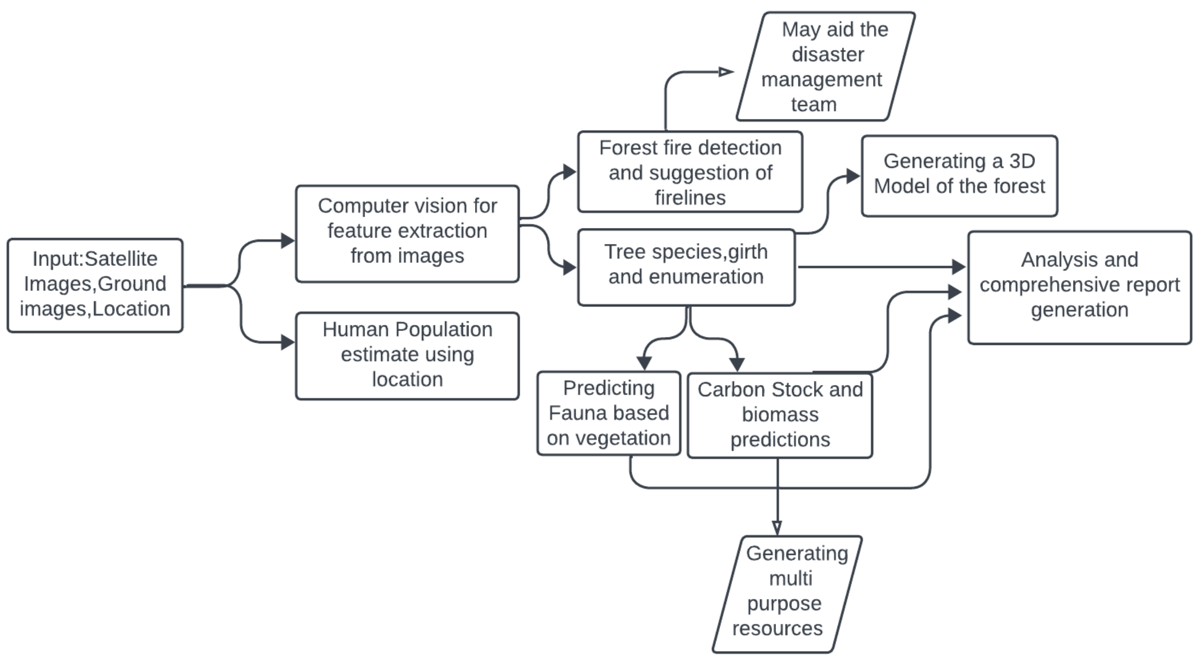
Documentation and Idea Description

Team: Segmentation Fault

Problem Statement: Application of Image Analytics for Tree enumeration for diversion of Forest Land

Introduction:



This project addresses the critical problem of forest land diversion and the need for accurate tree enumeration. Traditional methods of counting and quantifying trees on forested land involve labour-intensive manual surveys and extensive fieldwork. We propose an innovative approach that leverages image analytics, incorporating computer vision and machine learning to streamline and enhance tree enumeration processes.

Our solution aims to significantly reduce survey costs, improve precision, and ensure compliance with environmental regulations. By automating tree enumeration and related tasks, we provide a cost-effective and scalable method for accurately assessing forested areas. This project aligns with the broader goal of responsible environmental stewardship and sustainable land use, contributing to informed decision-making and conservation efforts.

The project also addresses security concerns over the availability of satellite captured images over a public domain and provides for visualisation methods.

Tree enumeration using OpenCV:

Computer vision is a tool that enables us to analyse images so as to perform feature extraction, object detection etc. Using computer vision we can achieve the task of counting the number of trees as seen in the satellite image.

A lot of image pre-processing would be done by resizing images, Fast NI means Denoising, Gaussian blur, dilation and erosion of images.

The idea is to use OpenCV to distinguish plains, settlements and other parts of the image from the forest land.Colour filtering using HSV or RGB colour space will enable us to filter out the green parts of the image.

The plains usually have a smoother texture than tree filled forests.
To distinguish between plains and forest we can do a texture based analysis using Gabor Filter.

A Gabor filter is a complex sinusoidal wavelet function modulated by a Gaussian envelope. It combines the aspects of both frequency and spatial domains. The complex sinusoidal wavelet can capture the oscillatory nature of textures, while the Gaussian envelope determines the scale and orientation of the filter.

