Минобрнауки России

ФГБОУ ВПО «НИУ МЭИ» АВТИ

Кафедра математического и компьютерного моделирования

**Лабораторная работа №11**

**Компьютерная графика**

**Работу выполнил:**

Солонин Егор А-14-19

**Работу принял:**

Бартеньев О.В.

Москва 2021

1. **Задание.**

Настроить предобученную нейронную сеть для классификации рукописных цифр. Набор данных - MNIST.

Результат оформить в виде отчета, включив в него

- описание выполненных действий;

- model.summary() полученной модели;

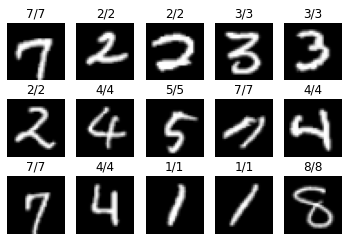
- графики обучения;

- полученную точность классификации изображений обучающего и проверочного множеств MNIST.

В качестве исходной берется любая модель из табл. 1 в ЛК6\_2021.

1. **Входные данные**

* MNIST – 70'000 рукописных цифр; из них 60'000 входят в обучающую выборку, а 10'000 – в тестовую; размер каждого образа – 28\*28 пикселей; рисунки выполнены в оттенках серого цвета;

1. **Выходные данные**
2. **Описание действий**
3. Загружаем mnist
4. Настраиваем нейронную сеть MobileNetV2 на наши данные
5. Устанавливаем всем слоям layer.trainable = True
6. Масштабируем массивы входных данных
7. Выполняем обучение и сохраняем модель в файл
8. Загружаем из файла и составляем прогноз
9. **Итоговая точность:**

Потери при тестировании (test): 0.0504

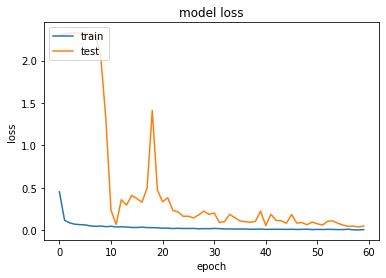
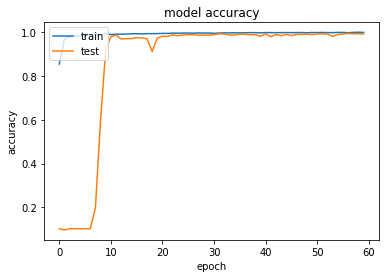
Точность при тестировании (test): 99.09%

Потери при тестировании (train): 0.0144

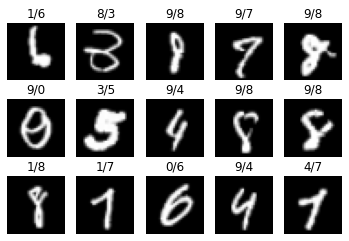
Точность при тестировании (train): 99.65%

Неверно классифицированно: 210

1. **Графики обучения**



1. **Примеры неверно классифицированных изображений**

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1. **Точность и потери на каждой эпохе**

Epoch 1/60

469/469 - 157s - loss: 0.4525 - accuracy: 0.8538 - val\_loss: 2.3061 - val\_accuracy: 0.1028

Epoch 2/60

469/469 - 150s - loss: 0.1174 - accuracy: 0.9684 - val\_loss: 2.3077 - val\_accuracy: 0.0974

Epoch 3/60

469/469 - 150s - loss: 0.0866 - accuracy: 0.9777 - val\_loss: 2.3205 - val\_accuracy: 0.1028

Epoch 4/60

469/469 - 150s - loss: 0.0711 - accuracy: 0.9821 - val\_loss: 2.3236 - val\_accuracy: 0.1028

Epoch 5/60

469/469 - 153s - loss: 0.0666 - accuracy: 0.9831 - val\_loss: 2.3168 - val\_accuracy: 0.1028

Epoch 6/60

469/469 - 153s - loss: 0.0631 - accuracy: 0.9838 - val\_loss: 2.3330 - val\_accuracy: 0.1028

Epoch 7/60

469/469 - 153s - loss: 0.0517 - accuracy: 0.9872 - val\_loss: 2.3043 - val\_accuracy: 0.1028

...

