ML Methods for Localization and Classification of Insects in Images

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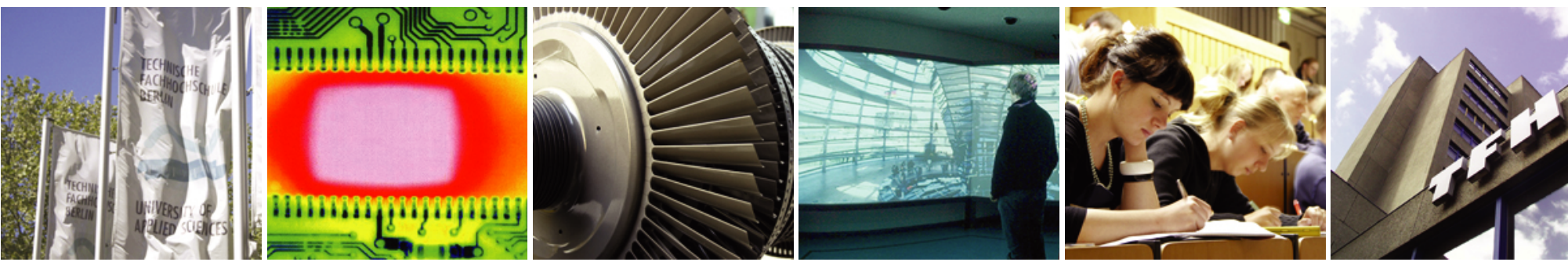


Content

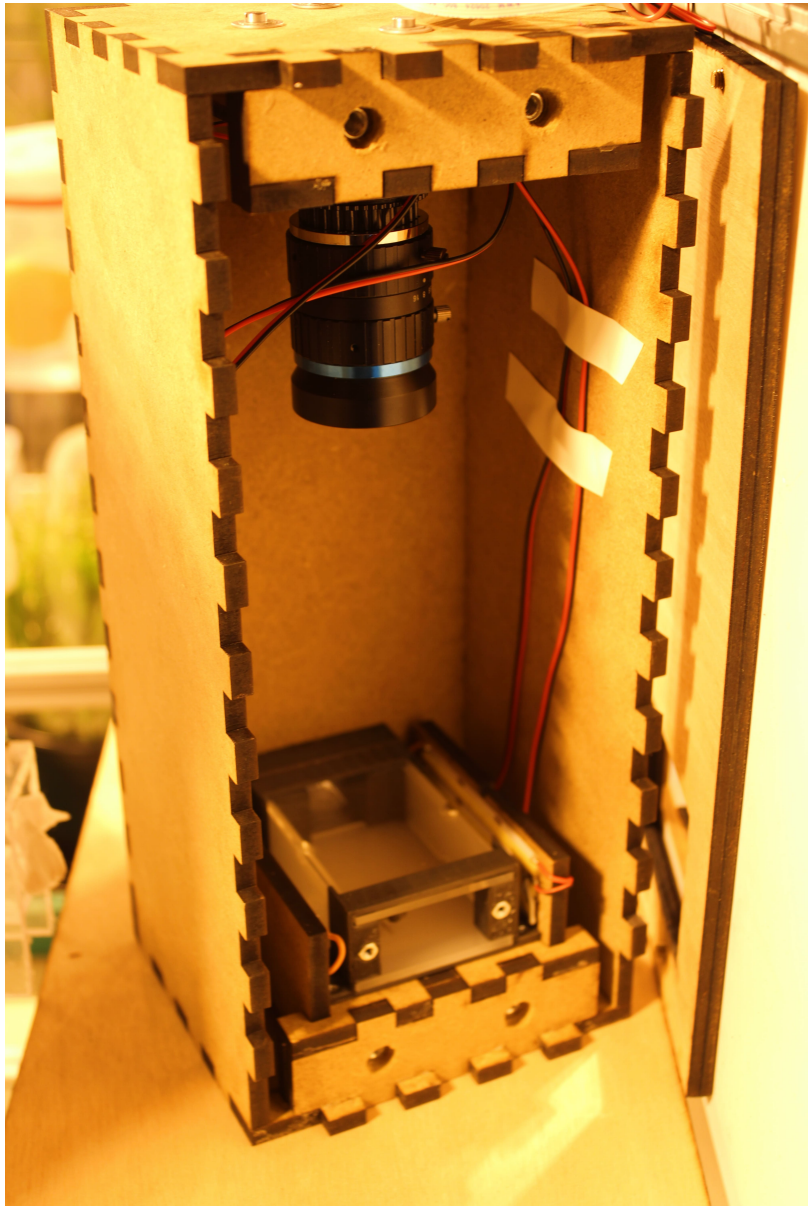
Part I

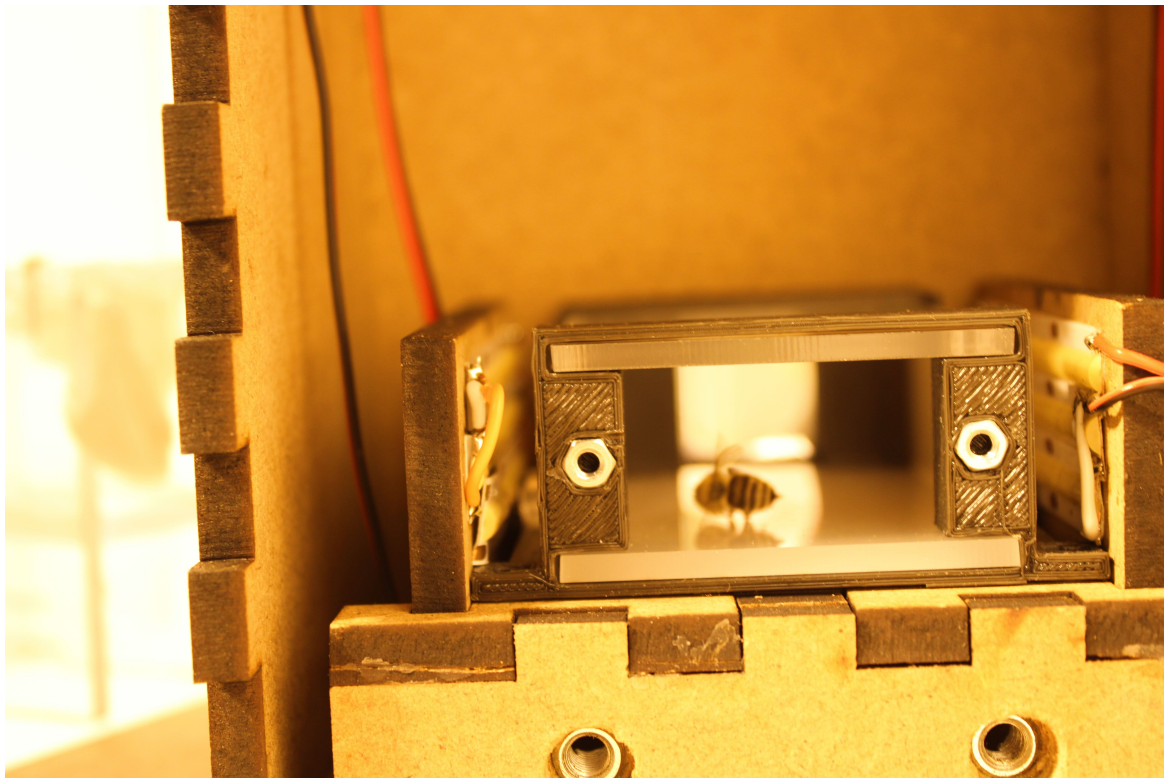
Intro

Motivation

- paper[1] from 2017 displays 75-80% decrease in insect biomass over the last 27 years
- KInsecta citizen science project of BHT
- Monitoring of insects
- required to run on Raspberry Pi

Monitoring Device





Problem description

Localization and classification of insects in images.

Input

Problem description

Localization and classification of insects in images.

Input

→ Method

Problem description

Localization and classification of insects in images.

Input

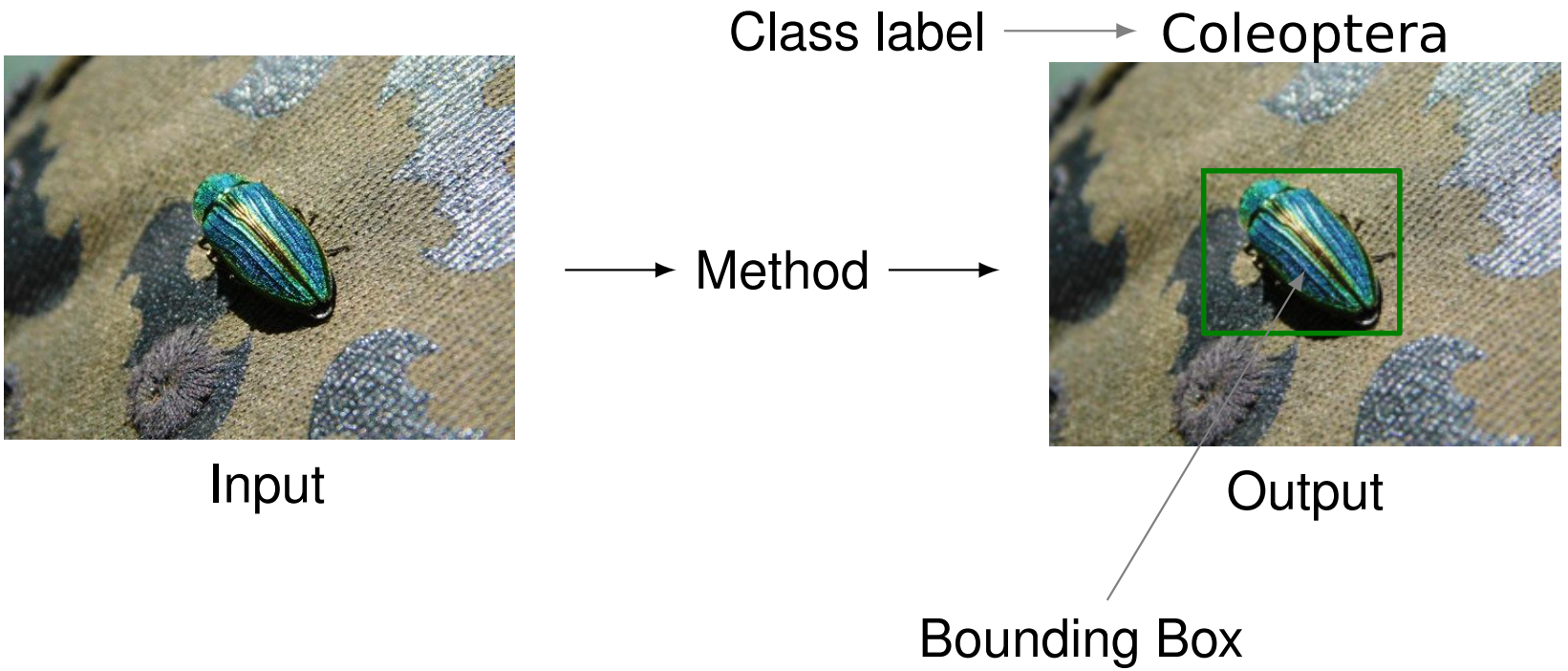
→ Method →

Coleoptera

Output

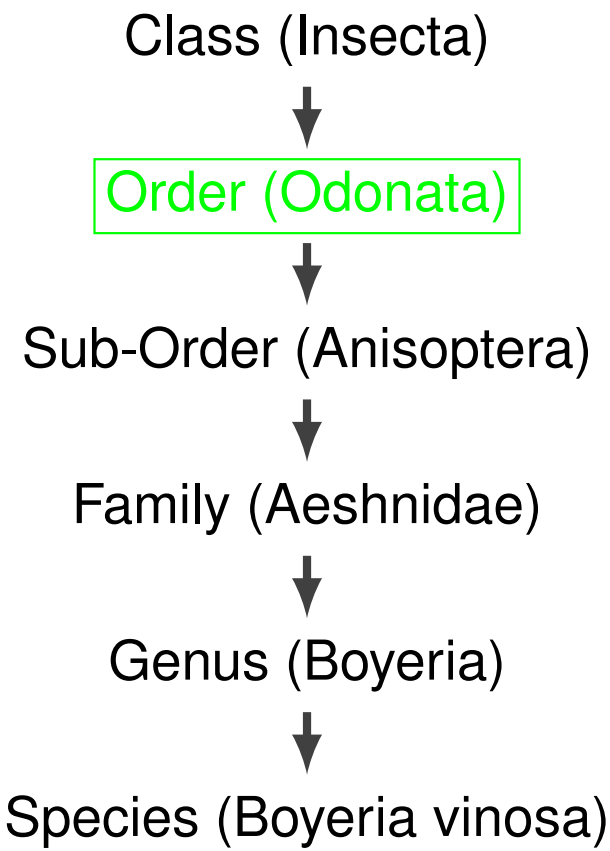
Problem description

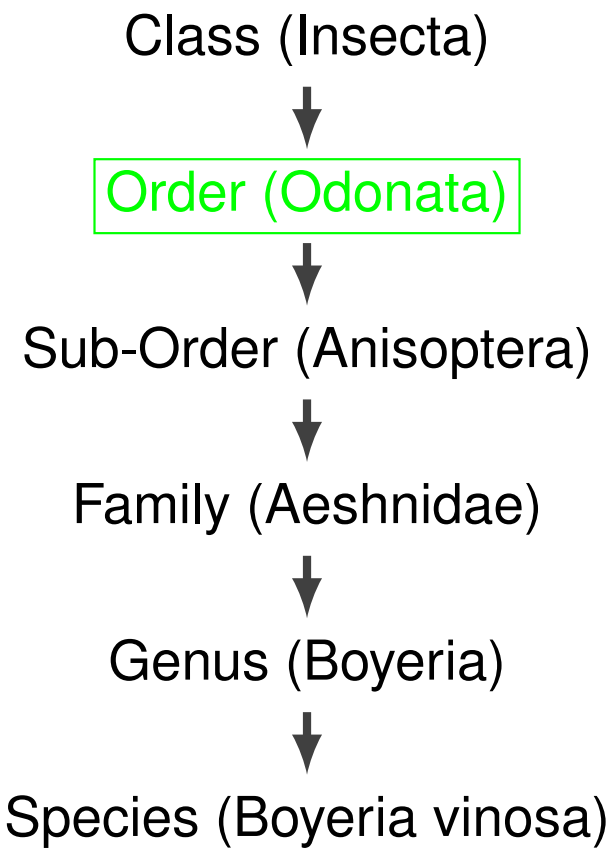
Localization and classification of insects in images.



