# contents

preface xiii acknowledgments about this book xvi about the author xix about the cover illustration  $\chi\chi$ 

## PARTI DEEP LEARNING FOUNDATION

# Welcome to computer vision 3

- Computer vision 4
  - What is visual perception? 5 Vision systems 5 Sensing devices 7 • Interpreting devices 8
- 1.2 Applications of computer vision 10
  - Image classification 10 Object detection and localization 12 Generating art (style transfer) 12 • Creating images 13 Face recognition 15 Image recommendation system 15
- Computer vision pipeline: The big picture 17 1.3
- - Image as functions 19 How computers see images 21

1.5	Image preprocessing 23
	Converting color images to grayscale to reduce computation complexity 23
1.6	Feature extraction 27
	What is a feature in computer vision? 27 • What makes a good (useful) feature? 28 • Extracting features (handcrafted vs. automatic extracting) 31
1.7	Classifier learning algorithm 33
Deep	learning and neural networks 36
2.1	Understanding perceptrons 37
	What is a perceptron? 38 • How does the perceptron learn? 43 Is one neuron enough to solve complex problems? 43
2.2	Multilayer perceptrons 45
	Multilayer perceptron architecture 46 • What are hidden layers? 47 • How many layers, and how many nodes in each layer? 47 • Some takeaways from this section 50
2.3	Activation functions 51
	Linear transfer function 53 • Heaviside step function (binary classifier) 54 • Sigmoid/logistic function 55 • Softmax function 57 • Hyperbolic tangent function (tanh) 58 Rectified linear unit 58 • Leaky ReLU 59
2.4	The feedforward process 62
	Feedforward calculations 64 • Feature learning 65
2.5	Error functions 68
	What is the error function? 69 • Why do we need an error function? 69 • Error is always positive 69 • Mean square error 70 • Cross-entropy 71 • A final note on errors and weights 72
2.6	Optimization algorithms 74
	What is optimization? 74 • Batch gradient descent 77 Stochastic gradient descent 83 • Mini-batch gradient descent 84 Gradient descent takeaways 85

What is backpropagation? 87 • Backpropagation takeaways

Backpropagation 86

Conve	olutional neural networks 92
3.1	Image classification using MLP 93
	Input layer 94 • Hidden layers 96 • Output layer 96 Putting it all together 97 • Drawbacks of MLPs for processing images 99
3.2	CNN architecture 102
	The big picture 102 • A closer look at feature extraction 104 A closer look at classification 105
3.3	Basic components of a CNN 106
	Convolutional layers 107 • Pooling layers or subsampling 11 Fully connected layers 119
3.4	Image classification using CNNs 121
	Building the model architecture 121 • Number of parameters (weights) 123
3.5	Adding dropout layers to avoid overfitting 124
	What is overfitting? 125 • What is a dropout layer? 125 Why do we need dropout layers? 126 • Where does the dropout layer go in the CNN architecture? 127
3.6	Convolution over color images (3D images) 128
	How do we perform a convolution on a color image? 129 What happens to the computational complexity? 130
3.7	Project: Image classification for color images 133
Struct	turing DL projects and hyperparameter tuning 145
4.1	Defining performance metrics 146
	Is accuracy the best metric for evaluating a model? 147  Confusion matrix 147 • Precision and recall 148  F-score 149
4.2	Designing a baseline model 149
4.3	Getting your data ready for training 151
	Splitting your data for train/validation/test 151  Data preprocessing 153
4.4	Evaluating the model and interpreting its
	performance 156
	Diagnosing overfitting and underfitting 156 • Plotting the learning curves 158 • Exercise: Building, training, and evaluating a network 159

4.5	Improving the network and tuning hyperparameters 162
	Collecting more data vs. tuning hyperparameters 162  Parameters vs. hyperparameters 163 • Neural network  hyperparameters 163 • Network architecture 164
4.6	Learning and optimization 166
	Learning rate and decay schedule 166 • A systematic approach to find the optimal learning rate 169 • Learning rate decay and adaptive learning 170 • Mini-batch size 171
4.7	Optimization algorithms 174
	Gradient descent with momentum 174 • Adam 175 Number of epochs and early stopping criteria 175 • Early stopping 177
4.8	Regularization techniques to avoid overfitting 177
	L2 regularization 177 • Dropout layers 179  Data augmentation 180
4.9	Batch normalization 181
	The covariate shift problem 181 • Covariate shift in neural networks 182 • How does batch normalization work? 183  Batch normalization implementation in Keras 184 • Batch normalization recap 185
4.10	Project: Achieve high accuracy on image
	classification 185
L'ART 2 IMAG	E CLASSIFICATION AND DETECTION193
Adva	nced CNN architectures 195
5.1	CNN design patterns 197
5.2	LeNet-5 199
	LeNet architecture 199 • LeNet-5 implementation in Keras 200 Setting up the learning hyperparameters 202 • LeNet performance on the MNIST dataset 203
5.3	AlexNet 203
	AlexNet architecture 205 • Novel features of AlexNet 205 AlexNet implementation in Keras 207 • Setting up the learning

