MobileNets

- For mobile and embedded devices
- Tradeoff between latency and accuracy
- Use depth-wise separable convolutions. Separate convolutions into:
  - Depth-wise (channel) convolutions, followed by
  - Point-wise 1x1 convolutions
- Further simplification parameters:
  - Width multiplier (fewer channels)
  - Resolution multiplier (smaller resolution)

The advantages of depthwise separable convolutions are:

1. Reduced computation: By applying a single filter to each input channel, the depthwise convolution reduces the number of computations required in comparison to traditional convolutional layers.
2. Reduced parameters: The pointwise convolution combines the intermediate feature maps with a 1x1 filter, which greatly reduces the number of parameters in the model.

MobileNet also uses other techniques to further reduce the model size and improve performance, such as:

1. Linear bottlenecks: To reduce the number of input channels to the depthwise convolution, MobileNet applies a linear bottleneck layer that compresses the input feature maps. This helps to reduce the number of parameters in the model.
2. Width multiplier: MobileNet uses a width multiplier to reduce the number of channels in each layer. This allows the model to be scaled up or down depending on the computational resources available.

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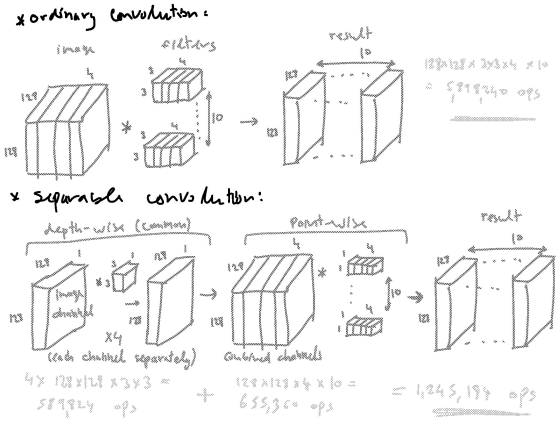

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* width multiplier:
  - Reduce # of input and output channels to each layer by a factor of α.

input channels: $M \rightarrow \alpha M$

output channels: $N \rightarrow \alpha N$

$\alpha \in [0,1]$

eg. 0.5

  - New computational cost:

$$D_k \times D_k \times \alpha M \times D_F \times D_F + \alpha M \times \alpha N \times D_f \times D_f$$

reduction by factor α — reduction by factor α^2

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* Resolution multiplier:
  - reduce input resolution by a factor $\beta \in [0,1]$

input resolution: $D_f \times D_f \rightarrow \beta D_f \times \beta D_f$

output resolution: $D_f \times D_f \rightarrow \beta D_f \times \beta D_f$

  - New computational cost:

$$D_k \times D_k \times \alpha M \times \beta D_F \times \beta D_F + \alpha M \times \alpha N \times \beta D_f \times \beta D_f$$

reduction by factor β^2

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* Experimental evaluation

Table 3. Resource usage for modifications to standard convolution. Note that each row is a cumulative effect adding on top of the previous row. This example is for an internal MobileNet layer with $D_K = 3$, $M = 512$, $N = 512$, $D_F = 14$.

Layer/Modification	Million Mult-Adds	Million Parameters
Convolution	462	2.36
Depthwise Separable Conv	52.3	0.27
$\alpha = 0.75$	29.6	0.15
$\rho = 0.714$	15.1	0.15

# of operations

Table 4. Depthwise Separable vs Full Convolution MobileNet

Model	ImageNet Accuracy	Million Mult-Adds	Million Parameters
Conv MobileNet	71.7%	4866	29.3
MobileNet	70.6%	569	4.2

accuracy

depth-wise separable conv.

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* Experimental evaluation (contd.)

