SISSA mathLab

New Research topics: examples of new projects in the group

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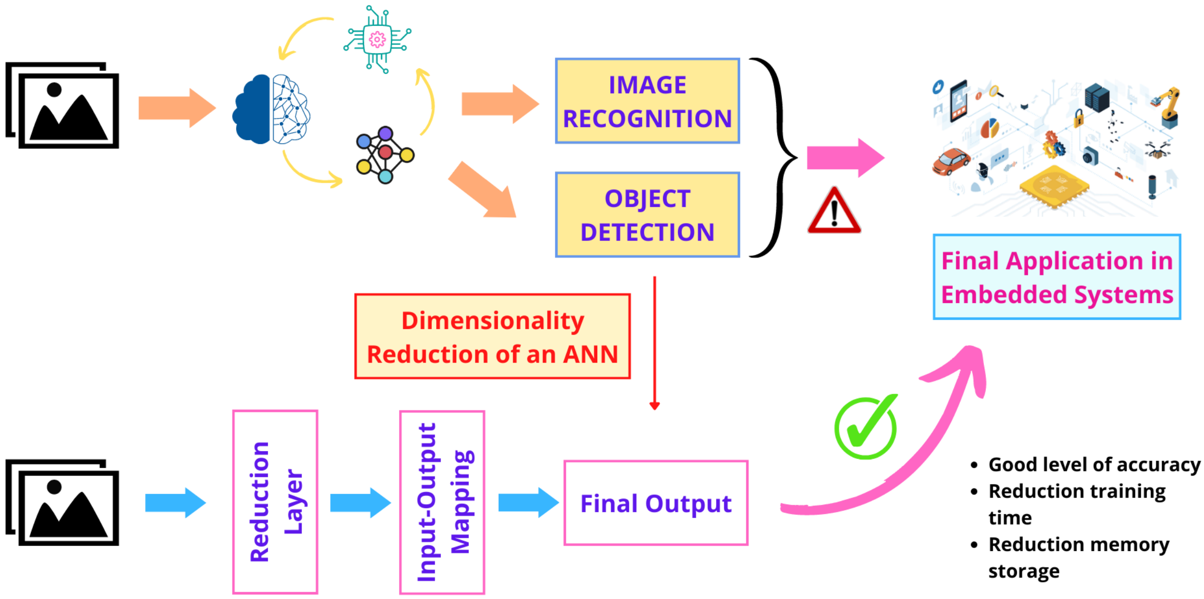
There are several projects completed and currently running in cooperation with different companies in the field of Machine Learning:

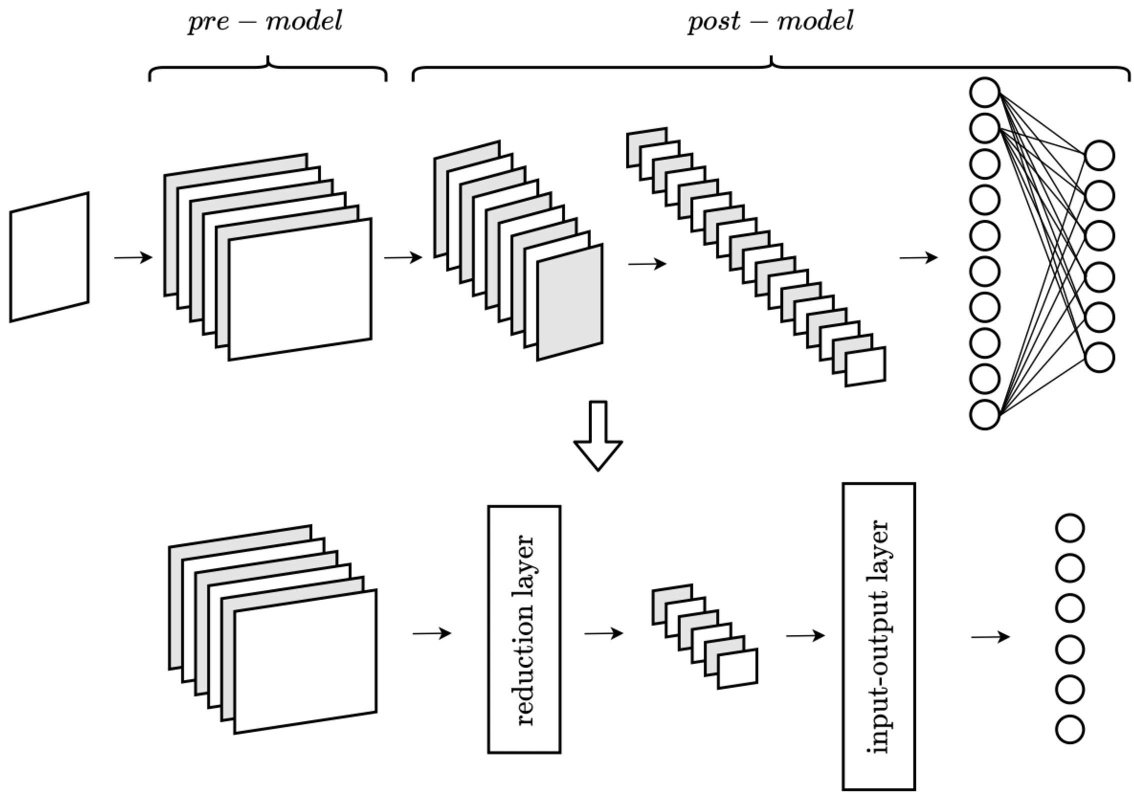
Object Recognition

The goal of this project is to build a Convolutional Neural Network (CNN) able to recognize and detect the position of different types of objects. In order to solve such a problem we have constructed a Python library (based on PyTorch) using as architecture SSD300 together with VGG16 as base network.

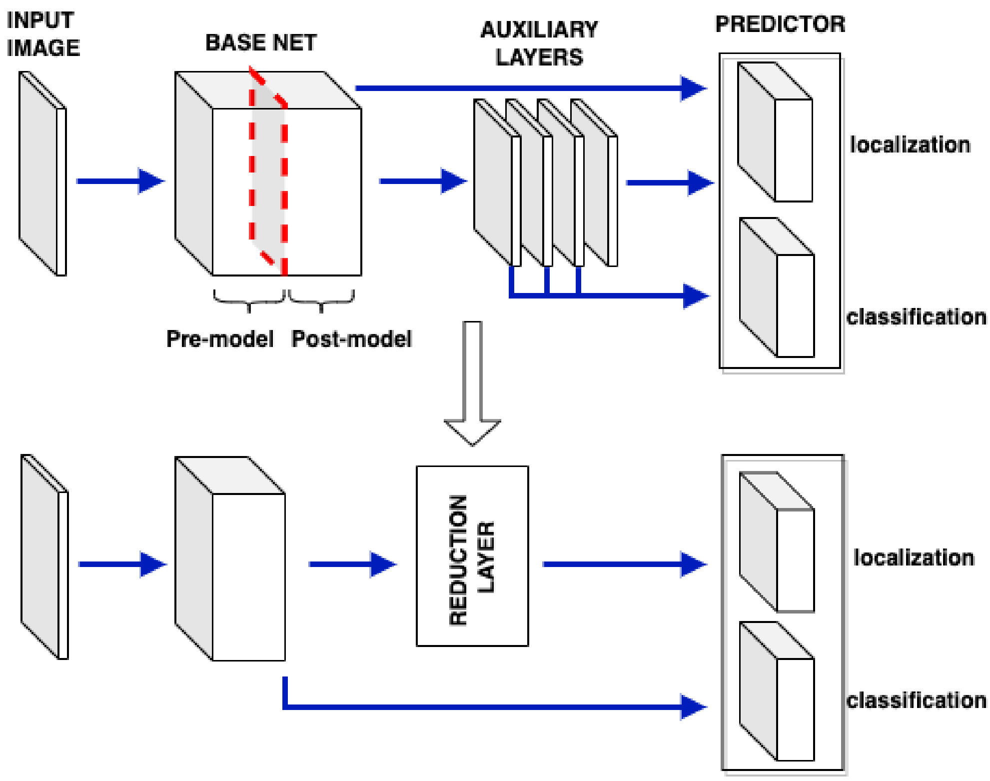


When trying to apply it inside a professional appliance and in particular in an embedded system, we faced the problem of memory storage since such a net requires a lot of space. Therefore in order to satisfy these memory constraints, we have extended the reduction approach proposed in **[1]** to obtain a network with few convolutional layers which can easily be integrated in an embedded system **[2]**. We exploit the proper orthogonal decomposition and the active subspace property to perform such reduction, aiming to keep an high accuracy in the network performance even with few layers.
We have thus developed a reduced method for a general artificial neural network (ANN) by retaining a certain number of layers of the original ANN and replacing the remaining ones with an input-output mapping (see the picture below). In this way, the net is splitted in two