The mathematical form of a 2D gabor filter is given by:

$$g(x, y) = e^{(-((x^2 + y^2)/(2\sigma^2)))} * e^{(j(\omega_0 x * cos(\theta) + \omega_0 y * sin(\theta)))}$$

After filtering out the forest area, we would calculate the density of the green area and find a rough estimate as to how many trees are present.

Using the same techniques of satellite image analytics we can also identify forest fires. It is also possible for us to predict where the forest “Fire Lines” have to be placed so as to prevent forest fires. This can be helpful to the Forest Department as well as the Disaster Management Team.

<u>Detecting tree species:</u>

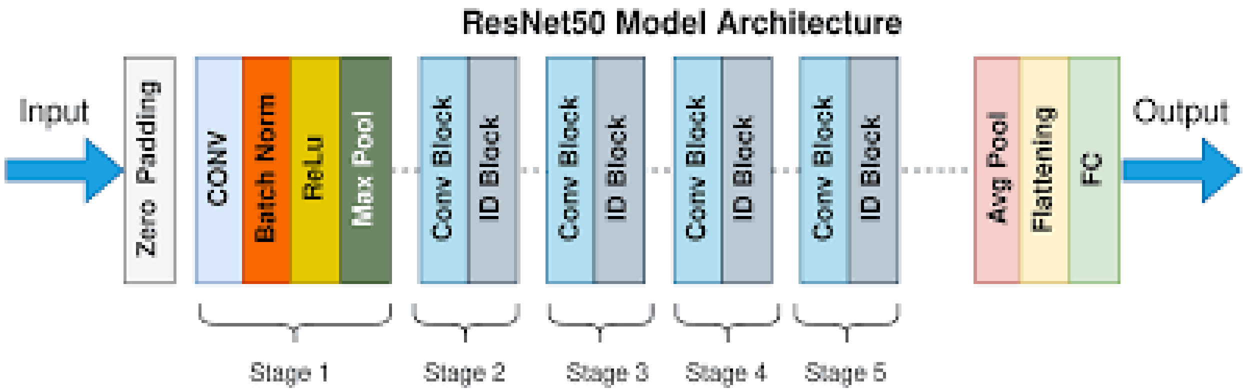
Using the ground based images of a section of the forest, we will be able to predict the different species available in the area. To achieve this we will be fine tuning Resnet models from torchvision. Resnet (Residual Networks) is a powerful tool in computer vision which can be used for object detection and image classification.Fine tuning will be done by altering hyperparameters based on the dataset available. For example there are many Resnet models such as Resnet-18, Resnet-101 where the number corresponds to the depth of the neural network. DenseNet and SqueezeNet are some of the other models which can be fine tuned. The best performing model will be selected.

The loss function used would be Cross Entropy loss function and the optimizer used would be Adam or SGD(Steepest Gradient Descent) depending on the performance.

Cross Entropy loss function:

$L(y, \hat{y}) = -\Sigma_i \, y_i * \log(\hat{y}_i)$

y->Represents the vector which contains true class labels ŷ-> A vector which represents the predicted probability distribution

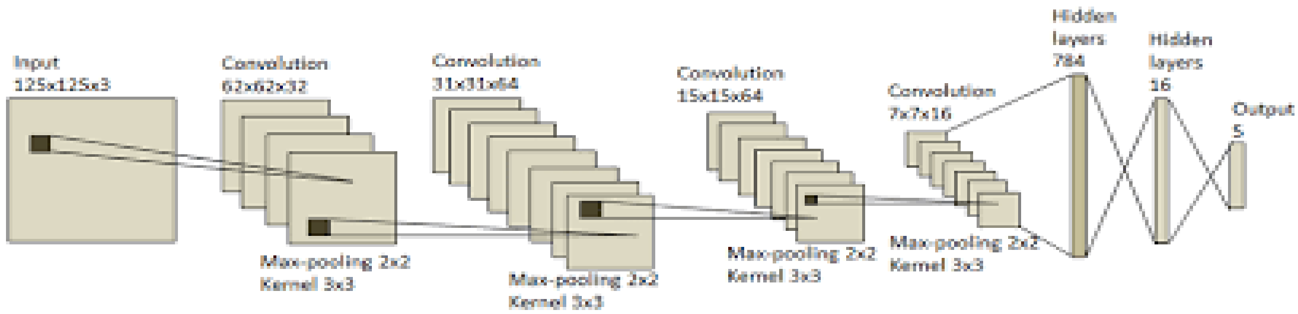


Girth estimation of trees:

Estimation of the girth/diameter of trees can be done using ground-level imagery and deep learning algorithms. To achieve this, we will use publicly available simulated datasets labelled with centimetre accurate segmentation masks, bounding boxes, and keypoints. This will aid us in both detection of trees and estimation of girth using convolutional neural network (CNN) architectures.