Part II

Available data sets

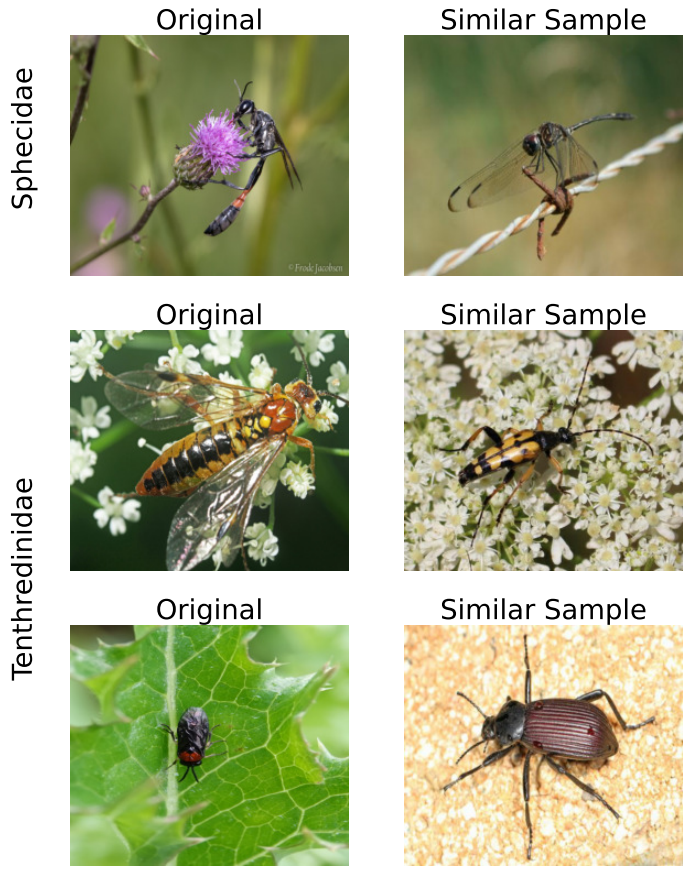

Class (Insecta)
Order (Odonata)
Sub-Order (Anisoptera)
Family (Aeshnidae)
Genus (Boyeria)
Species (Boyeria vinosa)



Here used orders:

- Coleoptera (Beetles)
- Lepidoptera (Butterflies)
- Hemiptera (True bugs)
- Hymenoptera
- Odonata (Dragon flies)

Samples for optical Cross-Order similarity



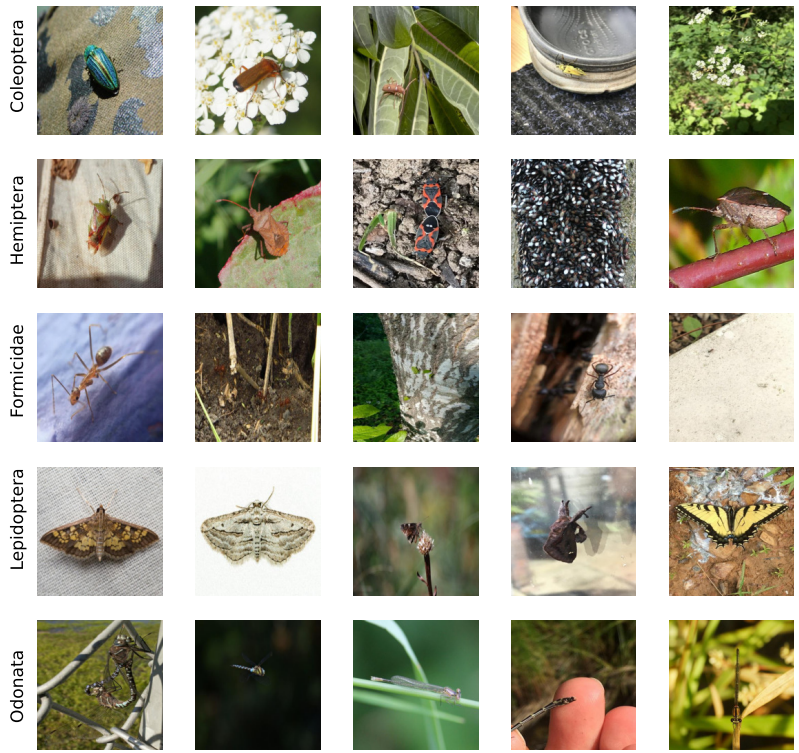
Here used orders:

- Coleoptera (Beetles)
- Lepidoptera (Butterflies)
- Hemiptera (True bugs)
- ~~Hymenoptera~~ Formicidae (Ants)
- Odonata (Dragon flies)

iNaturalist

- original iNaturalist (iNat) data set contains all sorts of organisms
- subset iNat data set
- JPEG image files
- ≈600.000 insect images

Representation of reduced *iNat* data set



Classification

Regression

Classification

- Labels given by data set
- No further data generation required

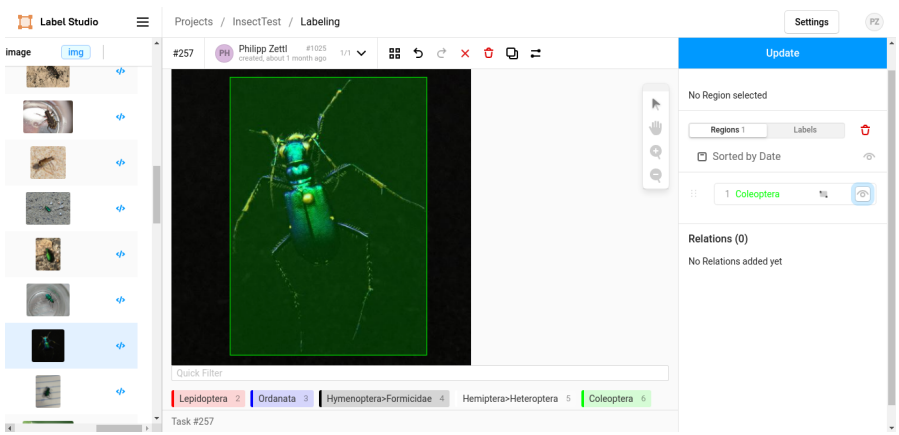
Regression

Classification

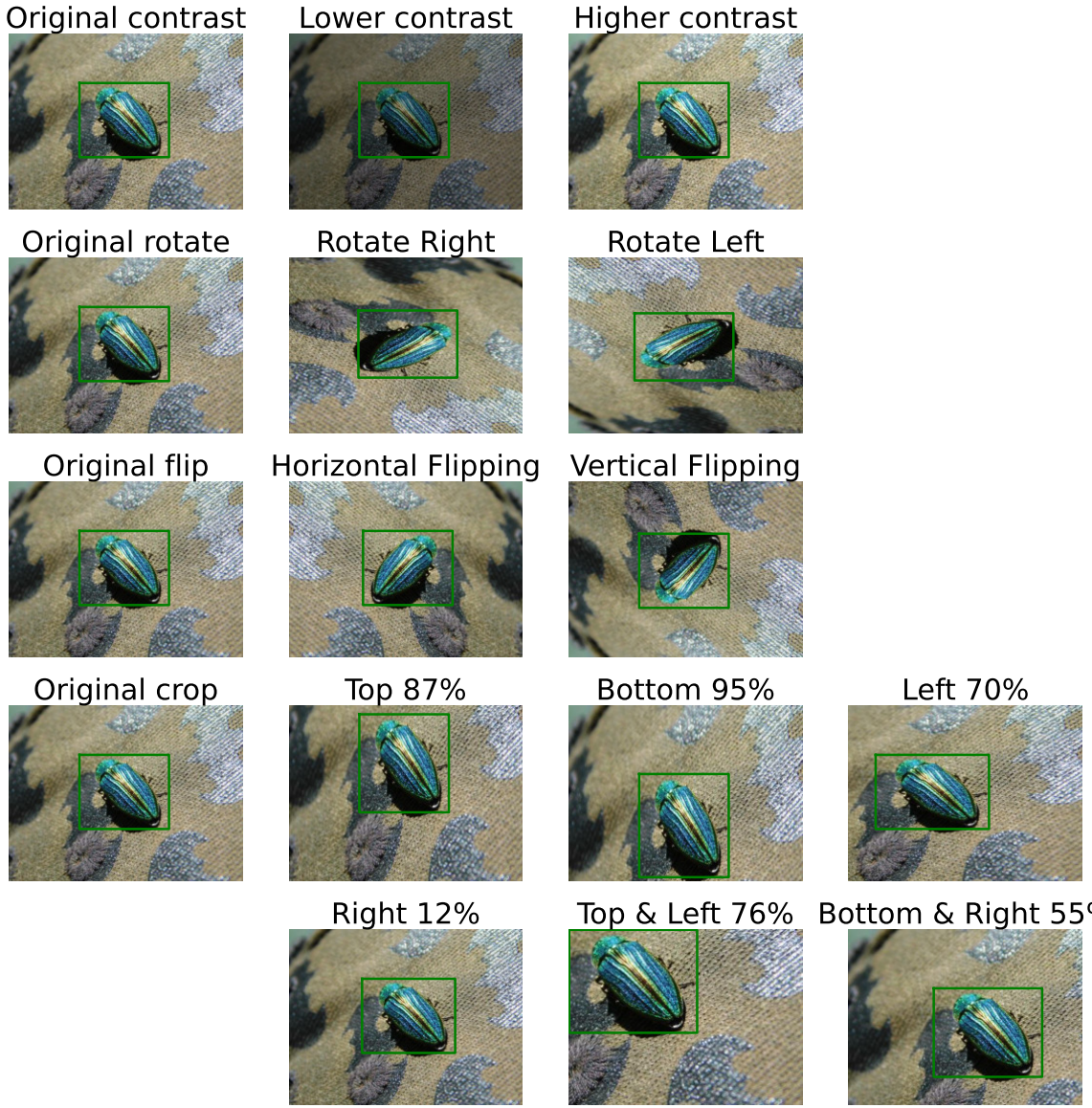
- Labels given by data set
- No further data generation required

Regression

- No labels available
- Manual generation required



Augmentation



Applied augmentation techniques visualized on one sample.

Part III

Machine Learning Methods

- Conventional Methods
  -
  -
- Artificial Neural Networks
  -
  -

- Conventional Methods
  - Linear/Ridge Regression
  - **S**upport **V**ector **M**achines (SVMs)
- Artificial Neural Networks
  -
  -

- Conventional Methods
  - Linear/Ridge Regression
  - SVMs
- Artificial Neural Networks
  - Neural Networks
  - Convolutional Neural Networks

- Conventional Methods
  - Linear/Ridge Regression (Regression)
  - SVMs
- Artificial Neural Networks (Regression)
  - Neural Networks
  - Convolutional Neural Networks

- Conventional Methods
  - Linear/Ridge Regression (Regression)
  - SVMs (Classification)
- Artificial Neural Networks (Regression & Classification)
  - Neural Networks
  - Convolutional Neural Networks

Losses

Classification

- Cross-Entropy
- Categorical-Cross-Entropy

Regression

- Vector distances
  - Mean Average Error (MAE)
  - Mean Squared Error (MSE)
- Object oriented
  - Intersection over Union (IoU) loss
  - Generalized IoU loss

Performance Metrics

Classification

- F1
- Accuracy

Regression

- RMSE
- (G)IoU

Performance Metrics

Classification

- F1 ($\uparrow 1.0$)
- Accuracy ($\uparrow 1.0$)

Regression

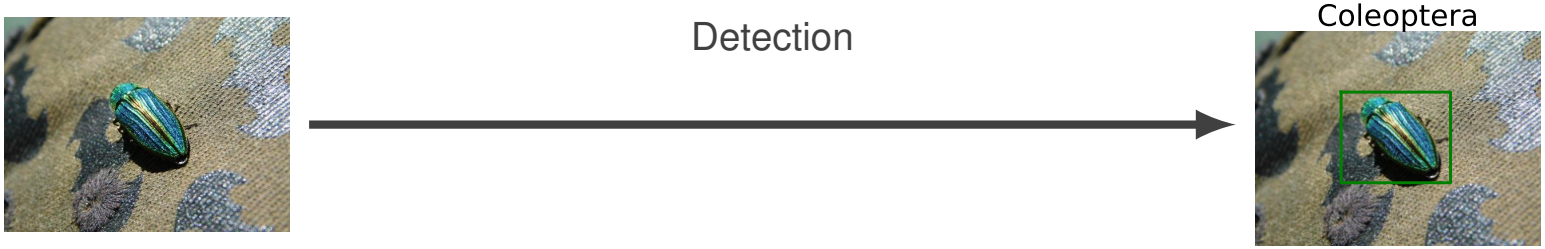
- RMSE ($\downarrow$)
- (G)IoU ($\uparrow 1.0$)

Desired outcome

2-Stage-Method

2-Stage-Method

Single-Stage-Method



Part IV

Application

Conventional Methods

SVMs

- Classification
- **O**ne **v**s. **R**est for 5 classes

Ridge Regression

- Bounding Box Regression
- OvR for 4 BBox coordinates

Input: Data transformed using `sklearn`'s [2] `PCA`, to reduce input features.

