A

()

Accumulator cells 800 Acquisition. See Image: acquisition Activation functions activation value, 1091 hyperbolic tangent, 1091 of perceptron, 1083 ReLU, 1091 sigmoid, 1090 Active contours definition, 878 evolving fronts, 878, 904 evolving interfaces, 878, 904 explicit representation, 878 implicit representation, 902 level curve, defined, 903 level sets. See Active contours (level sets) snakes. See Active contours (snakes) Active contours (level sets) comparisons with snakes, 934 convergence, 909 curvature of implicit functions, 912 derivation of iterative level set equation, 908 derivation of level set equation, 904 fast implementation, 938 forces, 917, 922, 927 implicit representation, 902 initializing level set functions, 913 interface, 902 iterative level set equation, 911 leakage, 924, 937, 943 level set equation, 907 level set function, definition, 903 narrow band, 943 reinitializing, 913 segmentation examples, 921-942 signed distance functions, 913, 915 specifying level set functions, 913 speed function, 906 stopping function, 923 upwind derivatives, 910 Active contours (snakes) accelerated convergence, 900 compared to level sets, 934 comparison of GVF and MOG force fields, 898 derivation of fundamental equation, 880 energy, 880 explicit representation, 878 forces, 883, 888, 896 fundamental snake equation, 883 GVF, 896 iterative solution in matrix form, 887 iterative solution of snake equation, 883 parametric representation, 878 reparameterization, 893, 948 rubber band analogy, 880 segmentation examples, 890-903 Adaptive filters. See Spatial filters Adjacency, 63, 125 Affine transformations, See Geometric transformations

Aliasing, 280 aliased pair, 267 anti-aliasing, 268 anti-aliasing filtering, 282 examples of, 269, 280, 282, 284 in 1-D functions, 267 in images, 279 moiré patterns, 284 spatial, 279 temporal, 280 Angiogram, 11, 144 Apodizing function, 303. See also Filtering window Arctangent, 254 Arithmetic coding, 617 Artificial intelligence, 2 Artificial neurons. See also Neural networks activation function, 1090 activation value, 1091 interconnecting, 1091 model, 1089 ReLU, 1091 schematic, 1090 sigmoid, 1091 sum-of-products computation, 1090 Augmented pattern. See Pattern Autocorrelation, 1061

B

Background flattening, 747. See also Shading correction Backpropagation. See Neural networks Band-limited function, 263, 271, 278. See also Function Bartlane cable system, 3 Basic rectangle, 974 Basis functions in the time-frequency plane, 467 of the cosine transform, 477 of the Fourier transform, 473 of the Haar transform, 492 of the Hartley transform, 474 of the sine transform, 481 of the slant transform, 490 of the Walsh-Hadamard transform, 487 standard, 472 Basis images, 471. See Basis functions Basis vectors, 468. See also Basis functions biorthonormal, 462 complex orthonormal, 461 Bayes classifier. See Bayes classifier Bayes' formula, 102 rule, 102 Bayes classifier. See also Pattern classification as a minimum-distance classifier, 1073 comparison with neural networks, 1110 derivation, 1069 for Gaussian pattern classes, 1071 special cases, 1073 Between-class variance, 810, 811

Bias, See Neural networks Bidirectional frame (B-frame), 656 Binomial coefficient, 106 Biorthogonal basis, 453 Biorthonormal basis, 453 Bit-plane decomposition, 145 reconstruction, 146 Bit-plane coding, 631 Bit rate, 606 Blind spot, 33 Block matching, 656 Block transform coding, 632 bit allocation for, 639 selection of transform for, 633 subimage size and, 638 threshold implementation, 641 zonal implementation, 640 BMP compression, 622 Border, 65. See also Boundary inner, outer, 65 Boundary. See also Border definition, 65 extraction using fuzzy sets, 236 following, 956 outer, 957 resampling, 959 tracing. See Boundary following Boundary descriptors, 974 basic rectangle, 974 bounding box, 974 diameter, 974 eccentricity, 974 Fourier descriptors, 977 longest chord, 974 major axis, 974 shape numbers, 976 statistical moments, 981 tortuosity, 974 Bounding box, 974 Brightness, 530 Bubble chamber, 871

C

Cartesian product, 79 Cascade algorithm, 527 CAT. See Computed tomography (CT) CCITT, 607 CCITT compression, 624 Ceiling function, 52, 192, 789 Cellular complex, 964–967 Center ray, 435 Central Limit Theorem, 118 Chain codes first difference, 959 Freeman, 958 normalized, 959 slope, 961 Classification. See Pattern classification Clustering k-means, 832 seeds, 833

1158 Index

Clustering (cont.) supervised, 832 unsupervised, 832 Code. See also Compression arithmetic, 617 CCITT makeup, 624 CCITT terminating, 624 Elias gamma, 616 Golomb, 612 Gray, 632 Huffman, 604 instantaneous, 611 length, 596 MH (Modified Huffman), 624 MMR (Modified Modified READ), 625, 630 MR (Modified READ), 625 natural binary, 598 Rice, 613 symbols, 596 unary, 613 uniquely decodable, 612 variable-length, 598 words, 596 Codec, 605 Coding. See also Compression N-largest 643 previous pixel, 652 redundancy, 596, 598 symbol-based (or token-based), 628 Cohen-Daubechies-Feauveau biorthogonal wavelets, 513, 671 Color image processing achromatic light, 530 brightness, 530 chromaticity, 533 chromaticity diagram, 534 chromatic light, 530 CMY color model, 538 CMYK color model, 538 CMYK to CMY conversion, 540 CMY to RGB conversion, 539 color circle, 564 color complements, 564 color fundamentals, 530 color "gradient", 580 color image compression, 585 color models, 535 color pixel, 537 color slicing, 566 color transformations, 560 device independent color model, 548 edge detection, 580 full-color image processing, 559 gray level, 530 HSI color model, 541 HSI image segmentation, 576 HSI to RGB conversion, 545 image segmentation, 575 intensity, 530 intensity to color transformations, 553 L*a*b* color model, 549 luminance, 530 noise in color images, 582 primary colors of light, 531 primary colors of pigments, 532 pseudocolor image processing, 550 radiance, 530

