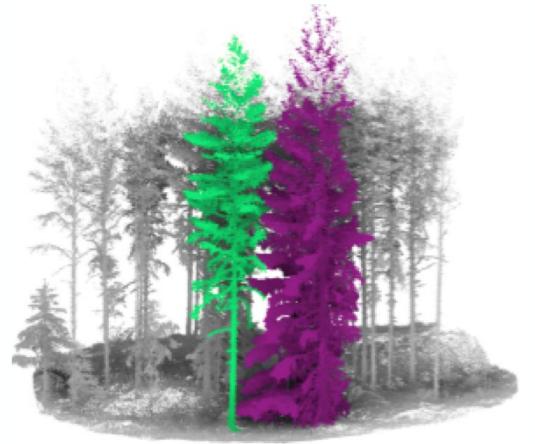
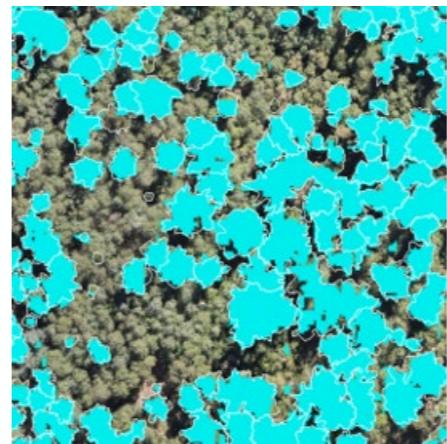


