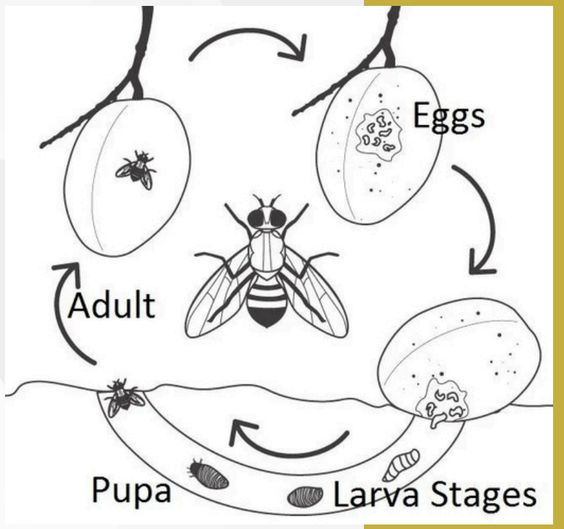
Data Science Lab in Biosciences

AUTOMATED DETECTION OF FRUIT FLY INFESTATIONS IN CITRUS USING CT IMAGING AND DEEP LEARNING ALGORITHMS

Salvatore Rastelli 903949
Marco Sallustio 906149
Marco Guarisco 789244

CONTENTS

INTRODUCTION



- **Fruit Fly Infestations in Agriculture:**
  - Fruit flies are a significant pest in agriculture, causing extensive damage to various crops, including lemons. Infestations can lead to substantial economic losses and pose a threat to both domestic and international trade.
- **Limitations of Traditional Inspection:**
  - Traditional methods of detecting fruit fly infestations, such as visual inspections and surface-level examinations, are often unreliable. These methods may fail to detect early stages of infestation that are not visible on the fruit's surface, making early intervention difficult.

MAIN GOALS

- **Explore the Potential of Deep Learning for Early Infestation Detection**
  - Assess the feasibility of using deep learning models to detect early signs of fruit fly infestation in lemons based on CT scan images.
- **Improve Classification Accuracy for Infested Lemons**
  - Develop models capable of accurately classifying lemons as infected or uninfected and further categorizing the degree and duration of infestation for infected lemons.
- **Enhance Data Utilization for Model Training**
  - Utilize innovative data augmentation techniques to expand the dataset and improve model robustness and performance.

METHODOLOGY

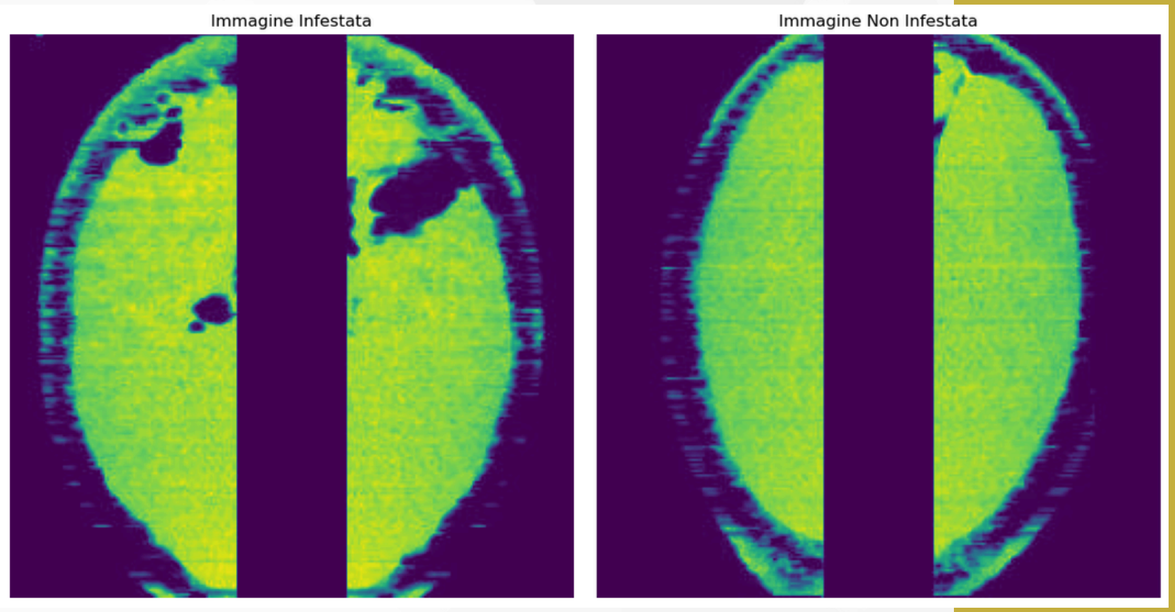
To achieve the same project objectives, three different approaches were used:

