Restoration of degraded images captured during adverse weather conditions with Generative Adversarial Networks

Deep Learning, Application of Engineering

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Autonomous vehicle's development history

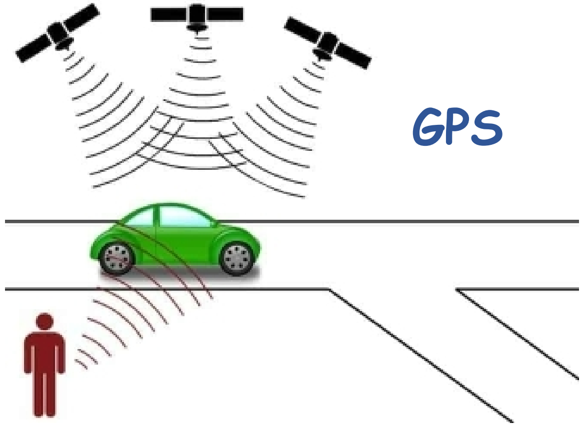
- The concept of self-driving cars equipped with a superior level of safety came into practice in the 20th century.
- In 2009, when Google announced to start their research in self-driving, the concept became majorly popular.

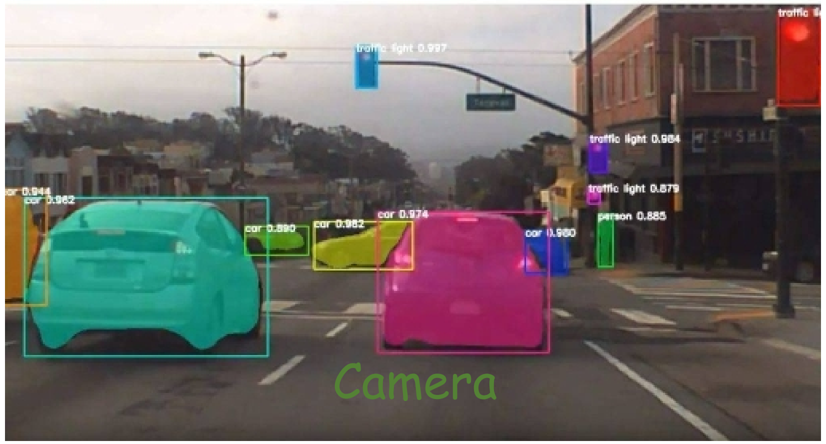
- In 2015, Tesla began to commercialize 'Autopilot' features in its cars and soon became one of the top autonomous vehicle companies in the world.
- Several automobile giants have announced their plans to launch fully autonomous cars during the last three years by 2020.

Introduction: Autonomous Vehicle Perception

- Perception operation in autonomous Vehicles enables sensing environments around the vehicle.
- Perception is crucial to making decisions, planning, and operating in real-world environments through numerous functionalities and operations from occupancy maps to object detection.
- Autonomous Vehicles use a variety of sensors, namely RADAR, LiDAR, GPS, and Camera.

Each sensor has its functionality such as
GPS: path planning
RADAR/Lidar: distance tracking/object detection
Camera: lane-keeping/ object detection





Problem: perception accuracy in adverse weather conditions

- Out of these sensors, LiDAR and Camera play a key role in sensing the environment around the system.
- LiDAR generates the point cloud of the surrounding environment providing the depth/distance of the objects from the vehicle.
- All perceptual-related tasks such as traffic sign and signal detection, lanes detection, etc., are handled by the Camera.

It is also possible to extract the depth information, like LiDAR, with the help of a stereo Camera through correspondence.

- During adverse weather conditions such as rain, fog, and snow, LiDAR performance degrades drastically.
- The quality of images captured by the Camera also degrades during such situations.

Is there any way to improve the perception accuracy of autonomous vehicles during adverse weather conditions for safe navigation?

Autonomous vehicle's background of perception

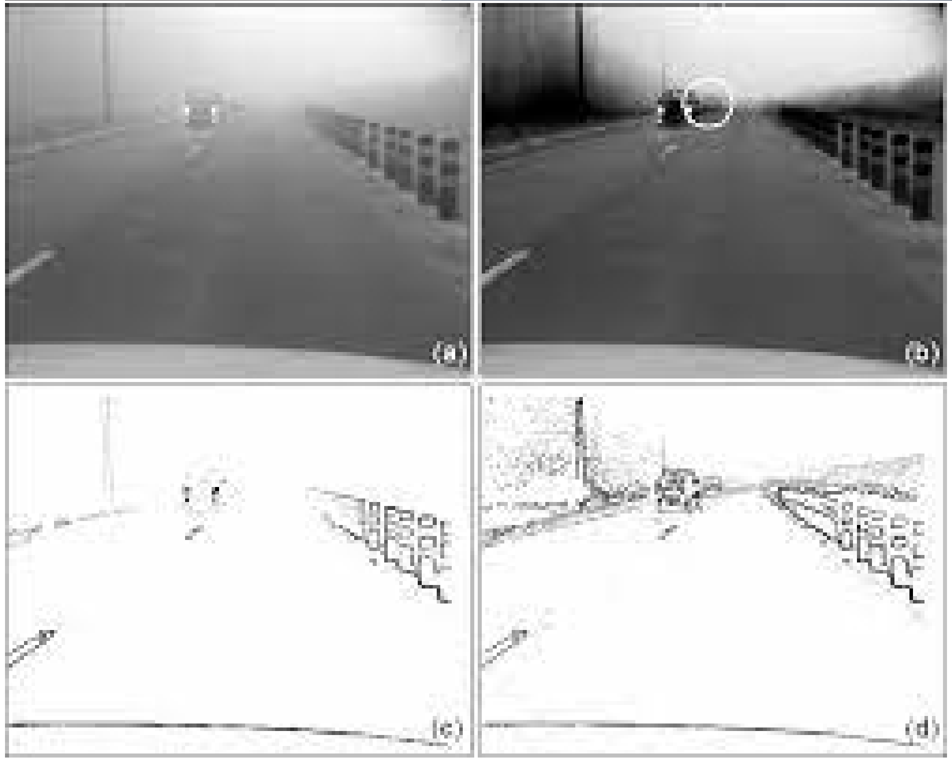
- The main objective of present autonomous companies is to use as few sensors as possible to perform perception operations without compromising safety.
- Tesla, relies only on cameras to see around the environment apart from Ultrasonic transducers and RADAR.
- Alphabet Inc.'s Waymo and GM's Cruise also use LiDAR along with a Camera for this purpose.
- John Dheere generates higher resolution data using Cameras (stereo) and RADAR alone, these systems are cost-efficient compared to other self-driving companies that use LiDAR, which is expensive

During adverse weather conditions such as foggy, snowy, and rainy conditions, the performance of LiDAR and Camera degrades. But unlike LiDAR, it is possible to restore the degraded images captured by the Camera with the help of low-level image processing techniques such as image enhancement and restoration.

Factors affecting the perception using Camera

- Rain and snow conditions introduce sharp intensity fluctuations in images. This condition changes the image intensity and blurs the edges of various objects in an image. Usually, rain reduces the image intensity, and heavy snow increases the image intensity.