09 – Introduction to Deep Learning

- Image-based pattern recognition
- Point Cloud-based pattern recognition



Chair of Sensorbased Geoinformatics (geosense)
www.geosense.uni-freiburg.de

09 – Introduction to Deep Learning

Image-based Pattern recognition

Image-based Pattern recognition

RGB Drone image



Image Pattern recognition

RGB Drone image

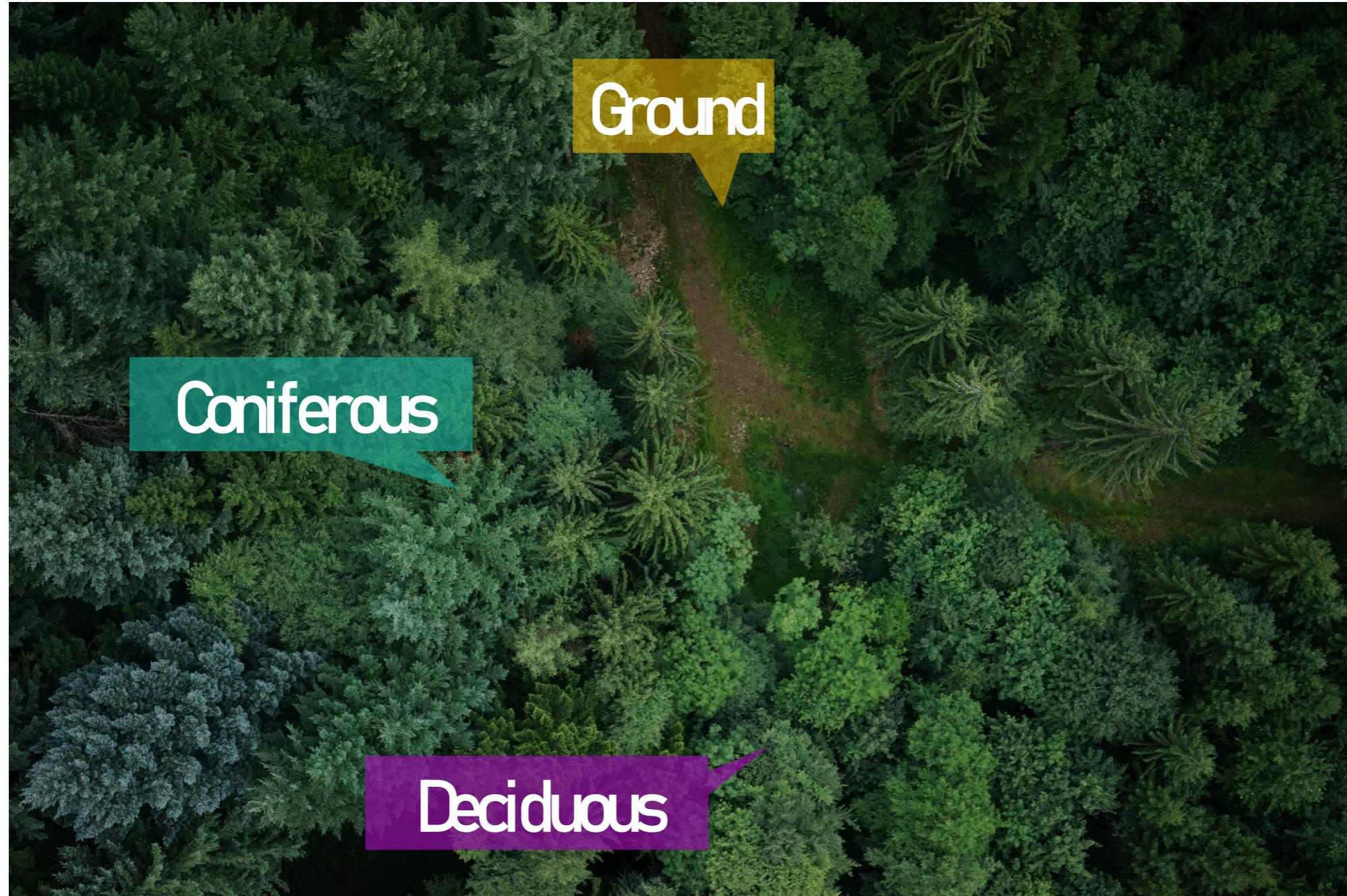


Image Pattern recognition

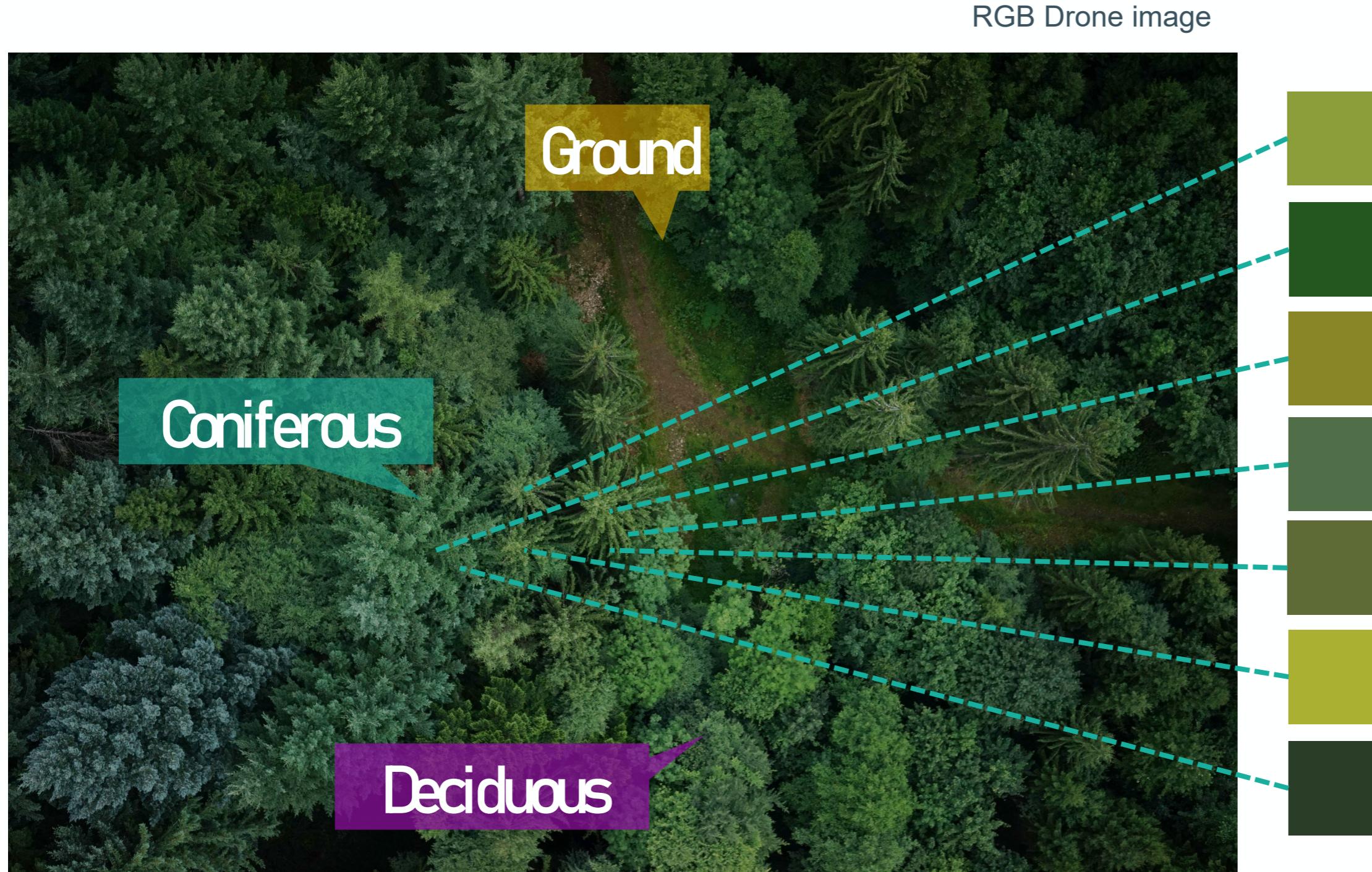


Image Pattern recognition

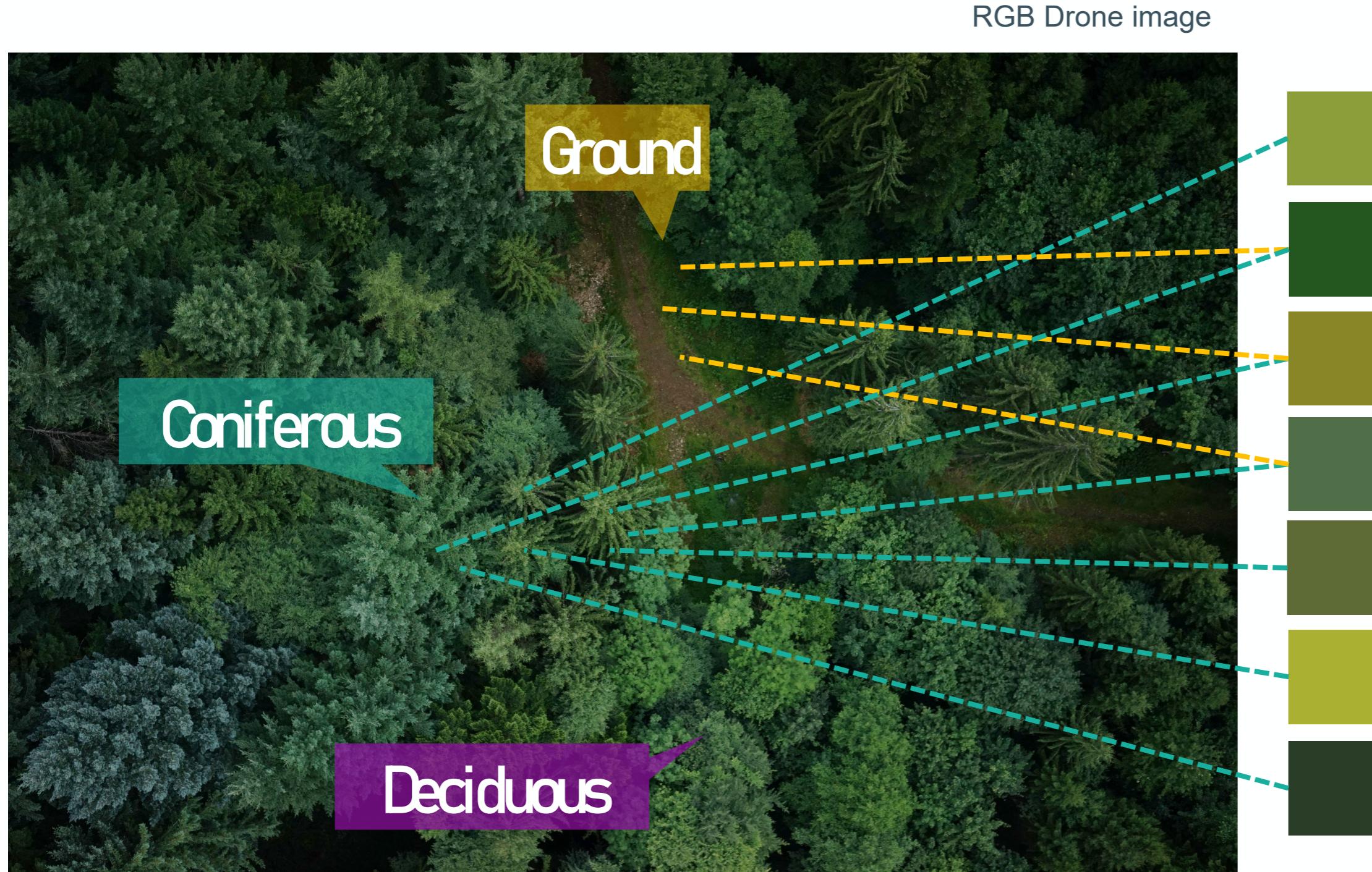


Image Pattern recognition

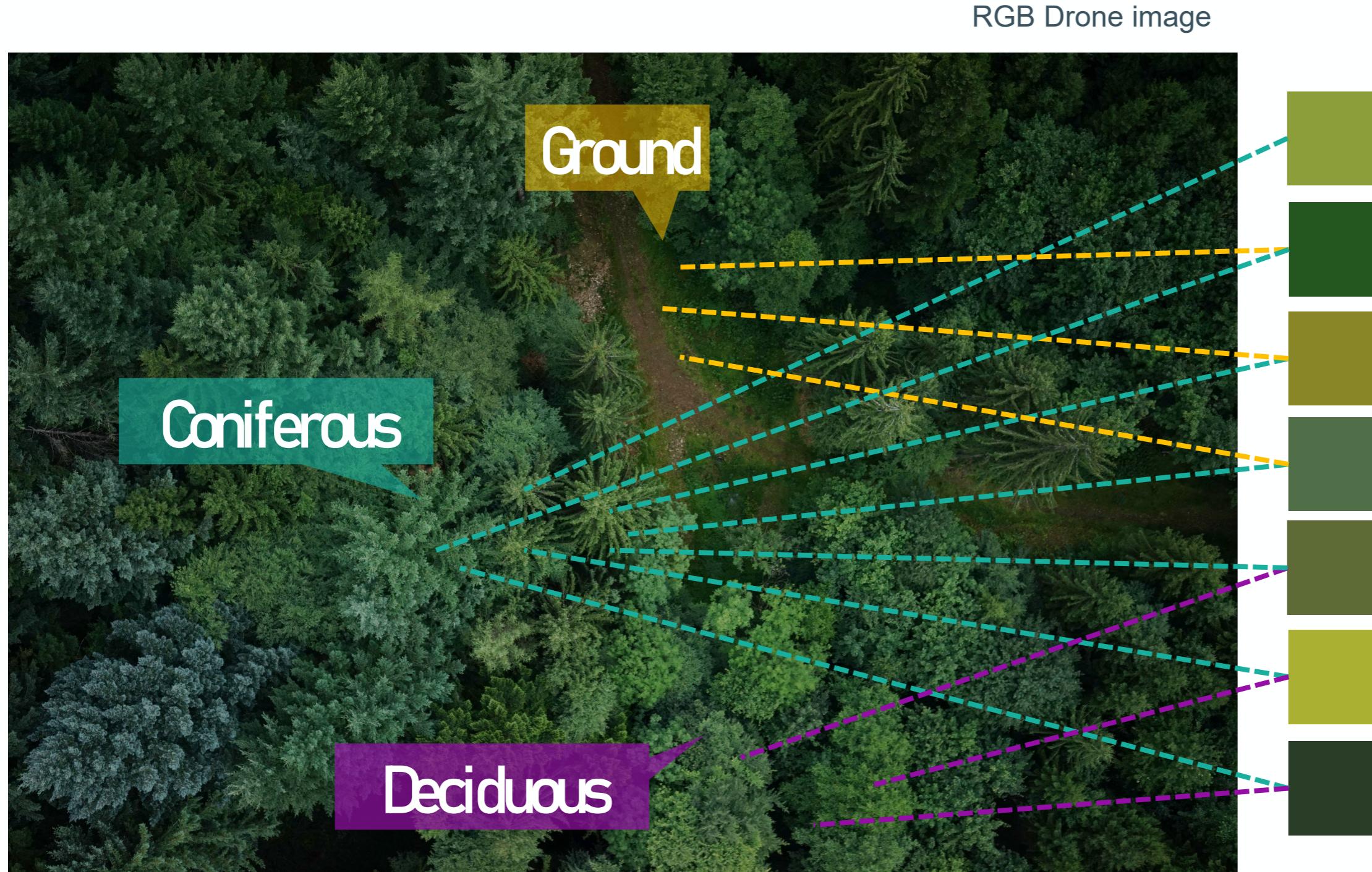
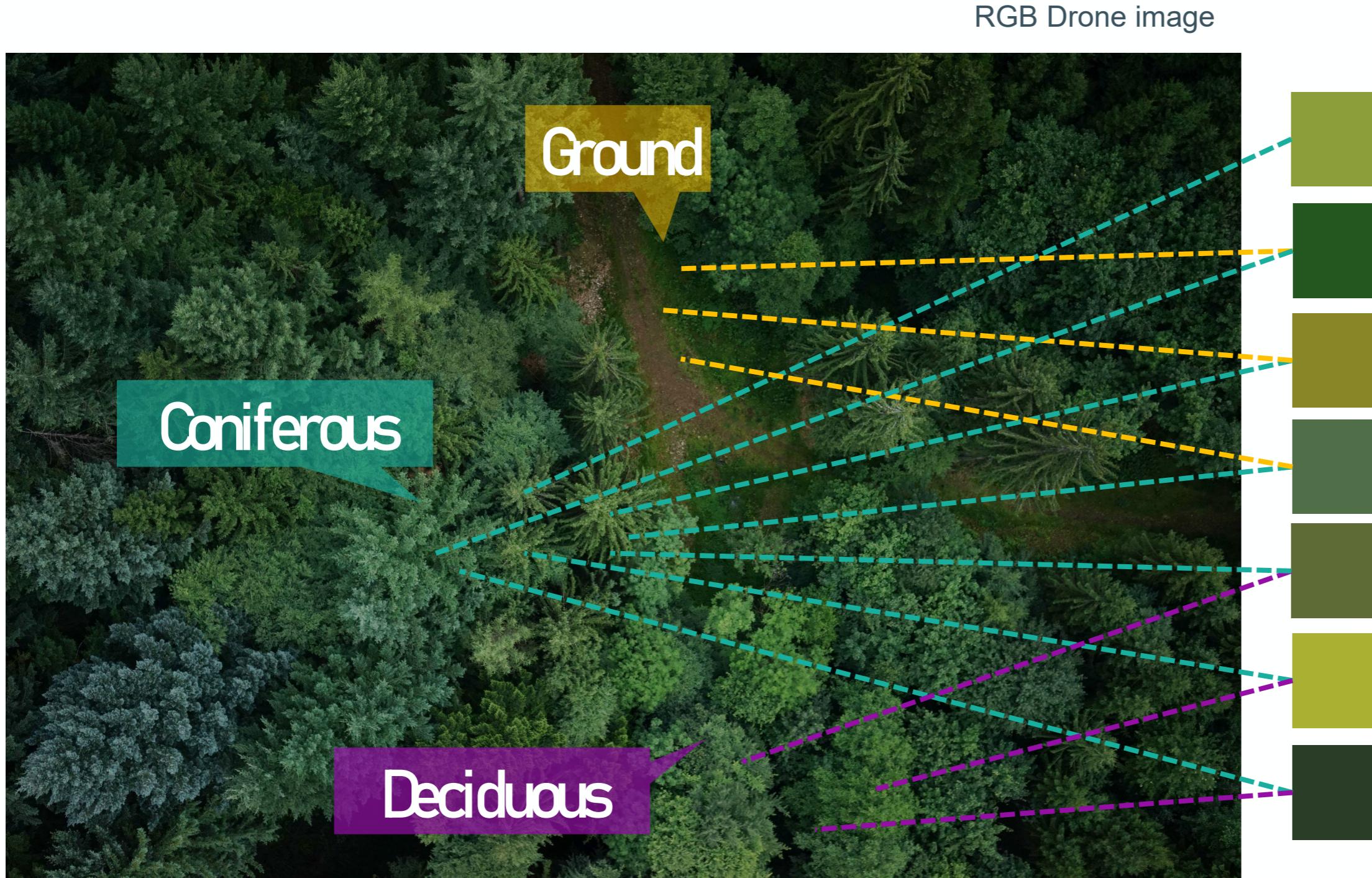
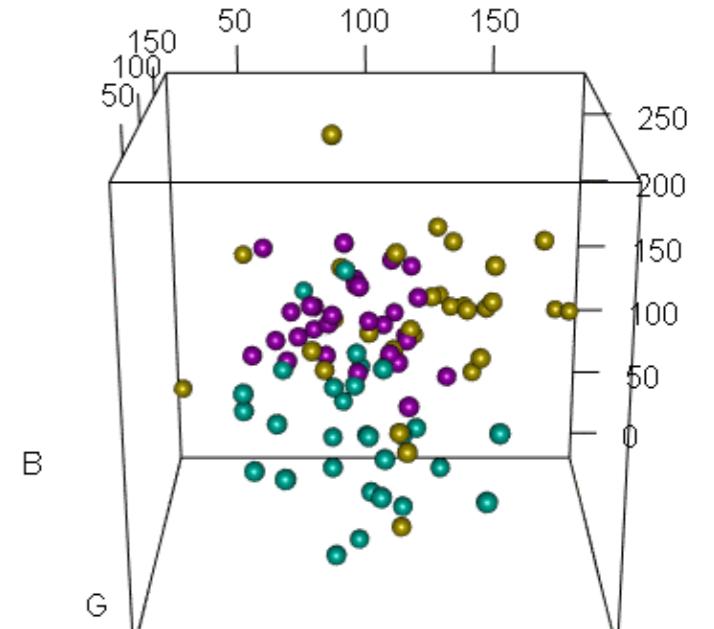


Image Pattern recognition



RGB color space:

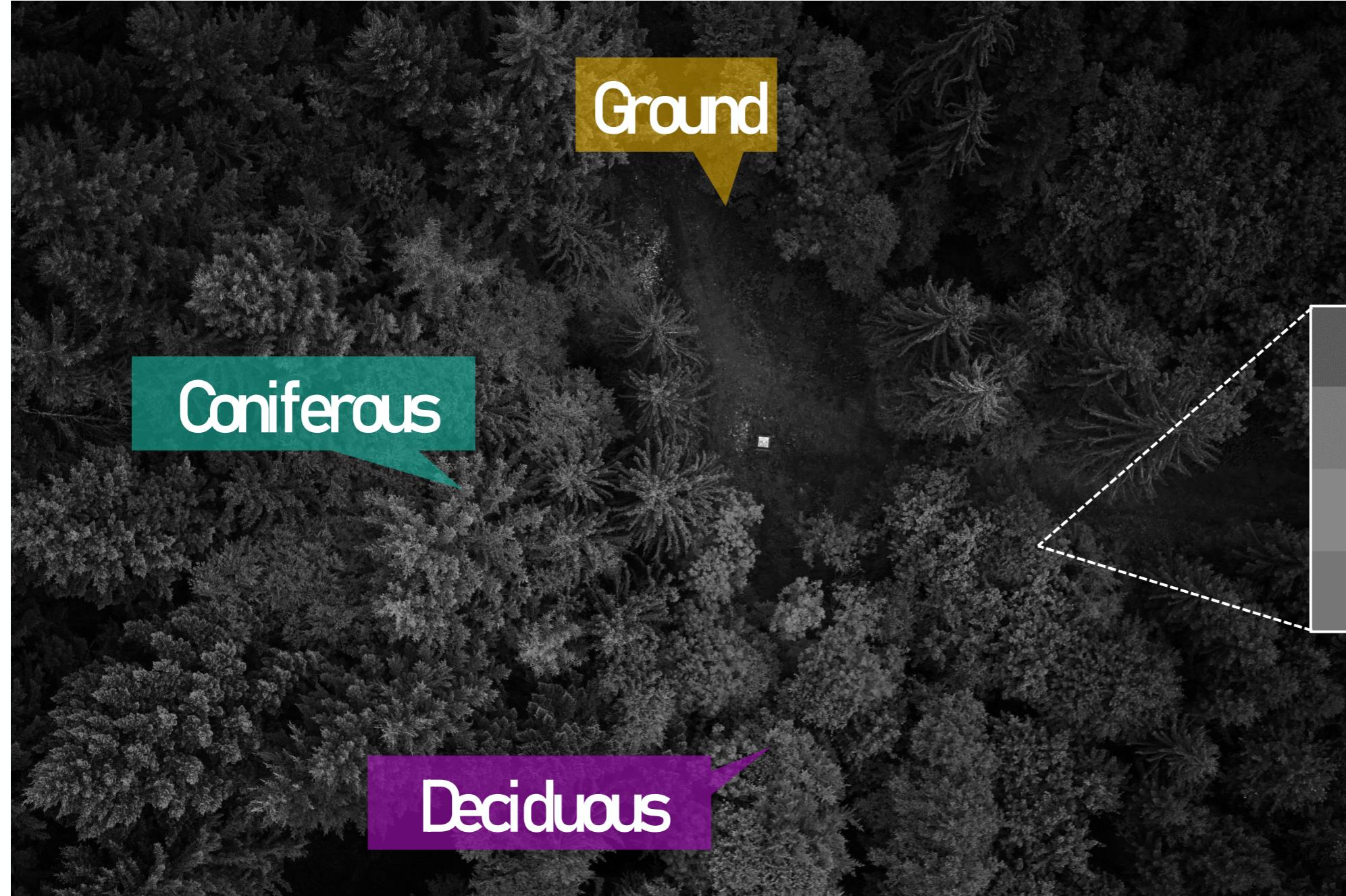


- Conifer
- Deciduous
- Ground

Image Pattern recognition



Image Pattern recognition



Response (y):

Class:
Deciduous

Predictors (y):

089	110	105	075
112	175	125	097
125	167	155	102
131	103	069	052



4 x 4 pixel matrix
(2D-tensor)

Image Pattern recognition



Texture Metrics

- Entropy
- Variance
- Mean
- Homogeneity
- etc...

input

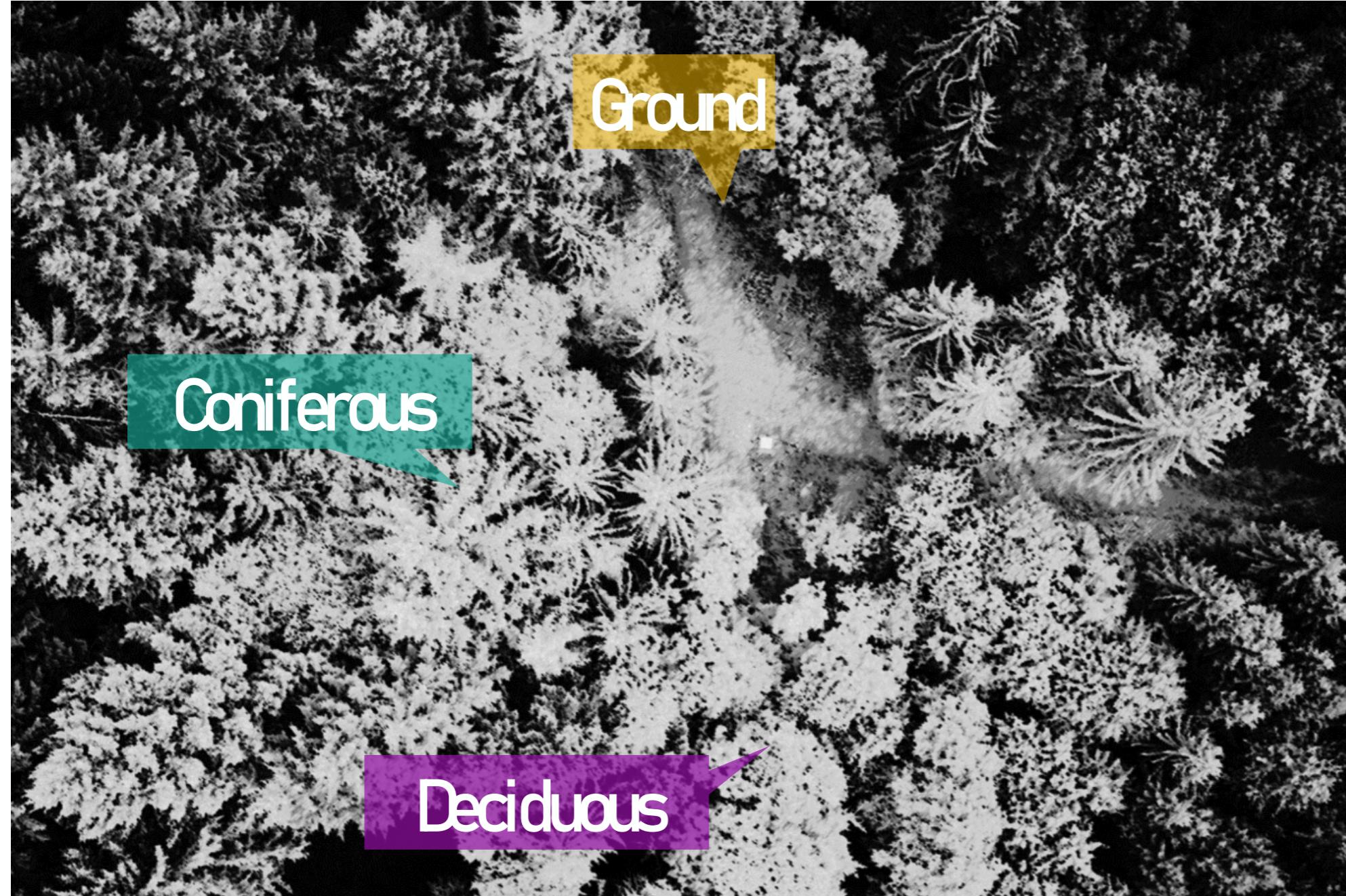
3 ₀	3 ₁	2 ₂	1	0
0 ₂	0 ₂	1 ₀	3	1
3 ₀	1 ₁	2 ₂	2	3
2	0	0	2	2
2	0	0	0	1

output

12.0	12.0	17.0
10.0	17.0	19.0
9.0	6.0	14.0

Haralick, R. M., & Shanmugam, K. (1973). Textural features for image classification. *IEEE Transactions on systems, man, and cybernetics*, (6), 610-621.

Image Pattern recognition



Texturmetriken

- Entropy
- Variance
- Mean
- Homogeneity
- etc...

input

3 ₀	3 ₁	2 ₂	1	0
0 ₂	0 ₂	1 ₀	3	1
3 ₀	1 ₁	2 ₂	2	3
2	0	0	2	2
2	0	0	0	1

output

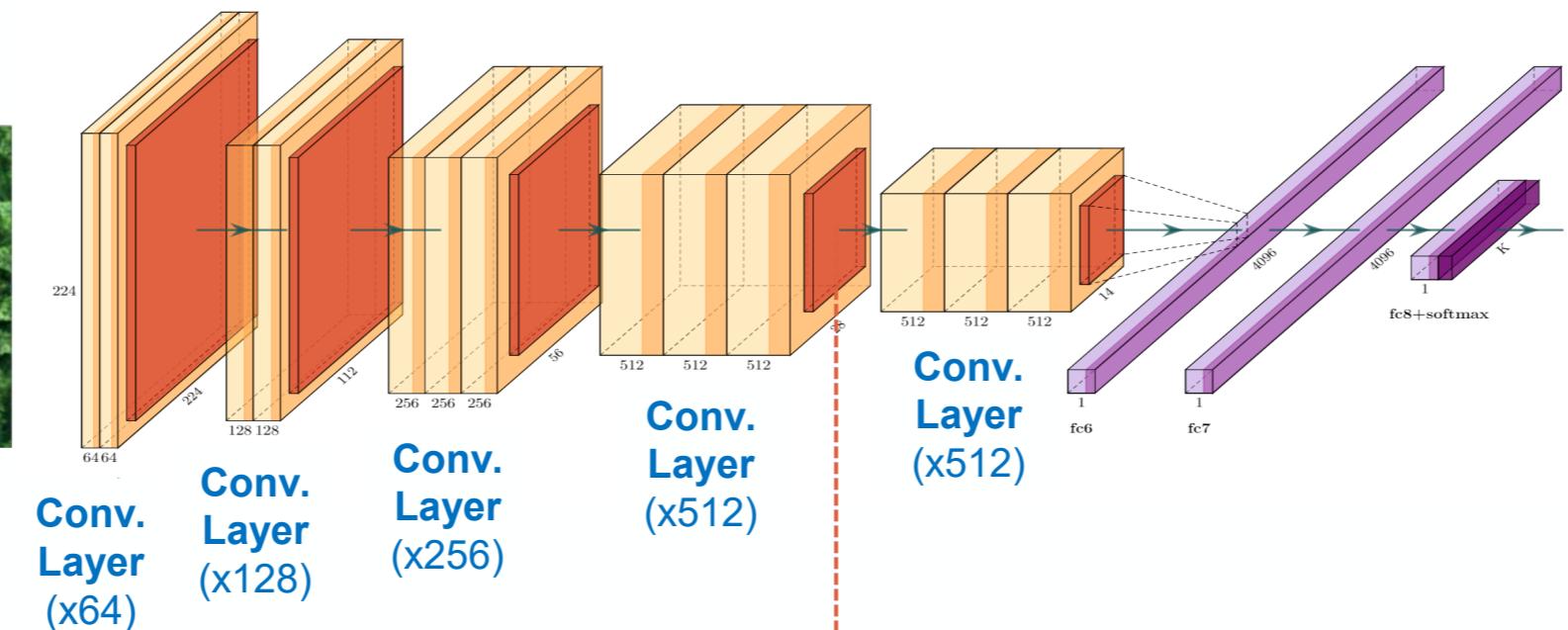
12.0	12.0	17.0
10.0	17.0	19.0
9.0	6.0	14.0

Haralick, R. M., & Shanmugam, K. (1973). Textural features for image classification. *IEEE Transactions on systems, man, and cybernetics*, (6), 610-621.