parts (the original layers of the ANN and the input-output mapping) connected by the reduced method, that aims in reducing the typically large dimensions of the intermediate layers by keeping only the most important information.

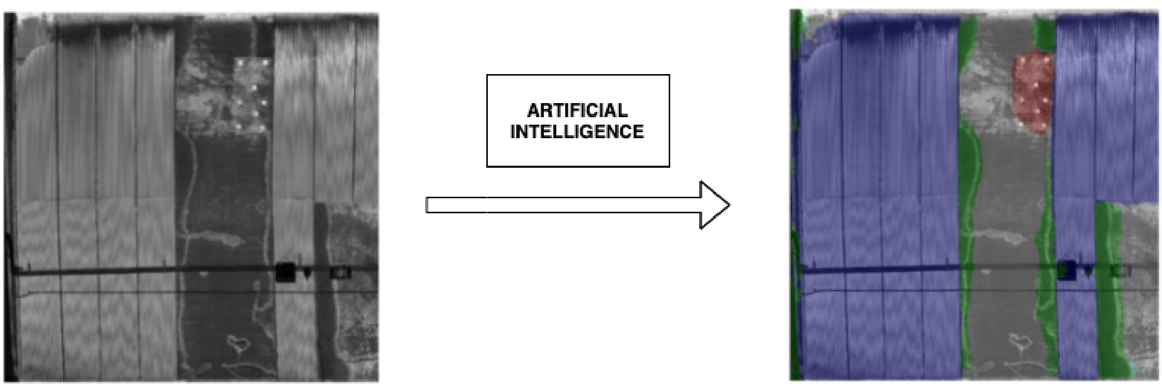


Starting from the idea developed in **[2]**, we have extended our reduction method to the problem of object detection and related architectures, i.e. object detectors. Due to the complexity of such models, we have focused on a type of one-stage object detectors called SSD or on SSD-type architectures, composed of mainly three parts: a base net (a CNN), some auxiliary (convolutional) layers and a predictor for classifying and detecting the position of objects in pictures. The figure below describes the proposed method, that starting from the full original network constructs the reduced version with the same process as before. Hence, only a certain number of layers of the full net is retained, defining the pre-model. The output of the pre-model is reduced using the reduction layer (in our case the Proper Orthogonal Decomposition) and then the final output is obtained through the input-output mapping, that in this case corresponds with the same predictor of the original network.



Infrastructures Monitoring

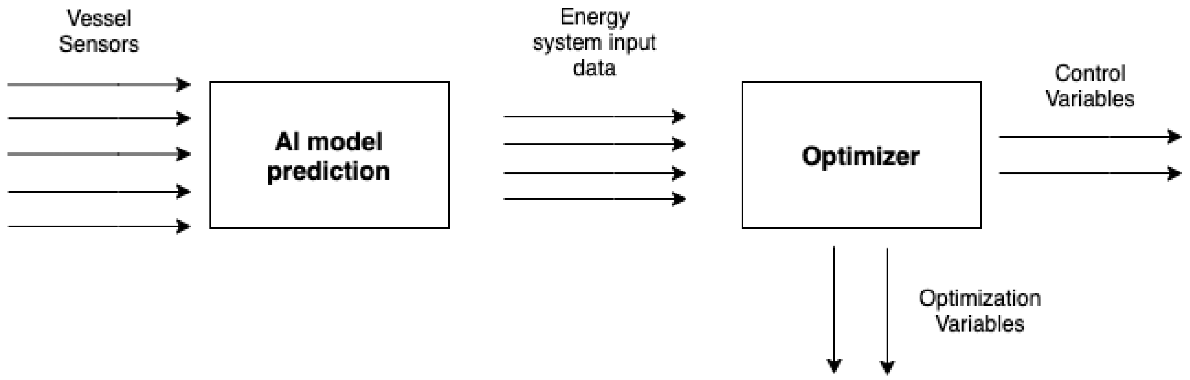
The goal of this project is to improve analysis of road tunnel defects with Machine Learning and Deep Learning in order to support engineers to plan and prepare targeted inspections in advance.