The CNN architectures will be using Basic 2D CNN layers, Pooling layers and non linear activation functions such as ReLU or GeLU.

We will use a combination of RGB and depth inputs to analyse images. Estimation of girth is typically done by formulating a mathematical 3D representation of the tree and then measuring the distance between points on the trunk at a consistent height above the ground.



Carbon stock and Biomass predictions

We begin by determining the total number of trees (N) and the species of trees (S) within the specified forest area using satellite imagery. This operation will be performed by the CV algorithm. Our program then employs allometric models to estimate the carbon content of individual trees.

What are these allometric models?

Allometric models are mathematical equations used to quantitatively describe the relationships between various tree characteristics, such as diameter at breast height (DBH), height(H), wood density(WD), and the critical parameters of biomass and carbon content.

Statistical techniques, such as linear or nonlinear regression analysis, will then be applied to these data to derive the most suitable mathematical equations that represent the relationships between tree characteristics and biomass or carbon content.

$C\ (carbon\ content)\ =\ a\ *\ (DBH)^{b}\ *\ H^{c}$

$b\ =\ (DBH)^{2}\ *\ H\ *\ \rho$

$A,\ B,\ and\ C\ are\ species\ -\ specific\ coefficients.$

$\rho\ represents\ wood\ density\ specific\ to\ the\ tree\ species.$

There are several approaches to estimate biomass from the carbon content that we have previously calculated. To relate carbon content to biomass, we need to account for the fact that a significant portion of the tree's dry biomass is composed of carbon. Trees store a substantial amount of carbon in their tissues, primarily in the form of cellulose, lignin, and other carbon compounds. To estimate the carbon content of a tree based on its biomass, we can use a conversion factor. The general formula for estimating Biomass from Carbon content is as follows:

$$B\ (Biomass)\ =\ C\ (carbon\ content)/f\ (carbon\ fraction)$$

Biomass can also be estimated without using the carbon content previously obtained. Since, biomass depends on the wood density, taking that into account, we have:

$$B\ (biomass)\ =\ Wood\ Density\ (\rho) \times Volume\ (V)$$
$$Volume\ (V)\ =\ \pi \times (DBH\ /\ 2)^2 \times Height$$

The above obtained biomass only accounts for the above-ground biomass. To calculate total Biomass, we multiply the obtained AGB with a factor of 1.28(approximate).

$$Total\ Biomass\ (AGB\ +\ BGB)\ =\ B\ *\ 1.28$$

<u>Parallel Processing:</u>

Our solution to the above problem statement has been broken down into many stages as stated. Some of the solutions to these sub problems are completely independent of each other. For example : Tree enumeration, tree species identification, Girth detection of trees,etc. Using parallel processing in such scenarios can be helpful. Here are a few points supporting the claim:

1. **Speedup**: Parallelism can significantly reduce the execution time of tasks, making it possible to process large datasets or perform complex computations more quickly.

2. **Resource Utilisation**: By utilising multiple processors or cores, parallel processing maximises the use of available computing resources, improving overall system efficiency.

3. **Scalability**: If more processing power is needed, it's relatively easy to add more processors or machines to the parallel computing cluster to further speed up the tasks.

4. **Independence**: Independent subtasks can be executed in parallel without affecting each other, minimising the risk of bottlenecks or delays.

<u>Security Concerns:</u>

Data Anonymization and De-Identification

Data Anonymization and De-identification in Tree Enumeration:
In the context of tree enumeration for forest land diversion using computer vision, data privacy is paramount. The challenge is to strike a balance between preserving data utility and protecting sensitive information.