Convolutional Neural Networks

Image Classification (VGG)

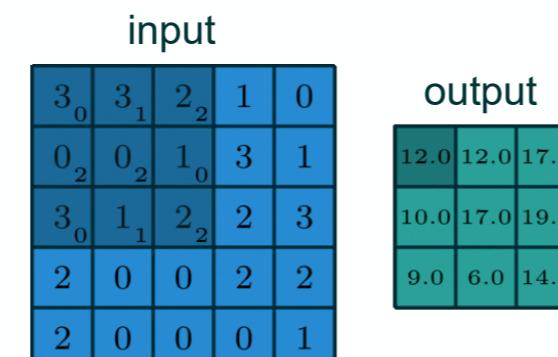
Predictors (x, image data)



Response (y, Class)

Klasse	Probability
Deciduous	0.39
Coniferous	0.37
Ground	0.26

Spatial aggregation (Pooling)



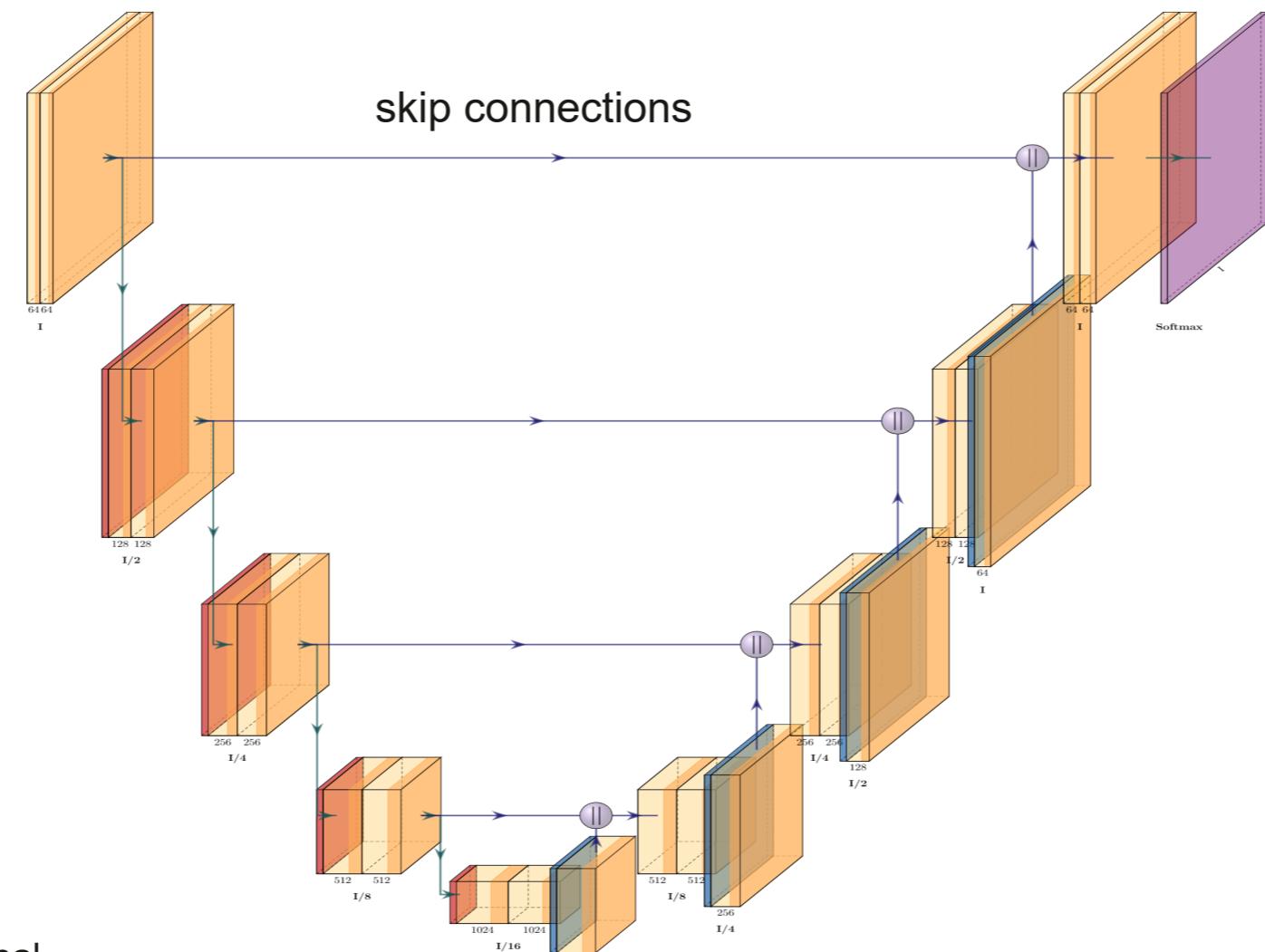
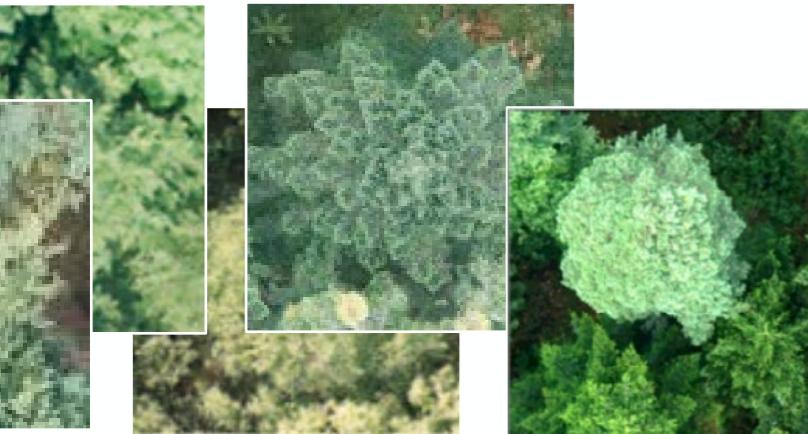
<https://github.com/Harislqbal88/PlotNeuralNet>
https://github.com/vdumoulin/conv_arithmetic

Kattenborn et al. 2022; Review on Convolutional Neural Networks for vegetation remote sensing, ISPRS.

Convolutional Neural Networks

Image Segmentation (Unet)

Predictors (x, image data)



Output: Segmentierung



█ Deciduous
█ Coniferous
█ Ground

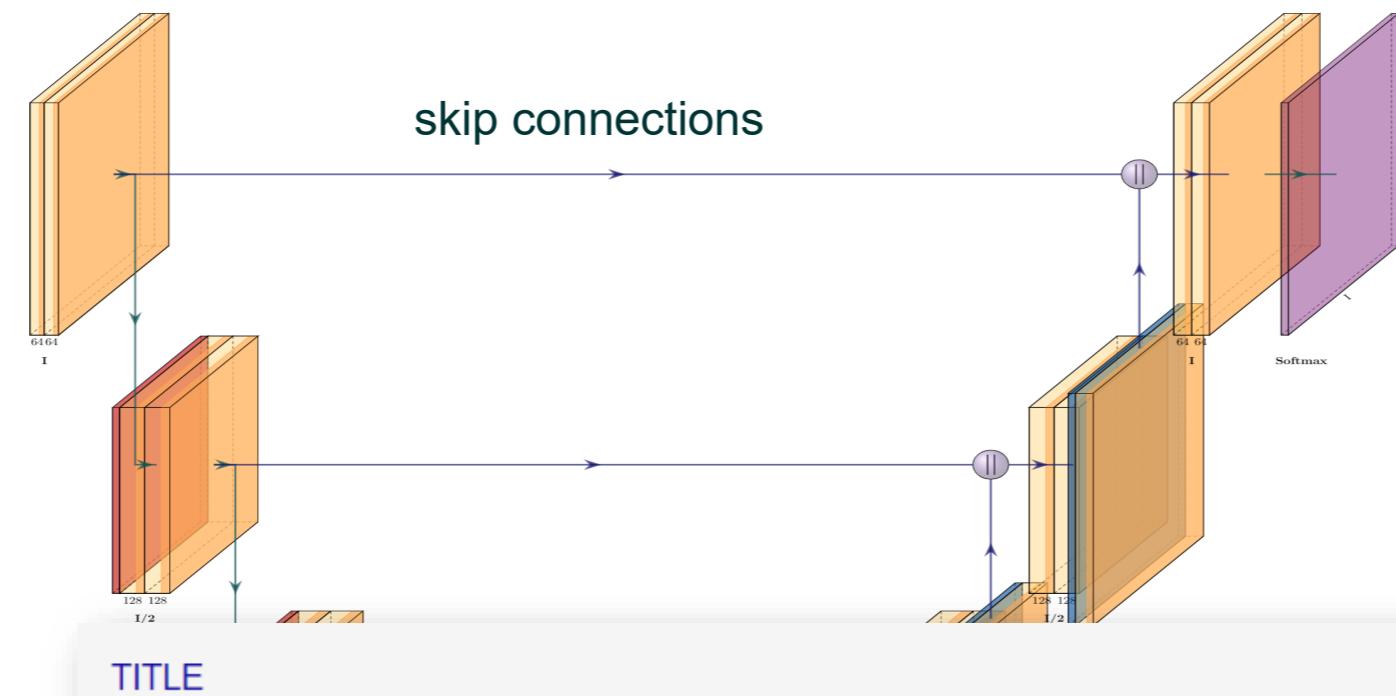
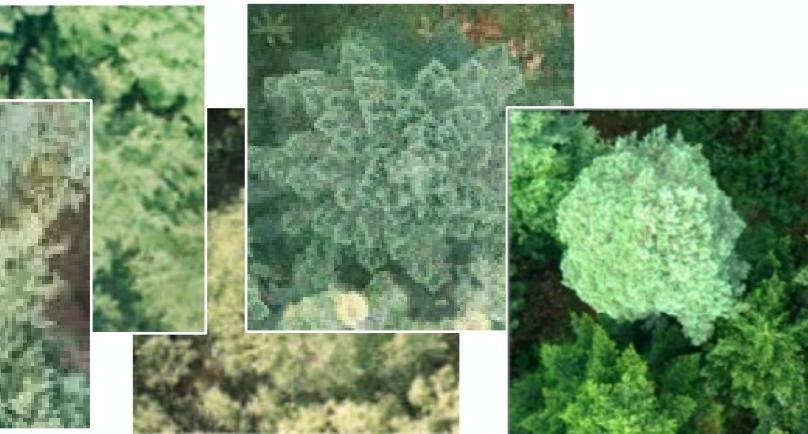
<https://github.com/Harislqbal88/PlotNeuralNet>

Kattenborn et al. 2022; Review on Convolutional Neural Networks for vegetation remote sensing, ISPRS.

Convolutional Neural Networks

Image Segmentation (Unet)

Predictors (x, image data)



Output: Segmentation mask



Deciduous
Coniferous
Ground

[U-net: Convolutional networks for biomedical image segmentation](#)

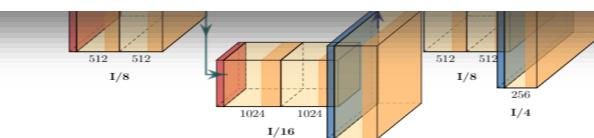
O Ronneberger, P Fischer, T Brox

International Conference on Medical image computing and computer-assisted ...