Epoch 55/60

469/469 - 131s - loss: 0.0082 - accuracy: 0.9981 - val\_loss: 0.0813 - val\_accuracy: 0.9886

Epoch 56/60

469/469 - 131s - loss: 0.0084 - accuracy: 0.9979 - val\_loss: 0.0607 - val\_accuracy: 0.9911

Epoch 57/60

469/469 - 130s - loss: 0.0123 - accuracy: 0.9967 - val\_loss: 0.0454 - val\_accuracy: 0.9932

Epoch 58/60

469/469 - 130s - loss: 0.0052 - accuracy: 0.9983 - val\_loss: 0.0487 - val\_accuracy: 0.9919

Epoch 59/60

469/469 - 130s - loss: 0.0042 - accuracy: 0.9990 - val\_loss: 0.0386 - val\_accuracy: 0.9926

Epoch 60/60

469/469 - 131s - loss: 0.0079 - accuracy: 0.9980 - val\_loss: 0.0504 - val\_accuracy: 0.9909

1. **Model.summary:**

Model: "model\_1"

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Layer (type) Output Shape Param # Connected to

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input\_2 (InputLayer) [(None, 32, 32, 1)] 0

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Conv1 (Conv2D) (None, 16, 16, 32) 288 input\_2[0][0]

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bn\_Conv1 (BatchNormalization) (None, 16, 16, 32) 128 Conv1[0][0]

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Conv1\_relu (ReLU) (None, 16, 16, 32) 0 bn\_Conv1[0][0]

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expanded\_conv\_depthwise (Depthw (None, 16, 16, 32) 288 Conv1\_relu[0][0]

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expanded\_conv\_depthwise\_BN (Bat (None, 16, 16, 32) 128 expanded\_conv\_depthwise[0][0]

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expanded\_conv\_depthwise\_relu (R (None, 16, 16, 32) 0 expanded\_conv\_depthwise\_BN[0][0]

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expanded\_conv\_project (Conv2D) (None, 16, 16, 16) 512 expanded\_conv\_depthwise\_relu[0][0

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expanded\_conv\_project\_BN (Batch (None, 16, 16, 16) 64 expanded\_conv\_project[0][0]

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block\_1\_expand (Conv2D) (None, 16, 16, 96) 1536 expanded\_conv\_project\_BN[0][0]

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block\_1\_expand\_BN (BatchNormali (None, 16, 16, 96) 384 block\_1\_expand[0][0]

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block\_1\_expand\_relu (ReLU) (None, 16, 16, 96) 0 block\_1\_expand\_BN[0][0]

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block\_1\_pad (ZeroPadding2D) (None, 17, 17, 96) 0 block\_1\_expand\_relu[0][0]

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block\_1\_depthwise (DepthwiseCon (None, 8, 8, 96) 864 block\_1\_pad[0][0]

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block\_1\_depthwise\_BN (BatchNorm (None, 8, 8, 96) 384 block\_1\_depthwise[0][0]

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block\_1\_depthwise\_relu (ReLU) (None, 8, 8, 96) 0 block\_1\_depthwise\_BN[0][0]

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block\_1\_project (Conv2D) (None, 8, 8, 24) 2304 block\_1\_depthwise\_relu[0][0]

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block\_1\_project\_BN (BatchNormal (None, 8, 8, 24) 96 block\_1\_project[0][0]

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block\_2\_expand (Conv2D) (None, 8, 8, 144) 3456 block\_1\_project\_BN[0][0]

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block\_2\_expand\_BN (BatchNormali (None, 8, 8, 144) 576 block\_2\_expand[0][0]

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block\_2\_expand\_relu (ReLU) (None, 8, 8, 144) 0 block\_2\_expand\_BN[0][0]

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block\_2\_depthwise (DepthwiseCon (None, 8, 8, 144) 1296 block\_2\_expand\_relu[0][0]

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block\_2\_depthwise\_BN (BatchNorm (None, 8, 8, 144) 576 block\_2\_depthwise[0][0]

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block\_2\_depthwise\_relu (ReLU) (None, 8, 8, 144) 0 block\_2\_depthwise\_BN[0][0]

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block\_2\_project (Conv2D) (None, 8, 8, 24) 3456 block\_2\_depthwise\_relu[0][0]

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block\_2\_project\_BN (BatchNormal (None, 8, 8, 24) 96 block\_2\_project[0][0]