Artificial Neural Networks

Custom architectures

- Split into CNN-backbone and NN-head
- backbones: Custom CNN (INet), MobileNet, VGG-16
- heads: NNs with regularization, target of HPO

YOLOv5

- implementation of YOLO[3] in PyTorch (`https://github.com/ultralytics/yolov5` [4])
- predicts (multiple) BBs and class labels at once (single-stage-method)

Conventional methods:

- Ind.: Independently trained SMVs and RidgeReg models
- Seq.: Sequentially trained, first RidgeReg models then SVMs based on predictions from RidgeReg models

Conventional methods:

Method	**GIoU**(↑)	**RMSE**(↓)	**Accuracy**(↑)	**F1**(↑)
PCA_{100}				
Ind.	0.3481	21.2985	0.4806	0.4725
Seq.	0.3481	21.2985	0.2840	0.2685
PCA_{400}				
Ind.	0.3525	20.9326	0.5339	0.5200
Seq.	0.3525	20.9326	0.3040	0.2704

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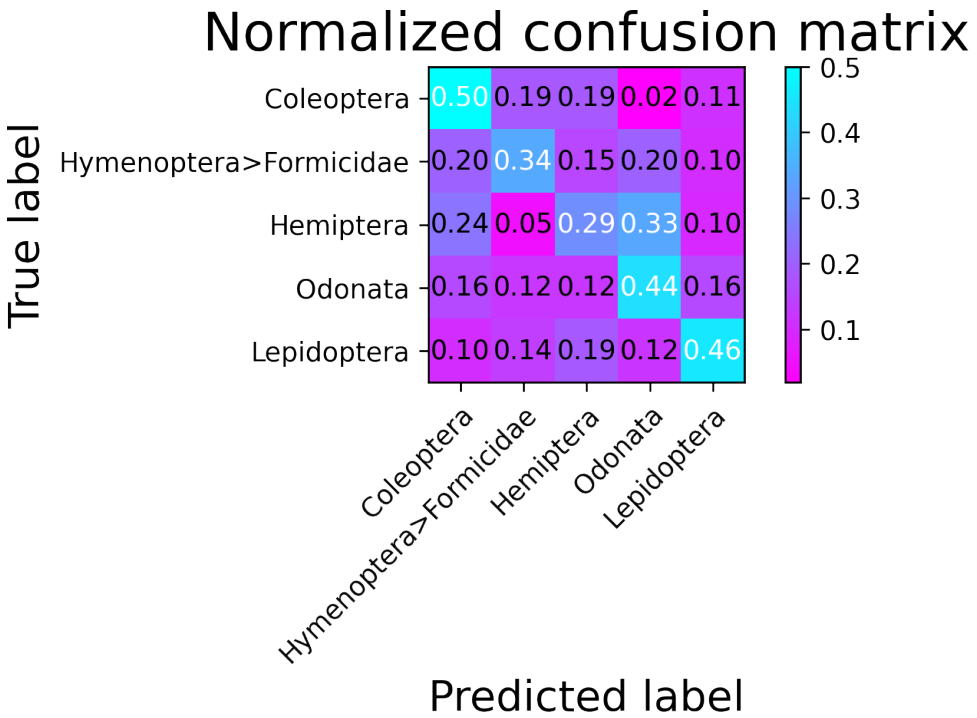
PCA_{400}				
Ind.	0.3525	20.9326	0.5339	0.5200
Seq.	0.3525	20.9326	0.3040	0.2704

Conventional methods

Ind.using input transformed by PCA_{400}



Regression

Backbone	**Data set**	**GIoU**(↑)	**RMSE**(↓)
INet	Raw	0.3838	25.9176
MobileNet	Raw	0.3877	25.3727
VGG-16	Raw	0.0525	24.2184
INet	Augmented	0.3670	26.3442
MobileNet	**Augmented**	0.5602	17.0061
VGG-16	Augmented	−0.4000	40.7438

Regression

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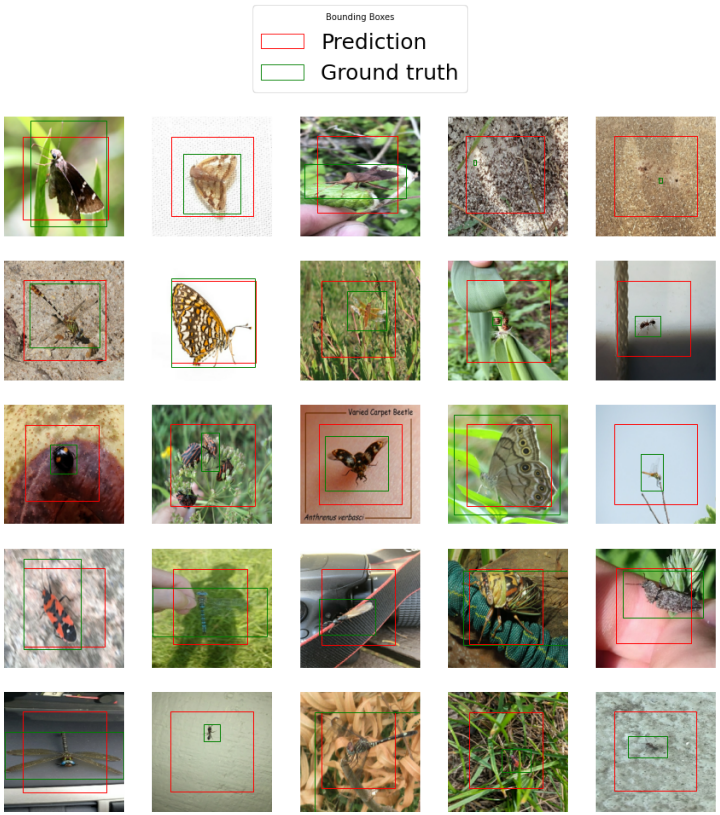
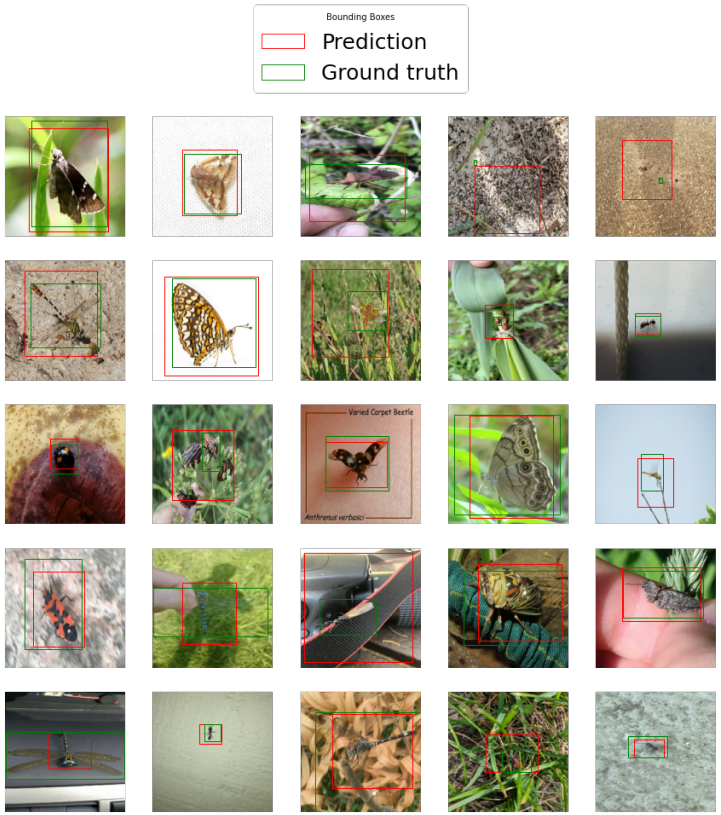
Regression
MobileNet

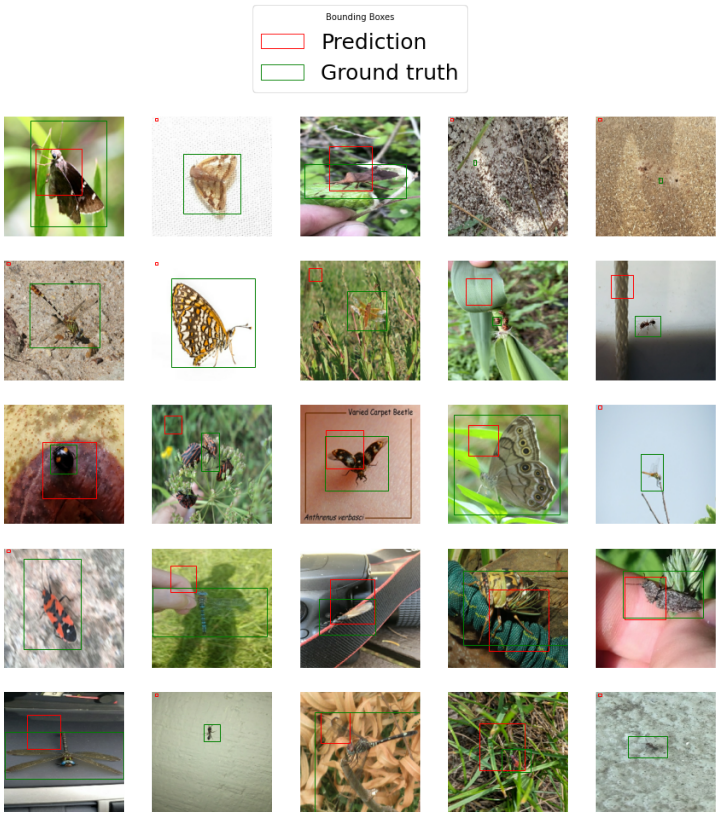


Trained using unaugmented data

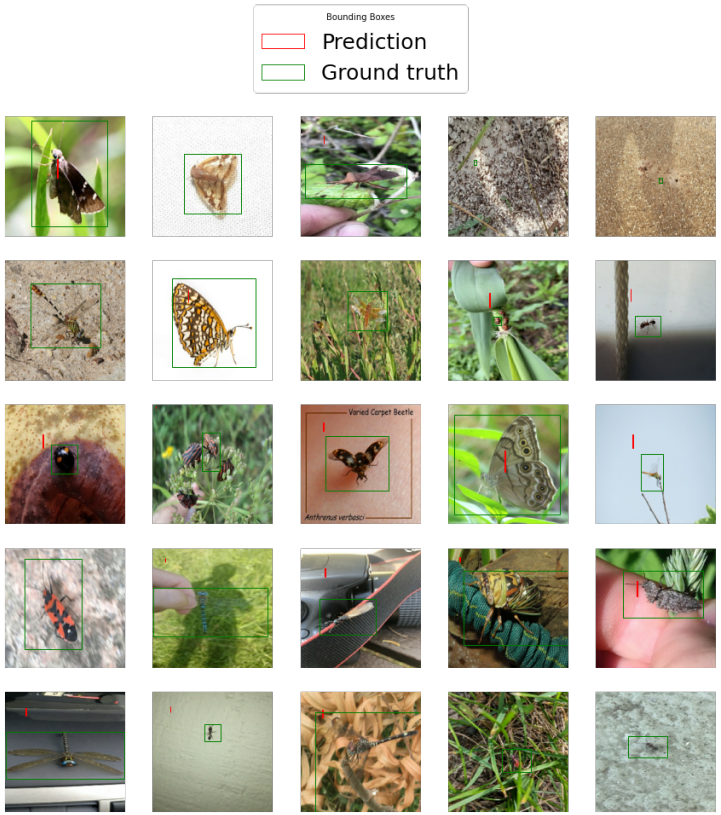


Trained using augmented data

Regression
VGG-16



Trained using unaugmented data



Trained using augmented data

Classification

Backbone	**Data set**	**Accuracy**(↑)	**F1**(↑)
INet	Raw	0.6422	0.7793
MobileNet	**Raw**	0.8511	0.8462
VGG-16	Raw	0.8467	0.8439
INet	Augmented	0.6422	0.7793
MobileNet	Augmented	0.8333	0.826
VGG-16	Augmented	0.8467	0.8439
MobileNet	Uncropped, Raw	0.7844	0.7793
MobileNet	Predicted, Raw	0.5289	0.5097