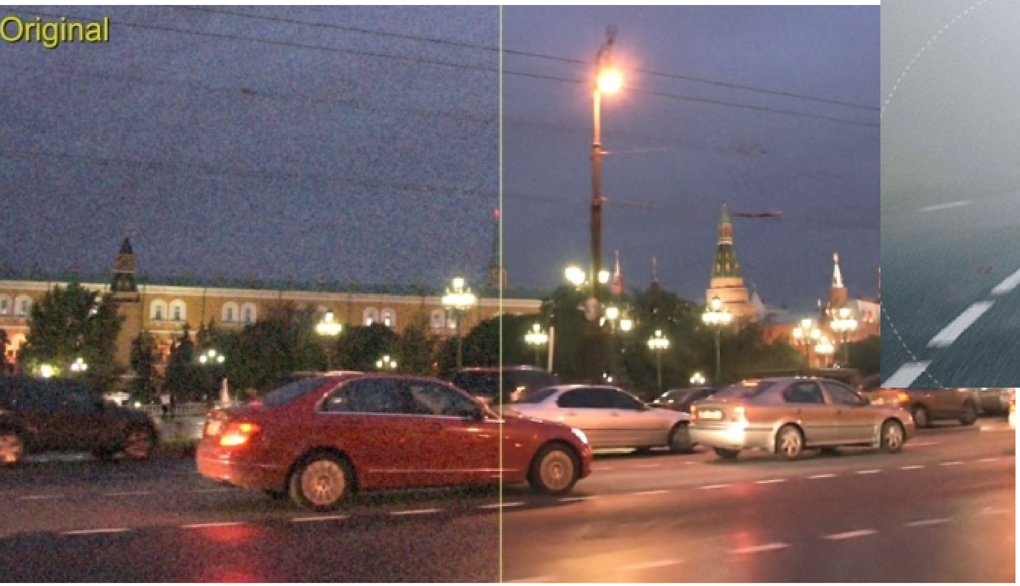
- Fog condition reduces the image's contrast and increases the difficulty of edge pattern recognition.



- In the case of an observed fog scene, the frequency components are concentrated at zero frequency, whereas in the absence of fog, the spectrum is widely spread. Sharp edges are defined by low and high frequencies, whereas smooth edges are determined solely by low frequencies

significant factors of degraded images

- Salt and Pepper Noise: Salt-and-pepper noise is a type of noise that can be seen in images. It is also referred to as impulse noise. Sharp and sudden disturbances in the image signal can cause this noise. It appears as sparsely distributed white and black pixels.
- Bilateral Image: These are images that contain huge noise and are non-linear. This image also shows the edges between various objects of the image. But the edge also includes the noise.
- Saturated Image: The intensity of a color is described by its saturation. A grayscale or black-and-white image has no color saturation, whereas a full-color image of a field of bright wildflowers may be highly saturated.



Existing methods for image restoration; Non-AI

a) Non-AI based image restoration:

- Traditionally, three types of non-AI based image restoration methods have been in use for this purpose, which work based on algebraic methods through the application of filters such as

1. Inverse filter – This type of restoration method is used when we have complete knowledge about the kind of blurring function/ filter leading to the degraded image.
2. Weiner filter – This method is used if we only have partial knowledge about the blurring function/ filter leading to the degraded image.
3. Blind restoration filter – This method is used if we do not have any prior knowledge about the blurring function/ filter causing image degradation etc.

Existing methods for image restoration; AI-based

a) AI-based image restoration:

- AI-based image restoration methods, such as the usage of Convolutional Neural Networks (CNNs), have resulted in better results in terms of quality and accuracy of the restored images in comparison with image restoration using algebraic methods. There are many types of neural networks that are based on CNN's which have been developed over time for restoring images, such as

i. CNNs – Plain convolutional neural networks for dirt or rain removal
ii. DehazeNet – Deep network for rain removal
iii. SPANet – Spatial attentive network for rain removal

DesnowNet | Input image | Plain CNN

Dataset consideration

- The data is divided into two parts:

1. Ground truth data: This data is basically self-driving data with no adverse conditions and noise. This data is considered with high accuracy and proper features.
2. Adverse data: This data is appropriate data with adverse and noise features for self-driving conditions.

Adverse weather Data

Ground truth clear weather Data

Dataset Selection criteria

- Dawn Dataset.
- Cityscapes
- ADUULM Dataset

- Radiate Dataset.

