing, machine learning, statistics, Python programming.

Materials and methods: annotated WDM dataset, annotated SEM images dataset, support from ST's engineers, reference algorithm based on sparse convolutions
Stage/Thesis: Low Rank and Sparse Decomposition

The problem is detect and localize the area of wafers hit by the leaked acid, perceived as a halos on the wafer surface image.

The objectives of the stage/thesis are:

The implementation of a batch-wise analysis of multiple images of wafer possibly using sparse-representation / deep learning techniques

• reference-free setup
• high-dimensional images
• locate anomalous regions by jointly analyzing multiple images that are vastly normal

Requirements: basics of image/signal analysis/processing, machine learning, computer vision, Matlab/Python programming.

Materials and methods: annotated wafer image dataset, support from ST's engineers, reference algorithm based on image processing
General Conditions

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

- Internship lasts 6 months and it’s typically extended up to other 6 months. Typically stages lasts 9 months
- The net salary is 600 €/month (graduate students: net salary of 750 €/month)
- Canteen + transportation from Gobba / Lambrate included
- **Contacts:** Pasqualina Fragneto [pasqualina.fragneto@st.com](mailto:pasqualina.fragneto@st.com)