()

RGB color cube, 538 RGB color model, 537 RGB color vector, 559, 576 RGB image segmentation, 576 RGB to CMY conversion, 539 RGB to HSI conversion, 543 secondary colors of light, 532 secondary colors of pigments, 532 sharpening, 572 smoothing, 572 tone and color corrections, 567 Complex conjugate, 253 Complex numbers, 253 angle, 254 magnitude, 253 Compression arithmetic coding, 596 bit-plane coding, 631 block diagram, 606 block transform coding, 632 BMP, 622 CCITT, 624 containers for, 607 fidelity criteria, 596 formats for, 607 fundamentals of, 596 Golomb coding, 607 Huffman coding, 607, 609 irrelevant information and, 600 JBIG2, 629 JPEG, 644 JPEG-2000, 674 Lempil-Ziv-Welch (LZW) coding, 620 measuring information for, 607 models for, 605 MPEG-4 AVC (or H.264), 659 predictive coding, 650 quantization and, 659 ratio, 596 run-length coding, 622 spatial redundancy, 659 standards for, 607 symbol-based coding, 628 temporal redundancy, 659 wavelet coding, 670 Computed tomography (CT), 5. See also Tomography Computer, history of, 5 Computerized axial tomography (CAT). See Computed tomography (CT) Conditional average risk. See Bayes classifier Conditional loss. See Bayes classifier Connectionist models. See Neural networks Contour, See Border; See Boundary Contrast. See also Enhancement enhancement radiography, 11 high, 148 manipulation, 140 measure, 993 ratio, 53 simultaneous, 38 stretching, 135, 143 Control (tie) points, 89 Convex. See also Morphological image processing deficiency, 715 digital set, 715 hull, 715

ConvNets. See Neural networks (Convolutional) Convolution (Frequency domain), 259, 274 circular, 274, 299, 302 theorem, 366 tie between spatial and frequency domain filtering, 300 Convolution (Spatial) 2-D, discrete, defined, 183 and correlation, 178 computational advantage with separable kernel, 186 filter, 184 kernel, 184 kernel rotation explained, 183 mask, 184 mechanics of, 179-184 padding, 183 properties, 183 simple example of, 182 size of, 183 tie between spatial and frequency domain filtering, 300 with separable kernel, 185 Convolution theorem, 260, 261, 262, 271, 274, 299, 305, 355, 356, 358 Co-occurrence matrix. See Region descriptors Correlation, 466. See also Matching coefficient, 1061 image, 1061 maximum, 1062 minimum, 1062 range of values, 1062 single-point, 466 template matching. See Matching Correlation (Frequency domain), 303, 304 theorem, 305 Correlation (Spatial) 2-D, discrete, defined, 182 and convolution, 178 mechanics of, 179-182 padding, 182 properties of, 183 size of, 183 Cost function, 1100 Countably infinite, 104, 115 Covariance matrix and shape of PDF, 120 bivariate, 119 defined, 119 diagonal, 1004 eigenvalues of, 1003 eigenvectors of, 1003 Cross-correlation, 1061 Cross-modulation, 506 CT. See Computed tomography (CT) Cumulative distribution function (CDF) continuous, definition, 111 discrete, definition, 105 Gaussian, 113 Curvature, 974 estimation, 1031 local, 1031 obtained using Hessian matrix, 1031 of edges, 1031 Curvature of implicit functions, 912 Cutoff frequency, 320

 (\mathbf{r})

D

()

Data compression, 596. See also Compression Daubechies wavelets, 513, 671 dc component, 296 Decision boundary, 1058 Decision function, 1058 for Bayes' classifier, 1070 for minimum-distance classifier, 1058 for perceptron, 1081 linear, 1081 Deep learning. See Learning Deep neural networks. See Neural networks Deformable models. See Active contours Delta modulation (DM), 663 Denoising, 755. See Image restoration Derivative. See Gradient; See also Laplacian Derivatives. See also Finite differences behavior in images, 776 requirement of approximations, 764 sensitivity to noise, 776 Description regional. See Regional descriptors DFT. See Discrete Fourier transform; Fourier transform Difference of Gaussians, 316 Difference operators. See Gradient operators Differential pulse code modulation (DPCM), 665 Digital angiography, 11 boundary, 65 computer, 5 curve, 64 filter. See Filters image. See Image image, definition of, 2 image representation, 49 path, 64 radiography, 9 Digital image processing. See Image; See also Image fundamentals of, 31 origins of, 3 scope of, 2 steps in, 25 system components, 28 uses of, 7 Dilation. See Morphological image processing Discrete cosine transform (DCT), 475. See also JPEG compression and lowpass filtering, 482 blocking artifact, 638 periodicity of, 479 Discrete Fourier transform (DFT), 463. See also Fourier transform circular convolution. See Convolution circular correlation. See Correlation Discrete sine transform (DST), 480 and lowpass filtering, 477 periodicity, 481 Discrete wavelet transform (DWT). See Wavelets; See also Wavelets one-dimensional, 500 two-dimensional, 508 Discriminant function. See Decision function Distance, 66 chessboard, 66

city-block, 66 D4, 66 D8, 66 Dm (mixed), 67 Euclidean, 66 function, 66 Mahalanobis, 1072 metric, 66 Distance transform, 971 Dot product, 92 Dots per inch (dpi), 284 DPI (dots per inch), 55 Dynamic range, 53, 148