1. **Multiclassification with Pretrained Models:** When testing AlexNet and GoogleNet for image classification, the results were initially unsatisfactory.
2. **Splitting the process into multiple steps:** We used AlexNet for a preliminary classification of lemons as infected or uninfected. Then, after removing the images of healthy lemons, we focused on classifying the degree and time of infestation in infected lemons.
3. **Video Classification:**
    a. We converted the individual images of the fruits into GIFs for a new multiclassification.
    b. Additionally, the dataset was enriched with GIFs generated by a GAN network.

DATASET

- **Dataset overview:** Experimental setup:
  a. Lemons were inoculated with different number of flies : **0** (control), **50**, **100**, **500**.
  b. Lemons were observed over time: **4**, **5**, **7**, **10** days.

- **Data Composition:**
  a. **Number of Folders**: **189** folders
  b. **Images per Folder**: Each folder contains **72** images.
     i. images correspond to lemons rotated every 5 degrees, covering a full 360°



DATASET

Based on the information present in the folders names, we built a dataset with the following labels:

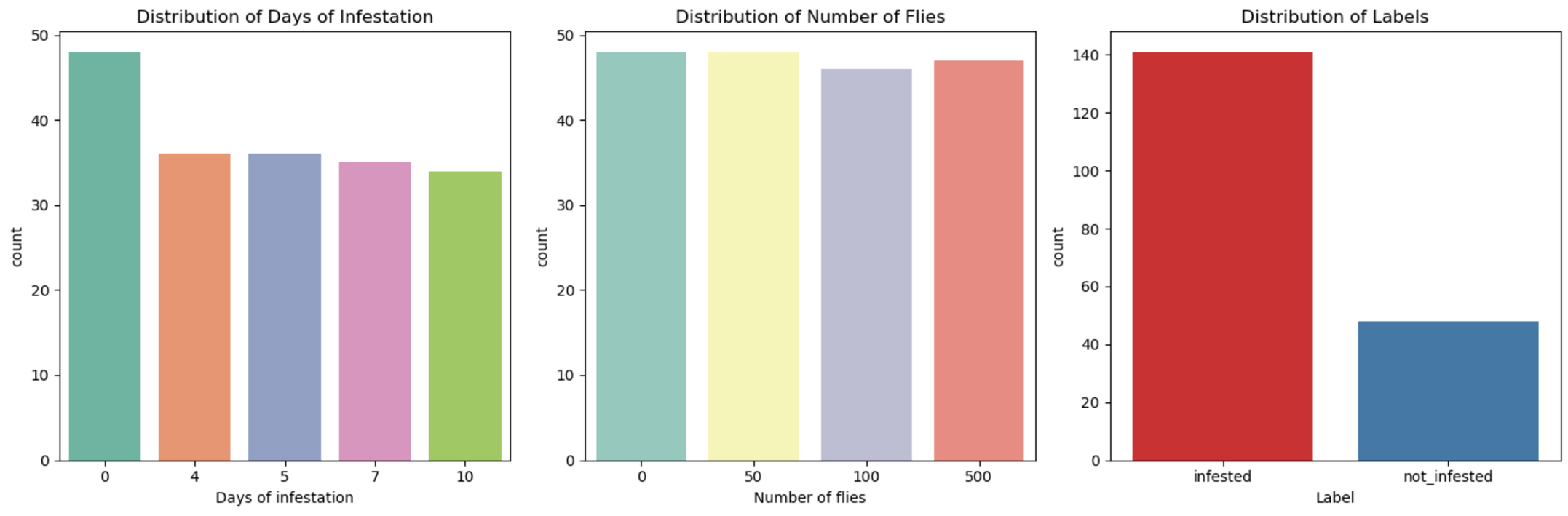
	Subfolder	Days of infestation	Number of flies	Label
0	/Users/sallu/Desktop/original/Day4/CRI_4_100_6...	4	100	infested
1	/Users/sallu/Desktop/original/Day4/CRI_D4_500_...	4	500	infested
2	/Users/sallu/Desktop/original/Day4/CRI_D4_Ctrl...	0	0	not_infested
3	/Users/sallu/Desktop/original/Day4/CRI_4_50_2_...	4	50	infested
4	/Users/sallu/Desktop/original/Day4/CRI_D4_50_5...	4	50	infested
...	...	...	...	...
184	/Users/sallu/Desktop/original/Day10/CRI_D10_50...	10	500	infested
185	/Users/sallu/Desktop/original/Day10/CRI_D10_co...	0	0	not_infested
186	/Users/sallu/Desktop/original/Day10/CRI_D10_50...	10	500	infested
187	/Users/sallu/Desktop/original/Day10/CRI_D10_50...	10	50	infested
188	/Users/sallu/Desktop/original/Day10/CRI_D10_50...	10	50	infested