Classification

Backbone	**Data set**	**Accuracy**(↑)	**F1**(↑)
INet	Raw	0.6422	0.7793
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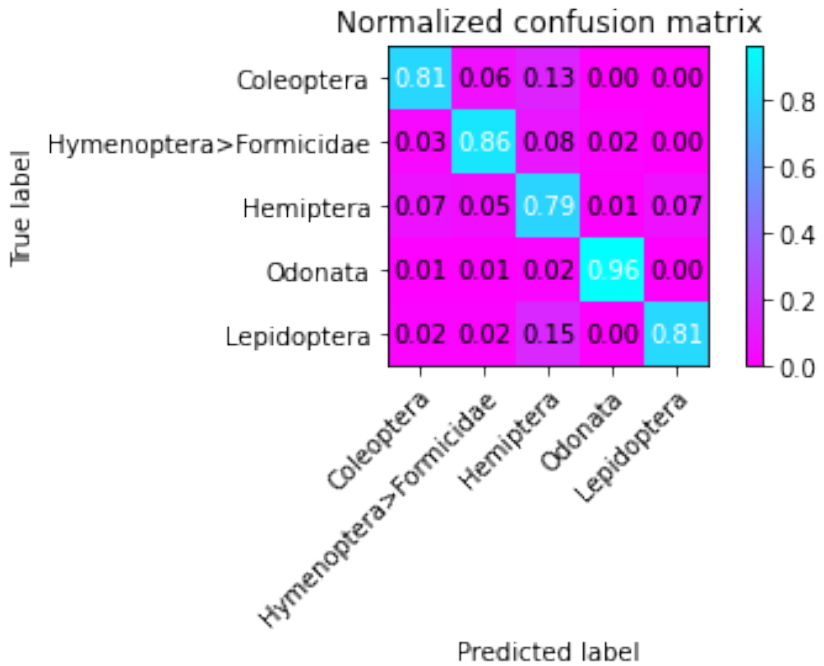
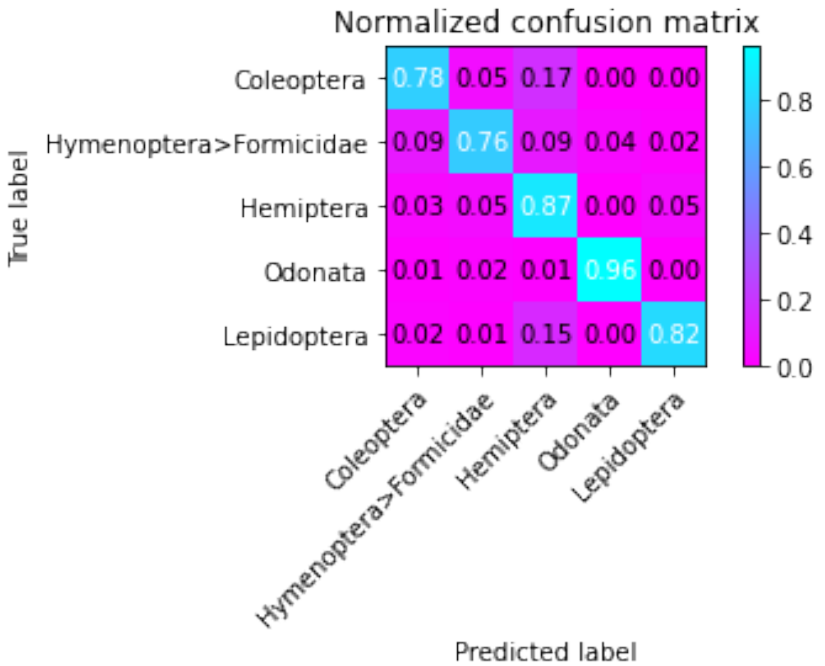
VGG-16	Augmented	0.8467	0.8439
MobileNet	Uncropped, Raw	0.7844	0.7793
MobileNet	Predicted, Raw	0.5289	0.5097

Classification
MobileNet



Trained using unaugmented data



Trained using augmented data

Two-Stage-Methods: Training results

- Sequential & Independent assembled of:
  - BB Regression: MobileNet trained on augmented data
  - Classification: MobileNet trained on unaugmented data
- Results of BB Regression are equal due to equal models

Two-Stage-Methods: Training results

Method	**GIoU**(↑)	**RMSE**(↓)	**Accuracy**(↑)	**F1**(↑)
Independent	0.5602	17.0061	0.8511	0.8462
Sequential	0.5602	17.0061	0.5666	0.5661

Two-Stage-Methods: Training results

Method	**GIoU**(↑)	**RMSE**(↓)	**Accuracy**(↑)	**F1**(↑)
Independent	0.5602	17.0061	0.8511	0.8462
Sequential	0.5602	17.0061	0.5666	0.5661

Single-Stage-Methods: Training results

Backbone	**Data set**	**GIoU**(↑)	**RMSE**(↓)	**Accuracy**(↑)	**F1**(↑)
INet	Raw	0.3566	24.2111	0.4844	0.4625
MobileNet	Raw	−0.4751	39.1935	0.7311	0.7793
VGG-16	Raw	−0.5731	39.1935	0.7311	0.7793
INet	Aug.	0.3042	24.2111	0.4844	0.4625
MobileNet	**Aug.**	0.3604	20.5186	0.7555	0.7496
VGG-16	Aug.	−0.4624	38.7296	0.7800	0.7779

Single-Stage-Methods: Training results

Backbone	**Data set**	**GIoU**(↑)	**RMSE**(↓)	**Accuracy**(↑)	**F1**(↑)
INet	Raw	0.3566	24.2111	0.4844	0.4625
MobileNet	Raw	−0.4751	39.1935	0.7311	0.7793
VGG-16	Raw	−0.5731	39.1935	0.7311	0.7793
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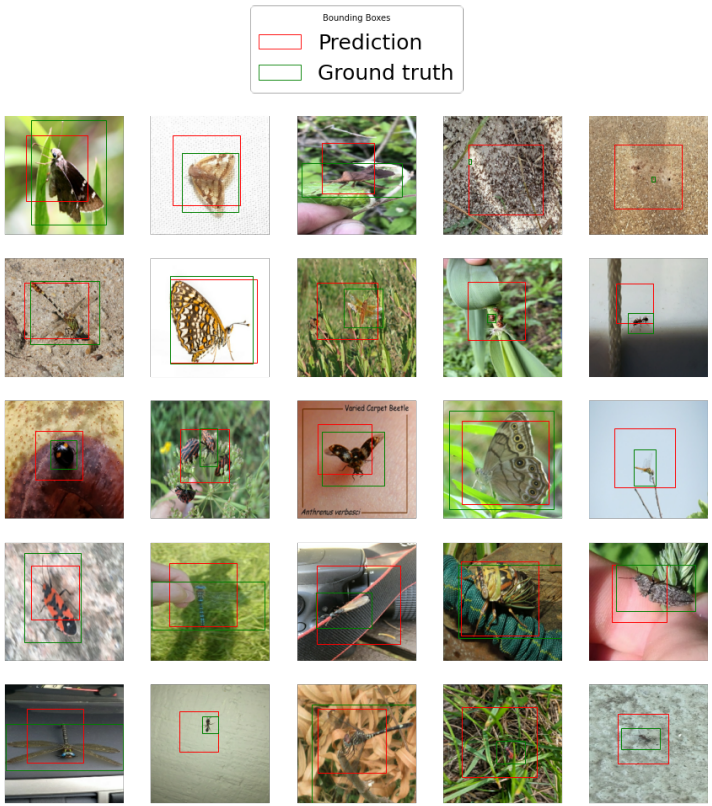
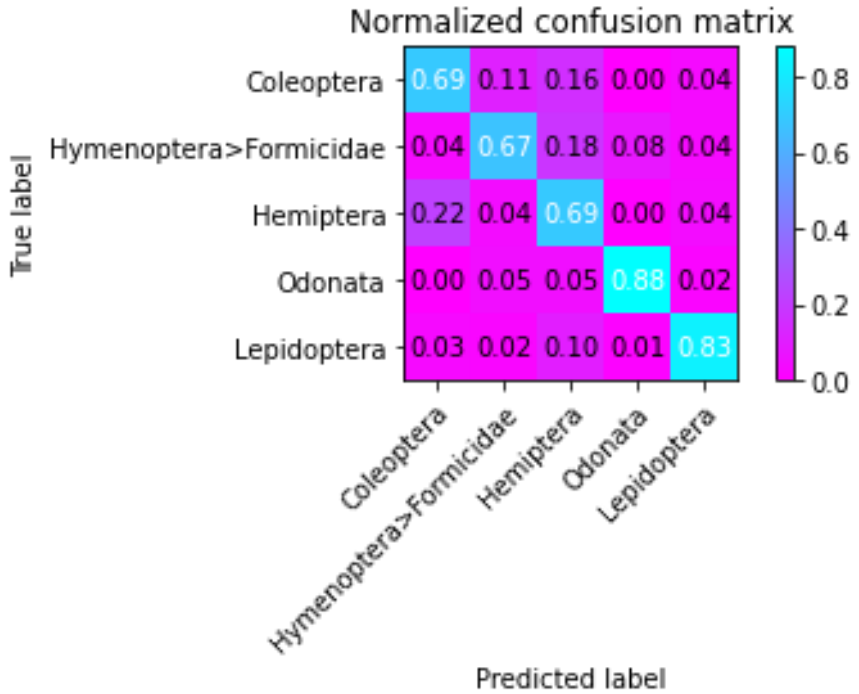
VGG-16	Aug.	−0.4624	38.7296	0.7800	0.7779

Unfortunately, it was not possible to generate metrics during training for YOLOv5

MobileNet

Trained using augmented data





Validation of trained models on test set

Method	**GIoU**(↑)	**RMSE**(↓)	**Accuracy**(↑)	**F1**(↑)	**Inf. time** [s]
Independent	0.56	17.35	0.92	0.92	0.60
Sequential	0.55	18.03	0.52	0.53	0.79
Single-Stage	0.37	19.67	0.92	0.92	0.22
YOLOv5	0.69	18.78	0.85	0.84	0.20

Validation of trained models on test set

Method	**GIoU**(↑)	**RMSE**(↓)	**Accuracy**(↑)	**F1**(↑)	**Inf. time** [s]
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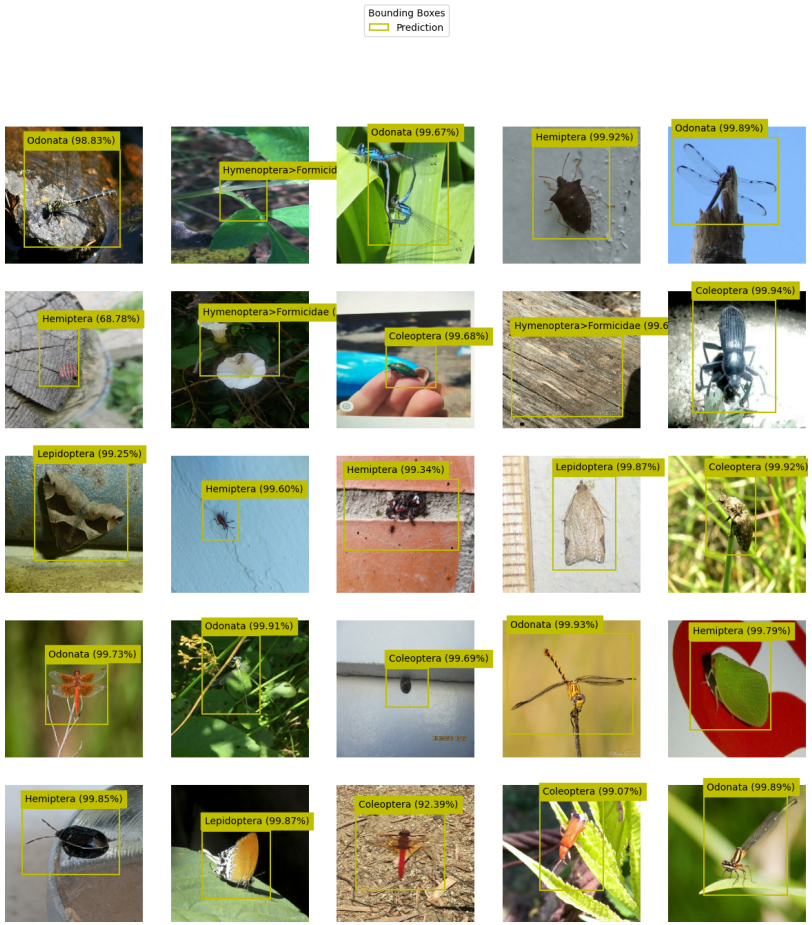
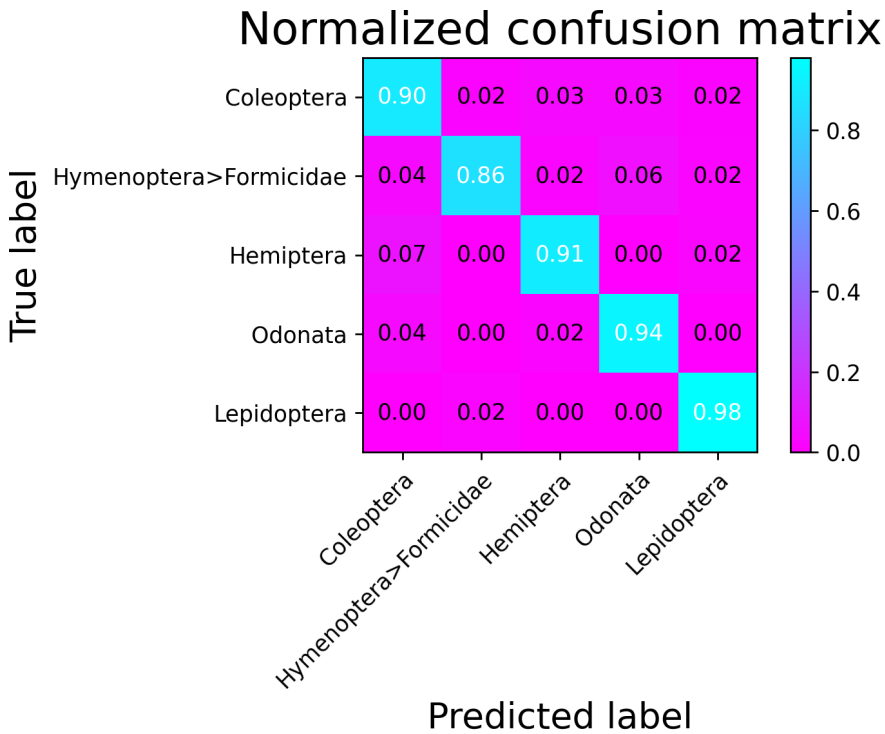
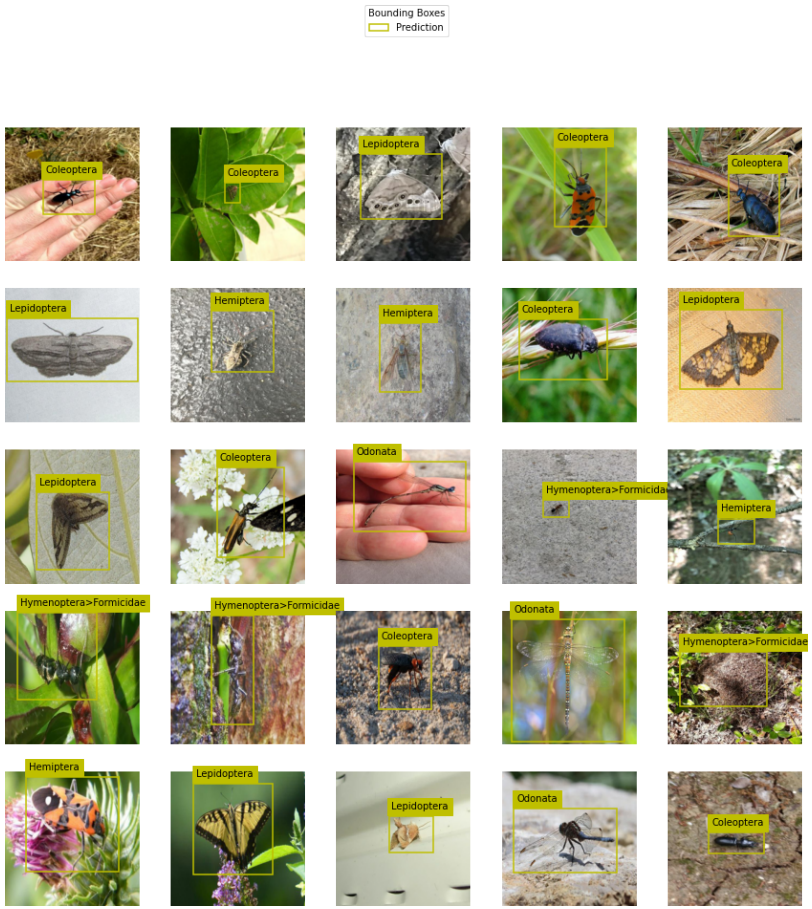
YOLOv5	0.69	18.78	0.85	0.84	0.20