GAN Selection

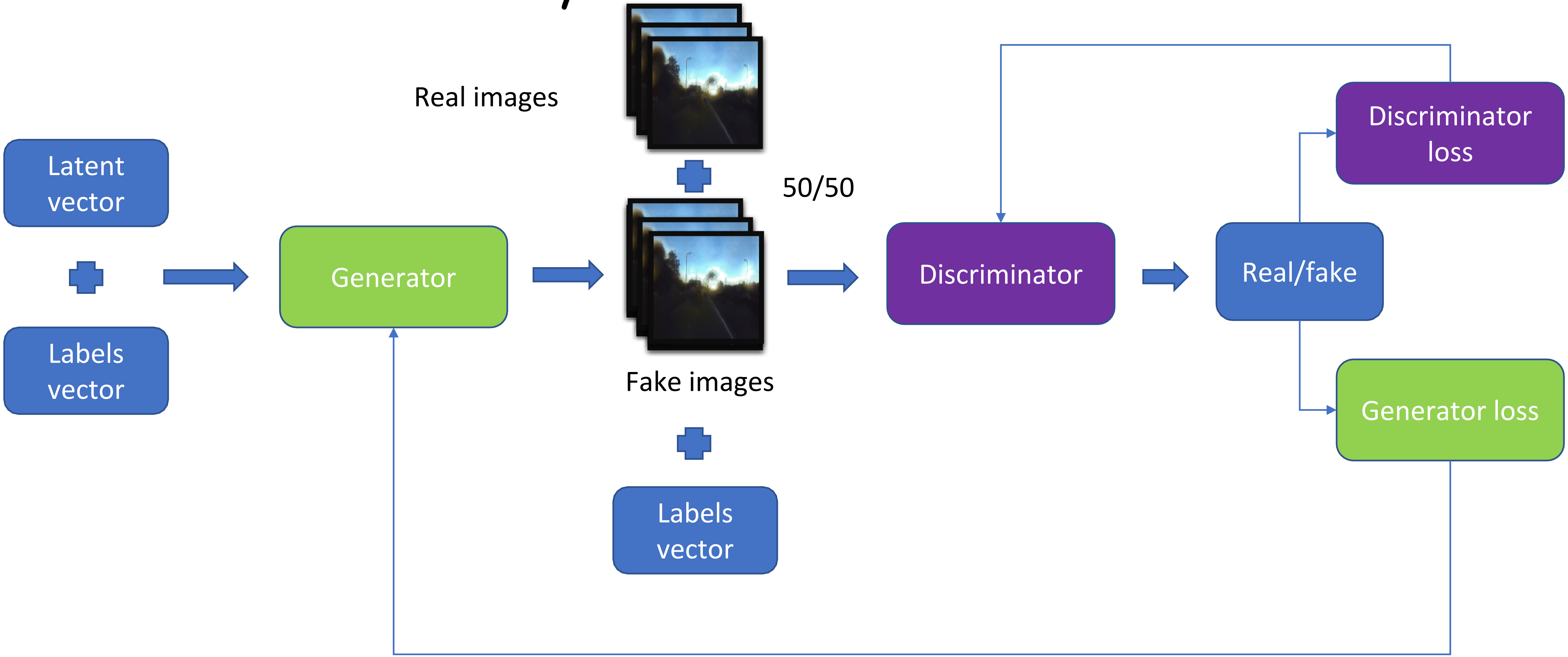
Paired Dataset with label

GAN or Conditional-GAN

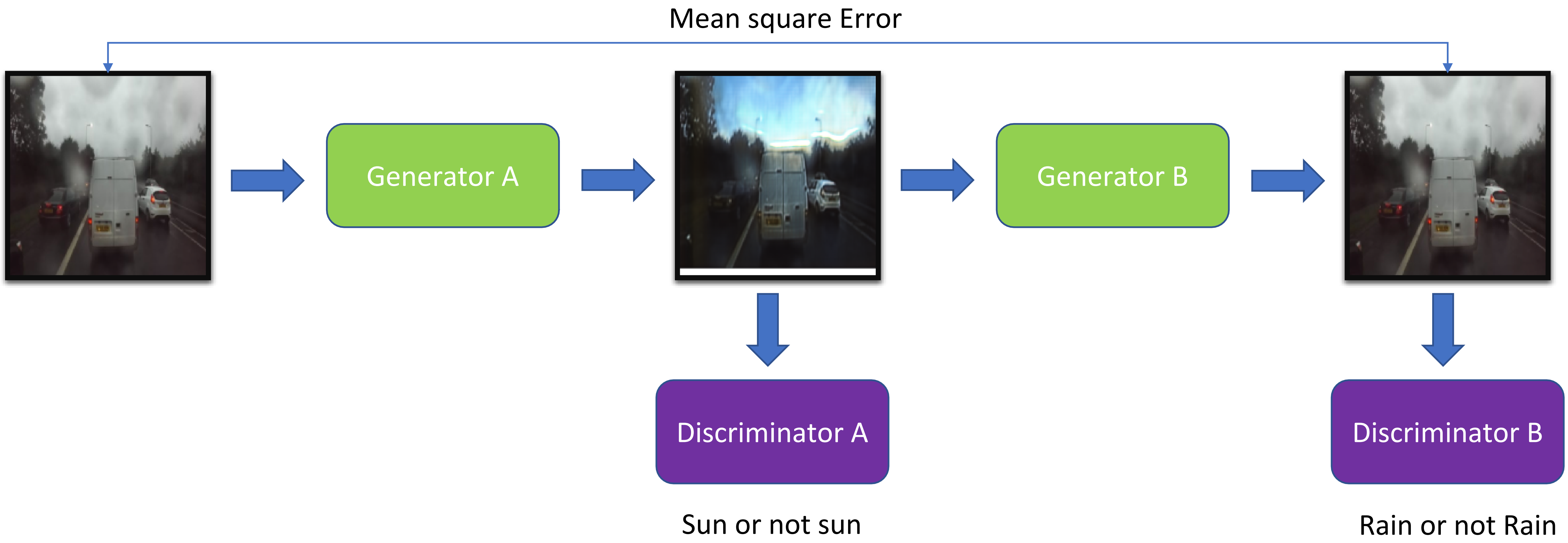
Unpaired Dataset

Cycle GAN

Conditional-GAN vs Cycle-GAN



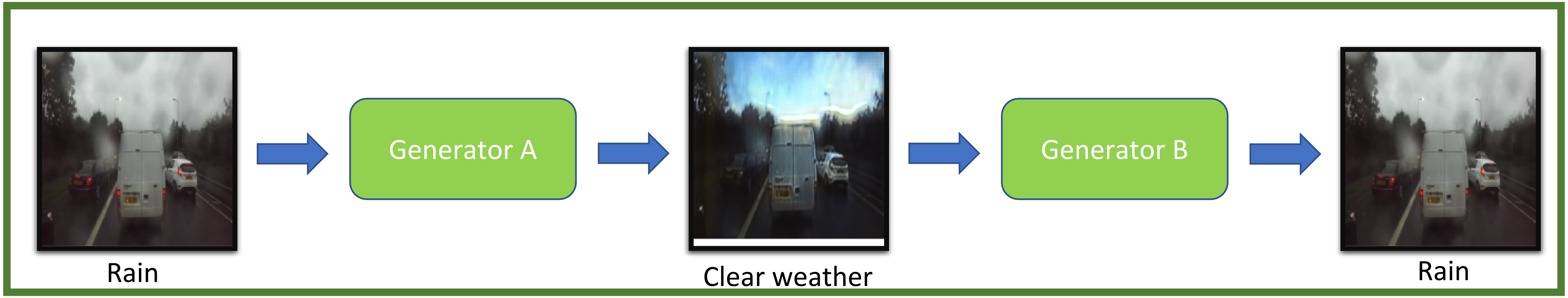
Cycle-GAN



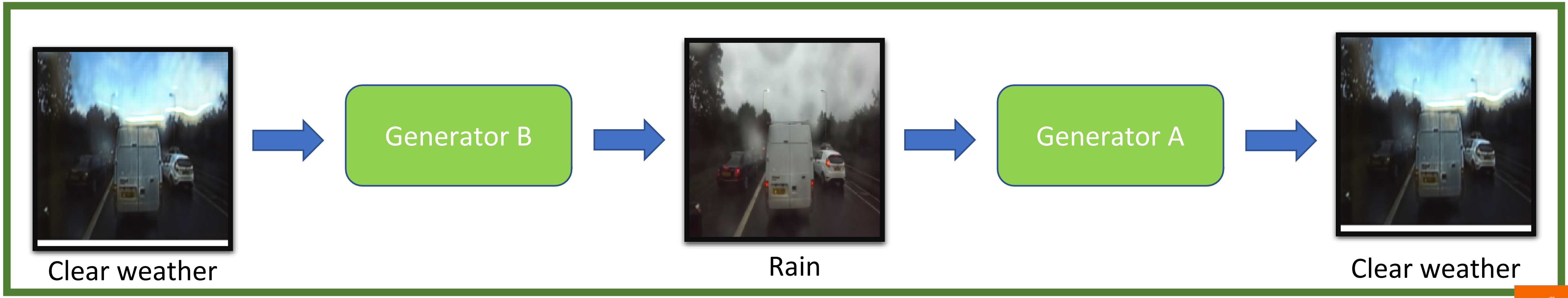
Errors are not mentionable in the flow chart because of complexity.