E

Edge, 65. See also Edge detection closed loops, 789 derivative properties, 768 detector, definition, 764 direction, 778 double, 768, 769 global processing with Hough transform, 799 magnitude, 778 map, 783, 888, 890 operators. See Gradient operators pixels, 764 point-linking, 797 ramp, 766, 774 roof, 766, 774 segments, 764 step, 766, 773 strength, 778 unit normal, 779 Edge detection basic steps, 776 behavior in noise, 776 Canny edge detector, 791 edge models. See Edge models gradient. See Gradient gradient based, 778 Laplacian of a Gaussian, 787 Marr-Hildreth detector, 786, 1027 three steps performed, 776 Edge models behavior in noise, 776 ideal edges, 773 ramp edges, 774 roof edges, 774 zero crossing, 774 Eigenvalue, defined, 1003 Eigenvalues. See Covariance matrix Eigenvector, defined, 1003 Electromagnetic (EM) spectrum, 7, 38 Elementwise operations, 67 Ellipse in standard form, 983 Encoding. See Compression End point. See also Morphological image processing definition, 723 Engineered features, 1050, 1059 Enhancement. See Image enhancement Entropy, 602 Epoch. See Training, epoch Erosion. See Morphological image processing Euclidean. See Distance measures

distance, 66. See also Distance space, 452 vector norm, 92 Euler formula, 987 Euler-Lagrange equation, 881, 897 Euler's formula, 253 Evolving interfaces. See Active contours Evolving interfaces. See Active contours Expansions linear, 455 Explicit (parametric) contours. See also Active contours Eye structure, 32

F

Face recognition, 1010 False color. See Pseudocolor image processing False contouring, 58 False negative, 793 False positive, 128, 793 Fast Fourier transform (FFT). See Discrete Fourier transform (DFT) Fast Fourier Transform (FFT) algorithm, 350 background, 250 computational advantage, 251, 315, 354 Fast marching, 943 Fast wavelet transform (FWT), 501 analysis filter bank, 503 approximation and detail coefficients, 508 synthesis filter bank, 507 two-dimensional, 508 Feature extraction chain codes, 958-962. See also Chain codes corner detection, 1011 covariant, 954 distance transform, 970 feature description, defined, 954 feature detection, defined, 954 feature space, 956 feature vector, 956 global, 955 invariant, 954 label, 954 local, 955 maximally stable extremal regions, 1018-1025 medial axis, 970 minimum-perimeter polygons, 963 Moore boundary tracing, 957 principal components, 1001-1011. See also Principal components region feature descriptors, 982-1001. See also Region descriptors SIFT (scale invariant feature transform), 1023-1039 signatures, 968 skeletons, 970 whole image features, 1010-1041 Fidelity criteria, 603 Fiducial marks, 89, 390 Filtering (Frequency domain), 249 anti-aliasing, 282 bandpass, 343

1160 Index

Filtering (cont.) bandreject, 343 basics of, 306 blind deconvolution, 400 computational advantage of, 251 correspondence with spatial filtering, 314, deblurring and denoising using constrained least squares filtering, 411 deblurring and denoising using Wiener filtering, 406 deconvolution, 400 foundation of, 261, 300 fundamentals, 307 high-boost, 337 high-frequency emphasis, 337 highpass (image sharpening), 330 highpass, offset, 309 homomorphic, 339 inverse filtering, 404 Laplacian, 335 linear, 300 lowpass (smoothing), 310, 318 notch, 345 periodic noise reduction ny notch filtering, 388 selective, 342 steps summary, 312 tie to spatial filtering, 300, 314, 317 to reduce aliasing, 268 unsharp masking, 337 Filtering (Spatial domain), 177-221 and convolution, 183 based on first derivative, 200 based on second derivative, 200 based on the gradient, 208 bias, 189, 205, 242 compared to frequency domain filters, 186 deconvolution, 400 denoising using mean filters, 376 for restoration, 375 fundamentals, 177 highboost, 206 highpass, 199 linear, 178, 184 linear, equation of, 183 lowpass, 188-198 nonlinear, 198 sharpening, 199 smoothing, 188-198 tie to frequency domain filtering, 300, 314, 317 unsharp masking, 206 Filtering windows, 303. See also Apodizing, Windowing Bartlett, 303 Hamming, 303 Hann, 303 Filtering windows (See also Apodizing) Hamming, 430 Hann, 430 Hanning, 430 Ram-Lak, 430 ramp, 430 Filters finite impulse response (FIR), 505 frequency domain. See Frequency domain filtering

()

kernels. See Spatial filters spatial. See Spatial filtering; See Spatial filters Filters, digital perfect reconstruction, 506 Filters (Frequency domain) anti-aliasing, 282 bandpass, 343 bandreject, 343 Butterworth highpass from lowpass, 330 Butterworth lowpass, 324 constrained least squares filter, 411 cutoff-frequency, 320 deconvolution, 400 difference of Gaussians, 316 filter transfer function, 307, 314 finite impulse response (FIR), 315 Gaussian highpass from lowpass, 330 Gaussian lowpass, 310, 323 geometric mean filter, 415 highpass, 308 homomorphic, 341 ideal highpass (from lowpass), 330 ideal lowpass, 266, 311, 319 inverse filter, 404 lowpass, 308 notch, 345 notch filter, 389 obtaining from spatial kernel, 317 optimum notch filter, 393 parametric Wiener filter, 415 reconstruction filters. 266 sharpening (highpass), 330 smoothing, 318 spectrum equalization, 416 Ŵiener filter, 406 zero-phase-shift, 312 Filters (Spatial domain). See also Kernels adaptive local noise filter, 384 adaptive median filter, 386 alpha-trimmed filter, 380 arithmetic mean filter, 376 bandpass from lowpass, 212 bandrejecct from lowpass, 212 contraharmonic mean filter, 377 geometric mean filter, 376 harmonic mean filter, 377 highpass, 199 highpass from lowpass, 212 kernel, 178 Laplacian, 202 linear, 177 max, 199 max filter, 380 median, 198 median filter, 378 midpoint filter, 380 min, 199 min filter, 380 nonlinear, 177, 198 sharpening, 199 Fingerprints, 16 Finite differences, 764 backward, 765 central, 765 forward, 765 fourth order, 766 second order, 765