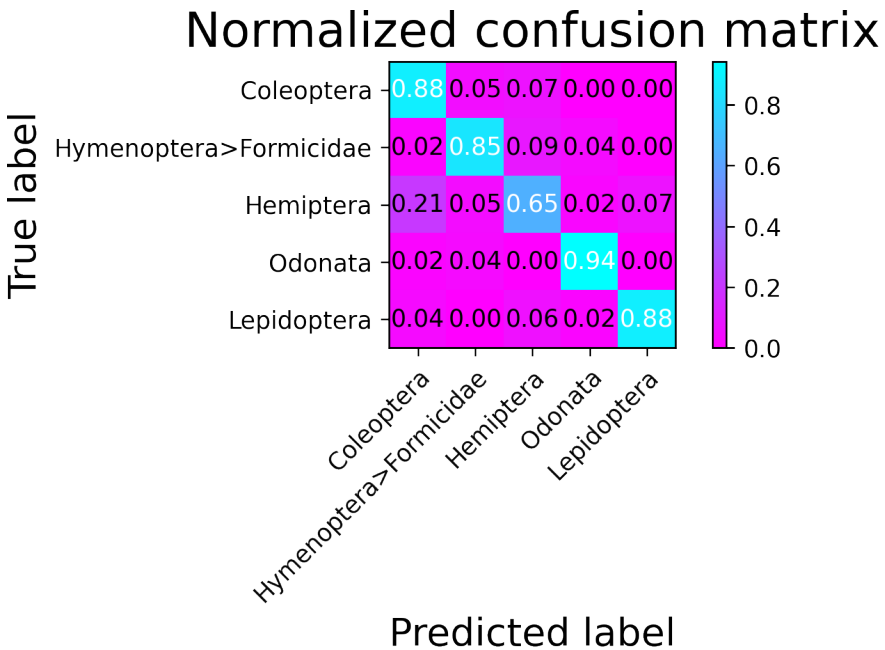
Independent





YOLOv5


Bounding Boxes
Prediction
Coleoptera
Coleoptera
Lepidoptera
Coleoptera
Coleoptera
Lepidoptera
Hemiptera
Hemiptera
Coleoptera
Lepidoptera
Lepidoptera
Coleoptera
Odonata
Hymenoptera>Formicidae
Hemiptera
Hymenoptera>Formicidae
Hymenoptera>Formicidae
Coleoptera
Odonata
Hymenoptera>Formicidae
Hemiptera
Lepidoptera
Lepidoptera
Odonata
Coleoptera


Normalized confusion matrix
True label
Coleoptera
Hymenoptera>Formicidae
Hemiptera
Odonata
Lepidoptera
0.88 0.05 0.07 0.00 0.00
0.02 0.85 0.09 0.04 0.00
0.21 0.05 0.65 0.02 0.07
0.02 0.04 0.00 0.94 0.00
0.04 0.00 0.06 0.02 0.88
0.8
0.6
0.4
0.2
0.0
Coleoptera
Hymenoptera>Formicidae
Hemiptera
Odonata
Lepidoptera
Predicted label

Model reduction

- MobileNet for classification: 14.2 MB $\rightarrow$ 13.7 MB using post training quantization
- MobileNet for regression: 40.6 MB $\rightarrow$ 13.3 MB using weight clustering
- Single-Stage model with MobileNet backbone: 42.2 MB $\rightarrow$ 13.9 MB using weight clustering

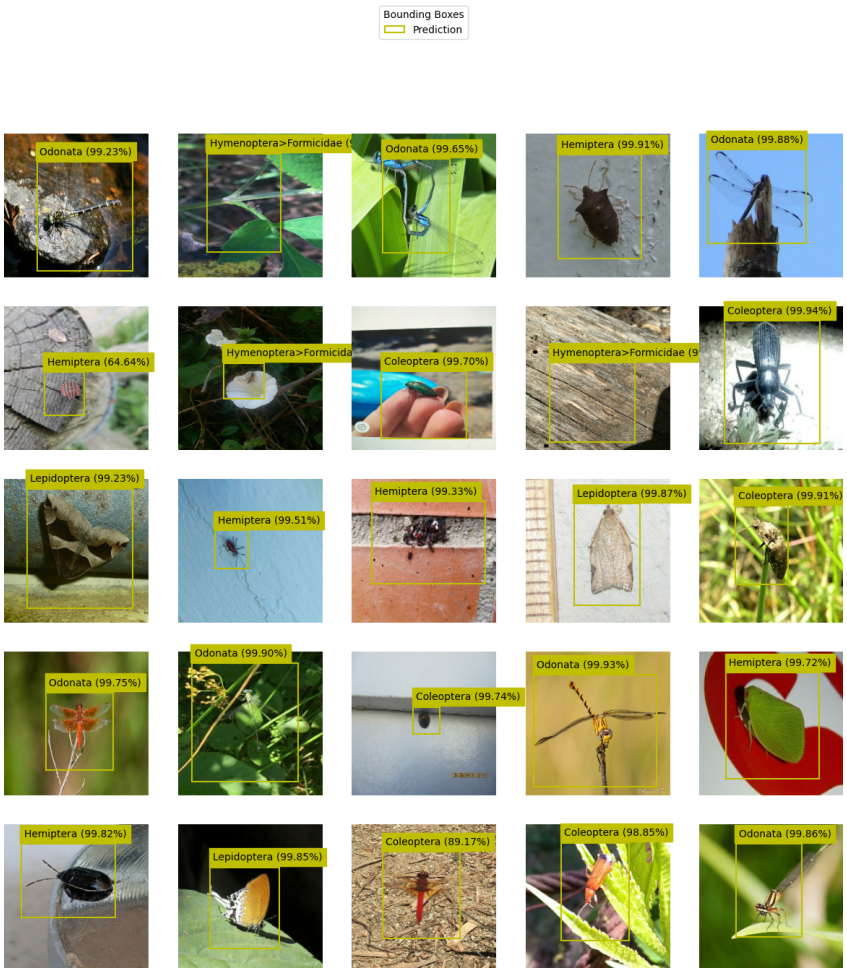
Final inference tests

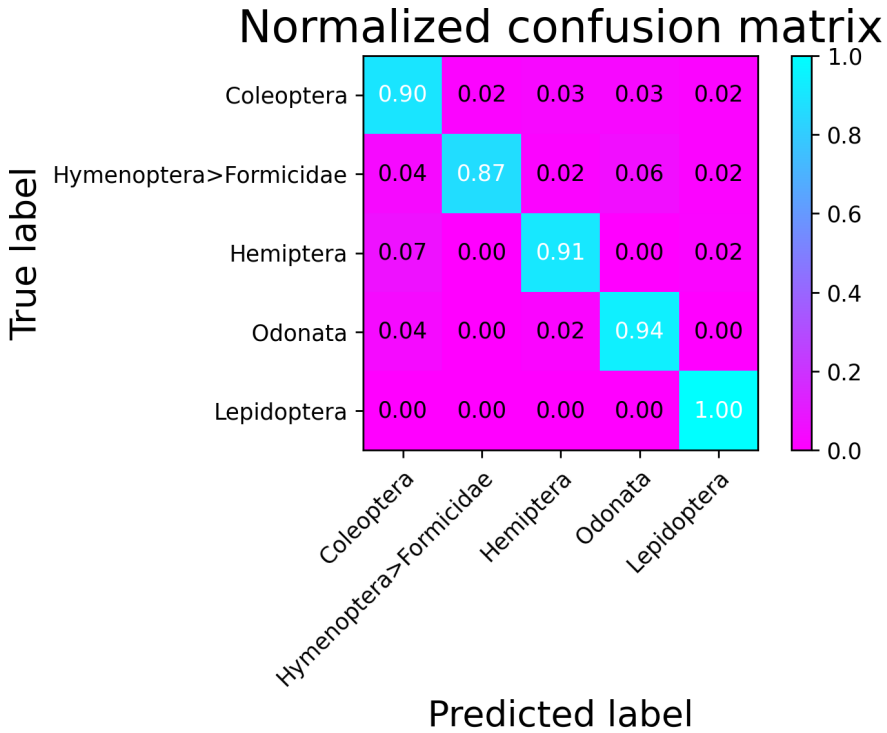
Method	**GIoU**(↑)	**RMSE**(↓)	**Accuracy**(↑)	**F1**(↑)	**Inf. time** [s]
Independent	0.5540	18.0264	0.9200	0.9210	1.3140
Sequential	0.5540	18.0262	0.5200	0.5285	2.2799
Single-Stage	0.1833	21.7866	0.6080	0.5804	0.7272
YOLOv5	0.6847	22.7424	0.8200	0.8091	2.0840

Final inference tests

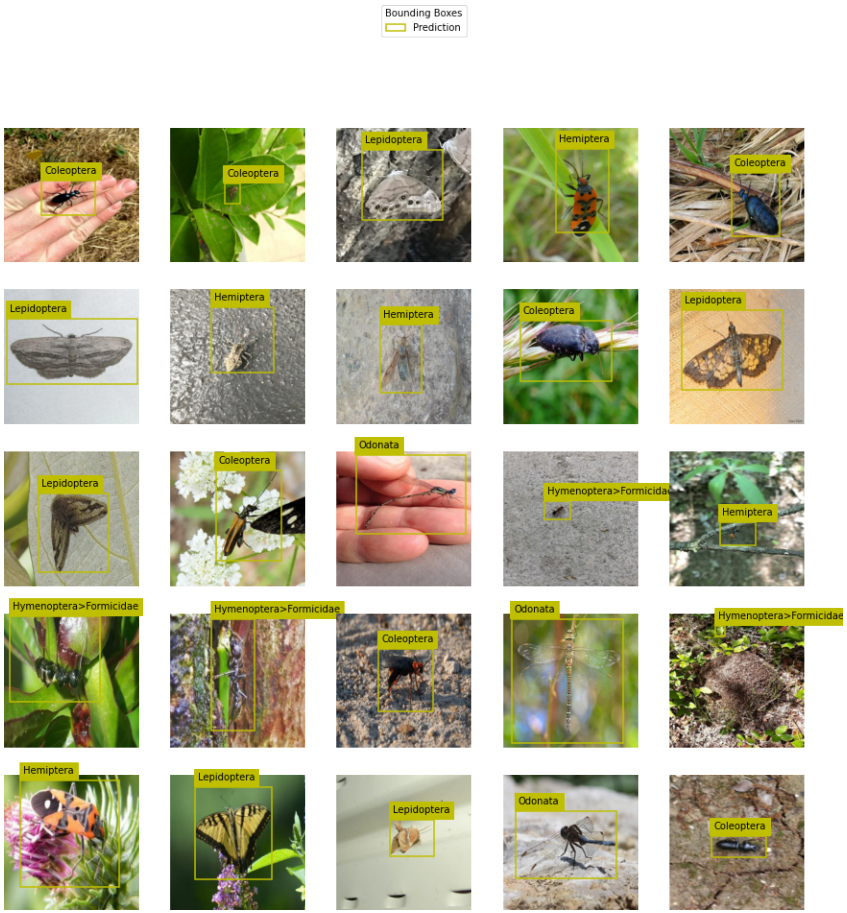
Method	**GIoU**(↑)	**RMSE**(↓)	**Accuracy**(↑)	**F1**(↑)	**Inf. time** [s]
Independent	0.5540	18.0264	0.9200	0.9210	1.3140
Sequential	0.5540	18.0262	0.5200	0.5285	2.2799
Single-Stage	0.1833	21.7866	0.6080	0.5804	0.7272
YOLOv5	0.6847	22.7424	0.8200	0.8091	2.0840