To solve the problem a CNN was used to classify the importance of defects using Keras and Pytorch as main frameworks.

Performance Optimization

The Smart Hybrid Energy Management System (SHEMS) project is capable of optimizing the performances of a hybrid energy system in different working conditions.



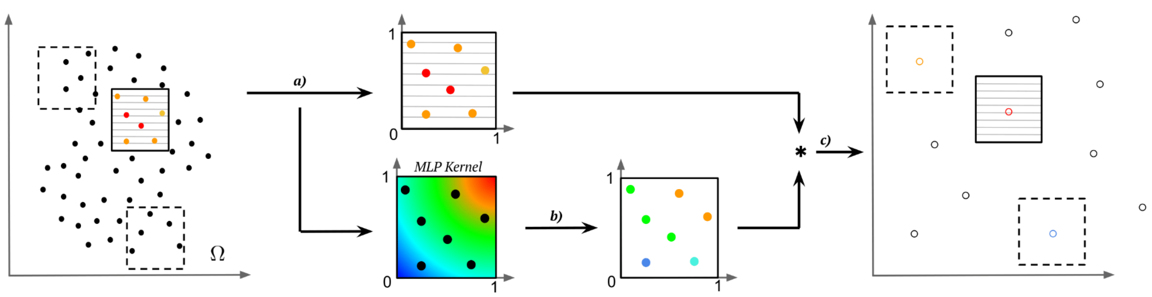
The framework manages the operations of an hybrid energy system such that fuel consumptions and emissions are minimized. We can identify two main parts in this project:

- AI prediction
- Optimization.

The first part is in charge for the prediction of the system behavior and takes advantage of acquired knowledge to learn how the system would function in different scenarios.
The second part is instead responsible for the optimization of the same working conditions, focusing on the minimization of emissions, exploiting as much as possible the usage of green energy.

Continuous Convolutional Filter

The key ingredient in Convolutional Neural Networks for detecting objects features is represented by filters, matrices able to capture the difference between objects in a picture thanks to their structure. Due to their discrete nature, their domain of application corresponds with structured data such as images. We have thus proposed in **[4]** an extension of the notion of discrete filter, characterizing CNNs, to a continuous one, as depicted in the following Figure.



The aim of this project is the application of CNN filters to unstructured data, by approximating the continuous filter with a trainable function constructed through a Feedforward Neural Network. Employing such modules instead of the classical ones can have several benefits:

- They can be exploited in the case of not complete images, e.g. characterized by the presence of holes or bad quality regions, or, in a general perspective, to sparse incomplete data. This can thus be useful also for the training of image reconstructors, aiming at restoring the quality of images.
- The possible application to non-structured data leads to a filter able to capture non-trivial relationships also in an unstructured context.
- They can be used to find latent space representations, namely the most important information enclosed in input data, for complex manifolds by the use of continuous AutoEncoder exploiting continuous filters. Hence, using the knowledge contained in the latent space, it is possible to reproduce, by only knowing the time of the snapshot, phenomena, like the complete liquid-gas state.
- They can be applied for solving parametric problems for a finite set of data, to obtain a generalization of the solution. Hence, a continuous convolution network, containing the convolution and the transpose convolution operation, can be employed in the context of Reduced Order Modeling to reconstruct the solution based on the finite input data.
- They can be included in a generative adversarial network to construct a continuous version of it, with the aim of enlarging, for example, the dataset for computational fluid dynamics simulations.

In this way, deep learning architectures, based on CNNs, coupled with continuous filters can hence be exploited to solve problems in different domain settings, such as the unstructured continuous one characterizing the aforementioned Navier-Stokes, or the liquid-gas phase problem.

References

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submitted