third order, 765 Fisher iris pattern classes, 1053 Flat-field correction, 197 Floor function, 52, 192, 789 Fourier phase angle, 295 power spectrum, 295 spectrum, 295 Fourier descriptors. See Boundary descriptors Fourier series, 463 defined, 254 history, 250 Fourier-slice theorem. See Image reconstruction from projections Fourier transform, 298 1-D continuous, 256 1-D discrete (DFT), 271, 272, 273 1-D inverse discrete (IDFT), 273 2-D, continuous, 277 2-D discrete (DFT), 286 and aliasing, 268 and convolution, 260 center, 289, 305 centering, 288 computing inverse from forward, 350 conditions for existence, 256 convolution. See Convolution dc component, 296 derivation of DFT, 271 discrete. See Discrete Fourier transform (DFT) forward, 256, 273, 274, 318 history, 250 inverse, 273 inverse, 1-D continuous, 256 inverse from forward algorihm, 350 magnitude, 295 of 2-D box, 277 of impulse, 254 of impulse and impulse train, 258 of pulse, 257 of sampled functions, 262 pair, 260, 273, 277 periodicity, 287 phase angle, 295 power spectrum, 295 properties of, 286, 292, 304 separability, 349 spectrum, 295 symmetry, 289 Four-quadrant arctangent, 253, 295 Fractals, 23 Frequency domain, defined, 257 rectangle, 289 units of, 257 Frequency domain filtering. See also Spatial filtering; See Filtering (Frequency domain) Frequency leakage, 303 Function antisymmetric, 290 band-limited. See Band-limited function Bessel, 322 circularly symmetric, 191 complex, 289 conjugate symmetric, 291 Dirac delta, 254

Index 1161

even, 289 frequency of a periodic, 269 generalized, 254 isotropic, 191 modulation, 394 odd, 289 period, 269 periodic, 269 real, 289, 291 reconstruction (recovery), 270 sinc, 258 symmetric, 290 weighting, 394 Functional, defined, 881 Fundus image, 975 Fuzzy sets, 217-237 aggregation, 228 background, 220 boundary detection, 236 definition of, 221 defuzzification, 229 for intensity transformations, 233 for spatial filtering, 236 fundamental steps, 231 fuzzification, 225 how to use in image processing, 224 IF-THEN rules, 225 implication, 226 inference, 226 linguistic value, 225 linguistic variable, 225 membership functions, 223 principles, 221 rule firing level, 233 rule strength, 233 set properties, 222

G

()

Gamma correction, 139 noise. See Noise Gaussian. See also Probability density function (PDF) 1-D CDF, 113 1-D PDF, 112 area under PDF curve, 113 bivariate PDF, 119 circularly symmetric shape, 191 convolution of Gaussians, 193 covariance matrix, 120 coveriance matrix. See also Covariance matrix curve, 114 difference of (DoG), 789, 1027 elliptical shape, 191 first derivative of, 791 isotropic shape, 191 kernel, 1025 kernel max size needed, 192. See also Kernels kurtosis for Gaussian with unit variance, 110 Laplacian of (LoG), 787 mean vector, 120 multivariate PDF, 118 noise, 71, 367

noise, white, 791 product of Gaussians, 193 random variable, 113 standard, 113 Gaussian noise. See Noise Generalized eigenvalue problem, 846 Geometric transformations, 84 Global thresholding. See Thresholding Golden image, 126 Golomb codes and coding, 612 Gradient combined with thresholding, 784 definition of, 208, 778 direction, 778 kernels, 780-783. See also Kernels magnitude, 209, 778 operators, 779 vector, 778 Gradient descent, 1086 Granular noise, 664 Granulometry, 743 Graph cuts (for segmentation). See Graph cuts directed, 841 nodes, 841 undirected, 841 vertices, 841 weighted, 841 Graph cuts, 840. See also Image segmentation computing, 846 max-flow, min-cut theorem, 844 minimum, 844 normalized cut, 844 segmentation algorithm, 847 Gray level, 2, 41, 530. See also Intensity Gray-level transformation. See Intensity transformations Gray scale, 47. See also Intensity Ground truth, 1075

Η

Haar functions, 490 Haar transform, 490, 510 Haar wavelets, 671 Hadamard product, 67, 478 Halftone dots, 284 Harris matrix, 1013 Harris-Stephens corner detector, 1011 Hartley transform, 473 and lowpass filtering, 482 Heaviside function, 930 Heisenberg-Gabor inequaltiy, 469 Heisenberg uncertainty principle, 469 Hertz, 257 Hessian matrix, 1030 Histogram bins, 109, 147 display, 107 equalization. See Histogram processing linearization. See Histogram, equalization normalized, 107, 147 shape as a function of moments, 109 specification. See Histogram processing, matching.

statistics, 174 unnormalized, 107, 147, 165 valid, 165 Histogram processing, 156 equalization, 148 exact matching, 163 exact specification, 163 local, 173, 176 matching, 156 using statistics, 174 Homogeneity, 68 Hotelling transform. See Principal components Hough transform, 799 Huffman coding, 609 Human eye. See Visual perception Hyperplanes, 1058 Hyperspheres, 1073