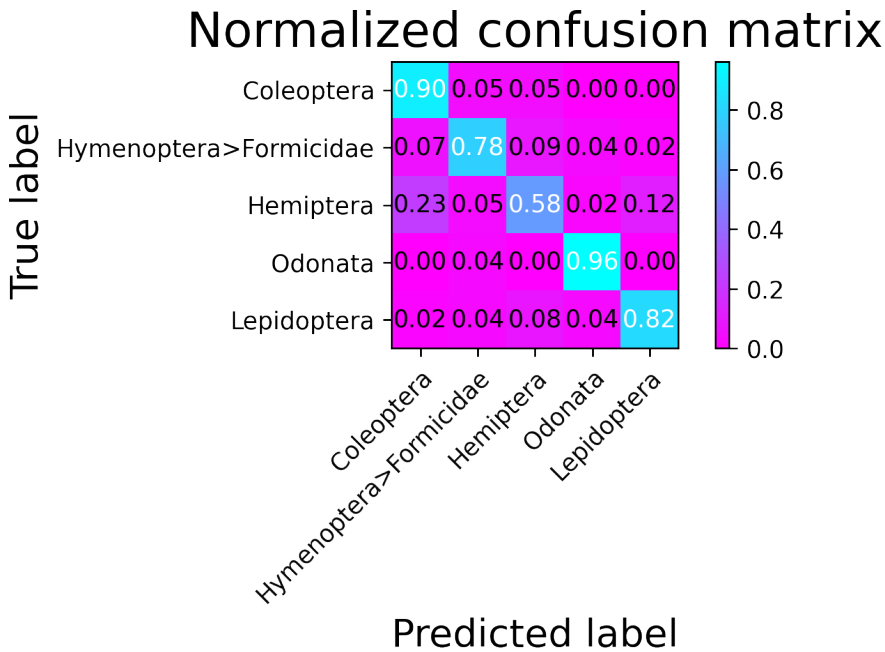
Independent





YOLOv5


Bounding Boxes
Prediction
Coleoptera
Coleoptera
Lepidoptera
Hemiptera
Coleoptera
Lepidoptera
Hemiptera
Hemiptera
Coleoptera
Lepidoptera
Lepidoptera
Coleoptera
Odonata
Hymenoptera>Formicidae
Hemiptera
Hymenoptera>Formicidae
Hymenoptera>Formicidae
Coleoptera
Odonata
Hymenoptera>Formicidae
Hemiptera
Lepidoptera
Lepidoptera
Odonata
Coleoptera


Normalized confusion matrix
True label
Coleoptera
Hymenoptera>Formicidae
Hemiptera
Odonata
Lepidoptera
0.90 0.05 0.05 0.00 0.00
0.07 0.78 0.09 0.04 0.02
0.23 0.05 0.58 0.02 0.12
0.00 0.04 0.00 0.96 0.00
0.02 0.04 0.08 0.04 0.82
0.8
0.6
0.4
0.2
0.0
Coleoptera
Hymenoptera>Formicidae
Hemiptera
Odonata
Lepidoptera
Predicted label

Part V

Conclusion

Conclusion

- INet and VGG-16 perform mediocre on all tasks
- using MobileNet generates good starting results
- YOLOv5 works out of the box better than regular CNN architectures

Final slide

A short presentation of manual labelling of 2.500 image files.
`https://youtu.be/twjyfQ7sXk4?t=43`

Tasks

- General supervised learning task

$$T : \mathbb{R}^N \mapsto \mathbb{R}^K, \boldsymbol{x}^{(m)} \mapsto \hat{\boldsymbol{y}}^{(m)}$$

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$$T : \mathbb{R}^N \mapsto \mathbb{R}^K, \boldsymbol{x}^{(m)} \mapsto \hat{\boldsymbol{y}}^{(m)}$$

- Bounding Box Regression:

$$T_r : \mathbb{R}^N \mapsto \mathbb{R}^4, \boldsymbol{x}^{(m)} \mapsto \hat{\boldsymbol{c}}^{(m)}$$

Tasks

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- Bounding Box Regression:

$$T_r : \mathbb{R}^N \mapsto \mathbb{R}^4, \boldsymbol{x}^{(m)} \mapsto \hat{\boldsymbol{c}}^{(m)}$$

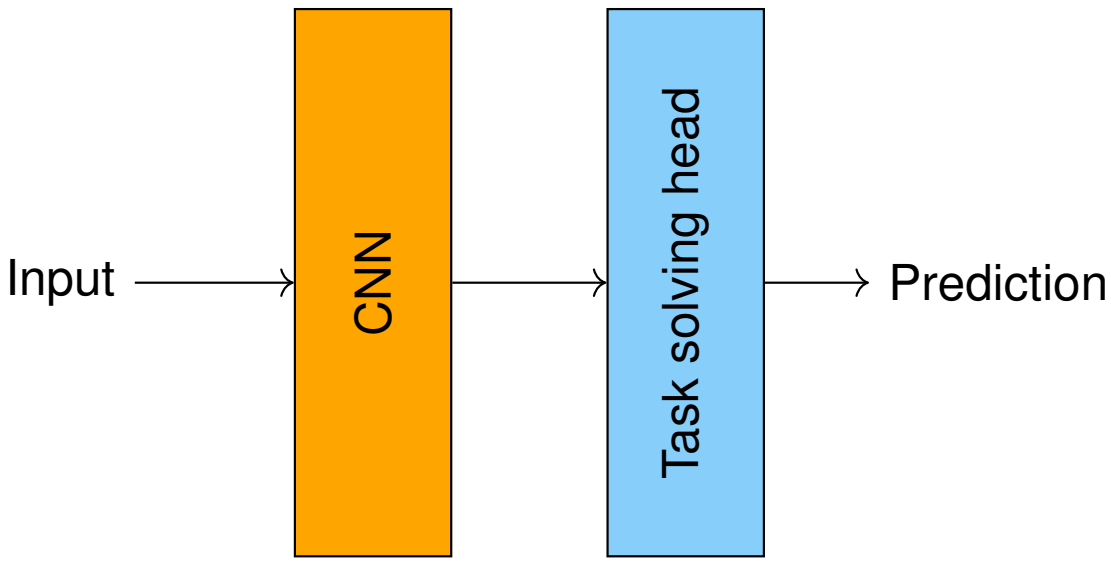
- Classification:

$$T_c : \mathbb{R}^N \mapsto [0,1]^5, \boldsymbol{x}^{(m)} \mapsto \hat{\boldsymbol{y}}^{(m)}$$

Artificial Neural Networks

CNN-Backbones

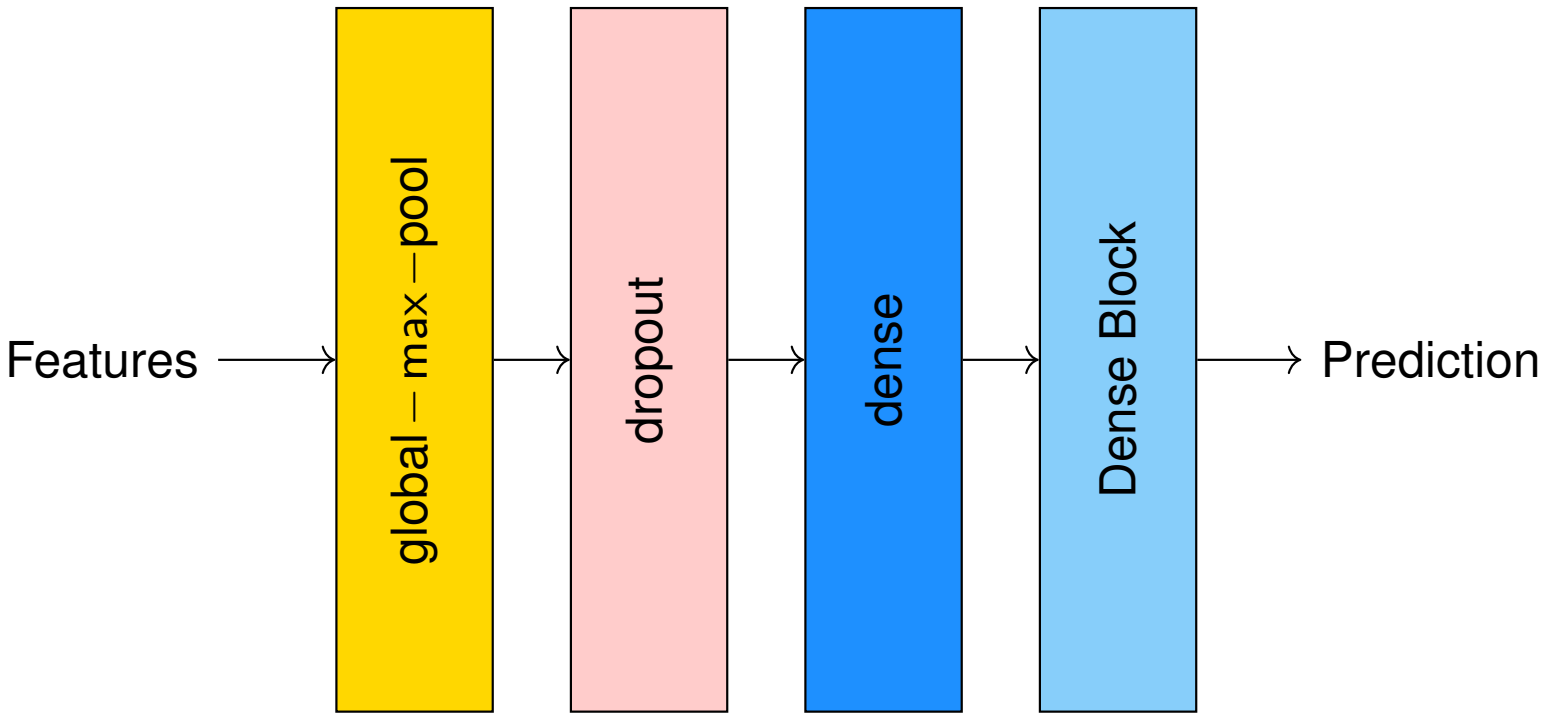
- Extract features from input
- Require additional ”Task solving head” to solve one or more tasks
- INet, MobileNet, VGG-16
- Input: normalized rescaled image data



Artificial Neural Networks

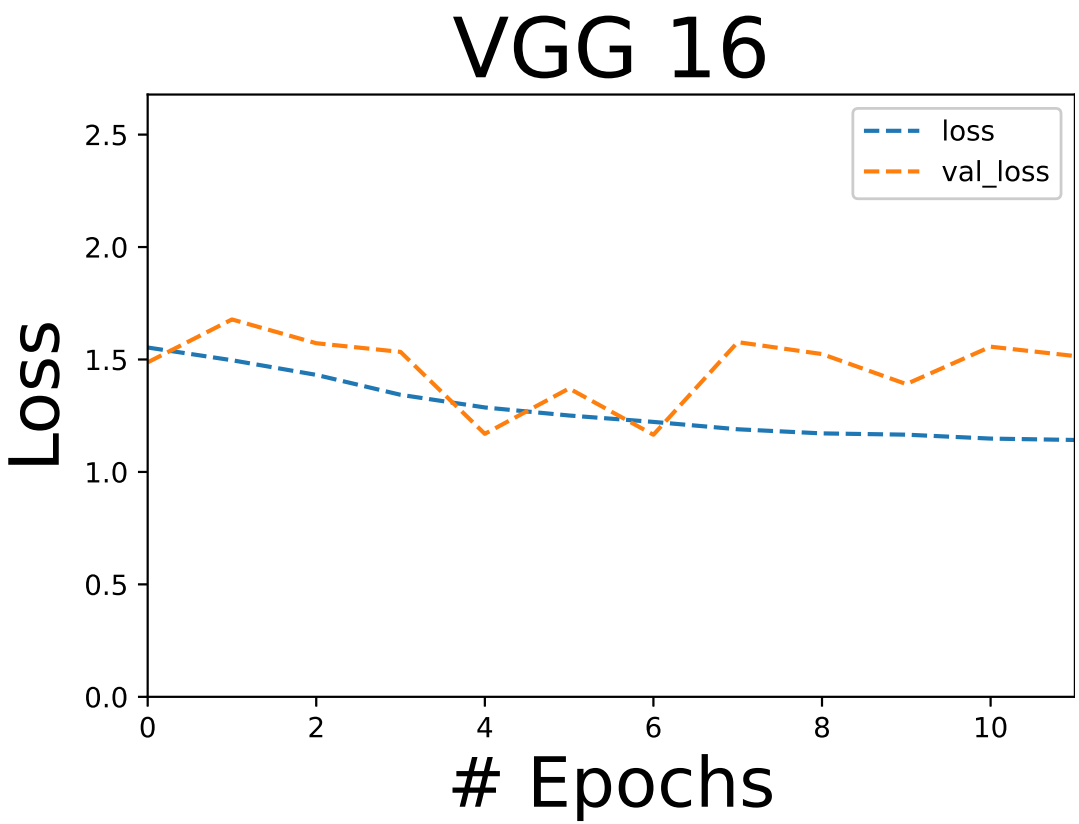
NN-Task solving heads

- can perform predictions for single task
- 4 elements: GlobalMaxPooling, Dropout, Dense, Dense-Block



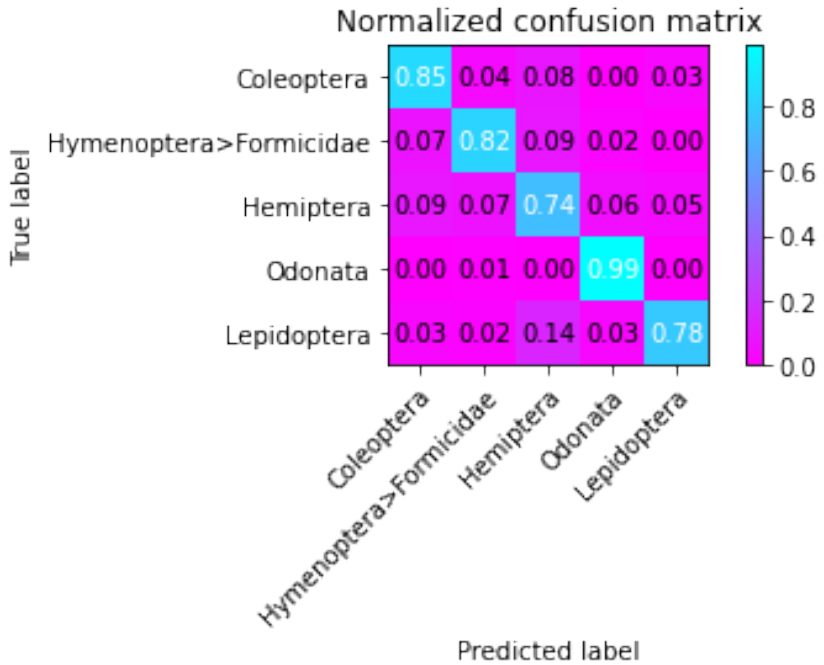
Regression

VGG-16 trained with augmented training data.