Table 6. MobileNet Width Multiplier

Width Multiplier	ImageNet Accuracy	Million Mult-Adds	Million Parameters
1.0 MobileNet-224	70.6%	569	4.2
0.75 MobileNet-224	68.4%	325	2.6
0.5 MobileNet-224	63.7%	149	1.3
0.25 MobileNet-224	50.6%	41	0.5

Table 7. MobileNet Resolution

Resolution	ImageNet Accuracy	Million Mult-Adds	Million Parameters
1.0 MobileNet-224	70.6%	569	4.2
1.0 MobileNet-192	69.1%	418	4.2
1.0 MobileNet-160	67.2%	290	4.2
1.0 MobileNet-128	64.4%	186	4.2

MobileNets

```
from tensorflow.keras.applications.mobilenet import MobileNet
from tensorflow.keras.layers import Input, GlobalAveragePooling2D, Dense
from tensorflow.keras.models import Model

# Define the input shape of the images
input_shape = (224, 224, 3)

# Load the pre-trained MobileNet model (without the top layers)
base_model = MobileNet(input_shape=input_shape, include_top=False,
weights='imagenet')

# Add a global average pooling layer to reduce the spatial dimensions of the
output
x = GlobalAveragePooling2D()(base_model.output)

# Add a dense layer with softmax activation for classification
x = Dense(1000, activation='softmax')(x)

# Create the final model
model = Model(inputs=base_model.input, outputs=x)

# Print the summary of the model
model.summary()
```

Summary of Keras backbone networks

Backbone (Keras)	Strengths	Common Applications
ResNet (ResNet50, ResNet101, ResNet152)	Strong for deep networks, residual connections for better gradient flow	Classification, object detection, segmentation (e.g., Mask R-CNN)
VGG (VGG16, VGG19)	Simple architecture, easy to use for transfer learning, deep features	Classification, transfer learning, feature extraction
InceptionV3	Multi-scale feature extraction, efficient factorized convolutions	Classification, object detection, transfer learning
Xception	Efficient, uses depthwise separable convolutions for better efficiency	Classification, segmentation, object detection
MobileNetV1/V2	Lightweight, highly efficient, designed for mobile devices	Mobile applications, real-time image processing, classification

Summary of Keras backbone networks

EfficientNet (B0-B7)	Compound scaling for efficient and accurate models, excellent performance-to-complexity ratio	Classification, object detection, segmentation
DenseNet (DenseNet121, DenseNet169, DenseNet201)	Feature reuse through dense connectivity, highly parameter-efficient	Classification, transfer learning, medical imaging
NASNet	Automatically discovered architecture, strong performance on various tasks	Classification, object detection, transfer learning
InceptionResNetV2	Combines residual connections with multi-scale Inception modules	Classification, object detection, segmentation
MobileNetV3	Lightweight and efficient, better performance with less complexity than MobileNetV2	Mobile applications, embedded systems, real-time classification
ResNeXt (ResNeXt50, ResNeXt101)	Grouped convolutions for improved efficiency and performance	Classification, object detection, segmentation

Comparisons

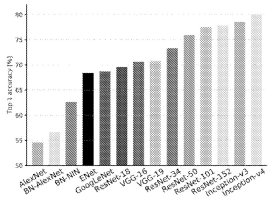


Figure 1: **Top1 *vs.* network.** Single-crop top-1 validation accuracies for top scoring single-model architectures. We introduce with this chart our choice of colour scheme, which will be used throughout this publication to distinguish effectively different architectures and their correspondent authors. Notice that networks of the same group share the same hue, for example ResNet are all variations of pink.

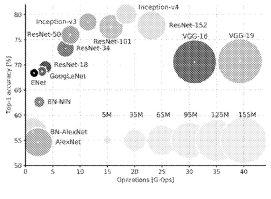
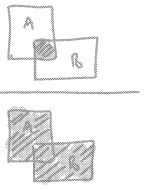


Figure 2: **Top1 *vs.* operations, size $\propto$ parameters.** Top-1 one-crop accuracy versus amount of operations required for a single forward pass. The size of the blobs is proportional to the number of network parameters; a legend is reported in the bottom right corner, spanning from 5×10^6 to 155×10^6 params. Both these figures share the same y-axis, and the grey dots highlight the centre of the blobs.