Ι

IDFT. See Fourier transform, 273 IEC, 607 IF-THEN rule antecedent, 225 consequent, 225 premise, 225 Illumination, 41. See also Intensity bias, 825 effect on thresholding, 807 sinusoidal, 826 spot, 825 Image, 11 acquisition, 41, 42, 44, 46 analysis, 2 arithmetic, 69 background, 65, 81, 805 bit planes, 145 center. 52 classification. See Pattern classification columns, 51 comparing, 71 complement, 83 compression. See Compression contrast, 53, 107, 110 contrast ratio, 53 coordinates, 2 correspondence between (x, y) and (row, col), 52 denoising. See Image restoration difference, 71 dynamic range, 53 element, 50. See Pixel EM spectrum, 7 enhancement. See Enhancement foreground, 65, 81 formation model, 45 gamma-ray, 8 golden, 126 grayscale, 41 illumination, 46. See Illumination indexing. See Indexing intensity, 2. See Intensity interpolation, 61, 283. See Interpolation masking, 74 mathematical tools, 67-122 microwave, 17

4/2/2017 9:03:48 PM

1162 Index

Image (cont.) morphology. See Morphological image processing MRI. 18 multispectral, 13 negative, 83, 137 neighborhood, 134 origin, definition, 51 padding, 181, 182 patch, 1012 PET, 8 pixel, 2. *See* Pixel quantization, 47 radar, 17 radio, 18 recognition. See Pattern classification reference, 88 reflectance, 46 registration, 88, 90 resampling, 283 resizing, 283 resolution. See Resolution restoration. See Image restoration rotation. See Geometric transformations rows, 51 sampling, 47 saturation, 53 scaling. See Geometric transformations sensing, 41 sharpening, 199 shearing. See Geometric transformations shrinking, 283 smoothing, 188 sound, 20 spatial coordinates, 2 synthetic, 7 transformation kernel, 93 translation. See Geometric transformations ultrasound, 22 ultraviolet, 11 understanding, 2 watermarking, 680 X-rav. 8 zooming, 283 Image enhancement character repair, 328 combined spatial methods, 216 contrast enhancement, 140 contrast stretching, 143 defined, 136 fuzzy, 217 fuzzy filtering, 236 gamma correction, 139 gradient based, 208 highboost filtering, 206, 337 high-frequency emphasis, 337 homomorphic, 339 intensity-level slicing, 144 intensity transformations, 136, 233 interference reduction, 329, 346, 348 Laplacian based, 202, 335 local, 175, 176 mask mode radiography, 73 median filtering, 198 noise reduction by averaging, 70 shading correction, 74, 197 sharpening, 330 sharpening and thresholding, 335 smoothing, 188, 318, 328

()

thresholding, 197 unsharp masking, 206, 337 using fuzzy techniques, 217 ImageNet Challenge, 1079 Image quantization, 47 Image reconstruction from projections absorption profile, 416 backprojections, 417, 419, 425, 435, 436 backprojections, fan-beam filtered, 434 backprojections, parallel-beam filtered, 428, 432 center ray, 434 CT principles, 418 CT scanner generations, 420 filtered backprojection, 431 Fourier-slice theorem, 427, 428 introductory example, 416 parallel-beam filtered backprojections, 428 parallel-ray beam projection, 422 Radon transform, 422, 423 Radon transform example, 424 Ram-Lak filter, 430 raysum, 416, 422 Shepp-Logan phantom, 425 sinogram, 425 slice, 428 smearing, 416 windowing, 430, 433 Image registration, 88 Image restoration adaptive filtering, 381 adaptive mean filter, 386 alpha-trimmed filtering, 380 arithmetic mean filter, 376 blind deconvolution 400 constrained least square filtering, 411 constrained least squares filtering, 411 contraharmonic mean filter, 377 deblurring, 409, 410, 412 deblurring by inverse filtering, 409 deblurring using a least squares filter, 412 deblurring using a Wiener filter, 412 deconvolution, 400 degradation function, 400 degradation function estimation, 400 denoising using adaptive median filtering, 387 denoising using linear spatial filters, 375 denoising using notch filtering, 390 denoising using order-statistic filtering, 381 denoising using spatial mean filters, 377 Erlang (Gamma) noise model, 369 exponential noise model, 369 Gaussian noise model, 367 geometric mean filtering, 415 harmonic mean filter, 377 image blurring caused by motion, 404 interactive, 415 interference removal using notch filters, 395 linear, position invariant degradations, 396 max filtering, 380 median filtering, 378 midpoint filtering, 380 min filtering, 380 modeling motion blurr, 402 model of, 366 noise reduction in the frequency domain, 388 notch filtering, 389

optimum noise filtering, 393 order-statistic filters, 378 periodic noise model, 372 Rayleigh noise nodel, 368 salt-and-pepper noise model, 370 uniform noise model, 369 Wiener filtering, 406 Image sampling, 47, 261 Image segmentation active contours. See Active contours (snakes); Active contours (level sets) clustering (K-means), 832 cluster seeds, 833 definition, 762 edge-based, 772-804 edge-point linking, 797 finite differences, 764 graph cuts. See Graph cuts level sets, 902-944. See also Active contours (level sets) line detection, 769 morphological watersheds, 849 motion-based, 859 point detection, 768 region growing, 826 region splitting and merging, 830 seeds, 826 snakes, 878-901. See also Active contours (snakes) superpixels, 834 textural segmentation, 745 texture based, 832 thresholding. See Thresholding unsupervised clustering, 832 Image transforms, 93. See Transforms Impulse (Frequency domain), 254 1-D continuous, 254 1-D discrete, 255 2-D continuous, 276 Fourier transform of, 258 sifting property, 254, 256, 276 train, 258, 262 unit, 254, 305 Impulse response, 315, 398 Impulse (Spatial domain) strength, 181 unit discrete, 181 Independent frames (I-frames), 655 Indexing, 54 coordinate, 54 linear, 54 Information theory, 601 Inner product, 92 Intensity, 2, 47, 51, 52 discrete, 52 discrimination, 37 levels, 54, 57 range, 52 resolution, 55, 56 scale, 47 scaling, 75 slicing, 144 variance. See also Moments Intensity mappings. See Intensity transformations Intensity transformations definition, 135 for histogram equalization, 148, 152 monotonic, 149

piecewise-linear, 142 single valued, 150 thresholding, 135 Interior angle, 964 Interpolation, 61, 84, 86, 271 bicubic, 62 bilinear, 61 control points, 89 nearest neighbor, 61 splines, 63 tie points, 89 wavelets, 63 Inverse proportionality, 257, 259, 275, 287, 322 Inverse transforms. See Transforms Iris data (Fisher), 1052 classification using min-dist-classifier, 1058 classification using perceptrons, 1085 **ISO 607** Isolated point definition. See also Image segmentation Isopreference curves, 60 ITU-T, 607