We have a different label for each characteristic of the fruit:

- Days of Infestation: 4, 5, 7 or 10 days
- Number of Flies: 50, 100 or 500 flies
- Label: *not_infested* when number of flies is equal to 0, *infested* otherwise

DATASET

Here is shown the distribution of the labels:



APPROACH 1: MULTICLASSIFICATION

- First of all, we employed **AlexNet** and **Google InceptionV3**, two Deep Convolutional Neural Networks (CNN) pretrained on **ImageNet**, to do a MultiLabel Classification of the images.

- We unified the labels in a single one considering both the days and the degree of flies infestation in the lemons, with the exception of control images, which were not divided by day.

- The resulting classes to be predicted were **13**.

APPROACH 1: MULTICLASSIFICATION

The labels have been unified as follows:

- When Number of flies = 0, the label is **not_infested**.
- For Number of flies = 50, 100, 500, the label follows the format:
  - **X_days_low_infestation** (50 flies)
  - **X_days_moderate_infestation** (100 flies)
  - **X_days_high_infestation** (500 flies)

Where X is the number of days (4, 5, 7, 10).

Example of labels:

*Number of days= 4 and Number of flies=500 ---> **4_days_high_infestation***
*Number of days= 10 and Number of flies=0 ----> **not_infested***

APPROACH 1: MULTICLASSIFICATION

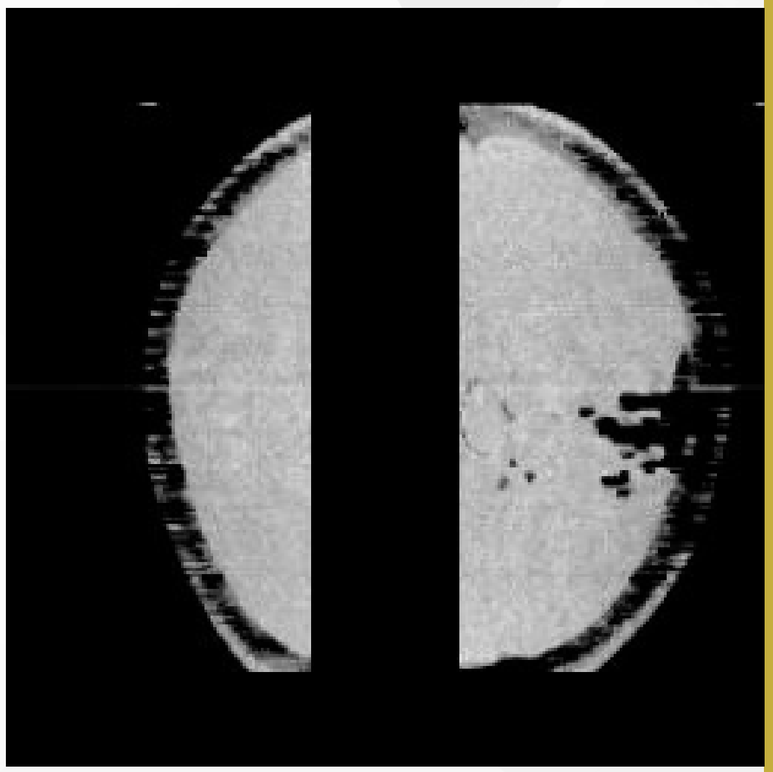
- Dividing the dataset in train and test, we made sure that the 72 images of a single lemon were either in the Train or the Test.
- This was to prevent that the model could be biased by recognising the lemon and not the features needed to predict the label.
- Moreover, the fact that the images were taken every 5 degrees meant that the first 36 image of a lemon were equal to the last 36,but mirrored.

