# VGG-16

Found 4123 images belonging to 3 classes.

Found 1031 images belonging to 3 classes.

Class weights: {0: 1.528735632183908, 1: 0.6632882882882883, 2: 1.1929976851851851}

Downloading data from <https://storage.googleapis.com/tensorflow/keras-applications/vgg16/vgg16_weights_tf_dim_ordering_tf_kernels_notop.h5>

**58889256/58889256** ━━━━━━━━━━━━━━━━━━━━ **4s** 0us/step

**Model: "functional"**

┏━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━┳━━━━━━━━━━━━━━━━━━━━━━━━━━━━━┳━━━━━━━━━━━━━━━━━┓

┃ **Layer (type)** ┃ **Output Shape** ┃ **Param #** ┃

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│ input\_layer (InputLayer) │ (None, 224, 224, 3) │ 0 │

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│ block1\_conv1 (Conv2D) │ (None, 224, 224, 64) │ 1,792 │

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│ block1\_conv2 (Conv2D) │ (None, 224, 224, 64) │ 36,928 │

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│ block1\_pool (MaxPooling2D) │ (None, 112, 112, 64) │ 0 │

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│ block2\_conv1 (Conv2D) │ (None, 112, 112, 128) │ 73,856 │

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│ block2\_conv2 (Conv2D) │ (None, 112, 112, 128) │ 147,584 │

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│ block2\_pool (MaxPooling2D) │ (None, 56, 56, 128) │ 0 │

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│ block3\_conv1 (Conv2D) │ (None, 56, 56, 256) │ 295,168 │

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│ block3\_conv2 (Conv2D) │ (None, 56, 56, 256) │ 590,080 │

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│ block3\_conv3 (Conv2D) │ (None, 56, 56, 256) │ 590,080 │

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│ block3\_pool (MaxPooling2D) │ (None, 28, 28, 256) │ 0 │

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│ block4\_conv1 (Conv2D) │ (None, 28, 28, 512) │ 1,180,160 │

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│ block4\_conv2 (Conv2D) │ (None, 28, 28, 512) │ 2,359,808 │

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│ block4\_conv3 (Conv2D) │ (None, 28, 28, 512) │ 2,359,808 │

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│ block4\_pool (MaxPooling2D) │ (None, 14, 14, 512) │ 0 │

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│ block5\_conv1 (Conv2D) │ (None, 14, 14, 512) │ 2,359,808 │

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│ block5\_conv2 (Conv2D) │ (None, 14, 14, 512) │ 2,359,808 │

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│ block5\_conv3 (Conv2D) │ (None, 14, 14, 512) │ 2,359,808 │

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│ block5\_pool (MaxPooling2D) │ (None, 7, 7, 512) │ 0 │

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│ global\_average\_pooling2d │ (None, 512) │ 0 │

│ (GlobalAveragePooling2D) │ │ │

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│ dense (Dense) │ (None, 1024) │ 525,312 │

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│ batch\_normalization │ (None, 1024) │ 4,096 │

│ (BatchNormalization) │ │ │

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│ re\_lu (ReLU) │ (None, 1024) │ 0 │

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│ dropout (Dropout) │ (None, 1024) │ 0 │

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│ dense\_1 (Dense) │ (None, 512) │ 524,800 │

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│ batch\_normalization\_1 │ (None, 512) │ 2,048 │

│ (BatchNormalization) │ │ │

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│ re\_lu\_1 (ReLU) │ (None, 512) │ 0 │

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│ dropout\_1 (Dropout) │ (None, 512) │ 0 │

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│ dense\_2 (Dense) │ (None, 3) │ 1,539 │

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**Total params:** 15,772,483 (60.17 MB)

**Trainable params:** 8,134,147 (31.03 MB)

**Non-trainable params:** 7,638,336 (29.14 MB)

/usr/local/lib/python3.11/dist-packages/keras/src/trainers/data\_adapters/py\_dataset\_adapter.py:121: UserWarning: Your `PyDataset` class should call `super().\_\_init\_\_(\*\*kwargs)` in its constructor. `\*\*kwargs` can include `workers`, `use\_multiprocessing`, `max\_queue\_size`. Do not pass these arguments to `fit()`, as they will be ignored.

self.\_warn\_if\_super\_not\_called()

Epoch 1/25

/usr/local/lib/python3.11/dist-packages/keras/src/models/functional.py:237: UserWarning: The structure of `inputs` doesn't match the expected structure.

Expected: ['keras\_tensor']

Received: inputs=Tensor(shape=(None, 224, 224, 3))

warnings.warn(msg)

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 584ms/step - accuracy: 0.3743 - auc: 0.5514 - loss: 1.6204 - precision: 0.3788 - recall: 0.3034

Epoch 1: val\_accuracy improved from -inf to 0.21823, saving model to Alzheimer\_Detection/models/vgg16\_best.keras

**129/129** ━━━━━━━━━━━━━━━━━━━━ **114s** 718ms/step - accuracy: 0.3745 - auc: 0.5516 - loss: 1.6198 - precision: 0.3790 - recall: 0.3036 - val\_accuracy: 0.2182 - val\_auc: 0.5038 - val\_loss: 1.5993 - val\_precision: 0.2187 - val\_recall: 0.2182 - learning\_rate: 1.0000e-04

Epoch 2/25

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 500ms/step - accuracy: 0.4177 - auc: 0.6063 - loss: 1.4458 - precision: 0.4370 - recall: 0.3524