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block\_2\_add (Add) (None, 8, 8, 24) 0 block\_1\_project\_BN[0][0]

block\_2\_project\_BN[0][0]

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block\_3\_expand (Conv2D) (None, 8, 8, 144) 3456 block\_2\_add[0][0]

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block\_3\_expand\_BN (BatchNormali (None, 8, 8, 144) 576 block\_3\_expand[0][0]

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block\_3\_expand\_relu (ReLU) (None, 8, 8, 144) 0 block\_3\_expand\_BN[0][0]

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block\_3\_pad (ZeroPadding2D) (None, 9, 9, 144) 0 block\_3\_expand\_relu[0][0]

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block\_3\_depthwise (DepthwiseCon (None, 4, 4, 144) 1296 block\_3\_pad[0][0]

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block\_3\_depthwise\_BN (BatchNorm (None, 4, 4, 144) 576 block\_3\_depthwise[0][0]

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block\_3\_depthwise\_relu (ReLU) (None, 4, 4, 144) 0 block\_3\_depthwise\_BN[0][0]

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block\_3\_project (Conv2D) (None, 4, 4, 32) 4608 block\_3\_depthwise\_relu[0][0]

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block\_3\_project\_BN (BatchNormal (None, 4, 4, 32) 128 block\_3\_project[0][0]

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block\_4\_expand (Conv2D) (None, 4, 4, 192) 6144 block\_3\_project\_BN[0][0]

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block\_4\_expand\_BN (BatchNormali (None, 4, 4, 192) 768 block\_4\_expand[0][0]

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block\_4\_expand\_relu (ReLU) (None, 4, 4, 192) 0 block\_4\_expand\_BN[0][0]

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block\_4\_depthwise (DepthwiseCon (None, 4, 4, 192) 1728 block\_4\_expand\_relu[0][0]

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block\_4\_depthwise\_BN (BatchNorm (None, 4, 4, 192) 768 block\_4\_depthwise[0][0]

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block\_4\_depthwise\_relu (ReLU) (None, 4, 4, 192) 0 block\_4\_depthwise\_BN[0][0]

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block\_4\_project (Conv2D) (None, 4, 4, 32) 6144 block\_4\_depthwise\_relu[0][0]

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block\_4\_project\_BN (BatchNormal (None, 4, 4, 32) 128 block\_4\_project[0][0]

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block\_4\_add (Add) (None, 4, 4, 32) 0 block\_3\_project\_BN[0][0]

block\_4\_project\_BN[0][0]

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block\_5\_expand (Conv2D) (None, 4, 4, 192) 6144 block\_4\_add[0][0]

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block\_5\_expand\_BN (BatchNormali (None, 4, 4, 192) 768 block\_5\_expand[0][0]

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block\_5\_expand\_relu (ReLU) (None, 4, 4, 192) 0 block\_5\_expand\_BN[0][0]

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block\_5\_depthwise (DepthwiseCon (None, 4, 4, 192) 1728 block\_5\_expand\_relu[0][0]

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block\_5\_depthwise\_BN (BatchNorm (None, 4, 4, 192) 768 block\_5\_depthwise[0][0]

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block\_5\_depthwise\_relu (ReLU) (None, 4, 4, 192) 0 block\_5\_depthwise\_BN[0][0]

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block\_5\_project (Conv2D) (None, 4, 4, 32) 6144 block\_5\_depthwise\_relu[0][0]

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block\_5\_project\_BN (BatchNormal (None, 4, 4, 32) 128 block\_5\_project[0][0]

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block\_5\_add (Add) (None, 4, 4, 32) 0 block\_4\_add[0][0]

block\_5\_project\_BN[0][0]

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block\_6\_expand (Conv2D) (None, 4, 4, 192) 6144 block\_5\_add[0][0]

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block\_6\_expand\_BN (BatchNormali (None, 4, 4, 192) 768 block\_6\_expand[0][0]

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block\_6\_expand\_relu (ReLU) (None, 4, 4, 192) 0 block\_6\_expand\_BN[0][0]

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block\_6\_pad (ZeroPadding2D) (None, 5, 5, 192) 0 block\_6\_expand\_relu[0][0]

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block\_6\_depthwise (DepthwiseCon (None, 2, 2, 192) 1728 block\_6\_pad[0][0]