APPROACH 1: MULTICLASSIFICATION

Lemon at 10 days with 500 flies

0 degree photo

180 degree photo



APPROACH 1: MULTICLASSIFICATION

- Being the dataset heavy imbalanced between the classes, we used a **weighted F1 score** to evaluate the performance of the model

$$F1 = \frac{2 \times Precision \times Recall}{Precision + Recall}$$

- After training the models for 30 epochs, we reached these results on the Test Set:

Architettura	Weighted F1 Score
AlexNet	**0.23**
Inception V3	**0.2408**

APPROACH 2: PROCESS SPLIT

- For the first part of this approach, we used **AlexNet** to do a *binary classification* between the *Infested* and *Not Infested* lemons.
- We preferred the first model out of the two because, despite the accuracy a little lower than GoogleNet, it was faster and least computationally expensive.
- Again, we considered the *F1 score* for the evaluation, being the dataset heavily imbalanced on the *Infested* side.
- We obtained an **F1 Score of 0.8165**

APPROACH 2: PROCESS SPLIT

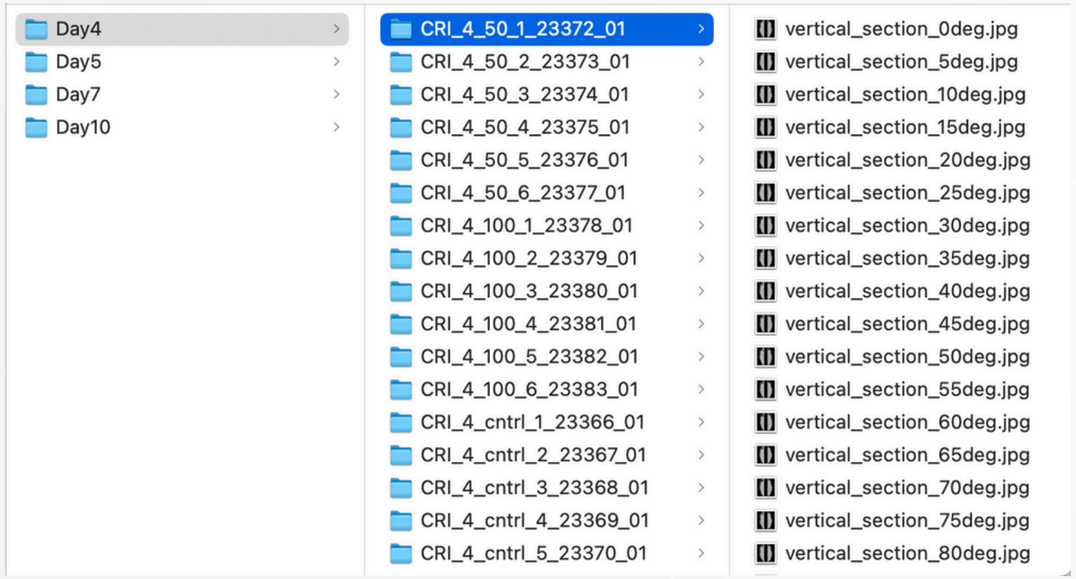
- Considering the good result obtained with the binary classification, we procedeed by deleting the images of healthy lemon in the dataset, reducing it to just 7992 images.
- We did two multilabel classification on the *infested* lemon, using the time and the degree of infestation as targets.

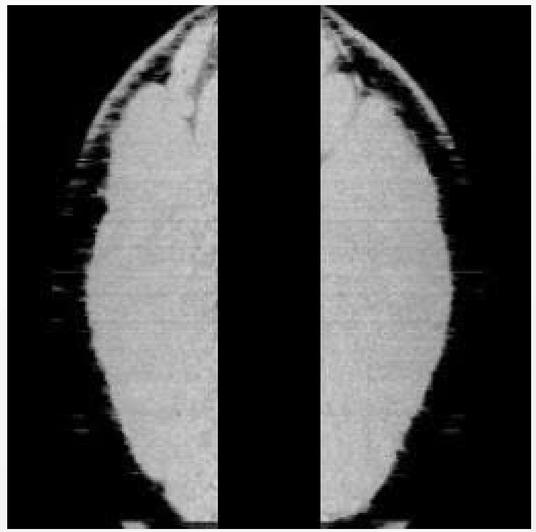
We obtained these results on the Test Set:

Label	Weighted F1 Score
Days of Infestation	**0.7440**
Number of Flies	**0.4115**

APPROACH 3: GIF CLASSIFICATION

- We converted each subfolder containing the slices of a single fruit at a specific time point and infestation degree in a GIF.
- This was motivated from the fact that certain slice images of infested fruits could seem healthy, and be predicted as healthy by the model.
- In this way, the model can predict the fruit as a whole, and not the single slices.