Epoch 2: val\_accuracy improved from 0.21823 to 0.35694, saving model to Alzheimer\_Detection/models/vgg16\_best.keras

**129/129** ━━━━━━━━━━━━━━━━━━━━ **74s** 573ms/step - accuracy: 0.4178 - auc: 0.6064 - loss: 1.4457 - precision: 0.4371 - recall: 0.3525 - val\_accuracy: 0.3569 - val\_auc: 0.5775 - val\_loss: 1.4370 - val\_precision: 0.3711 - val\_recall: 0.3240 - learning\_rate: 1.0000e-04

Epoch 3/25

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 494ms/step - accuracy: 0.4489 - auc: 0.6325 - loss: 1.4077 - precision: 0.4661 - recall: 0.3731

Epoch 3: val\_accuracy improved from 0.35694 to 0.50242, saving model to Alzheimer\_Detection/models/vgg16\_best.keras

**129/129** ━━━━━━━━━━━━━━━━━━━━ **83s** 578ms/step - accuracy: 0.4490 - auc: 0.6326 - loss: 1.4075 - precision: 0.4662 - recall: 0.3733 - val\_accuracy: 0.5024 - val\_auc: 0.6597 - val\_loss: 3.0762 - val\_precision: 0.5024 - val\_recall: 0.5024 - learning\_rate: 1.0000e-04

Epoch 4/25

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 488ms/step - accuracy: 0.4897 - auc: 0.6710 - loss: 1.3271 - precision: 0.5053 - recall: 0.4179

Epoch 4: val\_accuracy did not improve from 0.50242

**129/129** ━━━━━━━━━━━━━━━━━━━━ **72s** 558ms/step - accuracy: 0.4897 - auc: 0.6711 - loss: 1.3270 - precision: 0.5054 - recall: 0.4179 - val\_accuracy: 0.4850 - val\_auc: 0.6703 - val\_loss: 1.4637 - val\_precision: 0.4801 - val\_recall: 0.4219 - learning\_rate: 1.0000e-04

Epoch 5/25

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 494ms/step - accuracy: 0.5336 - auc: 0.7226 - loss: 1.2084 - precision: 0.5652 - recall: 0.4704

Epoch 5: val\_accuracy improved from 0.50242 to 0.52376, saving model to Alzheimer\_Detection/models/vgg16\_best.keras

**129/129** ━━━━━━━━━━━━━━━━━━━━ **75s** 577ms/step - accuracy: 0.5336 - auc: 0.7226 - loss: 1.2084 - precision: 0.5652 - recall: 0.4704 - val\_accuracy: 0.5238 - val\_auc: 0.7450 - val\_loss: 1.9765 - val\_precision: 0.5258 - val\_recall: 0.5238 - learning\_rate: 1.0000e-04

Epoch 6/25

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 495ms/step - accuracy: 0.5402 - auc: 0.7340 - loss: 1.2045 - precision: 0.5703 - recall: 0.4717

Epoch 6: val\_accuracy did not improve from 0.52376

**129/129** ━━━━━━━━━━━━━━━━━━━━ **81s** 573ms/step - accuracy: 0.5403 - auc: 0.7341 - loss: 1.2042 - precision: 0.5705 - recall: 0.4718 - val\_accuracy: 0.5131 - val\_auc: 0.7107 - val\_loss: 1.2397 - val\_precision: 0.5531 - val\_recall: 0.4549 - learning\_rate: 1.0000e-04

Epoch 7/25

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 495ms/step - accuracy: 0.5898 - auc: 0.7783 - loss: 1.0873 - precision: 0.6317 - recall: 0.5271

Epoch 7: val\_accuracy improved from 0.52376 to 0.58584, saving model to Alzheimer\_Detection/models/vgg16\_best.keras

**129/129** ━━━━━━━━━━━━━━━━━━━━ **86s** 607ms/step - accuracy: 0.5897 - auc: 0.7783 - loss: 1.0874 - precision: 0.6316 - recall: 0.5271 - val\_accuracy: 0.5858 - val\_auc: 0.7944 - val\_loss: 1.2085 - val\_precision: 0.6012 - val\_recall: 0.5761 - learning\_rate: 1.0000e-04

Epoch 8/25

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 486ms/step - accuracy: 0.6287 - auc: 0.8156 - loss: 1.0048 - precision: 0.6564 - recall: 0.5733

Epoch 8: val\_accuracy did not improve from 0.58584

**129/129** ━━━━━━━━━━━━━━━━━━━━ **76s** 557ms/step - accuracy: 0.6286 - auc: 0.8156 - loss: 1.0050 - precision: 0.6564 - recall: 0.5732 - val\_accuracy: 0.5810 - val\_auc: 0.7641 - val\_loss: 1.6492 - val\_precision: 0.5868 - val\_recall: 0.5771 - learning\_rate: 1.0000e-04

Epoch 9/25

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 496ms/step - accuracy: 0.6446 - auc: 0.8183 - loss: 1.0240 - precision: 0.6729 - recall: 0.5847

Epoch 9: val\_accuracy did not improve from 0.58584

**129/129** ━━━━━━━━━━━━━━━━━━━━ **74s** 573ms/step - accuracy: 0.6446 - auc: 0.8184 - loss: 1.0238 - precision: 0.6729 - recall: 0.5847 - val\_accuracy: 0.5694 - val\_auc: 0.7821 - val\_loss: 1.0640 - val\_precision: 0.5991 - val\_recall: 0.4956 - learning\_rate: 1.0000e-04