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block\_6\_depthwise\_BN (BatchNorm (None, 2, 2, 192) 768 block\_6\_depthwise[0][0]

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block\_6\_depthwise\_relu (ReLU) (None, 2, 2, 192) 0 block\_6\_depthwise\_BN[0][0]

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block\_6\_project (Conv2D) (None, 2, 2, 64) 12288 block\_6\_depthwise\_relu[0][0]

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block\_6\_project\_BN (BatchNormal (None, 2, 2, 64) 256 block\_6\_project[0][0]

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block\_7\_expand (Conv2D) (None, 2, 2, 384) 24576 block\_6\_project\_BN[0][0]

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block\_7\_expand\_BN (BatchNormali (None, 2, 2, 384) 1536 block\_7\_expand[0][0]

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block\_7\_expand\_relu (ReLU) (None, 2, 2, 384) 0 block\_7\_expand\_BN[0][0]

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block\_7\_depthwise (DepthwiseCon (None, 2, 2, 384) 3456 block\_7\_expand\_relu[0][0]

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block\_7\_depthwise\_BN (BatchNorm (None, 2, 2, 384) 1536 block\_7\_depthwise[0][0]

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block\_7\_depthwise\_relu (ReLU) (None, 2, 2, 384) 0 block\_7\_depthwise\_BN[0][0]

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block\_7\_project (Conv2D) (None, 2, 2, 64) 24576 block\_7\_depthwise\_relu[0][0]

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block\_7\_project\_BN (BatchNormal (None, 2, 2, 64) 256 block\_7\_project[0][0]

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block\_7\_add (Add) (None, 2, 2, 64) 0 block\_6\_project\_BN[0][0]

block\_7\_project\_BN[0][0]

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block\_8\_expand (Conv2D) (None, 2, 2, 384) 24576 block\_7\_add[0][0]

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block\_8\_expand\_BN (BatchNormali (None, 2, 2, 384) 1536 block\_8\_expand[0][0]

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block\_8\_expand\_relu (ReLU) (None, 2, 2, 384) 0 block\_8\_expand\_BN[0][0]

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block\_8\_depthwise (DepthwiseCon (None, 2, 2, 384) 3456 block\_8\_expand\_relu[0][0]

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block\_8\_depthwise\_BN (BatchNorm (None, 2, 2, 384) 1536 block\_8\_depthwise[0][0]

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block\_8\_depthwise\_relu (ReLU) (None, 2, 2, 384) 0 block\_8\_depthwise\_BN[0][0]

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block\_8\_project (Conv2D) (None, 2, 2, 64) 24576 block\_8\_depthwise\_relu[0][0]

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block\_8\_project\_BN (BatchNormal (None, 2, 2, 64) 256 block\_8\_project[0][0]

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block\_8\_add (Add) (None, 2, 2, 64) 0 block\_7\_add[0][0]

block\_8\_project\_BN[0][0]

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block\_9\_expand (Conv2D) (None, 2, 2, 384) 24576 block\_8\_add[0][0]

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block\_9\_expand\_BN (BatchNormali (None, 2, 2, 384) 1536 block\_9\_expand[0][0]

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block\_9\_expand\_relu (ReLU) (None, 2, 2, 384) 0 block\_9\_expand\_BN[0][0]

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block\_9\_depthwise (DepthwiseCon (None, 2, 2, 384) 3456 block\_9\_expand\_relu[0][0]

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block\_9\_depthwise\_BN (BatchNorm (None, 2, 2, 384) 1536 block\_9\_depthwise[0][0]

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block\_9\_depthwise\_relu (ReLU) (None, 2, 2, 384) 0 block\_9\_depthwise\_BN[0][0]

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block\_9\_project (Conv2D) (None, 2, 2, 64) 24576 block\_9\_depthwise\_relu[0][0]

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block\_9\_project\_BN (BatchNormal (None, 2, 2, 64) 256 block\_9\_project[0][0]

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block\_9\_add (Add) (None, 2, 2, 64) 0 block\_8\_add[0][0]

block\_9\_project\_BN[0][0]

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block\_10\_expand (Conv2D) (None, 2, 2, 384) 24576 block\_9\_add[0][0]

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block\_10\_expand\_BN (BatchNormal (None, 2, 2, 384) 1536 block\_10\_expand[0][0]