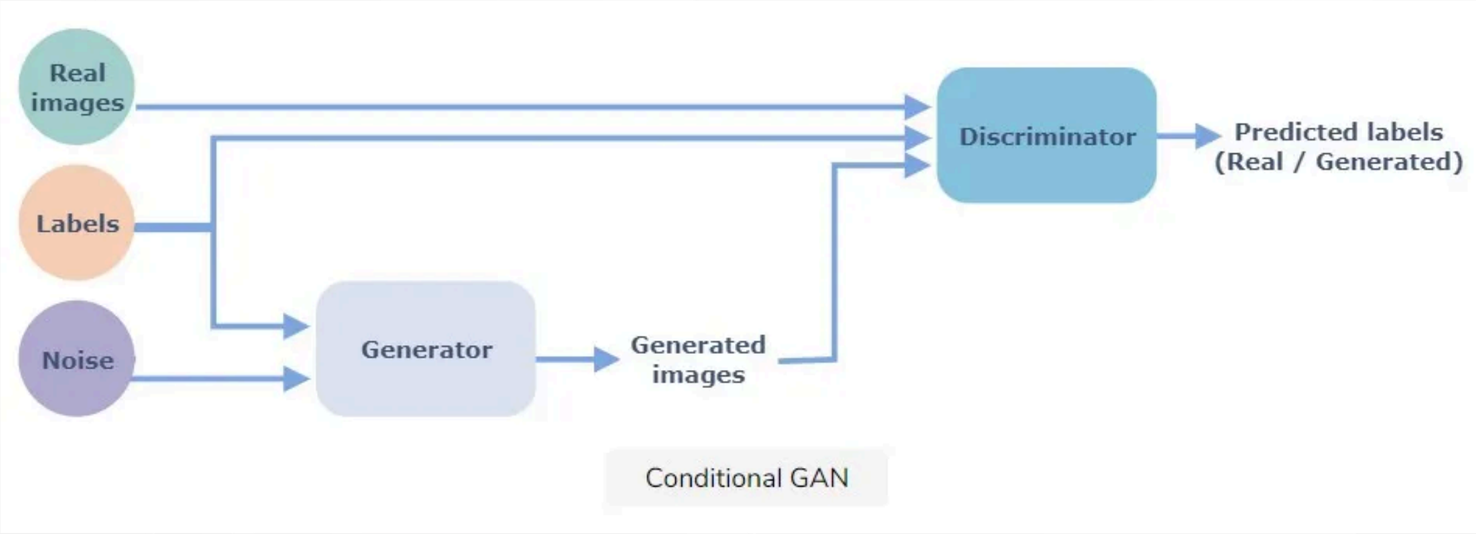


APPROACH 3: VIDEO TRANSFORMERS

- **What are Transformers?**
  - Transformers are a type of deep learning model originally designed for **natural language processing** (NLP) tasks.
  - They use a **self-attention mechanism** to focus on different parts of the input data simultaneously, making them highly effective at handling sequences and complex data relationships.
- **Why Use Transformers for CT Scan Analysis?**
  - **CT scans** consist of sequences of **2D images** (**slices**) that together represent a **3D object** (like our fruits).
  - Transformers are ideal for **capturing relationships** across these slices, understanding both **spatial** and **temporal** data.
  - **Self-attention** allows the model to identify important features in each slice and how they relate to others.