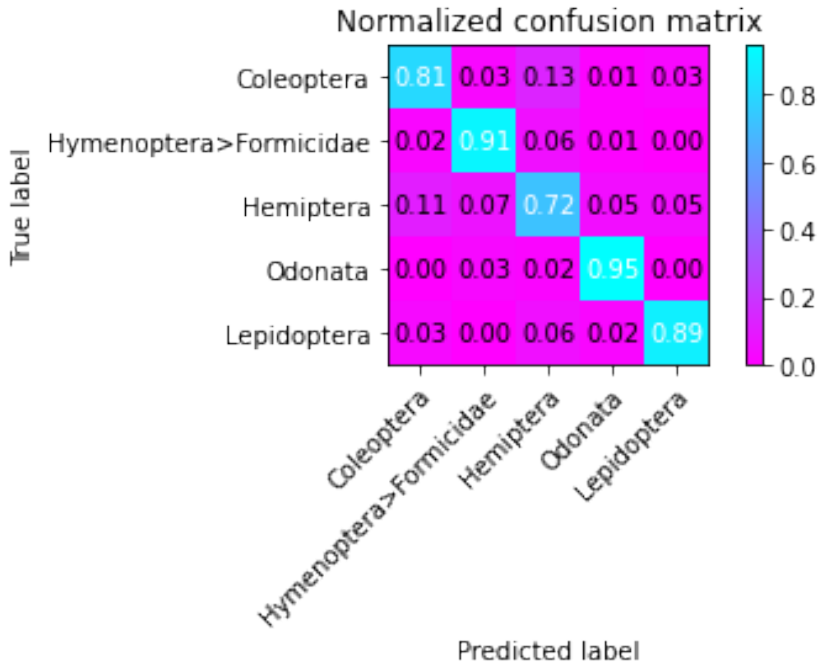


Classification

VGG-16



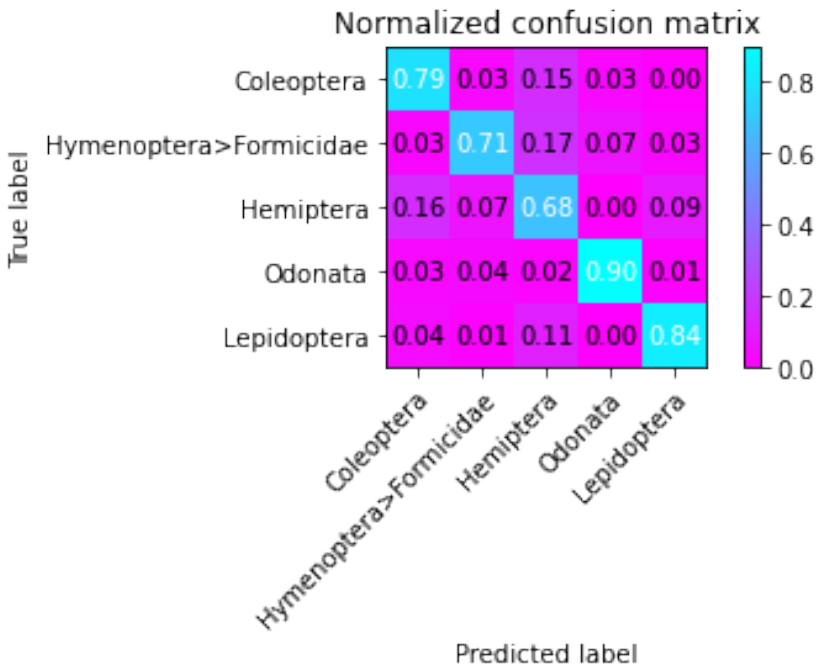
Trained using unaugmented data



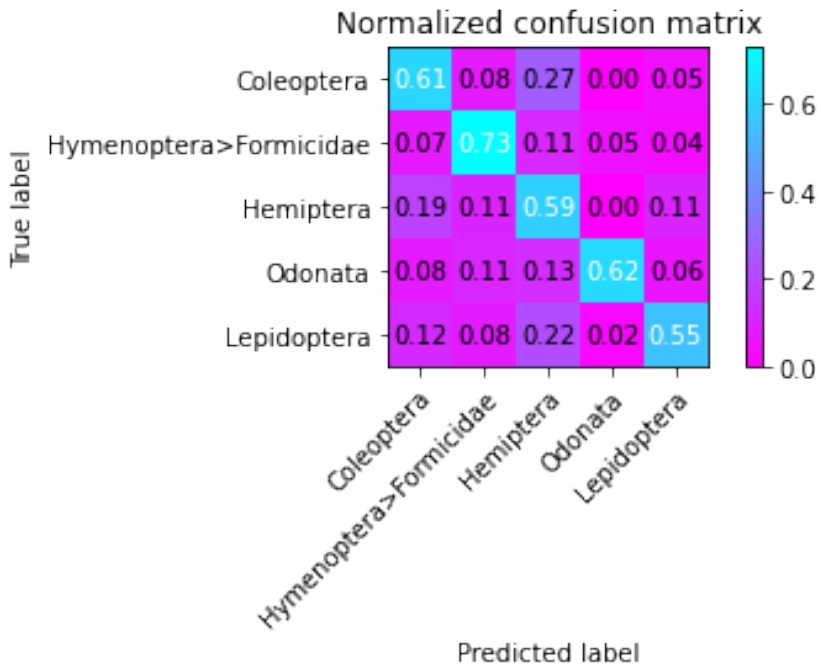
Trained using augmented data

Classification

MobileNet

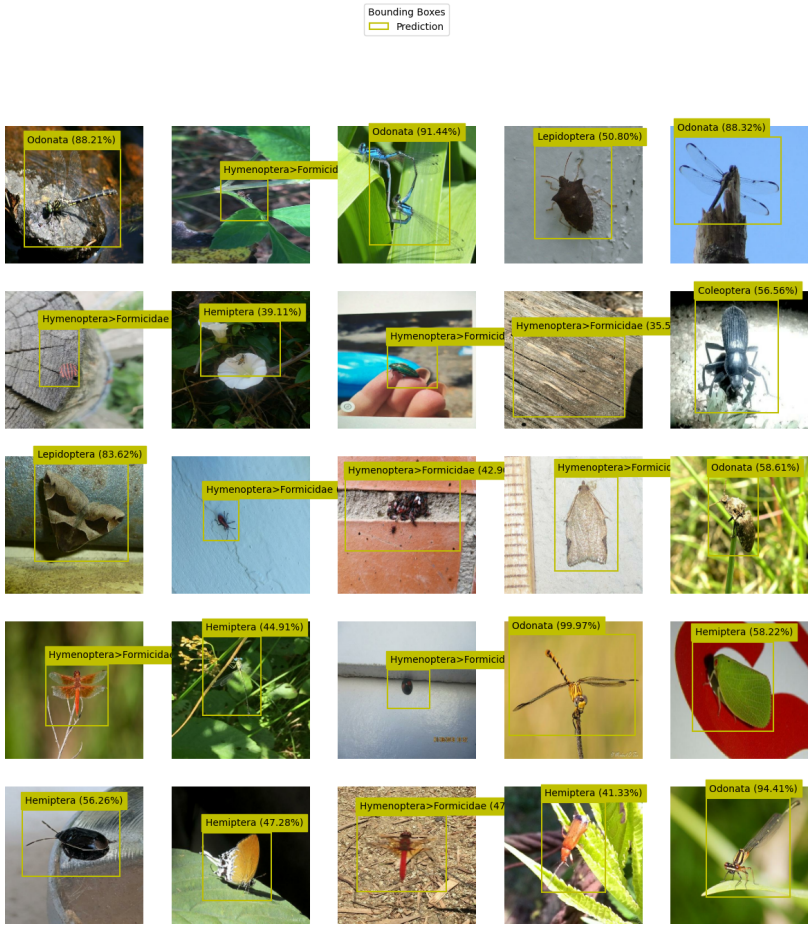


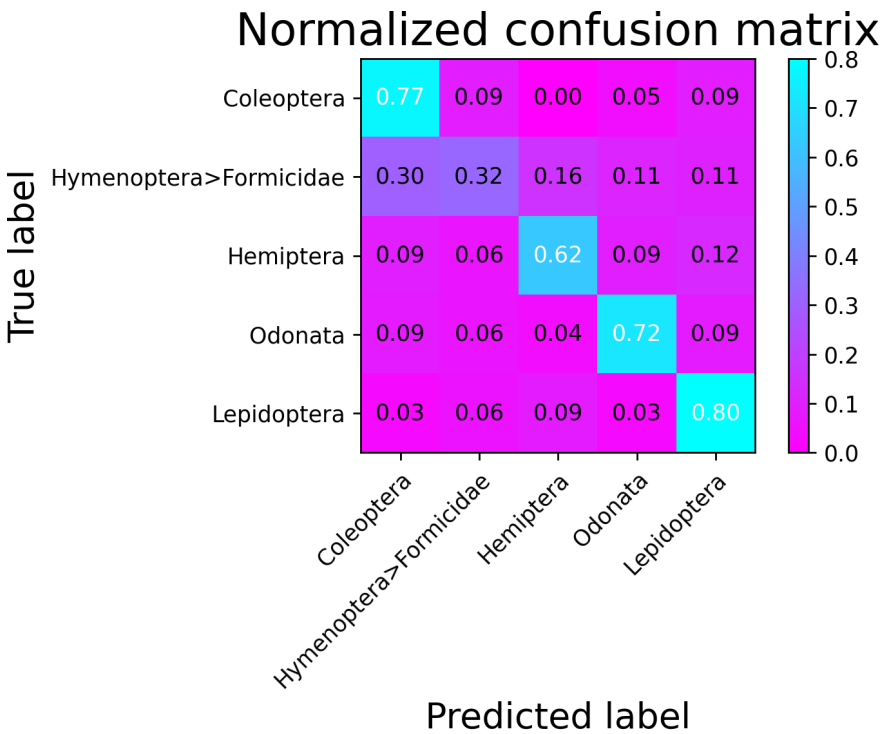
Trained using uncropped images



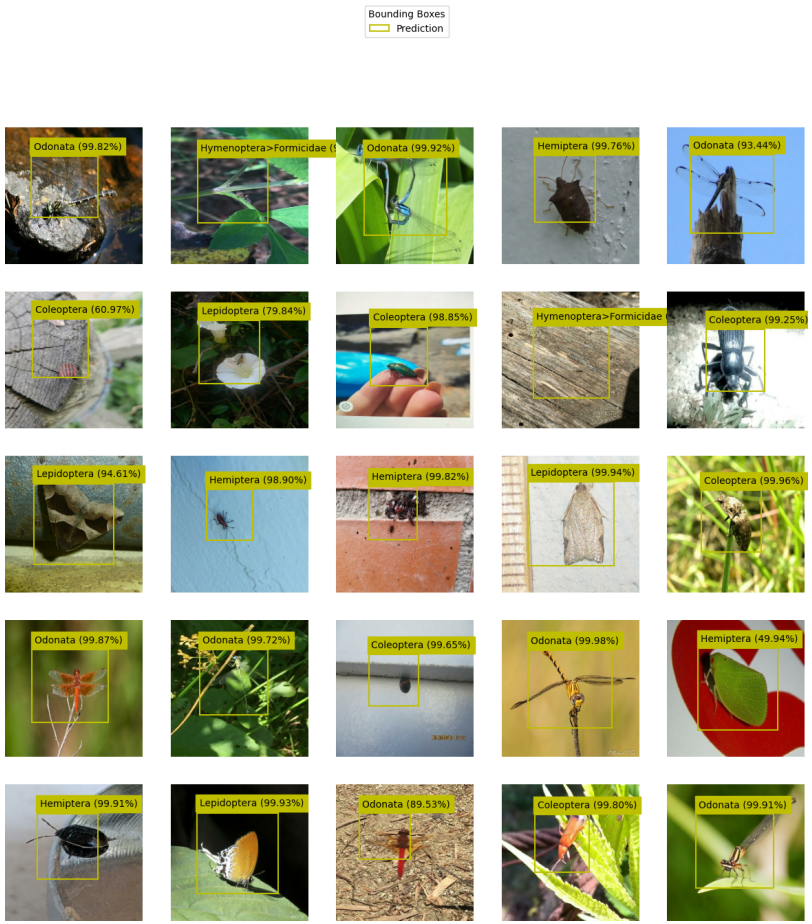
Trained using cropped images, based on BB predictions