Epoch 10/25

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 486ms/step - accuracy: 0.6482 - auc: 0.8349 - loss: 0.9529 - precision: 0.6899 - recall: 0.5993

Epoch 10: val\_accuracy improved from 0.58584 to 0.60718, saving model to Alzheimer\_Detection/models/vgg16\_best.keras

**129/129** ━━━━━━━━━━━━━━━━━━━━ **73s** 561ms/step - accuracy: 0.6484 - auc: 0.8350 - loss: 0.9528 - precision: 0.6901 - recall: 0.5995 - val\_accuracy: 0.6072 - val\_auc: 0.7874 - val\_loss: 1.0705 - val\_precision: 0.6416 - val\_recall: 0.5383 - learning\_rate: 1.0000e-04

Epoch 11/25

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 495ms/step - accuracy: 0.7026 - auc: 0.8618 - loss: 0.8856 - precision: 0.7331 - recall: 0.6479

Epoch 11: val\_accuracy did not improve from 0.60718

**129/129** ━━━━━━━━━━━━━━━━━━━━ **74s** 574ms/step - accuracy: 0.7025 - auc: 0.8618 - loss: 0.8856 - precision: 0.7330 - recall: 0.6479 - val\_accuracy: 0.5820 - val\_auc: 0.7776 - val\_loss: 1.4083 - val\_precision: 0.5962 - val\_recall: 0.5500 - learning\_rate: 1.0000e-04

Epoch 12/25

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 489ms/step - accuracy: 0.7192 - auc: 0.8840 - loss: 0.8456 - precision: 0.7499 - recall: 0.6769

Epoch 12: val\_accuracy improved from 0.60718 to 0.66343, saving model to Alzheimer\_Detection/models/vgg16\_best.keras

**129/129** ━━━━━━━━━━━━━━━━━━━━ **73s** 564ms/step - accuracy: 0.7191 - auc: 0.8840 - loss: 0.8456 - precision: 0.7498 - recall: 0.6769 - val\_accuracy: 0.6634 - val\_auc: 0.8371 - val\_loss: 1.1202 - val\_precision: 0.6776 - val\_recall: 0.6402 - learning\_rate: 1.0000e-04

Epoch 13/25

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 495ms/step - accuracy: 0.7501 - auc: 0.9092 - loss: 0.7751 - precision: 0.7819 - recall: 0.7090

Epoch 13: val\_accuracy did not improve from 0.66343

**129/129** ━━━━━━━━━━━━━━━━━━━━ **74s** 575ms/step - accuracy: 0.7500 - auc: 0.9091 - loss: 0.7752 - precision: 0.7818 - recall: 0.7090 - val\_accuracy: 0.5597 - val\_auc: 0.7281 - val\_loss: 1.3296 - val\_precision: 0.5762 - val\_recall: 0.5170 - learning\_rate: 1.0000e-04

Epoch 14/25

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 494ms/step - accuracy: 0.7663 - auc: 0.9158 - loss: 0.7582 - precision: 0.8015 - recall: 0.7266

Epoch 14: val\_accuracy improved from 0.66343 to 0.77207, saving model to Alzheimer\_Detection/models/vgg16\_best.keras

**129/129** ━━━━━━━━━━━━━━━━━━━━ **82s** 574ms/step - accuracy: 0.7663 - auc: 0.9158 - loss: 0.7582 - precision: 0.8014 - recall: 0.7266 - val\_accuracy: 0.7721 - val\_auc: 0.9205 - val\_loss: 0.7614 - val\_precision: 0.7937 - val\_recall: 0.7313 - learning\_rate: 1.0000e-04

Epoch 15/25

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 497ms/step - accuracy: 0.7771 - auc: 0.9208 - loss: 0.7412 - precision: 0.8024 - recall: 0.7433

Epoch 15: val\_accuracy did not improve from 0.77207

**129/129** ━━━━━━━━━━━━━━━━━━━━ **81s** 567ms/step - accuracy: 0.7771 - auc: 0.9208 - loss: 0.7412 - precision: 0.8023 - recall: 0.7433 - val\_accuracy: 0.5732 - val\_auc: 0.7673 - val\_loss: 2.3543 - val\_precision: 0.5750 - val\_recall: 0.5723 - learning\_rate: 1.0000e-04

Epoch 16/25

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 497ms/step - accuracy: 0.7987 - auc: 0.9378 - loss: 0.6840 - precision: 0.8235 - recall: 0.7712

Epoch 16: val\_accuracy did not improve from 0.77207

**129/129** ━━━━━━━━━━━━━━━━━━━━ **82s** 567ms/step - accuracy: 0.7987 - auc: 0.9378 - loss: 0.6840 - precision: 0.8235 - recall: 0.7712 - val\_accuracy: 0.7352 - val\_auc: 0.8966 - val\_loss: 0.8462 - val\_precision: 0.7593 - val\_recall: 0.7129 - learning\_rate: 1.0000e-04

Epoch 17/25

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 497ms/step - accuracy: 0.8041 - auc: 0.9388 - loss: 0.6893 - precision: 0.8328 - recall: 0.7798