APPROACH 3: DATASET AUGMENTATION

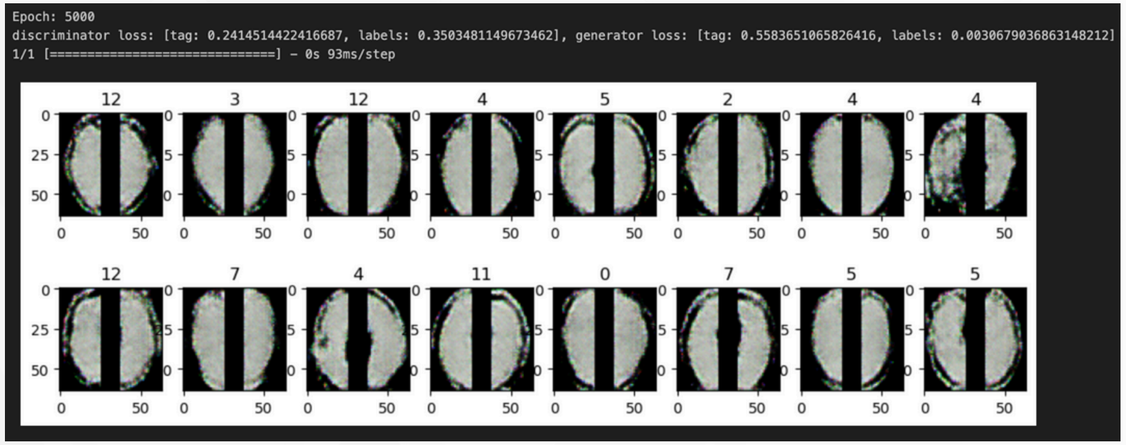
- Our dataset initially had 189 rows which would have been quite few for the final classification
- To increase the size of the dataset, we implemented a **CGAN** in order to create new GIFs from the original ones taking into account the corresponding label.
- A **CGAN** (*Conditional Generative Adversarial Network*) is a type of neural network that is used to generate images, sounds, or other data similar to real data, starting from a specific input.

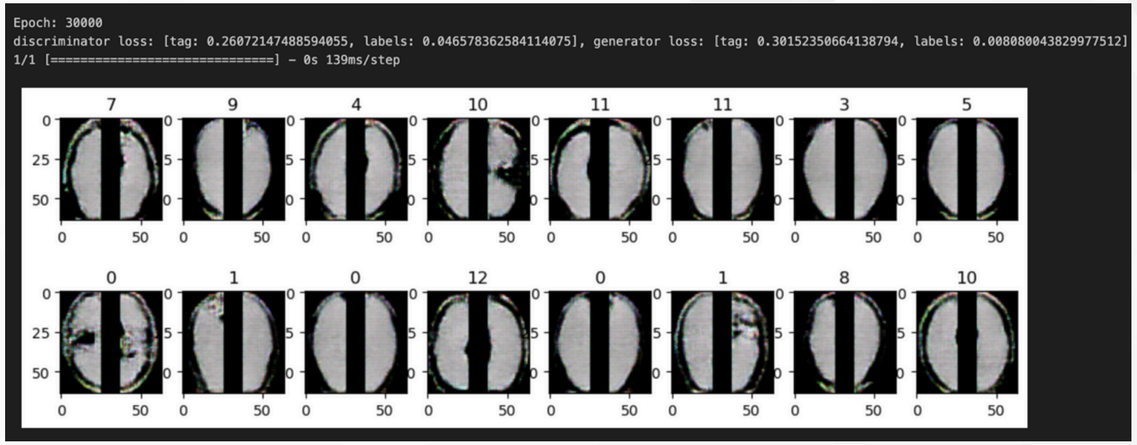


The generator does not just create random images, but generates images based on a specific input, called a "condition"

APPROACH 3: DATASET AUGMENTATION

- This CGAN has been trained on 35000 epochs and these are some results obtained during the training:





In order to carry out the training, it was necessary to map the original labels in order to transform them into numbers.

APPROACH 3: DATASET AUGMENTATION

- With the use of **CGAN** our dataset now had about 800 rows and was ready to be split into train and test sets using a 70%-30% split.
- To obtain even more satisfying results, the gifs in the train set were also augmented using data augmentation techniques (rotation, brightness increase/decrease, contrast increase/decrease, etc.).