Forward and backward cycle consistency

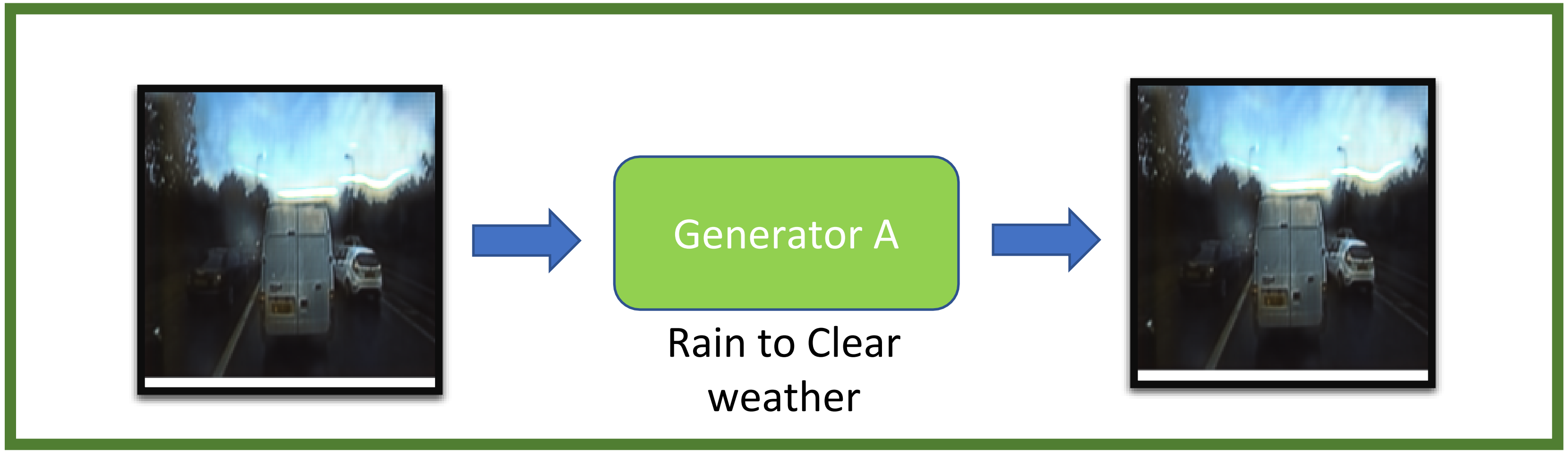
Forward Consistency

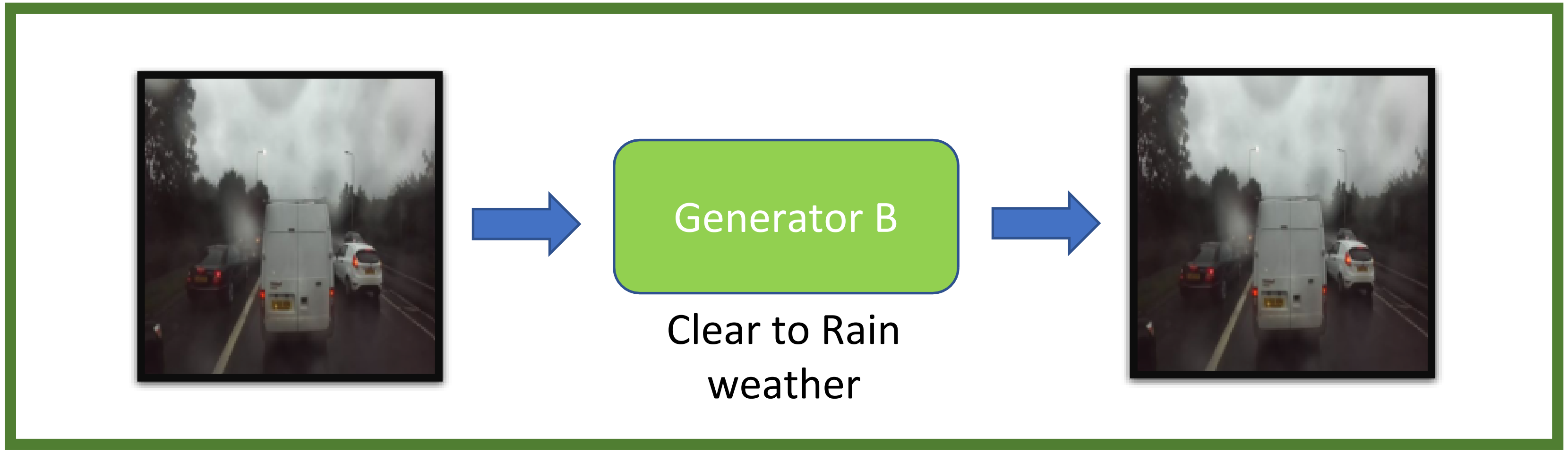


Backward Consistency

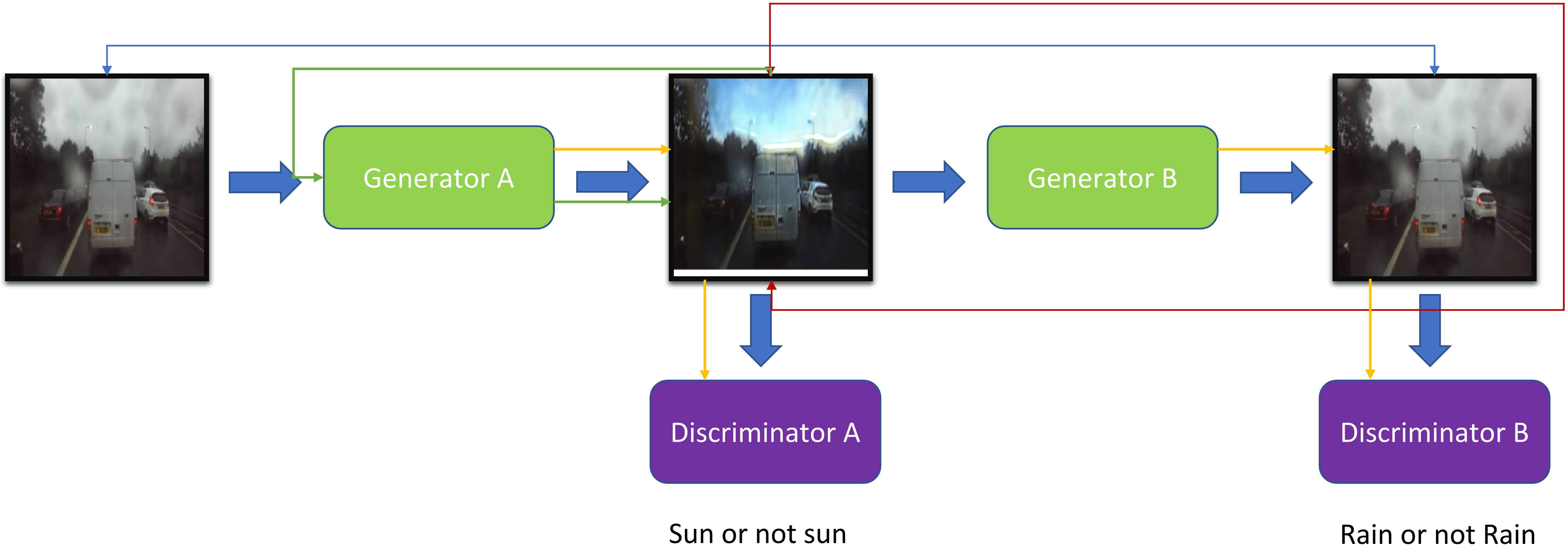


Identity Mapping





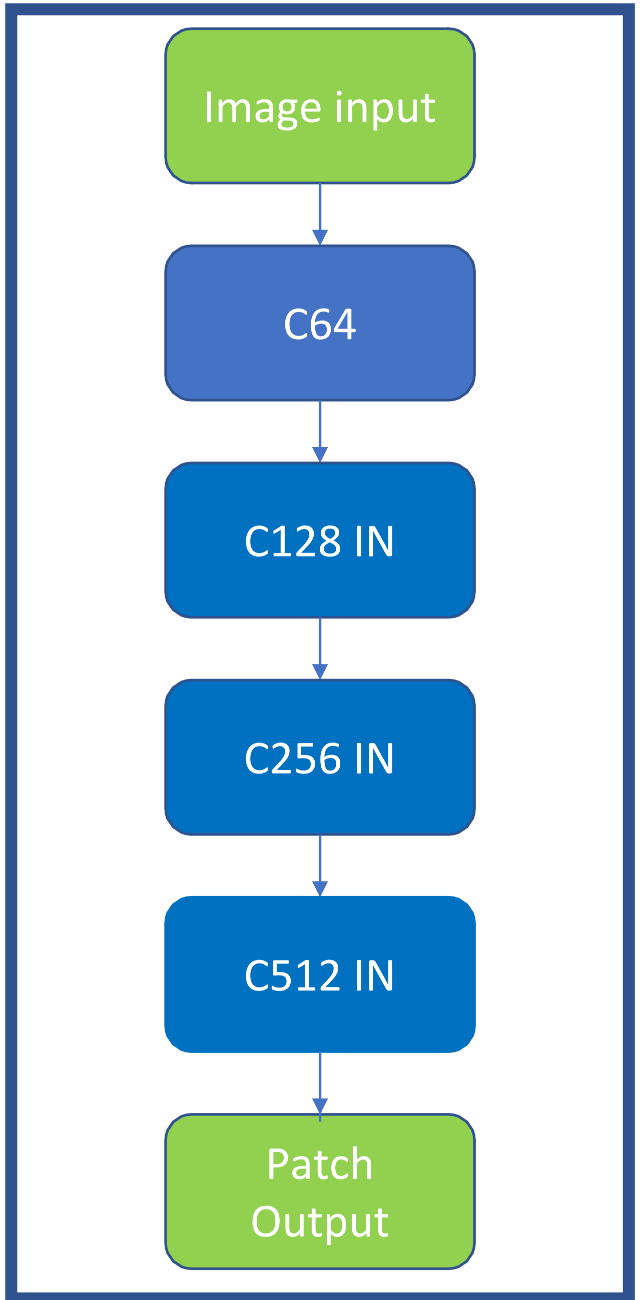