1. **Geographic Coordinate Anonymization**:
   Given the latitude (φ) and longitude (λ), we apply a perturbation technique using random offsets:
   $\varphi' = \varphi + \varepsilon\varphi$
   $\lambda' = \lambda + \varepsilon\lambda$
   Where $\varepsilon\varphi$ and $\varepsilon\lambda$ are small random perturbations. This ensures that the exact location cannot be determined, maintaining privacy.

2. **Image Feature Masking**:
   If the images capture sensitive features such as residential areas, we apply techniques for feature masking.Image masks can be generated using binary matrices. Consider an image matrix I(x, y), where (x, y) are pixel coordinates. We generate a binary mask M(x, y) such that:

   Depending on whether or not the data is sensitive we can then apply element wise masking, we have:

   $I'(x, y) = I(x, y) * (1 - M(x, y))$

This preserves the utility of non-sensitive regions while concealing sensitive features.

3. **Differential Privacy for Ground-Truth Data**:
   When collecting ground-truth data, we must protect individuals' identities while preserving the integrity of the dataset.

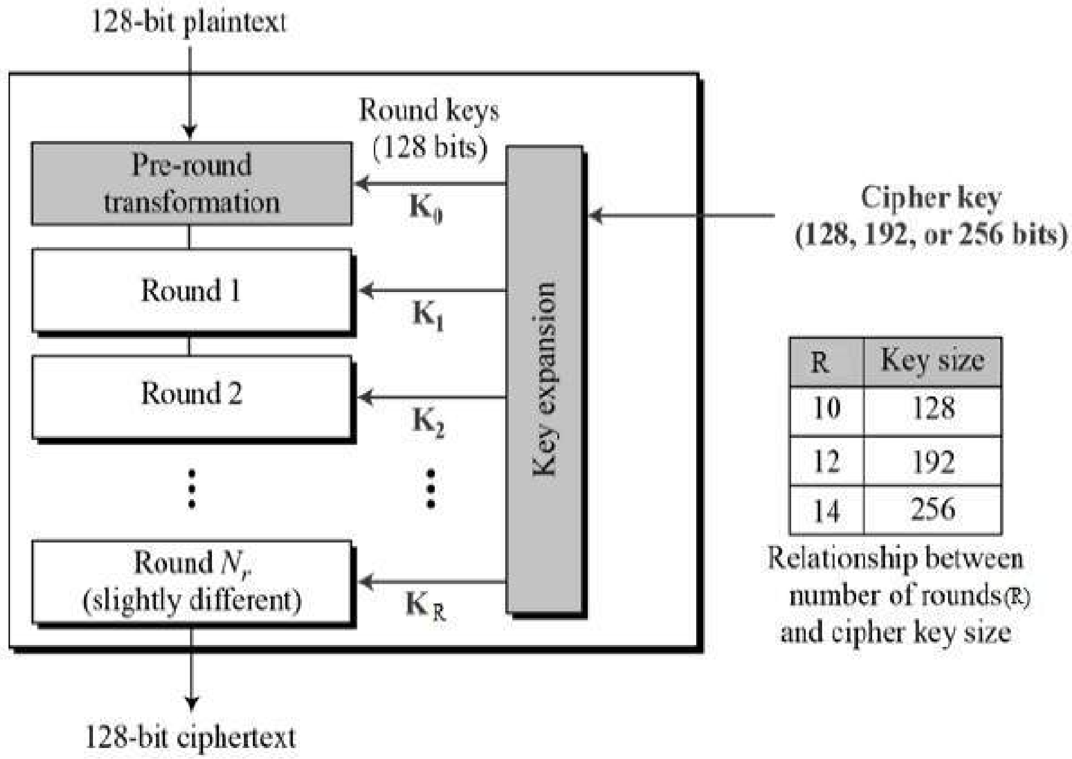
   To achieve this we add some noise to each datapoint in the set. Let D be the dataset, and ε be the privacy parameter:

   $$D'(x) = D(x) + \text{Laplace}(0, \Delta f/\varepsilon)$$

   Where Δf is the sensitivity function.
   This ensures that individual contributions are protected, and privacy is guaranteed.

4. **Data Encryption at Rest and in Transit**
   Protecting image data from unauthorised access both at rest and in transit is critical. Encryption techniques such as the Advanced encryption standard can be utilised
   Advanced Encryption Standard, AES: Utilising AES, a widely adopted symmetric encryption algorithm, we encrypt images during rest and transit.