52248

2015

(Google Scholar)



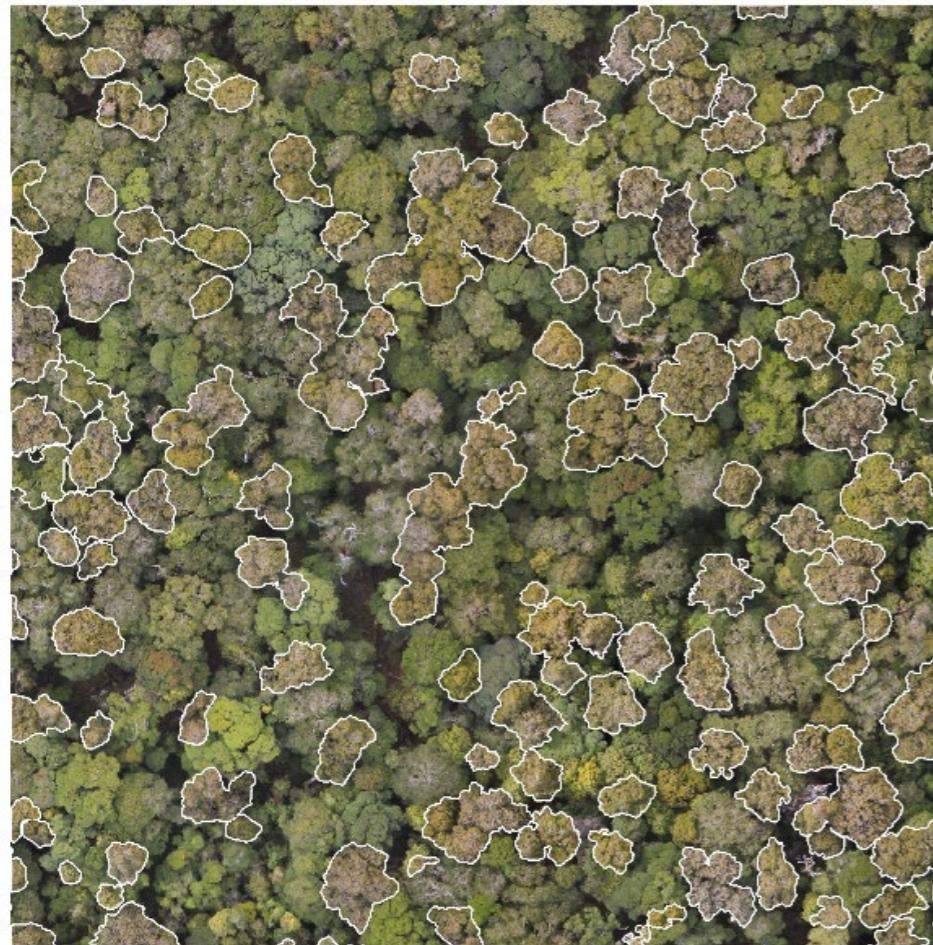
<https://github.com/Harislqbal88/PlotNeuralNet>

Kattenborn et al. 2022; Review on Convolutional Neural Networks for vegetation remote sensing, ISPRS.

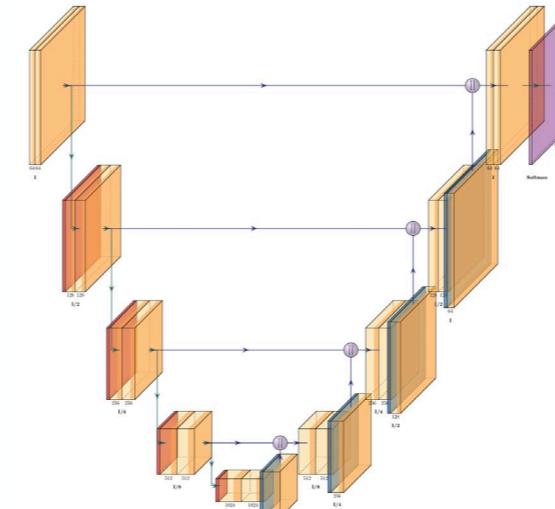
Convolutional Neural Networks

CNNTraining

(Training phase with reference data)



Visual
Interpretation



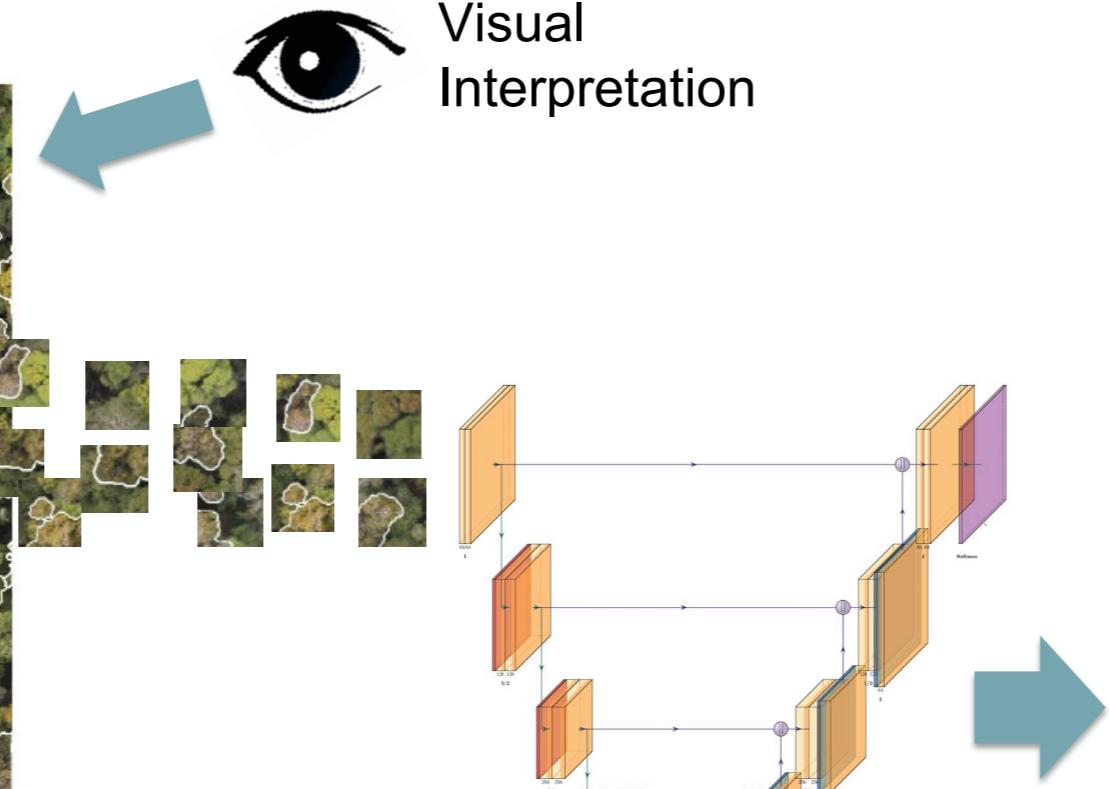
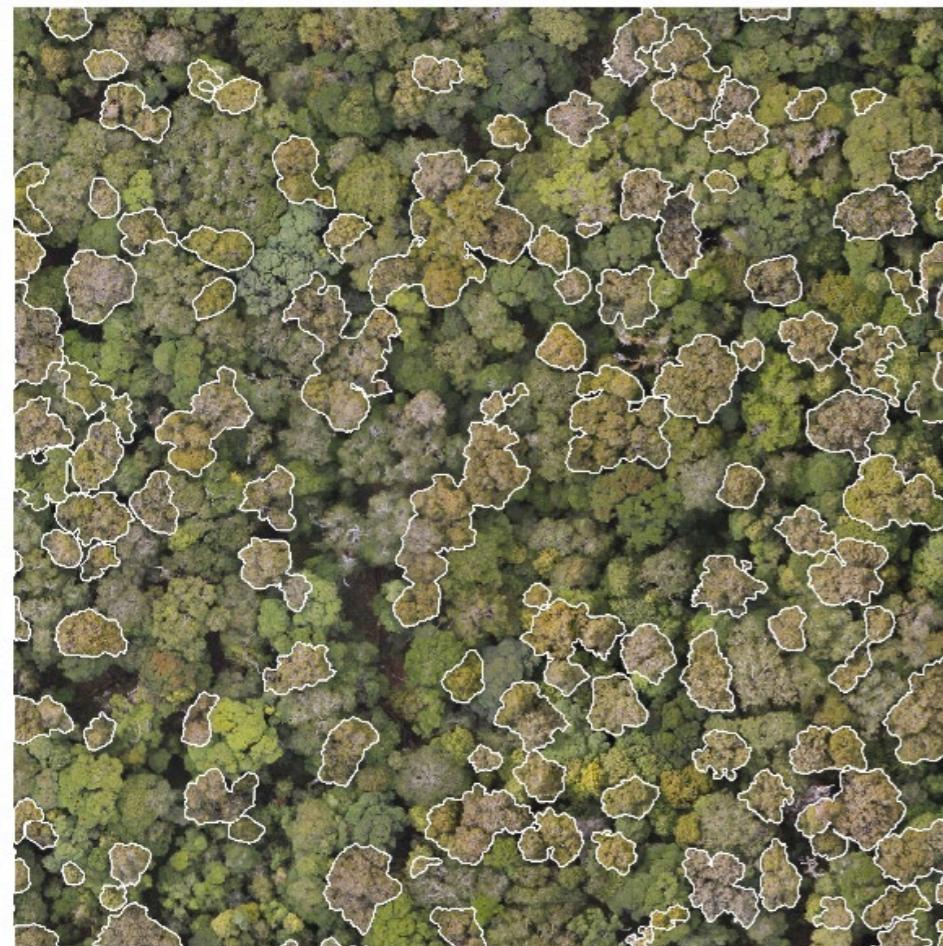
**Trained
Convolutional Neural Network
(Segmentation, UNet)**

Drone Orthomosaic
2 cm Resolution
> 56 Mio Pixel

Convolutional Neural Networks

CNN Training

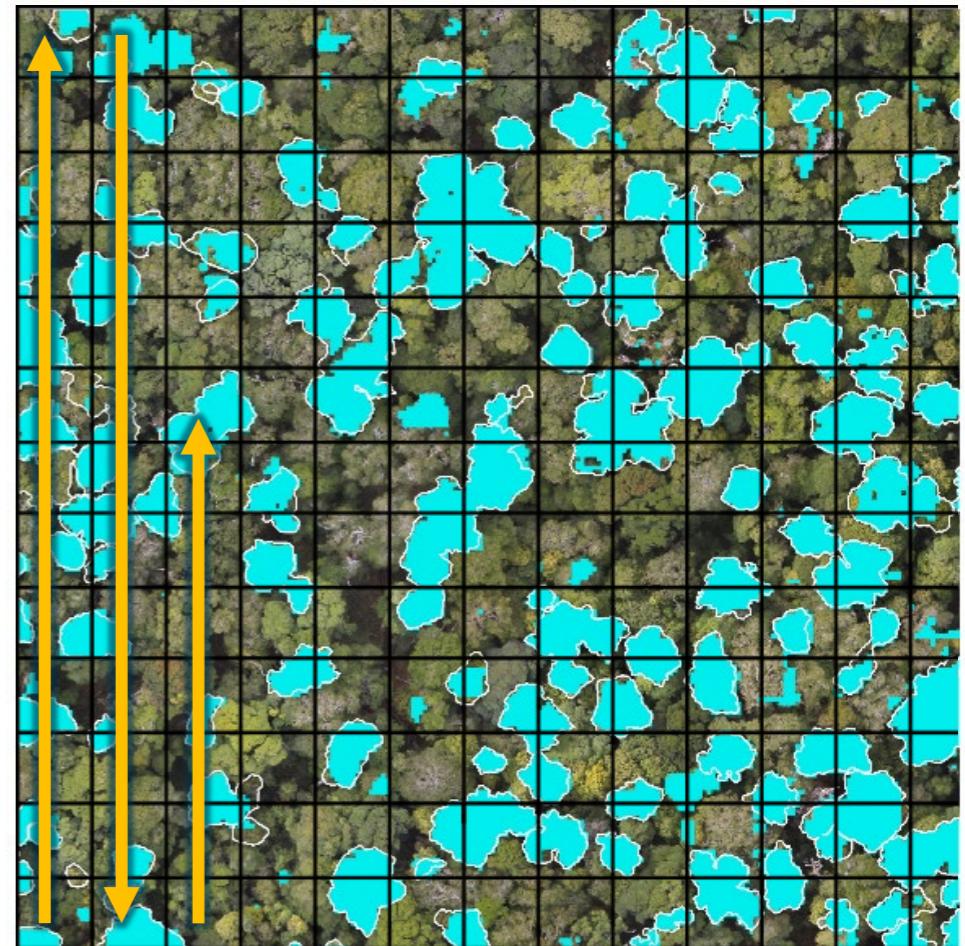
(Training phase with reference data)