Cycle-GAN training

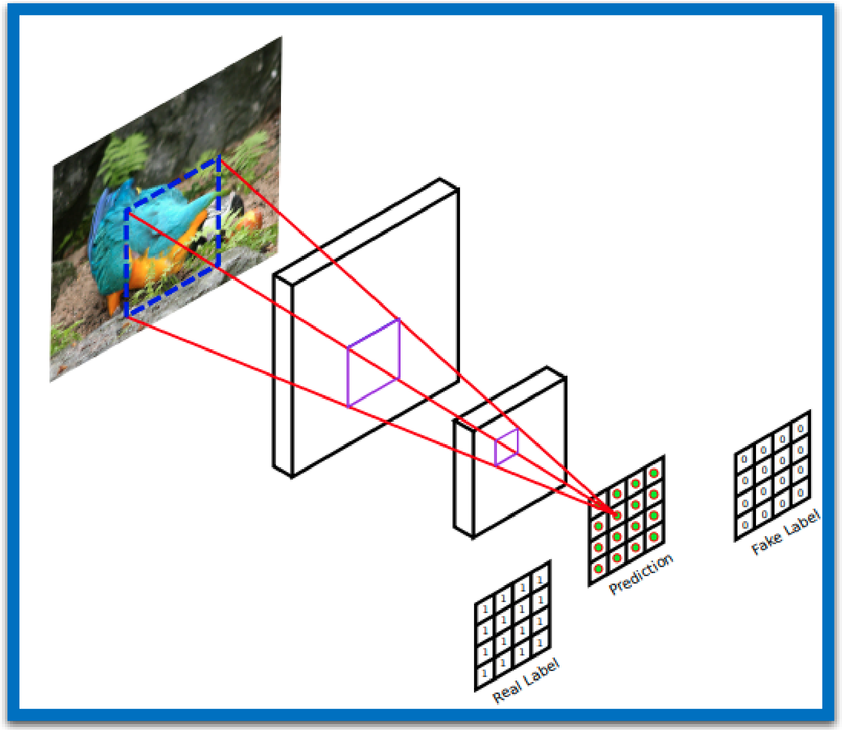


For Every Composite model we compute:

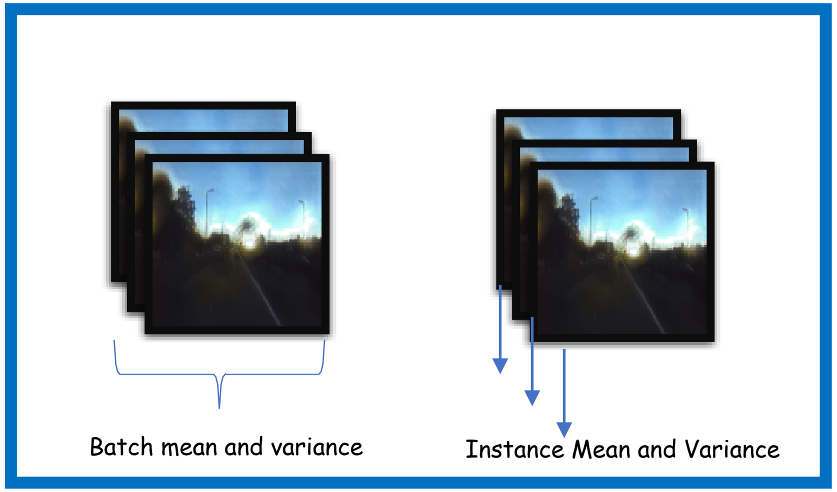
- Forward Consistency Loss
- Backward Consistency Loss
- Identity mapping loss
- Adversarial Loss