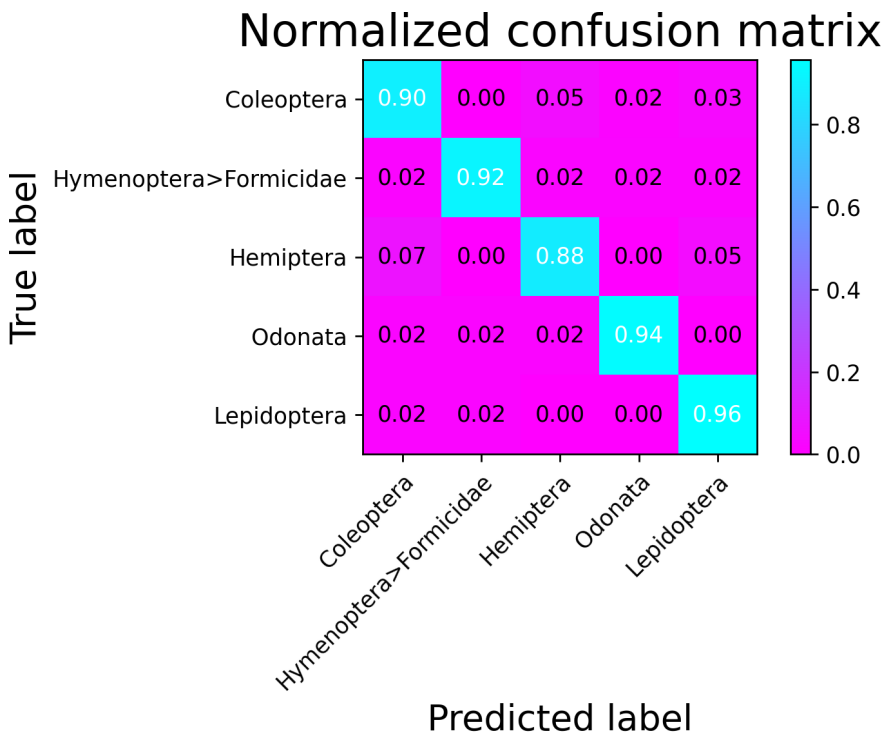
Sequential


Bounding Boxes
Prediction
Odonata (88.21%)
Hymenoptera>Formicid
Odonata (91.44%)
Lepidoptera (50.80%)
Odonata (88.32%)
Hymenoptera>Formicidae
Hemiptera (39.11%)
Hymenoptera>Formicid
Hymenoptera>Formicidae (35.5
Coleoptera (56.56%)
Lepidoptera (83.62%)
Hymenoptera>Formicidae
Hymenoptera>Formicidae (42.9
Hymenoptera>Formici
Odonata (58.61%)
Hymenoptera>Formicidae
Hemiptera (44.91%)
Hymenoptera>Formicid
Odonata (99.97%)
Hemiptera (58.22%)
Hemiptera (56.26%)
Hemiptera (47.28%)
Hymenoptera>Formicidae (47
Hemiptera (41.33%)
Odonata (94.41%)

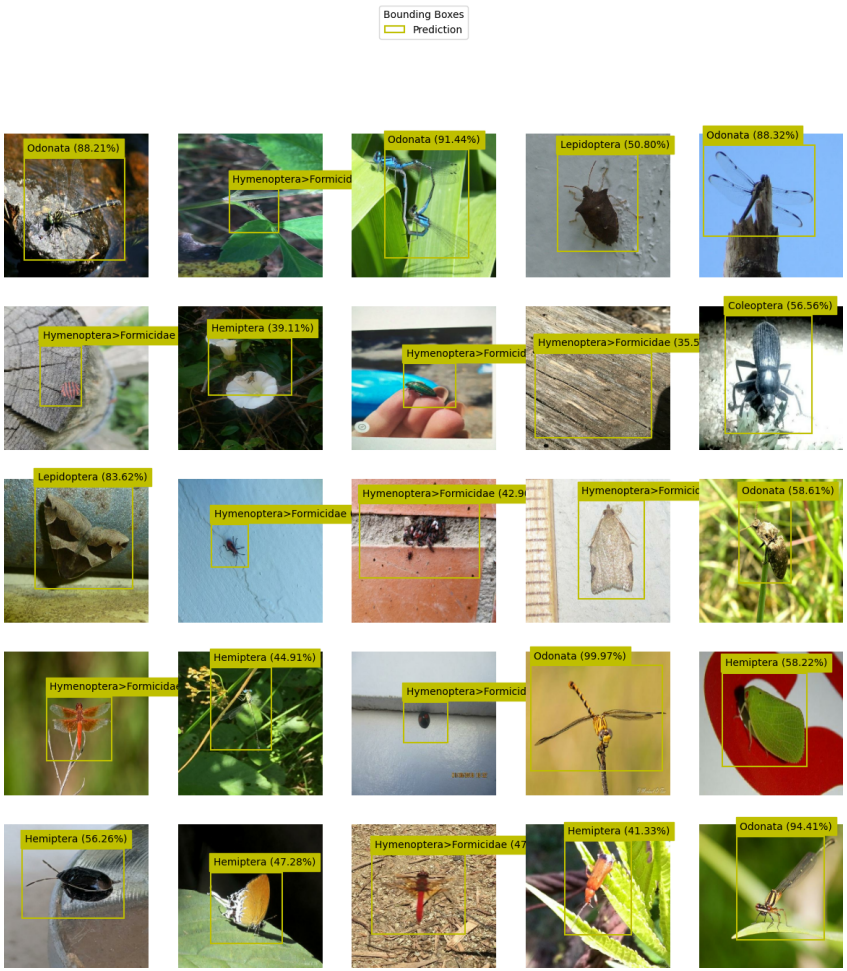

Normalized confusion matrix
True label
Coleoptera
Hymenoptera>Formicidae
Hemiptera
Odonata
Lepidoptera
0.77 0.09 0.00 0.05 0.09
0.30 0.32 0.16 0.11 0.11
0.09 0.06 0.62 0.09 0.12
0.09 0.06 0.04 0.72 0.09
0.03 0.06 0.09 0.03 0.80
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Predicted label

Single-Stage





Sequential


Bounding Boxes
Prediction
Odonata (88.21%)
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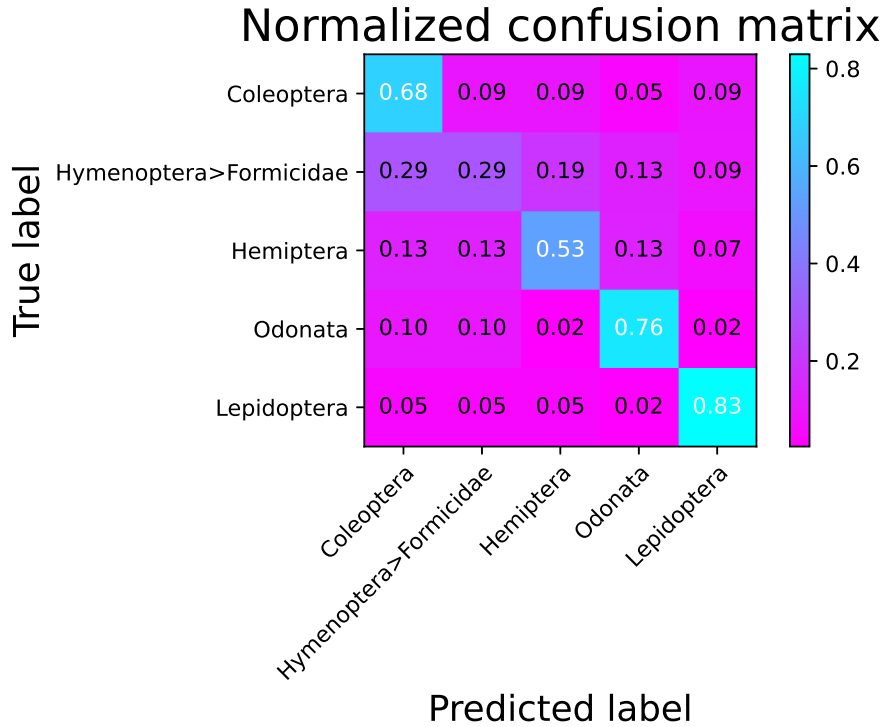
Normalized confusion matrix
True label
Coleoptera
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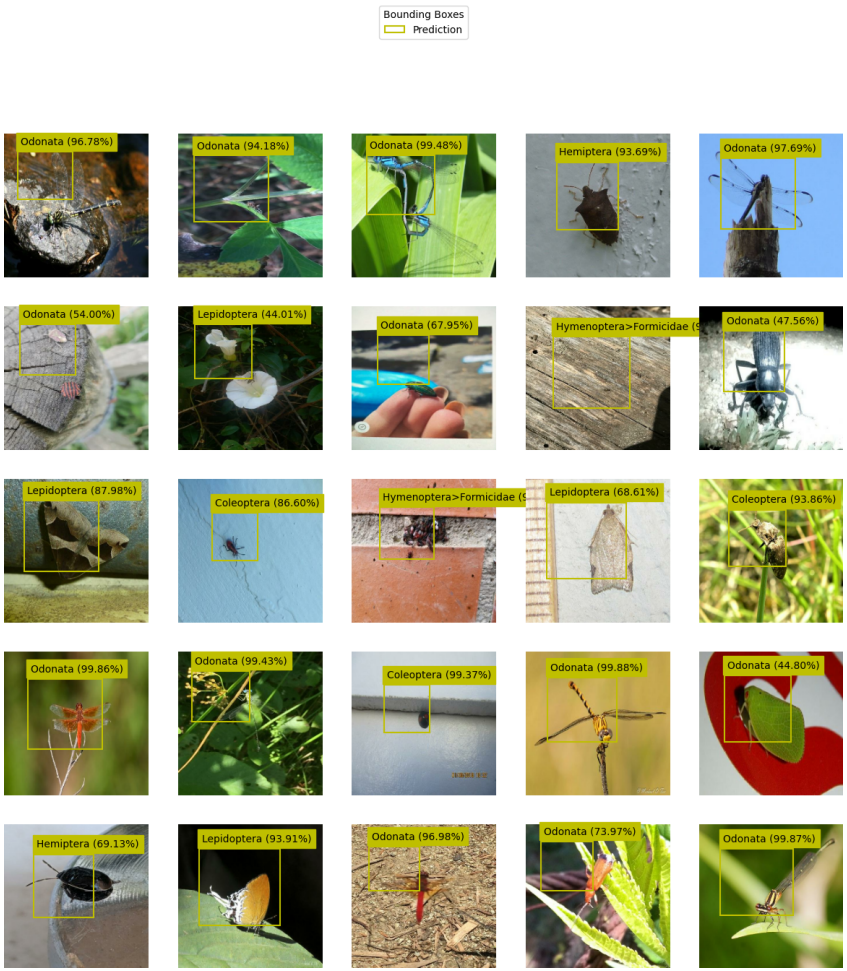
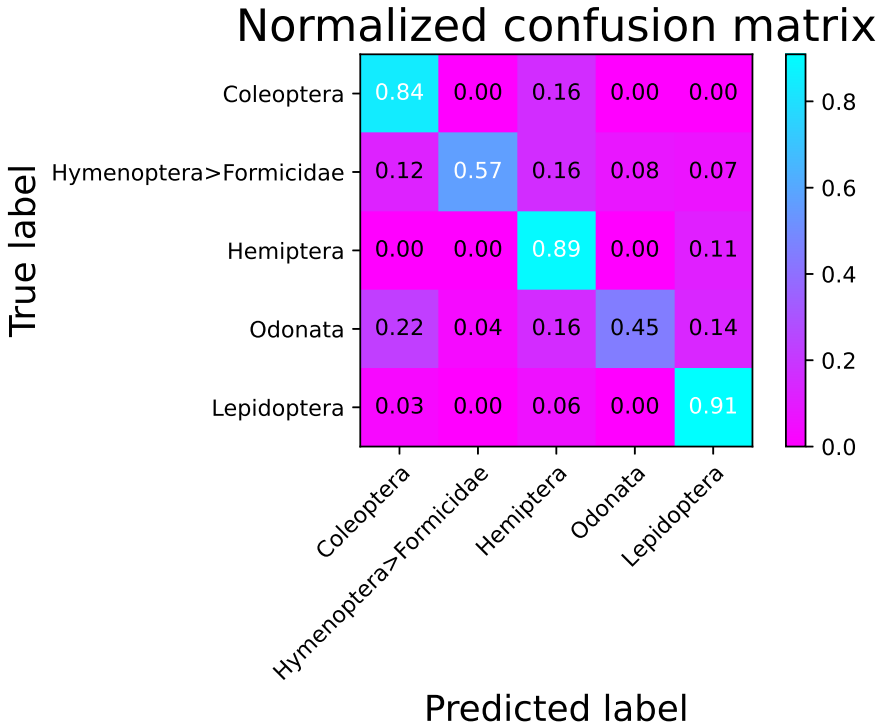
Hemiptera
Odonata
Lepidoptera
0.68 0.09 0.09 0.05 0.09
0.29 0.29 0.19 0.13 0.09
0.13 0.13 0.53 0.13 0.07
0.10 0.10 0.02 0.76 0.02
0.05 0.05 0.05 0.02 0.83
0.8
0.6
0.4
0.2
Predicted label

Single-Stage





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