Epoch 17: val\_accuracy did not improve from 0.77207

**129/129** ━━━━━━━━━━━━━━━━━━━━ **82s** 572ms/step - accuracy: 0.8041 - auc: 0.9388 - loss: 0.6892 - precision: 0.8328 - recall: 0.7799 - val\_accuracy: 0.7284 - val\_auc: 0.8996 - val\_loss: 0.8537 - val\_precision: 0.7557 - val\_recall: 0.7081 - learning\_rate: 1.0000e-04

Epoch 18/25

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 494ms/step - accuracy: 0.8248 - auc: 0.9468 - loss: 0.6514 - precision: 0.8454 - recall: 0.8018

Epoch 18: val\_accuracy did not improve from 0.77207

**129/129** ━━━━━━━━━━━━━━━━━━━━ **82s** 573ms/step - accuracy: 0.8248 - auc: 0.9468 - loss: 0.6515 - precision: 0.8454 - recall: 0.8018 - val\_accuracy: 0.7420 - val\_auc: 0.8985 - val\_loss: 0.8524 - val\_precision: 0.7571 - val\_recall: 0.7226 - learning\_rate: 1.0000e-04

Epoch 19/25

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 497ms/step - accuracy: 0.8347 - auc: 0.9528 - loss: 0.6414 - precision: 0.8517 - recall: 0.8168

Epoch 19: ReduceLROnPlateau reducing learning rate to 1.9999999494757503e-05.

Epoch 19: val\_accuracy did not improve from 0.77207

**129/129** ━━━━━━━━━━━━━━━━━━━━ **86s** 604ms/step - accuracy: 0.8347 - auc: 0.9528 - loss: 0.6413 - precision: 0.8517 - recall: 0.8168 - val\_accuracy: 0.7468 - val\_auc: 0.9072 - val\_loss: 0.8934 - val\_precision: 0.7583 - val\_recall: 0.7333 - learning\_rate: 1.0000e-04

Epoch 20/25

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 502ms/step - accuracy: 0.8800 - auc: 0.9731 - loss: 0.5402 - precision: 0.8943 - recall: 0.8660

Epoch 20: val\_accuracy improved from 0.77207 to 0.81086, saving model to Alzheimer\_Detection/models/vgg16\_best.keras

**129/129** ━━━━━━━━━━━━━━━━━━━━ **79s** 577ms/step - accuracy: 0.8800 - auc: 0.9731 - loss: 0.5402 - precision: 0.8943 - recall: 0.8661 - val\_accuracy: 0.8109 - val\_auc: 0.9457 - val\_loss: 0.6852 - val\_precision: 0.8279 - val\_recall: 0.7934 - learning\_rate: 2.0000e-05

Epoch 21/25

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 497ms/step - accuracy: 0.8900 - auc: 0.9772 - loss: 0.5247 - precision: 0.9050 - recall: 0.8716

Epoch 21: val\_accuracy improved from 0.81086 to 0.83026, saving model to Alzheimer\_Detection/models/vgg16\_best.keras

**129/129** ━━━━━━━━━━━━━━━━━━━━ **81s** 573ms/step - accuracy: 0.8901 - auc: 0.9772 - loss: 0.5246 - precision: 0.9050 - recall: 0.8716 - val\_accuracy: 0.8303 - val\_auc: 0.9518 - val\_loss: 0.6549 - val\_precision: 0.8434 - val\_recall: 0.8147 - learning\_rate: 2.0000e-05

Epoch 22/25

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 492ms/step - accuracy: 0.8947 - auc: 0.9807 - loss: 0.5067 - precision: 0.9099 - recall: 0.8800

Epoch 22: val\_accuracy improved from 0.83026 to 0.84966, saving model to Alzheimer\_Detection/models/vgg16\_best.keras

**129/129** ━━━━━━━━━━━━━━━━━━━━ **74s** 568ms/step - accuracy: 0.8947 - auc: 0.9807 - loss: 0.5067 - precision: 0.9099 - recall: 0.8800 - val\_accuracy: 0.8497 - val\_auc: 0.9621 - val\_loss: 0.6163 - val\_precision: 0.8675 - val\_recall: 0.8322 - learning\_rate: 2.0000e-05

Epoch 23/25

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 494ms/step - accuracy: 0.9086 - auc: 0.9835 - loss: 0.4923 - precision: 0.9210 - recall: 0.8948

Epoch 23: val\_accuracy did not improve from 0.84966

**129/129** ━━━━━━━━━━━━━━━━━━━━ **81s** 564ms/step - accuracy: 0.9086 - auc: 0.9835 - loss: 0.4923 - precision: 0.9210 - recall: 0.8948 - val\_accuracy: 0.8109 - val\_auc: 0.9450 - val\_loss: 0.6995 - val\_precision: 0.8273 - val\_recall: 0.7992 - learning\_rate: 2.0000e-05

Epoch 24/25

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 502ms/step - accuracy: 0.8969 - auc: 0.9799 - loss: 0.5200 - precision: 0.9121 - recall: 0.8852

Epoch 24: val\_accuracy improved from 0.84966 to 0.86809, saving model to Alzheimer\_Detection/models/vgg16\_best.keras

**129/129** ━━━━━━━━━━━━━━━━━━━━ **79s** 613ms/step - accuracy: 0.8970 - auc: 0.9800 - loss: 0.5199 - precision: 0.9121 - recall: 0.8853 - val\_accuracy: 0.8681 - val\_auc: 0.9669 - val\_loss: 0.5987 - val\_precision: 0.8771 - val\_recall: 0.8516 - learning\_rate: 2.0000e-05

Epoch 25/25

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 498ms/step - accuracy: 0.9083 - auc: 0.9834 - loss: 0.4840 - precision: 0.9195 - recall: 0.8934

Epoch 25: val\_accuracy did not improve from 0.86809

**129/129** ━━━━━━━━━━━━━━━━━━━━ **74s** 574ms/step - accuracy: 0.9083 - auc: 0.9834 - loss: 0.4840 - precision: 0.9195 - recall: 0.8934 - val\_accuracy: 0.8312 - val\_auc: 0.9533 - val\_loss: 0.6689 - val\_precision: 0.8422 - val\_recall: 0.8128 - learning\_rate: 2.0000e-05

Restoring model weights from the end of the best epoch: 24.