J

JBIG2 compression, 629 JPEG-2000 compression, 674 irreversible component transform, 674 lifting-based wavelet transform for, 675 tile components, 675 JPEG compression, 644

K

()

Karhunen-Loève transform. See Principal components Kernels bandpass from lowpass, 213 bandreject from lowpass, 213 box (lowpass), 189 defined, 178 edge detection, 779 for implementing gradient, 208 Gaussian, 184 Gaussian lowpass, 190, 789 highpass from lowpass, 213 how to construct, 188 in terms of lowpass kernels, 213 isotropic, 770, 787 Kirsch compass, 782 Laplacian, 203 line detection, 769 normalizing, 192 point detection, 768 Prewitt, 780 Roberts, 209, 780 separable, 94, 185 separable, computational advantage, 186 separable, construction of, 186 Sobel, 211, 781 symmetric, 94 transformation, 93 K-means clustering. See Image segmentation K-tuple, 166

L

Laminogram. See Image reconstruction from projections Laplacian defined, 203 kernel. See Kernels line detection, 770 sharpening, 204 used in level sets, 897 Laplacian of a Gaussian. See Edge detection Leakage. See Active contours (level sets) Learning. See also Pattern classification; Neural networks deep, 1051, 1077 defined, 1051 history of, 1077 increment, 1081 machines, 1078 over fitting, 1051, 1075 rate, 1081 supervised, 1051 unsupervised, 1051 Leftmost uppermost point, 957 Leibniz's rule, 150 Lempel-Ziv-Welch (LZW) coding, 620 Lens (of eye), 33 Level sets. See Active contours (level sets) Lexicographical ordering, 167 Light, 38. See also Electromagnetic (EM) spectrum achromatic, 41, 530 chromatic, 41, 530 color, 41 intensity, 41 luminance, 41 monochromatic, 41 photon, 40 radiance, 41 wavelength, 40 white, 41 Line definition. See also Image segmentation normal representation, 422, 800 slope-intercept form, 422, 800 Linear additivity property, 397 convolution. See Convolution correlation. See Correlation homogeneity property, 397 index. See Indexing operation, 396 operator, 68 transform pair, 93 transforms, 93 Linearly separable, 1081 Linear system, 398. See also Linear operator characterization by impulse, 398 convolution integral, 399 superposition (Fredholm) integral, 398 Line pairs, 55 Lloyd-Max quantizer, 669 LMSE algorithm. See Perceptrons Logical operations, 80 AND, 81 FALSE, 81 functionally complete, 81 NOT (complement), 81

OR, 81 TRUE, 81 XOR, 81 Lookup table, 136, 158 Luminance, 41, 530 LZW coding. *See* Lempel-Ziv-Welch (LZW) coding

Μ

Mach bands, 37 Macroblock 655 Magnetic Ink Character Recognition (MICR), 1060 Mahalanobis distance, 578, 820, 1072. See also Distance measures Major axis, 974 Mapper, 606 inverse, 660 Mapping. See Intensity: mapping Markov sources, 603 Mask mode radiography, 73, 130 Masks. See Spatial filters threshold, 642 zonal, 640 Matching. See also Pattern classification correlation, 1061 degree of similarity, 1066 prototypes, 1056 shape numbers, 1065 SIFT features, 1063 similarity matrix, 1066 similarity tree, 1066 strings, 1066 template, 1061 Matrix covariance. See Covariance matrix cyclic, diagonal-banded, 886 identity 887 product, 68 rank, 186 Matrix determinant in terms of eigenvalues, 1014 Matrix trace in terms of eigenvalues, 1014 Maximally stable extremal regions. See Feature extraction Maximally stable extremal regions (MSER's). See Feature extraction Mean absolute distortion (MAD), 656 Mean filters. See Spatial filters Mean of intensity. See Moments Mean squared error, 1085. See also Neural networks Mean-squared signal-to-noise ratio, 604 Medial axis, 970 Mexican hat operator, 787 Microdensitometers, 42 Microscopy electron, 23 fluorescence, 11 light, 12 Minimum-distance classifier, 1056 decision function, 1058 Minimum-perimeter polygons. See Feature extraction Minkowsky addition, 751 Minkowsky subtraction, 751

1164 Index

Minor axis, 974 MNIST, 1125 Modulation, 506 MOG. 888 Moiré patterns, 284 Moment invariants, 1000 Moments. See also Population central, 109, 115 estimating, 115, 120, 131 expected value, 107 global mean, 175 global variance, 175 histogram shape as a function of, 109 interpretation, 109 local mean, 175 local variance, 175 mean, 107 multivariate, 120 standard deviation, 109 statistical, 107, 114, 131 variance, 109 Monotonic function, 149 strict, 149 Moore boundary tracing algorithm. See Feature extraction Morphological algorithms. See Morphological image processing Morphological image processing algorithms (binary), 710 background flattening, 747 background pixels, 694, 696 border clearing, 730. See Morphological reconstruction bottom-hat transformation, 742 boundary extraction, 711 broken character repair, 700 closing, 702 closing by reconstruction, 728 closing by reconstruction, grayscale, 747 closing, grayscale, 738 closing, properties, 706 complement, 702, 704 computationally efficient, 725 conditional operations, 712, 725 connected component extraction, 713 convex deficiency, 715 convex digital set, 715 convex hull, 715 detecting foreign objects in packaged food, 714 dilation, 699 dilation, grayscale, 736 don't-care elements, 709 don't-care elements, 694, 697, 723, 731 duality, 702, 705 end point deletion, 758 end point detection, 723 erosion, 697 erosion, grayscale, 732 filtering, 699, 706, 740 foreground pixels, 694, 696 geodesic dilation, 725 geodesic dilation, grayscale, 746 geodesic erosion, 725 geodesic erosion, grayscale, 747 gradient, 740 granulometry, 743 grayscale images, 731