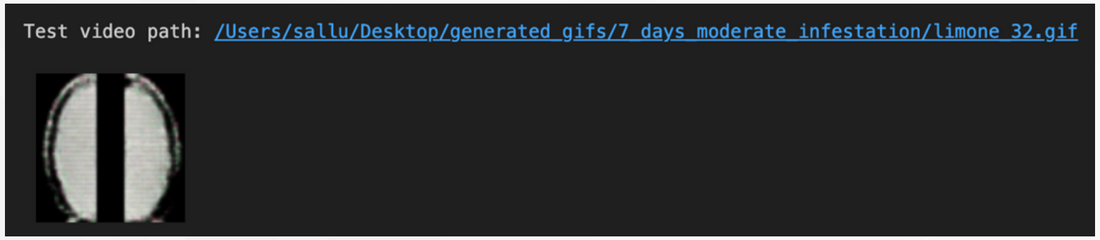
	Subfolder	Label
0	/Users/sallu/Desktop/generated_gifs/4_days_moderate_infestation/limone_39.gif	4_days_moderate_infestation
1	/Users/sallu/Desktop/original_gifs/5_days_high_infestation/CRI_D5_500_1_23186_01.gif	5_days_high_infestation
2	/Users/sallu/Desktop/generated_gifs/5_days_low_infestation/limone_21.gif	5_days_low_infestation
3	/Users/sallu/Desktop/generated_gifs/7_days_low_infestation/limone_25.gif	7_days_low_infestation
4	/Users/sallu/Desktop/generated_gifs/5_days_high_infestation/limone_43.gif	5_days_high_infestation
...	...	...
3325	/Users/sallu/Desktop/augmented_train_gifs/10_days_high_infestation/limone_0_aug_1.gif	10_days_high_infestation
3326	/Users/sallu/Desktop/augmented_train_gifs/10_days_high_infestation/limone_0_aug_2.gif	10_days_high_infestation
3327	/Users/sallu/Desktop/augmented_train_gifs/10_days_high_infestation/limone_0_aug_3.gif	10_days_high_infestation
3328	/Users/sallu/Desktop/augmented_train_gifs/10_days_high_infestation/limone_0_aug_4.gif	10_days_high_infestation
3329	/Users/sallu/Desktop/augmented_train_gifs/10_days_high_infestation/limone_0_aug_5.gif	10_days_high_infestation

3330 rows × 5 columns

APPROACH 3: DATASET AUGMENTATION

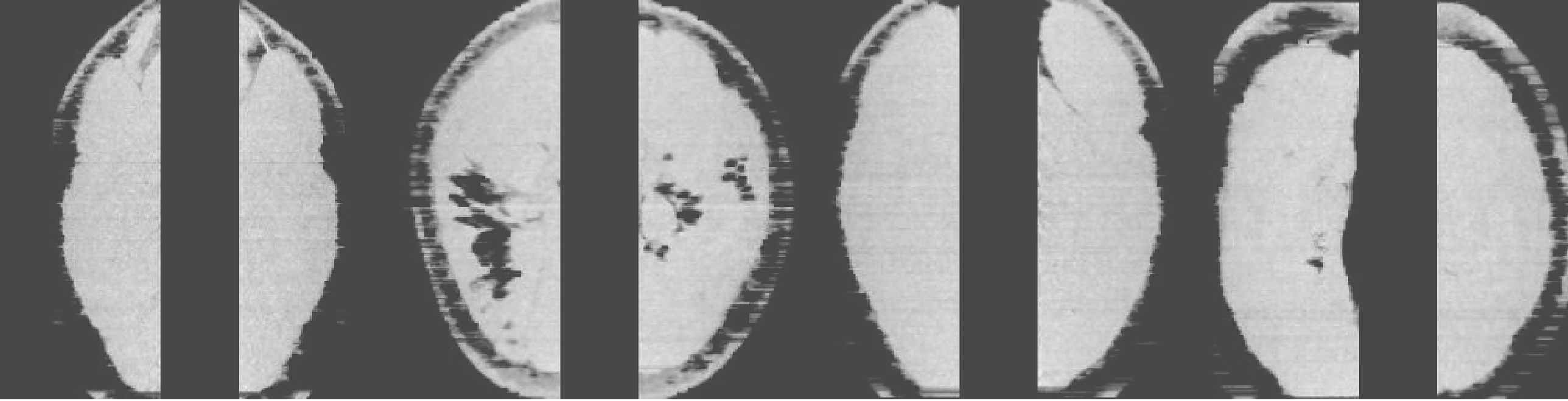
- The network based on Transformers, explained in the previous slides, was then trained for 30 epochs obtaining a **final Weighted F1-Score of 75%.**
- A test performed on the model is now shown:

Actual Label:7_days_moderate_infestation



Predicted Label:7_days_moderate_infestation at 100% of confidence

```
  7_days_moderate_infestation: 100.00%
  5_days_high_infestation:  0.00%
  not_infested:  0.00%
  4_days_high_infestation:  0.00%
...
  5_days_moderate_infestation:  0.00%
  5_days_low_infestation:  0.00%
  7_days_high_infestation:  0.00%
  7_days_low_infestation:  0.00%
```



THANK YOU

Università degli Studi Milano Bicocca