Starting fine-tuning phase...

Epoch 26/50

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 584ms/step - accuracy: 0.9125 - auc\_1: 0.9855 - loss: 0.4796 - precision\_1: 0.9254 - recall\_1: 0.9023

Epoch 26: val\_accuracy improved from -inf to 0.83511, saving model to Alzheimer\_Detection/models/vgg16\_ft\_best.keras

**129/129** ━━━━━━━━━━━━━━━━━━━━ **102s** 678ms/step - accuracy: 0.9125 - auc\_1: 0.9855 - loss: 0.4796 - precision\_1: 0.9255 - recall\_1: 0.9023 - val\_accuracy: 0.8351 - val\_auc\_1: 0.9545 - val\_loss: 0.6542 - val\_precision\_1: 0.8511 - val\_recall\_1: 0.8206 - learning\_rate: 5.0000e-06

Epoch 27/50

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 520ms/step - accuracy: 0.9254 - auc\_1: 0.9878 - loss: 0.4704 - precision\_1: 0.9333 - recall\_1: 0.9141

Epoch 27: val\_accuracy improved from 0.83511 to 0.85451, saving model to Alzheimer\_Detection/models/vgg16\_ft\_best.keras

**129/129** ━━━━━━━━━━━━━━━━━━━━ **77s** 596ms/step - accuracy: 0.9254 - auc\_1: 0.9877 - loss: 0.4705 - precision\_1: 0.9333 - recall\_1: 0.9140 - val\_accuracy: 0.8545 - val\_auc\_1: 0.9611 - val\_loss: 0.6331 - val\_precision\_1: 0.8692 - val\_recall\_1: 0.8380 - learning\_rate: 5.0000e-06

Epoch 28/50

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 525ms/step - accuracy: 0.9242 - auc\_1: 0.9875 - loss: 0.4577 - precision\_1: 0.9339 - recall\_1: 0.9082

Epoch 28: val\_accuracy improved from 0.85451 to 0.85645, saving model to Alzheimer\_Detection/models/vgg16\_ft\_best.keras

**129/129** ━━━━━━━━━━━━━━━━━━━━ **82s** 638ms/step - accuracy: 0.9242 - auc\_1: 0.9875 - loss: 0.4577 - precision\_1: 0.9339 - recall\_1: 0.9082 - val\_accuracy: 0.8565 - val\_auc\_1: 0.9623 - val\_loss: 0.6326 - val\_precision\_1: 0.8689 - val\_recall\_1: 0.8487 - learning\_rate: 5.0000e-06

Epoch 29/50

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 519ms/step - accuracy: 0.9268 - auc\_1: 0.9895 - loss: 0.4485 - precision\_1: 0.9360 - recall\_1: 0.9134

Epoch 29: val\_accuracy improved from 0.85645 to 0.87488, saving model to Alzheimer\_Detection/models/vgg16\_ft\_best.keras

**129/129** ━━━━━━━━━━━━━━━━━━━━ **136s** 595ms/step - accuracy: 0.9268 - auc\_1: 0.9895 - loss: 0.4486 - precision\_1: 0.9360 - recall\_1: 0.9134 - val\_accuracy: 0.8749 - val\_auc\_1: 0.9689 - val\_loss: 0.5968 - val\_precision\_1: 0.8826 - val\_recall\_1: 0.8681 - learning\_rate: 5.0000e-06

Epoch 30/50

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 518ms/step - accuracy: 0.9234 - auc\_1: 0.9881 - loss: 0.4562 - precision\_1: 0.9355 - recall\_1: 0.9124

Epoch 30: val\_accuracy did not improve from 0.87488

**129/129** ━━━━━━━━━━━━━━━━━━━━ **81s** 625ms/step - accuracy: 0.9233 - auc\_1: 0.9881 - loss: 0.4562 - precision\_1: 0.9355 - recall\_1: 0.9123 - val\_accuracy: 0.8739 - val\_auc\_1: 0.9706 - val\_loss: 0.5874 - val\_precision\_1: 0.8816 - val\_recall\_1: 0.8594 - learning\_rate: 5.0000e-06

Epoch 31/50

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 521ms/step - accuracy: 0.9247 - auc\_1: 0.9894 - loss: 0.4519 - precision\_1: 0.9368 - recall\_1: 0.9134

Epoch 31: val\_accuracy did not improve from 0.87488

**129/129** ━━━━━━━━━━━━━━━━━━━━ **81s** 628ms/step - accuracy: 0.9248 - auc\_1: 0.9894 - loss: 0.4518 - precision\_1: 0.9369 - recall\_1: 0.9135 - val\_accuracy: 0.8293 - val\_auc\_1: 0.9531 - val\_loss: 0.6626 - val\_precision\_1: 0.8371 - val\_recall\_1: 0.8177 - learning\_rate: 5.0000e-06