 (\mathbf{r})

hit-or-miss transform, 706 hole, defined, 709, 711 hole filling, 711, 729 marker image, 747 mask image, 747 opening, 702 opening by reconstruction, 728 opening by reconstruction, grayscale, 747 opening, grayscale, 738 opening, properties, 706 pruning, 722 reconstruction, 725. See Morphological reconstruction reconstruction by dilation, 726 reconstruction by dilation, grayscale, 747 reconstruction by erosion, 727 reconstruction by erosion, grayscale, 747 reconstruction, grayscale, 746 reflection, set, 694 rolling ball analogy, 703 segmentation, textural, 745 segmentation using watersheds, 849 SE. See Structuring element, 694 shading correction, 743 skeletons, 720. See also Skeletons smoothing, 740 spurs, 722 structuring element, defined, 694 structuring element, isotropic, 725 structuring element, nonflat, 736 structuring elements, examples of, 695 summary of binary operations, 731 surface area, 744 thickening, 718 thinning, 718 thinning, topology-preserving, 970 top-hat by reconstruction, 747 top-hat transformation, 741 translation, set, 695 Motion and its use in segmentation, 859. See also Image segmentation Motion compensation, predictive coding and, 655 MSER's. See Maximally stable extremal regions Multiresolution analysis, 494

Ν

National Institute of Standards and Technology, 1125 Nearest-neighbor classifier. See Minimumdistance classifier Neighbor 4-neighbor, 63 8-neighbor, 63 diagonal, 63 nearest. See also Interpolation north, south, east, west, 957 Neighborhood, 63 closed, 63 definition, 134 open, 63 operations, 83, 134 Neural networks activation functions. See Activation functions

backpropagation, 1078, 1099, 1120 convolutional. See Neural networks (Convolutional) deep, 1052, 1077, 1091, 1092 deep learning, 1078, 1079 design considerations, 1133 error (classification), 1105 error (mean squared) (MSE), 1105 feedforward, 1091 fully-connected. See Neural networks (Fully-connected) multilayer, 1089 over-fitting, 1127, 1135 pretrained, 1135 shallow, 1091 using GPUs, 1135 Neural networks (Convolutional) activation functions. See Activation functions activation value, 1091 artificial neuron. See Artificial neurons background, 1077 backpropagation derivation, 1120 backpropagation equations, 1120 basic architecture, 1110 bias, 1110 CNN for large character dataset, 1125 CNN for large image database, 1128 convolutional layer, 1112 convolution equations, 1121 dropout, 1135 feature map, 1112 forward pass equations, 1119 graphical illustration of functioning, 1114 implementation details, 1133 kernel, 1112 mean squared error, 1124, 1126 mini-batches,, 1135 multiple input images, 1119 neural computations, 1117 overfitting, 1135 padding, 1134 pooled feature maps, 1113 pooling, 1112 pooling methods, 1113 pooling neighborhoods, 1113 receptive fields, 1112 recognition error, 1124, 1127, 1131 rot180 (rotation), 1121 rotated kernel, 1121 stochastic gradient, 1135 stride, 1112 subsampling, 1112 summary table, 1123 sum of products, 1082, 1083 training by backpropagation, 1120 updsampling, 1123 vanishing gradients, 1134 vectorizing, 1114 visual cortex model, 1112 weight (parameter) sharing, 1112 Neural networks (Fully-connected) activation functions. See Activation functions activation value, 1094 artificial neuron. See Artificial neurons background, 1077 backpropagation, derivation, 1099

Index 1165

backpropagation, matric formulation, 1102 bias, 1081, 1090, 1093 chain rule, 1099 comparison with Bayes' classifier, 1110 comparison with the Bayes' classifier, 1110 correction increment, 1081 deep, 1091 dropout, 1135 error function, 1100 feedforward, 1091 forward pass, equations of, 1094 forward pass, matrix formulation, 1096 hidden layers, 1091 implementation details, 1133 input vectors, 1094 learning. See Learning learning increment, 1081 learning rate, 1081 mean squared error, 1107 mini-batches,, 1135 model of, 1092 multilayer, 1089 multispectral data classification, 1107 net input, 1094 overfitting, 1135 padding, 1134 pretrained network, 1135 recognition error, 1124 shallow, 1092 stochastic gradient, 1135 sum of products, 1083 training, 1099 training by backpropagation, 1099 training epoch. See Epoch upsampling, 1134 vanishing gradients, 1134 weights, 1092 XOR problem solution, 1105 Neurocomputers. See Neural networks Neuromorphic systems. See Neural networks NIST, 1125 Noise autocorrelation of, 407 bipolar impulse, 370 data-drop-out, 370 density, 370 Erlang (Gamma), 369 Exponential, 369 Gaussian, 367 granular, 664 impulse bipolar, 370 impulse unipolar, 370 parameter estimation, 373 periodic, 372, 388 Rayleigh, 368 salt-and-pepper, 370 spike, 370 uniform, 369 unipolar, 370 white, 367, 408, 791 white Gaussian, 791 Noiseless coding theorem, 602 Nonlinear operator, 68 Nonmaxima suppression, 792 Normalized central moments 1000 Notch filters. See Frequency domain filtering Nyquist rate, 265. See also Sampling; See also Sampling