Discriminator Model

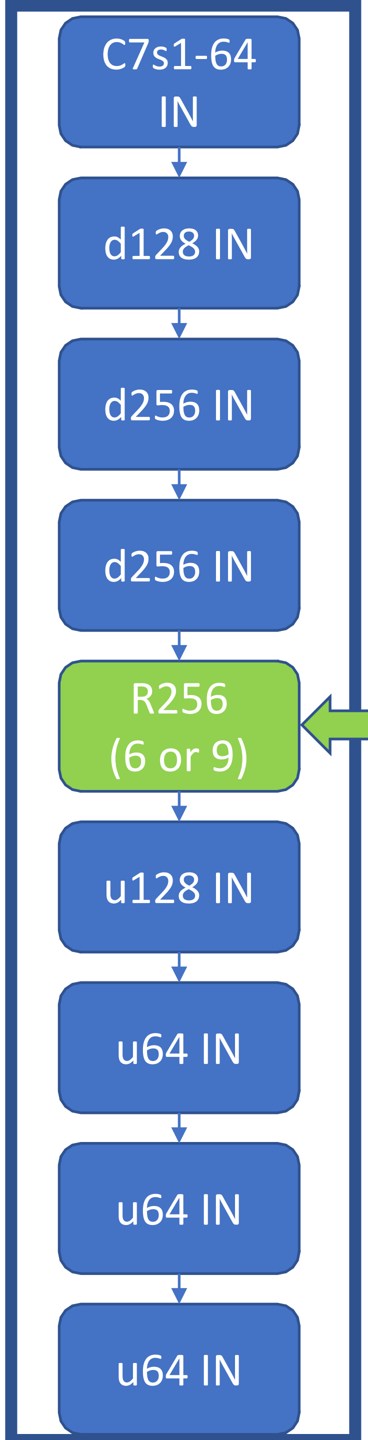




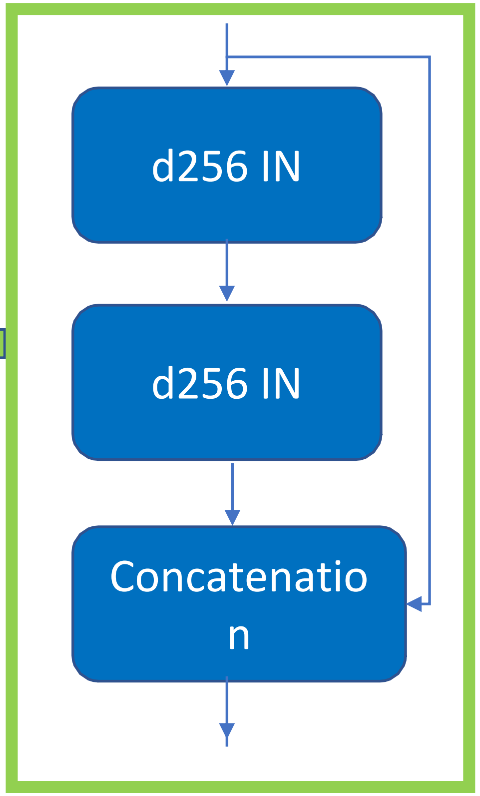
Patch GAN



Instance Normalization VS Batch normalization



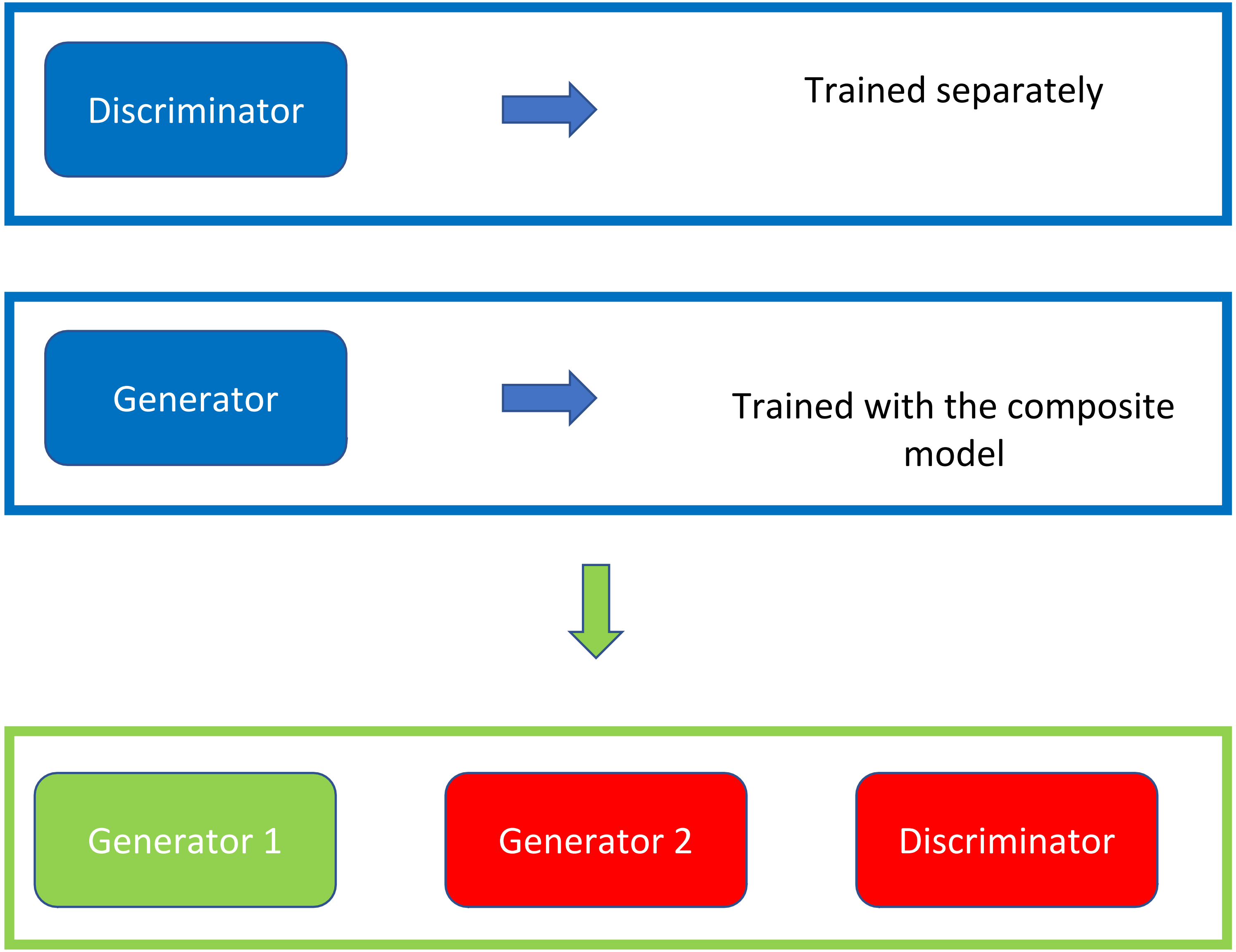
Generator Model



Generator Model:

- dN -> 3 x 3 Conv2D with N filters and ReLU activation.
- R256 -> Residual Network
- uN -> 3 x 3 Conv2D transpose with N filters and ReLU activation
- C7s1 N -> 7 x 7 Conv2D with N filters and stride 1

Composite Model training



Implementation

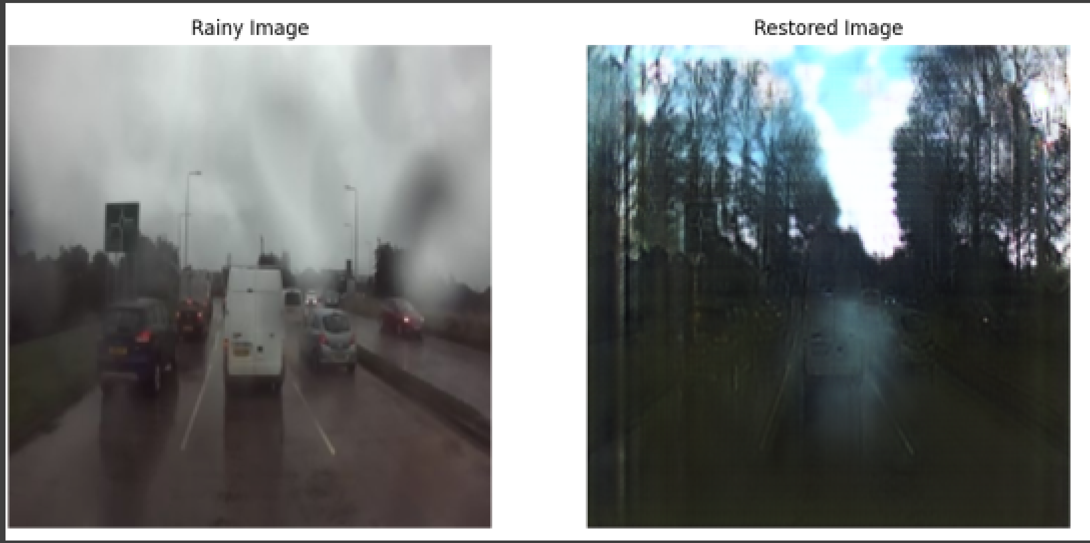
- Data preprocessing -
  - Data normalization – Images normalized to [-1, 1]
- Metrics -
  - Discriminator loss – Discriminator weights are updated based on MSE.
  - Composite model loss – Generator weights are updated based on the weighted average of the following errors
    - Discriminator loss – MSE
    - Identity loss – MAE
    - Forward loss – MAE
    - Backward loss – MAE
- Hardware -
  - # CPU cores - 12
  - RAM – 300 gb
  - GPU – V100
  - Simulation time – 48:00:00

Iteration 1 – image shape

- Image shapes
  1. 256x256
  2. 512x512
- Similar results with both image shapes.
- Fast results with image shape 512x512.