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block\_10\_expand\_relu (ReLU) (None, 2, 2, 384) 0 block\_10\_expand\_BN[0][0]

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block\_10\_depthwise (DepthwiseCo (None, 2, 2, 384) 3456 block\_10\_expand\_relu[0][0]

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block\_10\_depthwise\_BN (BatchNor (None, 2, 2, 384) 1536 block\_10\_depthwise[0][0]

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block\_10\_depthwise\_relu (ReLU) (None, 2, 2, 384) 0 block\_10\_depthwise\_BN[0][0]

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block\_10\_project (Conv2D) (None, 2, 2, 96) 36864 block\_10\_depthwise\_relu[0][0]

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block\_10\_project\_BN (BatchNorma (None, 2, 2, 96) 384 block\_10\_project[0][0]

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block\_11\_expand (Conv2D) (None, 2, 2, 576) 55296 block\_10\_project\_BN[0][0]

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block\_11\_expand\_BN (BatchNormal (None, 2, 2, 576) 2304 block\_11\_expand[0][0]

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block\_11\_expand\_relu (ReLU) (None, 2, 2, 576) 0 block\_11\_expand\_BN[0][0]

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block\_11\_depthwise (DepthwiseCo (None, 2, 2, 576) 5184 block\_11\_expand\_relu[0][0]

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block\_11\_depthwise\_BN (BatchNor (None, 2, 2, 576) 2304 block\_11\_depthwise[0][0]

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block\_11\_depthwise\_relu (ReLU) (None, 2, 2, 576) 0 block\_11\_depthwise\_BN[0][0]

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block\_11\_project (Conv2D) (None, 2, 2, 96) 55296 block\_11\_depthwise\_relu[0][0]

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block\_11\_project\_BN (BatchNorma (None, 2, 2, 96) 384 block\_11\_project[0][0]

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block\_11\_add (Add) (None, 2, 2, 96) 0 block\_10\_project\_BN[0][0]

block\_11\_project\_BN[0][0]

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block\_12\_expand (Conv2D) (None, 2, 2, 576) 55296 block\_11\_add[0][0]

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block\_12\_expand\_BN (BatchNormal (None, 2, 2, 576) 2304 block\_12\_expand[0][0]

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block\_12\_expand\_relu (ReLU) (None, 2, 2, 576) 0 block\_12\_expand\_BN[0][0]

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block\_12\_depthwise (DepthwiseCo (None, 2, 2, 576) 5184 block\_12\_expand\_relu[0][0]

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block\_12\_depthwise\_BN (BatchNor (None, 2, 2, 576) 2304 block\_12\_depthwise[0][0]

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block\_12\_depthwise\_relu (ReLU) (None, 2, 2, 576) 0 block\_12\_depthwise\_BN[0][0]

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block\_12\_project (Conv2D) (None, 2, 2, 96) 55296 block\_12\_depthwise\_relu[0][0]

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block\_12\_project\_BN (BatchNorma (None, 2, 2, 96) 384 block\_12\_project[0][0]

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block\_12\_add (Add) (None, 2, 2, 96) 0 block\_11\_add[0][0]

block\_12\_project\_BN[0][0]

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block\_13\_expand (Conv2D) (None, 2, 2, 576) 55296 block\_12\_add[0][0]

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block\_13\_expand\_BN (BatchNormal (None, 2, 2, 576) 2304 block\_13\_expand[0][0]

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block\_13\_expand\_relu (ReLU) (None, 2, 2, 576) 0 block\_13\_expand\_BN[0][0]

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block\_13\_pad (ZeroPadding2D) (None, 3, 3, 576) 0 block\_13\_expand\_relu[0][0]

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block\_13\_depthwise (DepthwiseCo (None, 1, 1, 576) 5184 block\_13\_pad[0][0]

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block\_13\_depthwise\_BN (BatchNor (None, 1, 1, 576) 2304 block\_13\_depthwise[0][0]

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block\_13\_depthwise\_relu (ReLU) (None, 1, 1, 576) 0 block\_13\_depthwise\_BN[0][0]

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block\_13\_project (Conv2D) (None, 1, 1, 160) 92160 block\_13\_depthwise\_relu[0][0]

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block\_13\_project\_BN (BatchNorma (None, 1, 1, 160) 640 block\_13\_project[0][0]