   Ciphertext = AES_Encrypt(Plaintext, Key)
   Plaintext = AES_Decrypt(Ciphertext, Key)



The AES algorithm uses a substitution-permutation, or SP network, with multiple rounds to produce ciphertext. The number of rounds depends on the key size being used. A 128-bit key size dictates ten rounds, a 192-bit key size dictates 12 rounds, and a 256-bit key size has 14 rounds.

5. **Secure Data Disposal**

We use cryptographic algorithms to securely dispose of data. One effective method is the Gutmann method, which involves overwriting data with random values multiple times and then shredding the overwritten data to make it irrecoverable.

The Gutmann method involves overwriting the data with typically 35 passes with each pass mapping to some noise introduction into the data
and at the end of the 35 passes the data becomes unidentifiable and cannot be recovered by any currently known methods.

Deployment:

We deploy the web application using the Vercel architecture. Vercel uses the JAMstack architecture(Javascript, API's, MArkup).

Vercel utilises the global CDN (Content Delivery Network), with edge locations around the world. This CDN ensures that the static assets, such as JavaScript, HTML, CSS and images, are cached and served from the nearest edge location to the end user. This reduces latency and improves the page load time.

Vercel allows seamless integration with popular version control platforms, including GitHub, GitLab etc. Every code push triggers automatic deployment, ensuring that the latest code changes are deployed.

Vercel places a strong emphasis on security. It provides automatic SSL certificate provisioning, DDoS protection, and continuous security updates to protect hosted applications.

An efficient solution?

Our proposed image analytics solution for automated tree enumeration using satellite imagery or aerial photographs offers significant benefits to multiple sectors. By replacing labour-intensive and time-consuming manual surveys, the solution reduces survey costs and the need for extensive fieldwork, leading to cost savings and enhanced efficiency. Its rapid data processing capabilities improve accuracy and decision-making, while scalability allows for handling large volumes of data efficiently. Additionally, the solution minimises safety risks associated with fieldwork, and reallocates human resources to more valuable roles.

Our solution not only reduces survey costs and enhances efficiency but also eliminates the need for field experts to manually identify trees, ensuring consistently high accuracy that can be challenging even for seasoned experts. This automation of tree identification using advanced computer vision algorithms significantly streamlines the process, making it accessible to a wider range of users.

In addition to its primary function of automated tree enumeration, the program's secondary solutions play a crucial role in facilitating environmental compliance and advancing sustainability practices. By accurately categorising trees by species and size, the program provides essential data for evaluating the environmental impact of land diversion projects. This information is instrumental in ensuring adherence to stringent regulations governing land use and conservation, as well as minimising potential ecological disturbances. Moreover, the program's ability to seamlessly integrate with existing systems empowers organisations to efficiently manage and monitor their environmental responsibilities. Ultimately, the program's secondary solutions enhance not only regulatory compliance but also the long-term sustainability and responsible stewardship of forested areas, aligning with broader environmental objectives and societal expectations.

Unity forest model:

Creating a 3D model of a tree is vital for visualisation, allowing a perspective from every angle. We use Unity and blender for implementing this, using the widely used method of ‘Procedural generation’ to achieve this. The process typically involves using a numbered matrix, often referred to as a seed or procedural input, which serves as the foundation for generating various elements within the forest. Initially, the matrix is processed through a set of algorithms, which determine the placement of trees, vegetation, terrain features, and other environmental elements. By utilising procedural generation, we ensure that each forest image results in a unique and immersive forest environment.

Citations:

Guide for calculating a Significant Environmental Benefit

Tree enumeration:
Tree counting with high spatial-resolution satellite imagery based on deep neural networks

Girth estimation:
Vincent Grondin, Jean-Michel Fortin, François Pomerleau, Philippe Giguère, Tree detection and diameter estimation based on deep learning, *Forestry: An International Journal of Forest Research*, Volume 96, Issue 2, April 2023, Pages 264–276, Tree detection and diameter estimation based on deep learning | Forestry: An International Journal of Forest Research | Oxford Academic

Carbon Stock and biomass estimations
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K.M. Ngo, B.L. Turner, H.C. Muller-Landau, S.J. Davies, M. Larjavaara, N.F. Bin Nik Hassan, S. Lum
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Advanced Encryption Standard
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National Institute of Standards and Technology