Epoch 32/50

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 521ms/step - accuracy: 0.9204 - auc\_1: 0.9884 - loss: 0.4557 - precision\_1: 0.9306 - recall\_1: 0.9101

Epoch 32: val\_accuracy did not improve from 0.87488

**129/129** ━━━━━━━━━━━━━━━━━━━━ **76s** 591ms/step - accuracy: 0.9205 - auc\_1: 0.9884 - loss: 0.4557 - precision\_1: 0.9306 - recall\_1: 0.9102 - val\_accuracy: 0.8312 - val\_auc\_1: 0.9599 - val\_loss: 0.6415 - val\_precision\_1: 0.8460 - val\_recall\_1: 0.8206 - learning\_rate: 5.0000e-06

Epoch 33/50

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 519ms/step - accuracy: 0.9294 - auc\_1: 0.9903 - loss: 0.4478 - precision\_1: 0.9377 - recall\_1: 0.9181

Epoch 33: val\_accuracy did not improve from 0.87488

**129/129** ━━━━━━━━━━━━━━━━━━━━ **81s** 626ms/step - accuracy: 0.9294 - auc\_1: 0.9903 - loss: 0.4477 - precision\_1: 0.9378 - recall\_1: 0.9181 - val\_accuracy: 0.8632 - val\_auc\_1: 0.9669 - val\_loss: 0.6087 - val\_precision\_1: 0.8765 - val\_recall\_1: 0.8535 - learning\_rate: 5.0000e-06

Epoch 34/50

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 519ms/step - accuracy: 0.9414 - auc\_1: 0.9926 - loss: 0.4282 - precision\_1: 0.9489 - recall\_1: 0.9335

Epoch 34: val\_accuracy did not improve from 0.87488

**129/129** ━━━━━━━━━━━━━━━━━━━━ **76s** 591ms/step - accuracy: 0.9413 - auc\_1: 0.9925 - loss: 0.4283 - precision\_1: 0.9488 - recall\_1: 0.9334 - val\_accuracy: 0.8749 - val\_auc\_1: 0.9679 - val\_loss: 0.5980 - val\_precision\_1: 0.8811 - val\_recall\_1: 0.8623 - learning\_rate: 5.0000e-06

Epoch 35/50

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 520ms/step - accuracy: 0.9434 - auc\_1: 0.9914 - loss: 0.4305 - precision\_1: 0.9507 - recall\_1: 0.9338

Epoch 35: val\_accuracy did not improve from 0.87488

**129/129** ━━━━━━━━━━━━━━━━━━━━ **86s** 627ms/step - accuracy: 0.9433 - auc\_1: 0.9914 - loss: 0.4305 - precision\_1: 0.9507 - recall\_1: 0.9337 - val\_accuracy: 0.8468 - val\_auc\_1: 0.9625 - val\_loss: 0.6455 - val\_precision\_1: 0.8539 - val\_recall\_1: 0.8390 - learning\_rate: 5.0000e-06

Epoch 36/50

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 527ms/step - accuracy: 0.9416 - auc\_1: 0.9928 - loss: 0.4203 - precision\_1: 0.9506 - recall\_1: 0.9335

Epoch 36: ReduceLROnPlateau reducing learning rate to 2.499999936844688e-06.

Epoch 36: val\_accuracy did not improve from 0.87488

**129/129** ━━━━━━━━━━━━━━━━━━━━ **78s** 597ms/step - accuracy: 0.9416 - auc\_1: 0.9929 - loss: 0.4202 - precision\_1: 0.9506 - recall\_1: 0.9335 - val\_accuracy: 0.8632 - val\_auc\_1: 0.9669 - val\_loss: 0.6009 - val\_precision\_1: 0.8740 - val\_recall\_1: 0.8545 - learning\_rate: 5.0000e-06

Epoch 37/50

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 518ms/step - accuracy: 0.9523 - auc\_1: 0.9945 - loss: 0.4043 - precision\_1: 0.9600 - recall\_1: 0.9442

Epoch 37: val\_accuracy improved from 0.87488 to 0.87585, saving model to Alzheimer\_Detection/models/vgg16\_ft\_best.keras

**129/129** ━━━━━━━━━━━━━━━━━━━━ **77s** 594ms/step - accuracy: 0.9523 - auc\_1: 0.9945 - loss: 0.4044 - precision\_1: 0.9599 - recall\_1: 0.9442 - val\_accuracy: 0.8758 - val\_auc\_1: 0.9700 - val\_loss: 0.5896 - val\_precision\_1: 0.8792 - val\_recall\_1: 0.8681 - learning\_rate: 2.5000e-06

Epoch 38/50

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 519ms/step - accuracy: 0.9511 - auc\_1: 0.9948 - loss: 0.4056 - precision\_1: 0.9583 - recall\_1: 0.9442

Epoch 38: val\_accuracy did not improve from 0.87585

**129/129** ━━━━━━━━━━━━━━━━━━━━ **81s** 589ms/step - accuracy: 0.9511 - auc\_1: 0.9947 - loss: 0.4057 - precision\_1: 0.9583 - recall\_1: 0.9441 - val\_accuracy: 0.8710 - val\_auc\_1: 0.9728 - val\_loss: 0.5716 - val\_precision\_1: 0.8910 - val\_recall\_1: 0.8642 - learning\_rate: 2.5000e-06