Novel features of VGGNet 212 • VGGNet configurations 213 Learning hyperparameters 216 • VGGNet performance 216

hyperparameters 210 • AlexNet performance 211

VGGNet 212

#### 5.5 Inception and GoogLeNet 217

Novel features of Inception 217 • Inception module: Naive version 218 • Inception module with dimensionality reduction 220 • Inception architecture 223 • GoogLeNet in Keras 225 • Learning hyperparameters 229 • Inception performance on the CIFAR dataset 229

#### 5.6 ResNet 230

Novel features of ResNet 230 • Residual blocks 233 • ResNet implementation in Keras 235 • Learning hyperparameters 238 ResNet performance on the CIFAR dataset 238

#### Transfer learning 240

- 6.1 What problems does transfer learning solve? 241
- 6.2 What is transfer learning? 243
- 6.3 How transfer learning works 250

  How do neural networks learn features? 252 Transferability of features extracted at later layers 254
- 6.4 Transfer learning approaches 254

  Using a pretrained network as a classifier 254 Using a pretrained network as a feature extractor 256 Fine-tuning 258
- 6.5 Choosing the appropriate level of transfer learning 260

  Scenario 1: Target dataset is small and similar to the source
  dataset 260 Scenario 2: Target dataset is large and similar
  to the source dataset 261 Scenario 3: Target dataset is small and
  different from the source dataset 261 Scenario 4: Target dataset
  is large and different from the source dataset 261 Recap of the
  transfer learning scenarios 262
- 6.6 Open source datasets 262

  MNIST 263 Fashion-MNIST 264 CIFAR 264

  ImageNet 265 MS COCO 266 Google Open Images 267

  Kaggle 267
- 6.7 Project 1: A pretrained network as a feature extractor 268
- 6.8 Project 2: Fine-tuning 274

#### Object detection with R-CNN, SSD, and YOLO 283

7.1 General object detection framework 285

Region proposals 286 • Network predictions 287

Non-maximum suppression (NMS) 288 • Object-detector evaluation metrics 289

7.2	Region-based convolutional neural networks			
	(R-CNNs) 292			
	R-CNN 293 • Fast R-CNN 297 • Faster R-CNN	300		
	Recap of the R-CNN family 308			

- 7.3 Single-shot detector (SSD) 310

  High-level SSD architecture 311 Base network 313

  Multi-scale feature layers 315 Non-maximum suppression 319
- 7.4 You only look once (YOLO) 320

  How YOLOv3 works 321 YOLOv3 architecture 324
- 7.5 Project: Train an SSD network in a self-driving car application 326

Step 1: Build the model 328 • Step 2: Model configuration 329 Step 3: Create the model 330 • Step 4: Load the data 331

Step 5: Train the model 333 • Step 6: Visualize the loss 334

Step 7: Make predictions 335

#### PART 3 GENERATIVE MODELS AND VISUAL EMBEDDINGS... 339

## Generative adversarial networks (GANs) 341

8.1 GAN architecture 343

Deep convolutional GANs (DCGANs) 345 • The discriminator model 345 • The generator model 348 • Training the GAN 351 • GAN minimax function 354

- 8.2 Evaluating GAN models 357

  Inception score 358 Fréchet inception distance (FID) 358

  Which evaluation scheme to use 358
- 8.3 Popular GAN applications 359

  Text-to-photo synthesis 359 Image-to-image translation (Pix2Pix GAN) 360 Image super-resolution GAN (SRGAN) 361

  Ready to get your hands dirty? 362
- 8.4 Project: Building your own GAN 362

### DeepDream and neural style transfer 374

9.1 How convolutional neural networks see the world 375

Revisiting how neural networks work 376 • Visualizing CNN
features 377 • Implementing a feature visualizer 381

- 9.2 DeepDream 384

  How the DeepDream algorithm works 385 DeepDream implementation in Keras 387
- 9.3 Neural style transfer 392

  Content loss 393 Style loss 396 Total variance loss 397

  Network training 397

### Visual embeddings 400

- 10.1 Applications of visual embeddings 402

  Face recognition 402 Image recommendation systems 403

  Object re-identification 405
- 10.2 Learning embedding 406
- 10.3 Loss functions 407

  Problem setup and formalization 408 Cross-entropy loss 409

  Contrastive loss 410 Triplet loss 411 Naive implementation and runtime analysis of losses 412
- 10.4 Mining informative data 414

  Dataloader 414 Informative data mining: Finding useful triplets 416 Batch all (BA) 419 Batch hard (BH) 419

  Batch weighted (BW) 421 Batch sample (BS) 421
- 10.5 Project: Train an embedding network 423

  Fashion: Get me items similar to this 424 Vehicle
  re-identification 424 Implementation 426 Testing
  a trained model 427
- 10.6 Pushing the boundaries of current accuracy 431
- appendix A Getting set up 437 index 445