Trained
Convolutional Neural Network
(Segmentation, UNet)

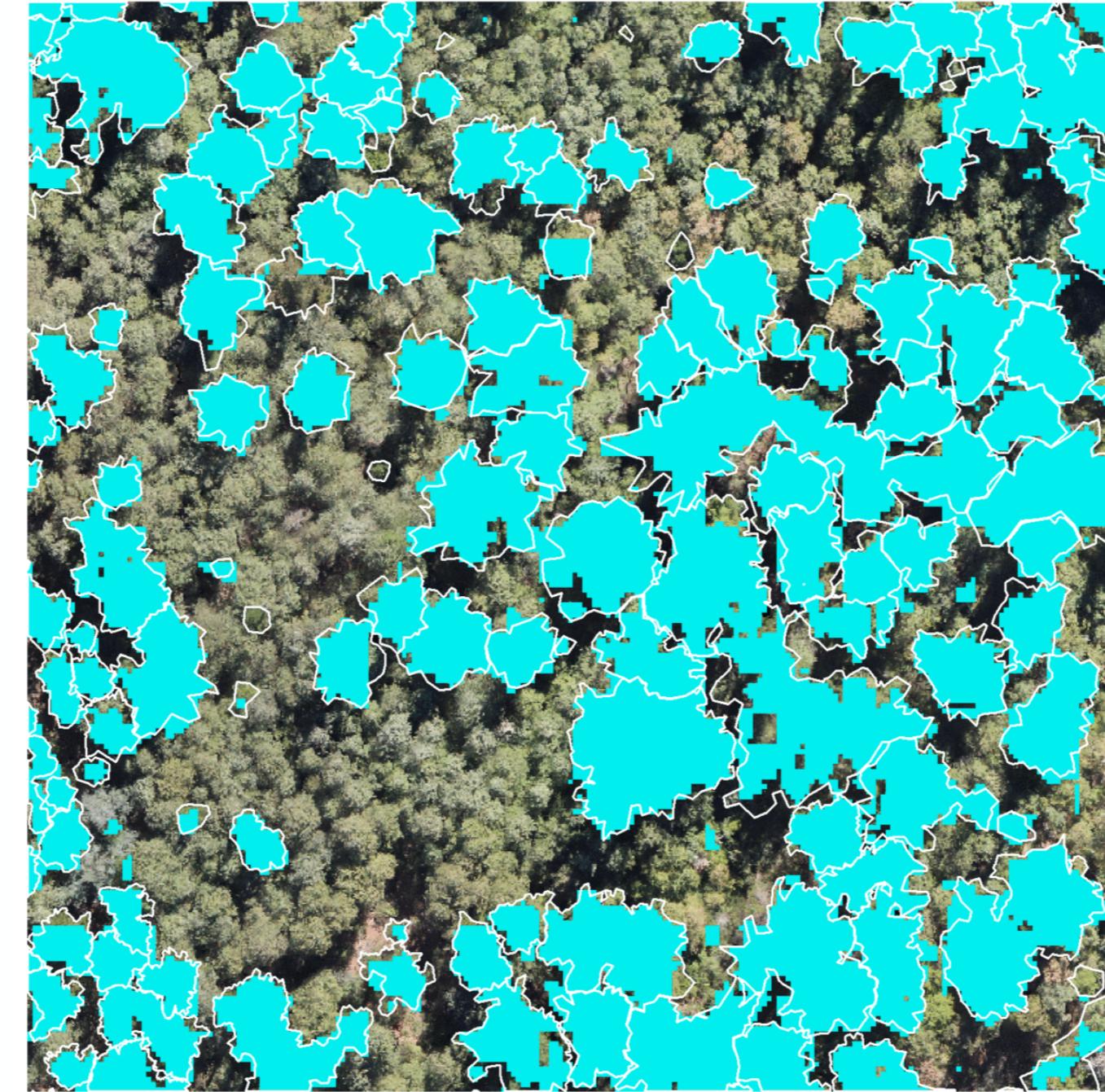
CNN Inference

(Application to new data)

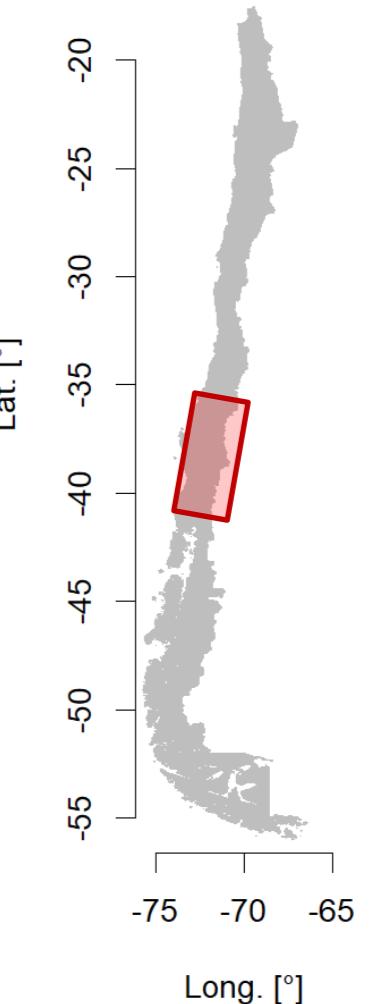


Drone Orthomosaic
2 cm Resolution
> 56 Mio Pixel

Convolutional Neural Networks



Study area:
Central Chile



Convolutional Neural Networks

Image Segmentation (Unet)

Input (Image data)

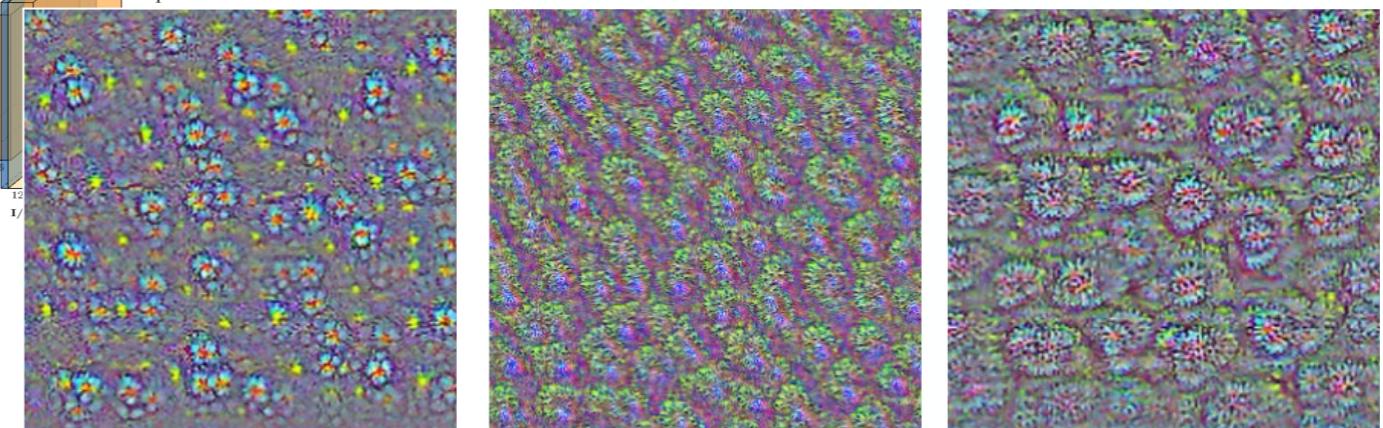


Output: Segmentation mask



Deciduous
Coniferous
Ground

Filter representations



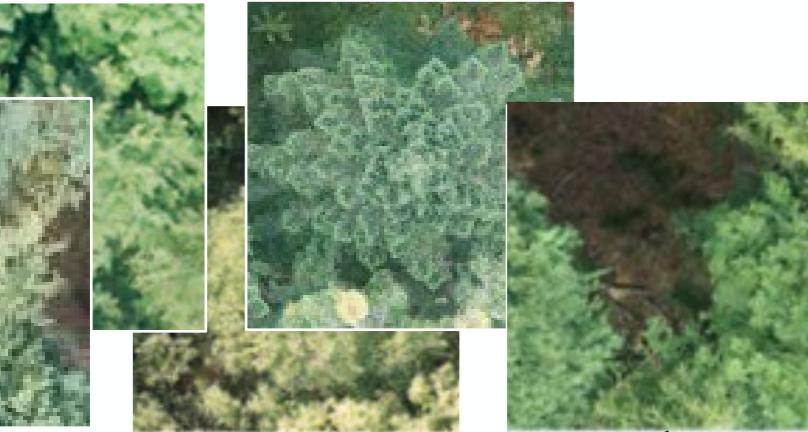
<https://github.com/Harislqbal88/PlotNeuralNet>

Kattenborn et al. 2022; Review on Convolutional
Neural Networks for vegetation remote sensing, ISPRS.

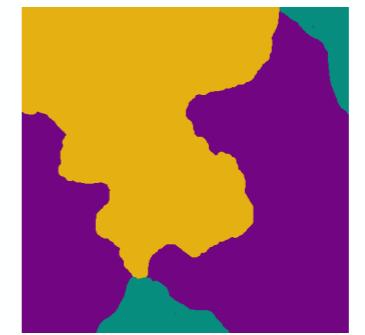
Convolutional Neural Networks

Image Segmentation (Unet)

Predictors (x, image data)