Epoch 39/50

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 519ms/step - accuracy: 0.9494 - auc\_1: 0.9938 - loss: 0.4181 - precision\_1: 0.9568 - recall\_1: 0.9406

Epoch 39: val\_accuracy did not improve from 0.87585

**129/129** ━━━━━━━━━━━━━━━━━━━━ **76s** 590ms/step - accuracy: 0.9494 - auc\_1: 0.9938 - loss: 0.4180 - precision\_1: 0.9568 - recall\_1: 0.9406 - val\_accuracy: 0.8758 - val\_auc\_1: 0.9731 - val\_loss: 0.5726 - val\_precision\_1: 0.8850 - val\_recall\_1: 0.8661 - learning\_rate: 2.5000e-06

Epoch 40/50

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 521ms/step - accuracy: 0.9552 - auc\_1: 0.9956 - loss: 0.3992 - precision\_1: 0.9610 - recall\_1: 0.9456

Epoch 40: val\_accuracy improved from 0.87585 to 0.87876, saving model to Alzheimer\_Detection/models/vgg16\_ft\_best.keras

**129/129** ━━━━━━━━━━━━━━━━━━━━ **82s** 634ms/step - accuracy: 0.9552 - auc\_1: 0.9956 - loss: 0.3992 - precision\_1: 0.9610 - recall\_1: 0.9456 - val\_accuracy: 0.8788 - val\_auc\_1: 0.9709 - val\_loss: 0.5778 - val\_precision\_1: 0.8839 - val\_recall\_1: 0.8710 - learning\_rate: 2.5000e-06

Epoch 41/50

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 519ms/step - accuracy: 0.9541 - auc\_1: 0.9949 - loss: 0.4050 - precision\_1: 0.9600 - recall\_1: 0.9462

Epoch 41: val\_accuracy improved from 0.87876 to 0.88458, saving model to Alzheimer\_Detection/models/vgg16\_ft\_best.keras

**129/129** ━━━━━━━━━━━━━━━━━━━━ **77s** 595ms/step - accuracy: 0.9541 - auc\_1: 0.9949 - loss: 0.4051 - precision\_1: 0.9599 - recall\_1: 0.9462 - val\_accuracy: 0.8846 - val\_auc\_1: 0.9742 - val\_loss: 0.5642 - val\_precision\_1: 0.8987 - val\_recall\_1: 0.8778 - learning\_rate: 2.5000e-06

Epoch 42/50

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 519ms/step - accuracy: 0.9528 - auc\_1: 0.9954 - loss: 0.4052 - precision\_1: 0.9595 - recall\_1: 0.9472

Epoch 42: val\_accuracy did not improve from 0.88458

**129/129** ━━━━━━━━━━━━━━━━━━━━ **77s** 597ms/step - accuracy: 0.9529 - auc\_1: 0.9954 - loss: 0.4052 - precision\_1: 0.9595 - recall\_1: 0.9472 - val\_accuracy: 0.8623 - val\_auc\_1: 0.9688 - val\_loss: 0.5902 - val\_precision\_1: 0.8709 - val\_recall\_1: 0.8506 - learning\_rate: 2.5000e-06

Epoch 43/50

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 520ms/step - accuracy: 0.9492 - auc\_1: 0.9945 - loss: 0.4050 - precision\_1: 0.9541 - recall\_1: 0.9389

Epoch 43: val\_accuracy did not improve from 0.88458

**129/129** ━━━━━━━━━━━━━━━━━━━━ **82s** 594ms/step - accuracy: 0.9493 - auc\_1: 0.9945 - loss: 0.4050 - precision\_1: 0.9542 - recall\_1: 0.9390 - val\_accuracy: 0.8836 - val\_auc\_1: 0.9738 - val\_loss: 0.5664 - val\_precision\_1: 0.8922 - val\_recall\_1: 0.8749 - learning\_rate: 2.5000e-06

Epoch 44/50

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 525ms/step - accuracy: 0.9595 - auc\_1: 0.9961 - loss: 0.3954 - precision\_1: 0.9647 - recall\_1: 0.9520

Epoch 44: val\_accuracy did not improve from 0.88458

**129/129** ━━━━━━━━━━━━━━━━━━━━ **82s** 595ms/step - accuracy: 0.9596 - auc\_1: 0.9961 - loss: 0.3954 - precision\_1: 0.9647 - recall\_1: 0.9520 - val\_accuracy: 0.8788 - val\_auc\_1: 0.9727 - val\_loss: 0.5726 - val\_precision\_1: 0.8858 - val\_recall\_1: 0.8729 - learning\_rate: 2.5000e-06

Epoch 45/50

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 518ms/step - accuracy: 0.9572 - auc\_1: 0.9950 - loss: 0.3978 - precision\_1: 0.9603 - recall\_1: 0.9489

Epoch 45: val\_accuracy improved from 0.88458 to 0.89040, saving model to Alzheimer\_Detection/models/vgg16\_ft\_best.keras

**129/129** ━━━━━━━━━━━━━━━━━━━━ **82s** 594ms/step - accuracy: 0.9572 - auc\_1: 0.9950 - loss: 0.3978 - precision\_1: 0.9604 - recall\_1: 0.9489 - val\_accuracy: 0.8904 - val\_auc\_1: 0.9769 - val\_loss: 0.5441 - val\_precision\_1: 0.8960 - val\_recall\_1: 0.8778 - learning\_rate: 2.5000e-06