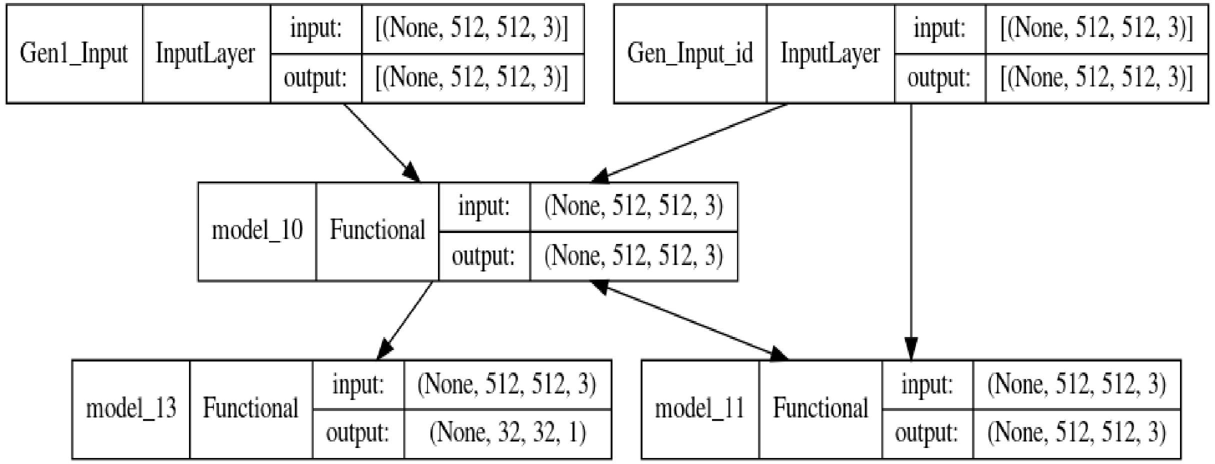
Iteration 1 – Issue

- The network is masking the vehicles as well along with the droplets.
- Also started overfitting, with fake realistic scenarios.



Composite model architecture

- Generator A
- Discriminator A/B
- Generator B
- MSE – discriminator loss
- MAE – identity, forward and backward losses.
- Loss weights

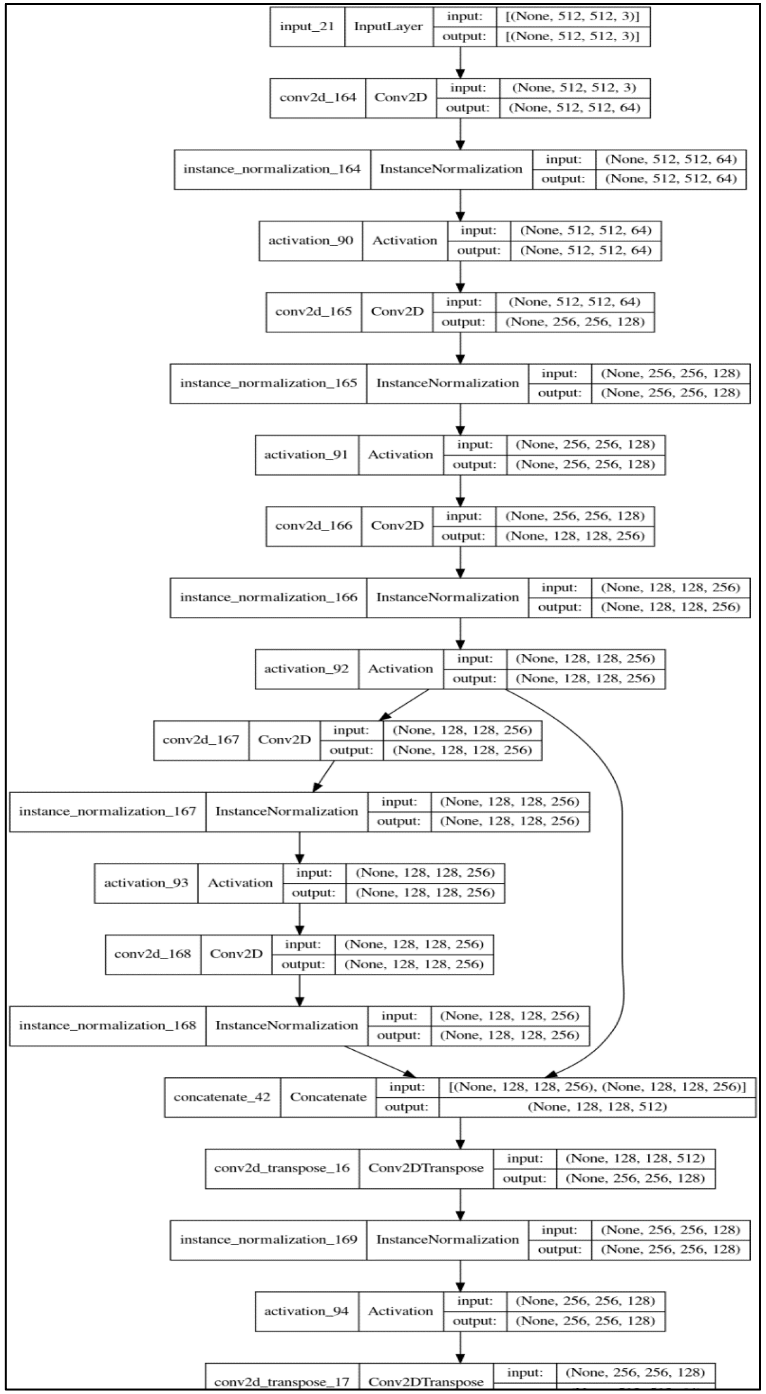


Iteration 2 – Composite model weights

- Weights
    1. 1, 1, 1, 1
    2. 1, 3, 3, 3
- Poor performance of the network.
- Unable to filter noise even from the images without vehicles.