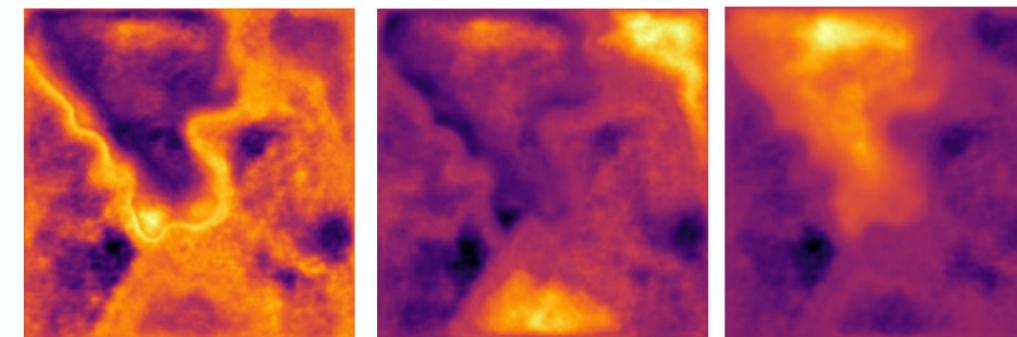


Output: Segmentation mask



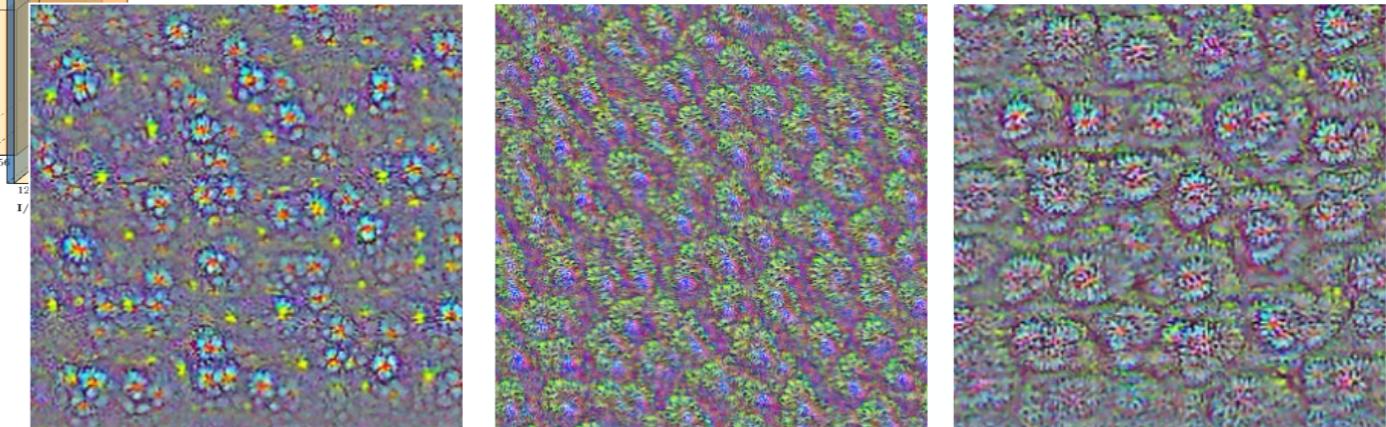
Deciduous
Coniferous
Ground

Feature Attribution



Deciduous Coniferous Ground

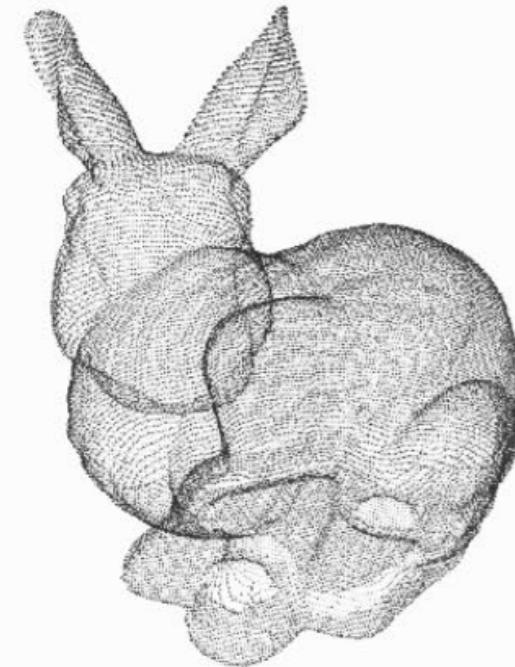
Filter representations



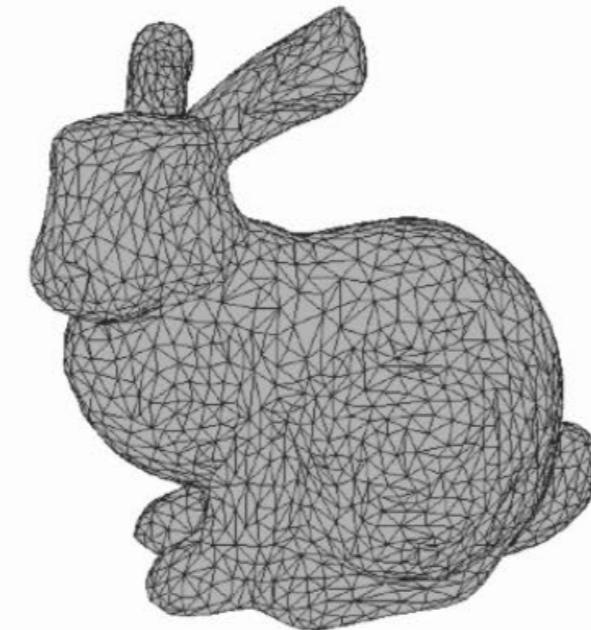
09 – Introduction to Deep Learning

Point cloud-based Pattern recognition

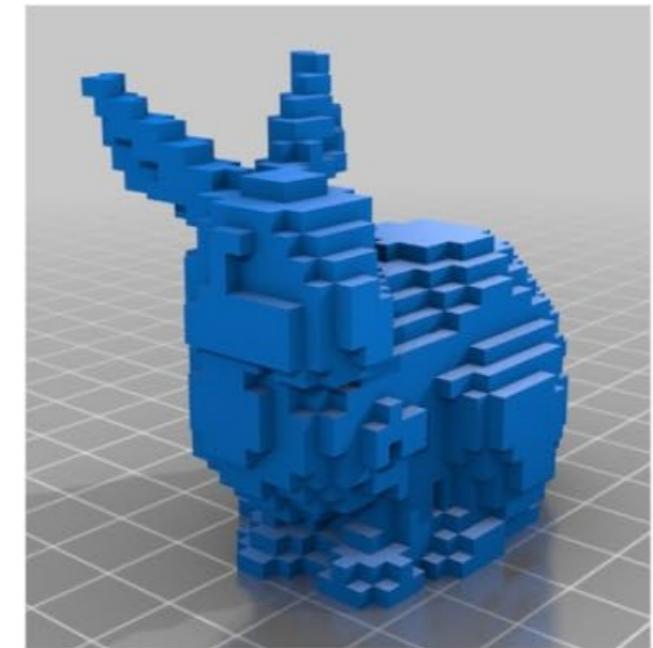
Point Cloud Pattern Recognition



Point Cloud



Mesh

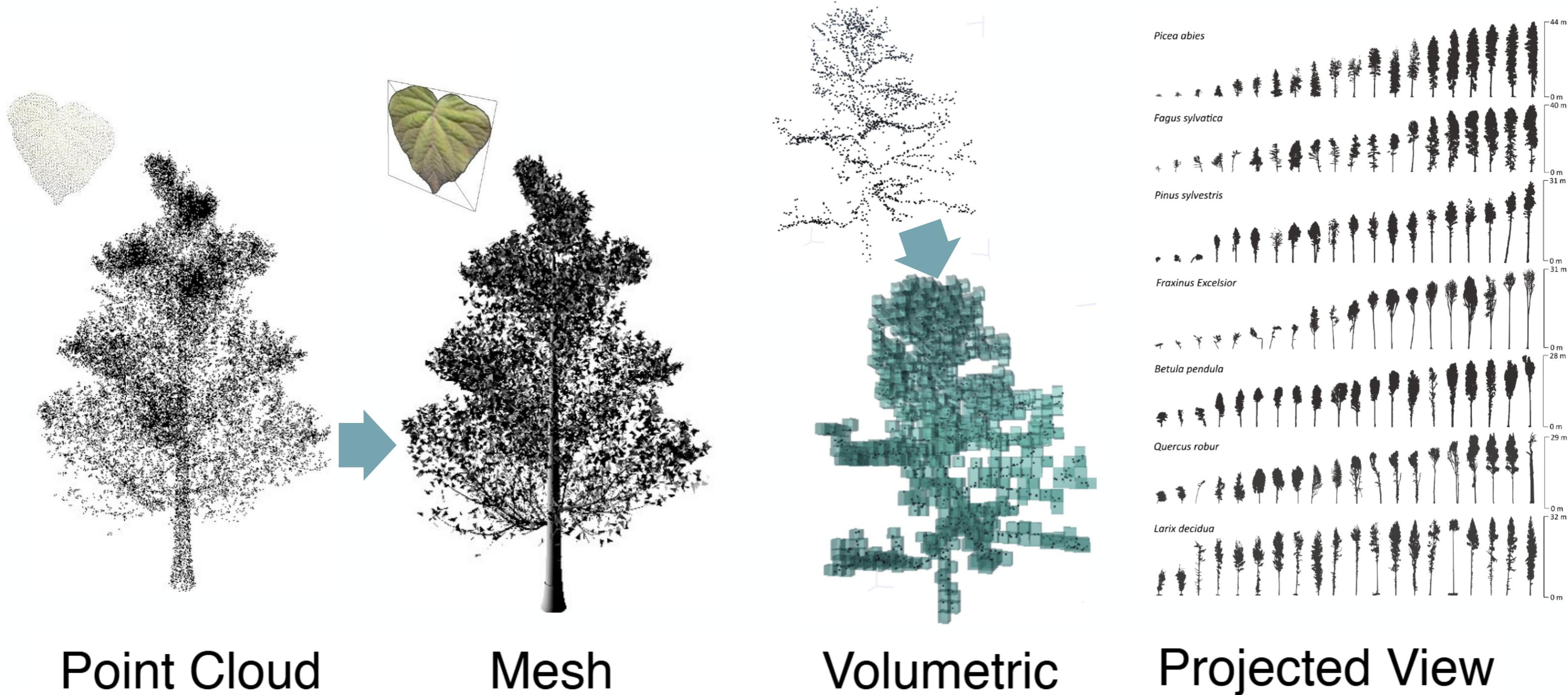


Volumetric



Projected View

Point Cloud Pattern Recognition



Point Cloud

Mesh

Volumetric

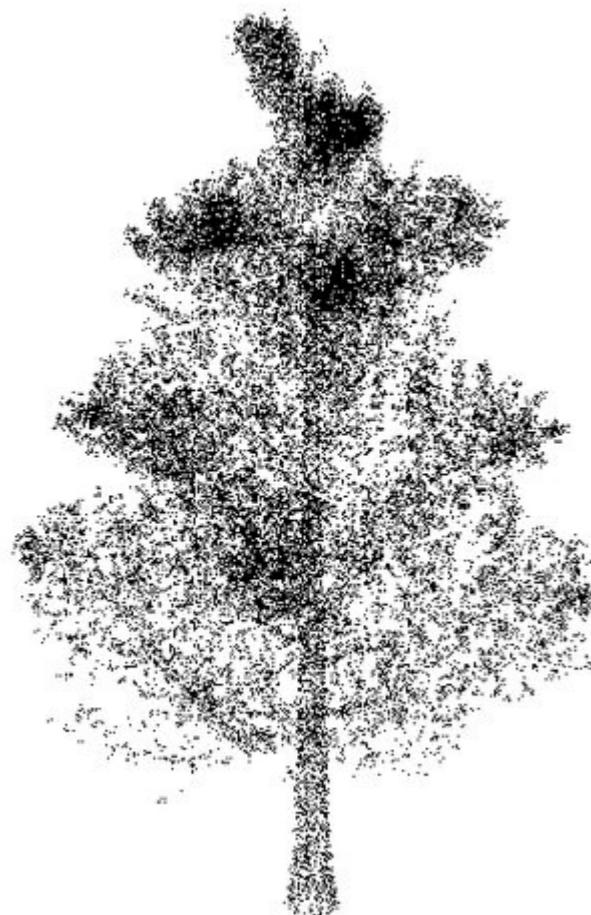
Projected View

<https://peterwonka.net/Publications/pdfs/2005.PBG.Rovira.PointSamplingUniformLines.pdf>

<https://doi.org/10.1016/j.ufug.2021.127324>

<https://doi.org/10.48550/arXiv.2408.06507>

Point Cloud Pattern Recognition



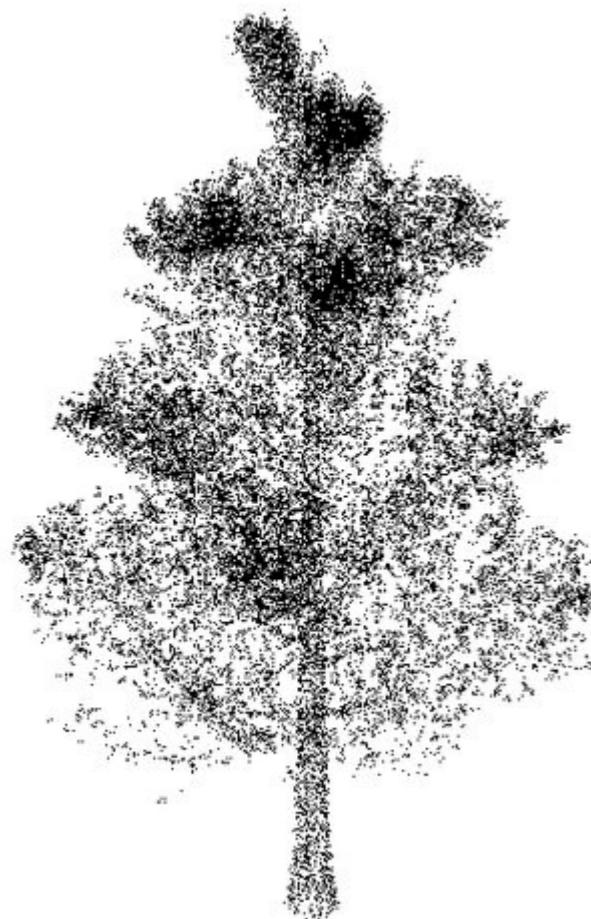
Preferably extract information from point clouds

- no information loss

Challenges with points

- Unstructured, Unordered
- Needs to be rotation invariant
 - > point cloud rotation should not alter classification result

Point Cloud Pattern Recognition



How is it done?