Epoch 46/50

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 521ms/step - accuracy: 0.9519 - auc\_1: 0.9955 - loss: 0.4058 - precision\_1: 0.9589 - recall\_1: 0.9482

Epoch 46: val\_accuracy did not improve from 0.89040

**129/129** ━━━━━━━━━━━━━━━━━━━━ **87s** 634ms/step - accuracy: 0.9519 - auc\_1: 0.9955 - loss: 0.4058 - precision\_1: 0.9589 - recall\_1: 0.9482 - val\_accuracy: 0.8894 - val\_auc\_1: 0.9768 - val\_loss: 0.5457 - val\_precision\_1: 0.8982 - val\_recall\_1: 0.8817 - learning\_rate: 2.5000e-06

Epoch 47/50

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 520ms/step - accuracy: 0.9607 - auc\_1: 0.9958 - loss: 0.3955 - precision\_1: 0.9661 - recall\_1: 0.9575

Epoch 47: val\_accuracy did not improve from 0.89040

**129/129** ━━━━━━━━━━━━━━━━━━━━ **136s** 593ms/step - accuracy: 0.9607 - auc\_1: 0.9958 - loss: 0.3955 - precision\_1: 0.9661 - recall\_1: 0.9575 - val\_accuracy: 0.8758 - val\_auc\_1: 0.9734 - val\_loss: 0.5652 - val\_precision\_1: 0.8901 - val\_recall\_1: 0.8642 - learning\_rate: 2.5000e-06

Epoch 48/50

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 520ms/step - accuracy: 0.9651 - auc\_1: 0.9971 - loss: 0.3880 - precision\_1: 0.9703 - recall\_1: 0.9594

Epoch 48: val\_accuracy did not improve from 0.89040

**129/129** ━━━━━━━━━━━━━━━━━━━━ **83s** 598ms/step - accuracy: 0.9651 - auc\_1: 0.9970 - loss: 0.3880 - precision\_1: 0.9703 - recall\_1: 0.9593 - val\_accuracy: 0.8797 - val\_auc\_1: 0.9731 - val\_loss: 0.5714 - val\_precision\_1: 0.8847 - val\_recall\_1: 0.8710 - learning\_rate: 2.5000e-06

Epoch 49/50

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 521ms/step - accuracy: 0.9592 - auc\_1: 0.9967 - loss: 0.3878 - precision\_1: 0.9616 - recall\_1: 0.9518

Epoch 49: val\_accuracy did not improve from 0.89040

**129/129** ━━━━━━━━━━━━━━━━━━━━ **81s** 594ms/step - accuracy: 0.9592 - auc\_1: 0.9967 - loss: 0.3878 - precision\_1: 0.9617 - recall\_1: 0.9518 - val\_accuracy: 0.8826 - val\_auc\_1: 0.9750 - val\_loss: 0.5591 - val\_precision\_1: 0.8922 - val\_recall\_1: 0.8749 - learning\_rate: 2.5000e-06

Epoch 50/50

**129/129** ━━━━━━━━━━━━━━━━━━━━ **0s** 517ms/step - accuracy: 0.9652 - auc\_1: 0.9974 - loss: 0.3798 - precision\_1: 0.9699 - recall\_1: 0.9575

Epoch 50: val\_accuracy did not improve from 0.89040

**129/129** ━━━━━━━━━━━━━━━━━━━━ **86s** 624ms/step - accuracy: 0.9652 - auc\_1: 0.9974 - loss: 0.3799 - precision\_1: 0.9698 - recall\_1: 0.9575 - val\_accuracy: 0.8758 - val\_auc\_1: 0.9733 - val\_loss: 0.5695 - val\_precision\_1: 0.8863 - val\_recall\_1: 0.8691 - learning\_rate: 2.5000e-06

Restoring model weights from the end of the best epoch: 45.

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AI-generated content may be incorrect.

**33/33** ━━━━━━━━━━━━━━━━━━━━ **6s** 165ms/step - accuracy: 0.8812 - auc\_1: 0.9686 - loss: 0.5772 - precision\_1: 0.8902 - recall\_1: 0.8726

Final validation results: {'loss': 0.5441412329673767, 'compile\_metrics': 0.8903976678848267}

/usr/local/lib/python3.11/dist-packages/keras/src/models/functional.py:237: UserWarning: The structure of `inputs` doesn't match the expected structure.

Expected: ['keras\_tensor']

Received: inputs=Tensor(shape=(32, 224, 224, 3))

warnings.warn(msg)

**32/33** ━━━━━━━━━━━━━━━━━━━━ **0s** 168ms/step

/usr/local/lib/python3.11/dist-packages/keras/src/models/functional.py:237: UserWarning: The structure of `inputs` doesn't match the expected structure.

Expected: ['keras\_tensor']

Received: inputs=Tensor(shape=(None, 224, 224, 3))

warnings.warn(msg)

**33/33** ━━━━━━━━━━━━━━━━━━━━ **7s** 186ms/step

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AI-generated content may be incorrect.

Classification Report:

precision recall f1-score support

AD 0.84 0.88 0.86 225

CMI 0.93 0.90 0.91 518

CN 0.86 0.89 0.87 288

accuracy 0.89 1031

macro avg 0.88 0.89 0.88 1031

weighted avg 0.89 0.89 0.89 1031

---------------------------------------------------------------------------