Detection evaluation

* IoU / Jaccard index (similarity)

$$IoU = \frac{|A \cap B|}{|A \cup B|} = \frac{|A \cap B|}{|A| + |B| - A \cap B}$$



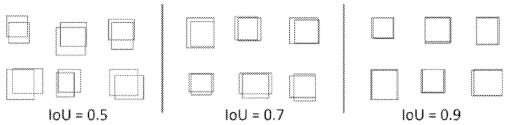
$IoU \in [0, 1]$ ← same; ↙ mutually exclusive

* Jaccard distance

$$d_J(A, B) = 1 - IoU(A, B) = \frac{|A \cup B| - |A \cap B|}{|A \cup B|}$$

Detection evaluation

- A threshold could be used to determine correct detection



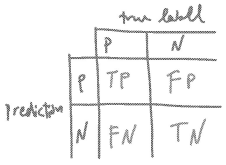
- In addition to evaluating localization, we also need to evaluate classification. That is, evaluate the class that is attached to each detection.
- Include a background class for proper evaluation

Detection evaluation

- Mean average precision (MAP)
- Commonly used to evaluate object detection
- Whereas IOU only takes into account localization accuracy, MAP measures classification accuracy of detected objects (determined at different IOU threshold values)

Detection evaluation

- Precision and recall:



$$\text{recall} = \frac{TP}{\text{total positive}} = \frac{TP}{TP + FN}$$

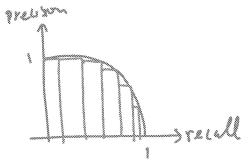
$$\text{Precision} = \frac{TP}{\text{total P predictions}} = \frac{TP}{TP + FP}$$

- There's a trade off between precision and recall:
  - A higher confidence threshold leads to higher precision and lower recall
  - A lower confidence threshold leads to lower precision and higher recall

Detection evaluation

* ROC curve:

- Record precision and recall at different confidence levels.



AUC = area under curve

AUC $\in [0, 1]$ bigger is better

AP = average precision (computes AUC)

r_i recall at threshold t_i

p_i precision at threshold t_i

$$AP = \sum_{\substack{\text{confidence} \\ \text{thresholds } t_i}} (r_{i+1} - r_i)\, p_{i+1}$$

Detection evaluation

- Average precision interpretation:

$$AP = \sum_{\substack{\text{confidence} \\ \text{thresholds } t_i}} (r_{i+1} - r_i)\, p_{i+1}$$

- Average precision (AP) can be viewed as a weighted sum of precision values at different confidence level thresholds. The weight coefficients are defined by the increase in recall values
- With AP we no longer need to select a threshold to determine a single set of precision and recall values
- Mean average precision (mAP):
  - Compute average precision (AP) for each class, and average the AP for all classes (i.e. ROC curve for each class)
  - In detection problems, include a class of background (no object)

Detection evaluation

- IOU threshold:
  - In the context of detection, to compute AP we first have to select on IOU threshold to determine there was a detection
  - We can then compute AP as a measure of classification correctness
- The selection of IOU threshold is somewhat ambiguous and will affect AP results:
  - With a lower IOU threshold standard we will have more detections but with worse localization and possibly worse accuracy
  - With a higher IOU threshold standard we will have fewer detections but with better localization and possibly more accuracy
- Coco mAP:
  - Calculate mAP at different IOU threshold values and average them

$AP\ @\ [.5 : .05 : .95]$ — 10 threshold values

$$mAP = \frac{mAP_{0.5} + mAP_{0.55} + \cdots + mAP_{0.95}}{10}$$

Object localization

- To localize an object we need to specify a bounding box:

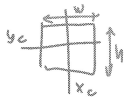
$(x_{min}, y_{min}, x_{max}, y_{max})$

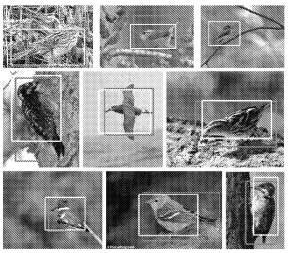
- Because we process the image at different scales, absolute coordinates cannot be used in so we use relative location:

$x_{min}, x_{max}, y_{min}, y_{max} \in [0,1]$

- Alternatively, use:

(x_c, y_c, w, h)





Object localization

- Training:
  - For each example mark bounding box and label class
  - Include background (no object) boxes
  - One hot encode class labels

$y = [p_c, x_c, y_c, w, h, c_1, \dots, c_k]$

p_c: 1 if object box, 0 if not object box; x_c, y_c, w, h: bounding box; $c_1, \dots, c_k$: one-hot encoded class

- Classification:

$\hat{y} = [p_c, x_c, y_c, w, h, c_1, \dots, c_k]$

p_c: object probability; x_c, y_c, w, h: bounding box; $c_1, \dots, c_k$: class probabilities