Generator architecture

- Convolution layer
- Instance normalization
- Leaky ReLU
- Residual network layer
- Deconvolution layer

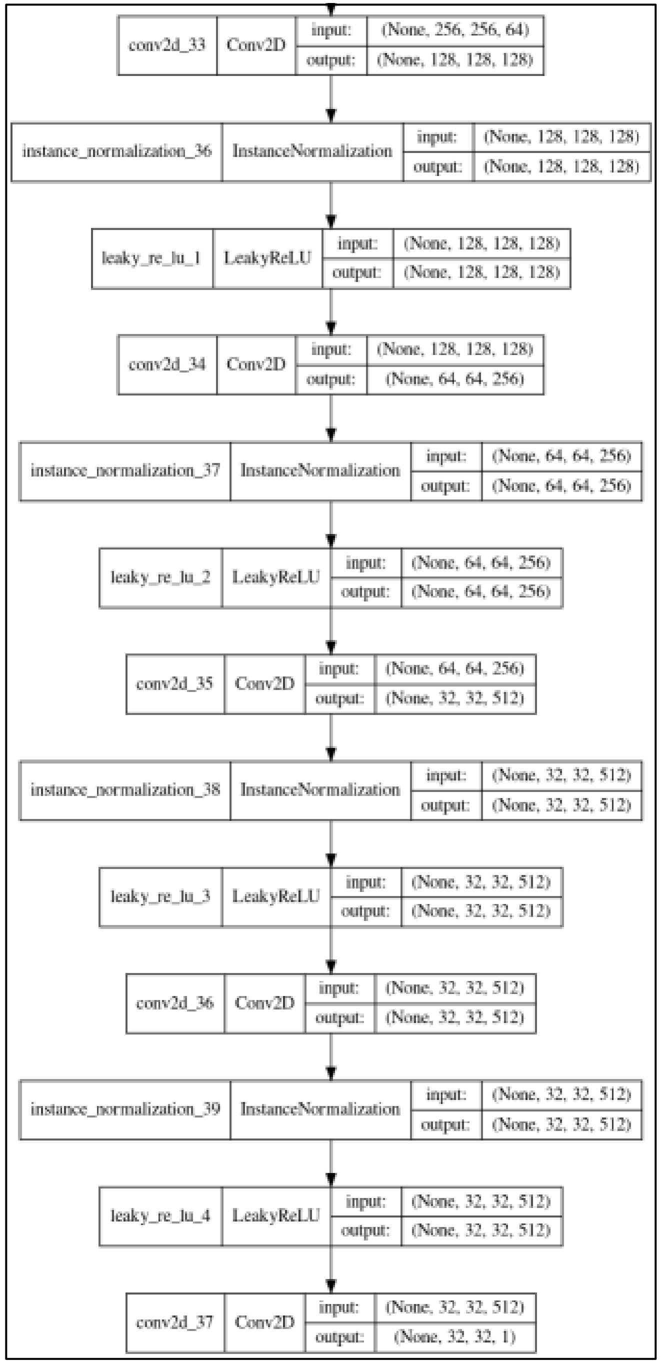


Iteration 3 – Generator

- Filter sizes
  1. 5x5
  2. 7x7
- Similar results with both filter sizes.
- Stopped masking vehicles if only 1 or 2 vehicles present in the image.
- Masking vehicles as well if many of them are present.

Discriminator architecture

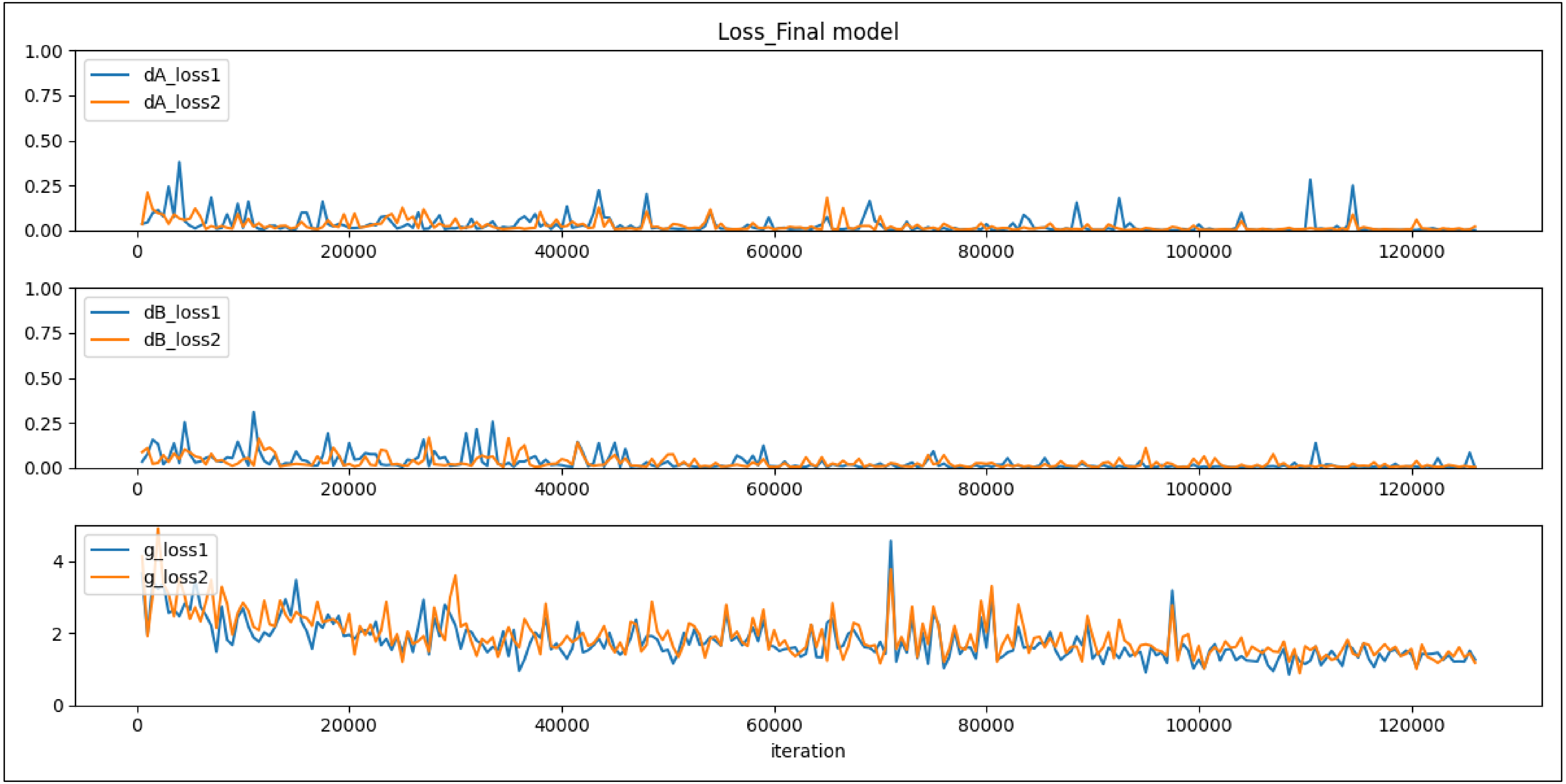
- Convolution layer
- Instance normalization
- Leaky ReLU
- Patch output
- MSE loss



Iteration 4 - Discriminator

- Number of layers
  1. 5
- Now, the discriminator started to discriminate between droplets and vehicles.
- Stopped masking vehicles along with droplets.

Results



Loss_Final model
dA_loss1
dA_loss2
1.00
0.75
0.50
0.25
0.00
0
20000
40000
60000
80000
100000
120000
dB_loss1
dB_loss2
1.00
0.75
0.50
0.25
0.00
0
20000
40000
60000
80000
100000
120000
g_loss1
g_loss2
4
2
0
0
20000
40000
60000
80000
100000
120000
iteration

Conclusions

- In all the rainy images, the dark clouds have been replaced with the clear sky.
- Overtraining of the network is leading to the generation of fake trees in the image.
- More diverse dataset may give better results by better reconstructing of the vehicles.

Rainy Image

Restored Image

Future Work

- More improved dataset with good features needs to be collected.
- The resolution of the image needs to improved in order to apply further perception operations.
- Geometric limitation issues.

Rainy Image

Restored Image