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block\_14\_expand (Conv2D) (None, 1, 1, 960) 153600 block\_13\_project\_BN[0][0]

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block\_14\_expand\_BN (BatchNormal (None, 1, 1, 960) 3840 block\_14\_expand[0][0]

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block\_14\_expand\_relu (ReLU) (None, 1, 1, 960) 0 block\_14\_expand\_BN[0][0]

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block\_14\_depthwise (DepthwiseCo (None, 1, 1, 960) 8640 block\_14\_expand\_relu[0][0]

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block\_14\_depthwise\_BN (BatchNor (None, 1, 1, 960) 3840 block\_14\_depthwise[0][0]

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block\_14\_depthwise\_relu (ReLU) (None, 1, 1, 960) 0 block\_14\_depthwise\_BN[0][0]

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block\_14\_project (Conv2D) (None, 1, 1, 160) 153600 block\_14\_depthwise\_relu[0][0]

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block\_14\_project\_BN (BatchNorma (None, 1, 1, 160) 640 block\_14\_project[0][0]

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block\_14\_add (Add) (None, 1, 1, 160) 0 block\_13\_project\_BN[0][0]

block\_14\_project\_BN[0][0]

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block\_15\_expand (Conv2D) (None, 1, 1, 960) 153600 block\_14\_add[0][0]

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block\_15\_expand\_BN (BatchNormal (None, 1, 1, 960) 3840 block\_15\_expand[0][0]

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block\_15\_expand\_relu (ReLU) (None, 1, 1, 960) 0 block\_15\_expand\_BN[0][0]

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block\_15\_depthwise (DepthwiseCo (None, 1, 1, 960) 8640 block\_15\_expand\_relu[0][0]

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block\_15\_depthwise\_BN (BatchNor (None, 1, 1, 960) 3840 block\_15\_depthwise[0][0]

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block\_15\_depthwise\_relu (ReLU) (None, 1, 1, 960) 0 block\_15\_depthwise\_BN[0][0]

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block\_15\_project (Conv2D) (None, 1, 1, 160) 153600 block\_15\_depthwise\_relu[0][0]

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block\_15\_project\_BN (BatchNorma (None, 1, 1, 160) 640 block\_15\_project[0][0]

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block\_15\_add (Add) (None, 1, 1, 160) 0 block\_14\_add[0][0]

block\_15\_project\_BN[0][0]

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block\_16\_expand (Conv2D) (None, 1, 1, 960) 153600 block\_15\_add[0][0]

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block\_16\_expand\_BN (BatchNormal (None, 1, 1, 960) 3840 block\_16\_expand[0][0]

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block\_16\_expand\_relu (ReLU) (None, 1, 1, 960) 0 block\_16\_expand\_BN[0][0]

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block\_16\_depthwise (DepthwiseCo (None, 1, 1, 960) 8640 block\_16\_expand\_relu[0][0]

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block\_16\_depthwise\_BN (BatchNor (None, 1, 1, 960) 3840 block\_16\_depthwise[0][0]

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block\_16\_depthwise\_relu (ReLU) (None, 1, 1, 960) 0 block\_16\_depthwise\_BN[0][0]

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block\_16\_project (Conv2D) (None, 1, 1, 320) 307200 block\_16\_depthwise\_relu[0][0]

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block\_16\_project\_BN (BatchNorma (None, 1, 1, 320) 1280 block\_16\_project[0][0]

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Conv\_1 (Conv2D) (None, 1, 1, 1280) 409600 block\_16\_project\_BN[0][0]

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Conv\_1\_bn (BatchNormalization) (None, 1, 1, 1280) 5120 Conv\_1[0][0]

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out\_relu (ReLU) (None, 1, 1, 1280) 0 Conv\_1\_bn[0][0]

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global\_average\_pooling2d\_1 (Glo (None, 1280) 0 out\_relu[0][0]

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predictions (Dense) (None, 1000) 1281000 global\_average\_pooling2d\_1[0][0]

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activation\_1 (Activation) (None, 1000) 0 predictions[0][0]

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dense\_2 (Dense) (None, 256) 256256 activation\_1[0][0]

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dense\_3 (Dense) (None, 10) 2570 dense\_2[0][0]

==================================================================================================

**Total params: 3,797,234**

**Trainable params: 3,763,122**

**Non-trainable params: 34,112**