- Translation from X,Y,Z into artificial higher order space
- Symmetric functions (functions that do not care about order)
- Transformation (e.g. rotation on the fly, learned by the model)

→ Global features

- The overall pattern of points and their properties

→ Local features

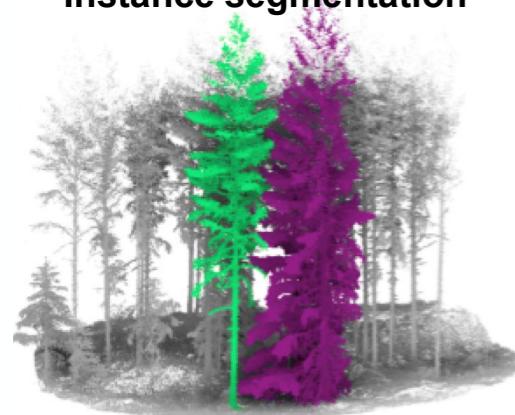
- Relation between points (e.g. curvature)
- Enables segmentation tasks (e.g. which trees belong to the trunk, which are leaves, what are ground points)

Point Cloud Pattern Recognition

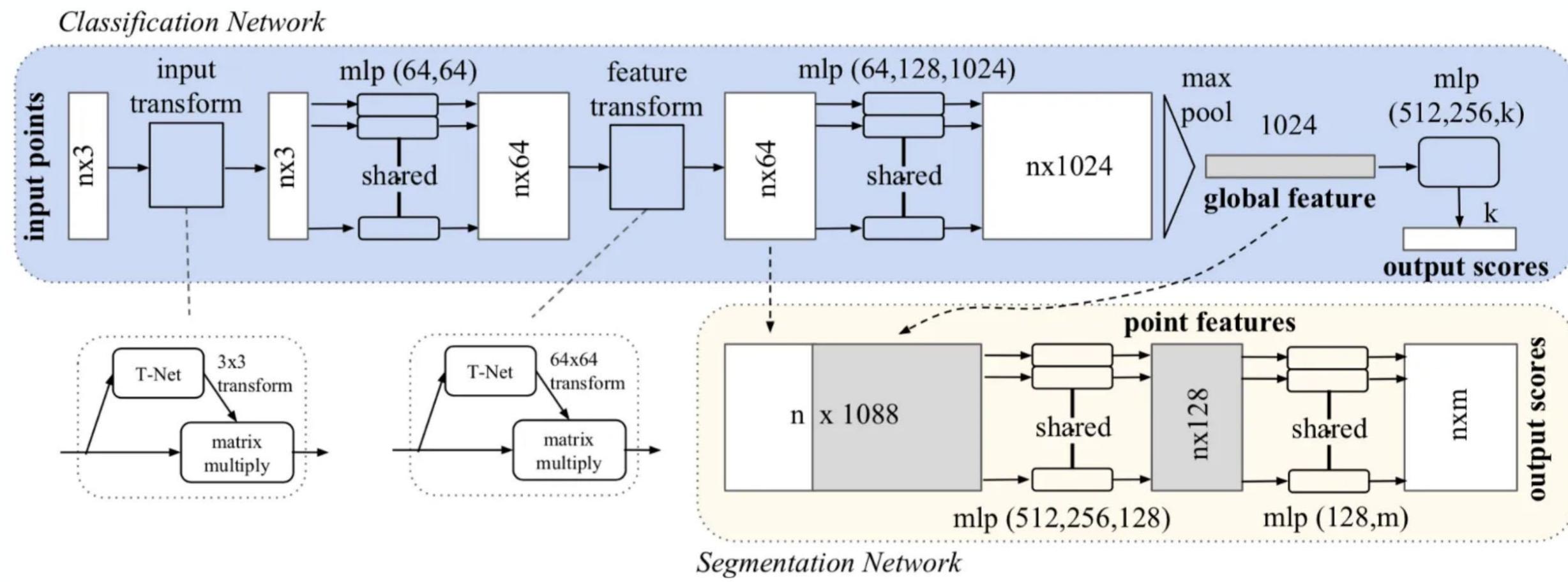
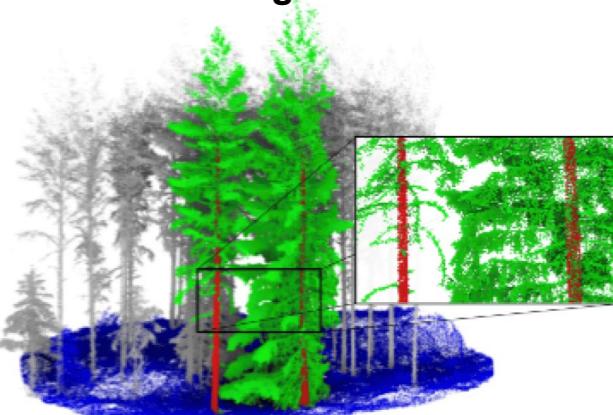
Raw point cloud



Instance segmentation



Semantic segmentation

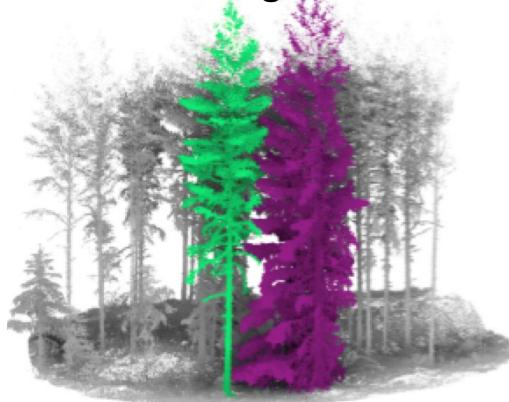


Point Cloud Pattern Recognition

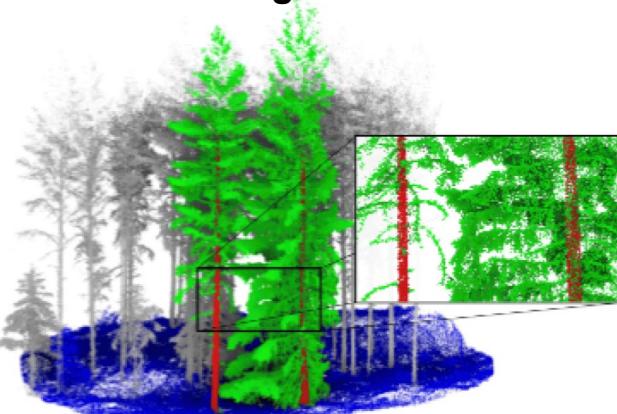
Raw point cloud



Instance segmentation

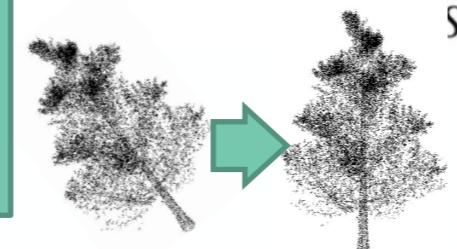
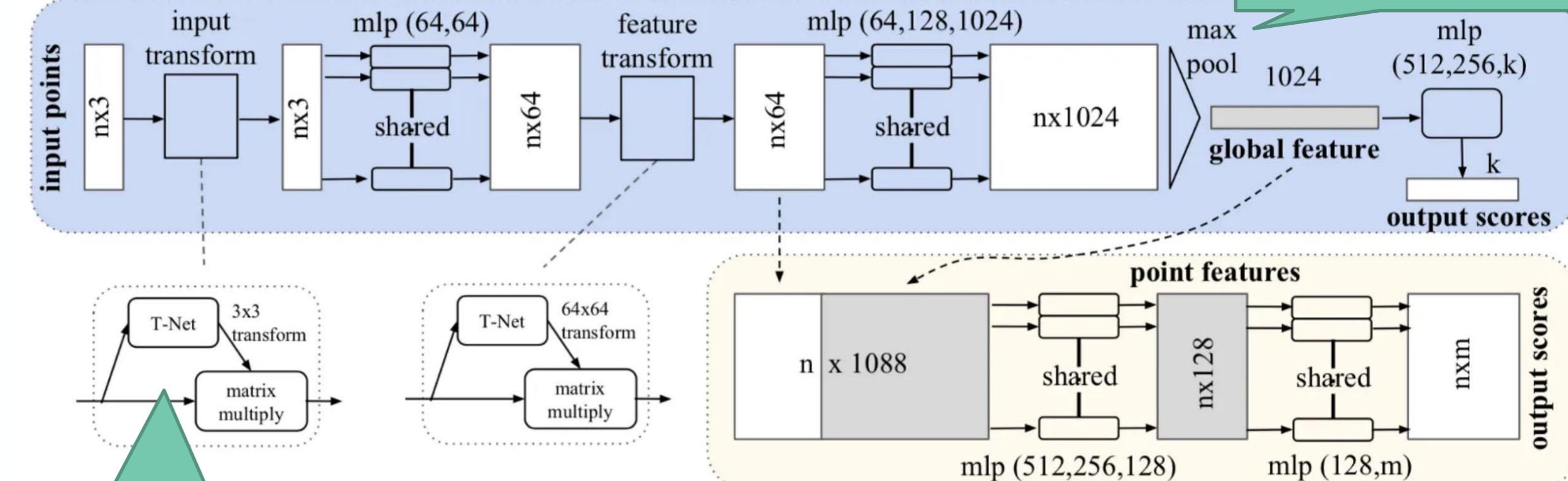


Semantic segmentation



Canonical representation
(Model will „rotate“ objects
on the fly)

Classification Network



**Relation between
neighbouring points**

Symmetric functions
(e.g. max) that do not
care about the order of
points

Point Cloud Pattern Recognition



How is it done?

- Translation from X,Y,Z into artificial higher order space
- Symmetric functions (functions that do not care about order)
- Transformation (e.g. rotation on the fly, learned by the model)

→ Global features

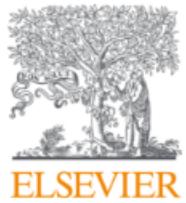
- The overall pattern of points and their properties

→ Local features

- Relation between points (e.g. curvature)
- Enables segmentation tasks (e.g. which trees belong to the trunk, which are leaves, what are ground points)

09 – Introduction to Deep Learning

Hands-on on:
Evaluation of Point Cloud-based Segmentation



Remote Sensing of Environment

Volume 313, 1 November 2024, 114367



SegmentAnyTree: A sensor and platform agnostic deep learning model for tree segmentation using laser scanning data

Maciej Wielgosz ^{a,1} , Stefano Puliti ^{a,1}, Binbin Xiang ^b, Konrad Schindler ^b,
Rasmus Astrup ^a

Highlights

- Developed a versatile deep learning method for tree segmentation with lidar.
- Evaluated model performance across various platforms with sparsity impact analysis.
- Showed that gradual sparsification as a training strategy is effective for lidar.
- Improved understory tree detection with lower computational needs than others.
- Set new performance standards in Wytham Woods and TreeLearn datasets.