()

0

Objective function, 1100 Object recognition. See Patterns: recognition and Opening. See Morphological image processing Operations arithmetic, 69 elementwise, 67 linear, 68 logical, 75, 80 matrix, 68, 90 neighborhood, 83 nonlinear, 68 set, 75 spatial, 83 vector, 90 Operator linear, operator. See Linear operator position invariance, 397 space invariance, 397 Optical illusions, 38 Order partial, 80 strict, 80, 167 Ordered pairs, 79. See also Cartesian product Order. See also Relation lexicographical, 167 Order-statistic filters. See Spatial filters origins of, 3 Orthogonal basis, 453 Orthonormal basis, 453 Otsu's method. See Threshold; See Thresholding Outer product, 92 Over fitting. See Learning Over-segmentation, 856

P

Padding, 179, 182, 302 and periodicity, 310 difference between spatial and frequency, 311 function, 246 illustration, 195, 196 mirror, 195 replicate, 195 size, 183, 302, 312 symmetric, 195 zero, 189, 190, 195, 302, 311 Parameter space, 800 Parametric equations, 879 Path, 64, 67 Pattern augmented, 1082 classes, 1052 definition of, 1050 formation, 1052 labeling, 1051 recognition. See Pattern classification space, 1052 strings, 1056 test, 1051 training, 1051 trees, 1056

unlabeled, 1051 validation, 1051 vectors, 1052, 1055 Pattern classification. See also Learning approaches, 1050 Bayes' classifier. See Classifier correlation, 1061 decision functions, 1058. See also Decision functions deep learning. See Learning discriminant functions., 1058 feature extraction. See Feature extraction hyperplane, 1058 minimum-distance classifier, 1056 pattern. See Pattern pattern class, definition of, 1050 pattern classes, 1052 pattern recognition, stages, 1050 pattern strings. See Pattern pattern tree. See Pattern pattern vectors, 1052 prototype matching. See Matching SIFT. See Matching string matching. See Matching supervised learning. See Learning test set, 1051 training set, 1051 unsupervised learning, 1051 validation set, 1051 Pattern recognition. See also Pattern classification stages of, 1050 PDF. See Probability density function (PDF) Pel. See Pixel Perceptrons bias, 1081 convergence theorem, 1082 correction increment, 1081 decision boundary, 1084 decision surfaces, 1080 hyperplanes, 1081 learning rate, 1081 least-mean-squared-error (LMSE), 1087 linearly separable. See Linearly separable parameters, 1081 schematic, 1083 sum of products computation, 1083 training algorithm, 1081 training epoch, 1083 weights, 1081 weight vector, 1081 XOR problem, 1088 Photons, 7, 40 Pixel adjacency of, 64 connected, 64 definition, 2, 50 foreground. See Image, background; See Image, foreground interpolation. See Interpolation neighborhood operations. See also Spatial filtering neighbors of, 63 object, 805 replication, 283 transformation. See Intensity: transformations

Point processing, 135

Point spread function, 398 Pointwise min and max operators, 746 Population, 115. See also Moments, Sample central moments, 116 difference from sample, 115 excess kurtosis, 117 kurtosis, 117 mean, 116 skewness 117 unbiased estimate of mean, 116 unbiased estimates of mean and variance, 116 variance, 116 Positron emission tomography, 8. See also Tomography Predicate region growing, 828 thresholding, 824 Prediction errors, 653 Prediction residuals, 653 motion compensated, 655 Predictive coding, 650 delta modulation (DM), 663 differential pulse code modulation (DPCM), 665 lossless, 650 lossy 661 motion compensation and, 655 optimal predictors for, 665 optimal quantization in, 667 prediction error, 650 Predictive frame (P-frame), 655 Prewitt gradient operators. See Spatial filters Principal components covariance matrix, 1003 eigenvalues, 1003 eigenvectors, 1003 Hotelling transform, 1003 Karhunen-Loève transform, 1003 mean vector, 1003 rotation normalization, 1007 size normalization, 1007 transformation, 1003 translation normalization, 1007 vector formation, 1005 Probability addition rule, 97 a priori, 1069 axioms of, 96 Bayes' rule, 102 conditional, 98 cumulative distribution function (CDF). See Cumulative distribution function (CDF) definition, 96 density function (PDF), 105. See also Probability density function event, 96 functions, 105 independence, 100 joint, 98 mass function (PMF), 105. See also Probability mass function multiplication rule, 101 multivariate 118 of occurrence, 106 partition theorem, 101 prior, 1069

()

product (or chain) rule, 100 random experiment, 96 random variable, definition, 104 sample space, 96 total law of 101 Probability density function (PDF) bivariate Gaussian, 119 Erlang (Gamma), 369 estimating, 106 Exponential, 369 Gaussian, 112-113, 367 multivariate Gaussian, 118 normal, 112 Rayleigh, 368 Salt-and-Pepper, 370 standard Gaussian, 113 standard normal, 113 uniform, 111, 112 Uniform, 369 Probability mass function (PMF), 614 Bernoulli, 106 Binomial, 106 discrete uniform, 105 Probability models, 618 Projection-slice theorem. See Image reconstruction from projections Pruning. See Morphological image processing

Q

Quad tree, 830 Quantization, 601. See also Sampling Quantizer, 606 inverse, 660 Lloyd-Max, 669 optimum uniform, 670

R

Radar band, 17 Radiance, 41, 530 Radon transform formulation, 422 history, 419 Ramp edges. See Edges Random variable. See also Probability central moments, 109, 115 continuous, 104 countably infinite, 104, 115 covariance, 119 discrete, 104 mean, 107, 115 multivariate, 117 negatively correlated, 119 positively correlated, 119 range, 104 standard deviation, 109 standard Gaussian, 113 uncorrelated, 119 univariate, 117 variance, 109, 115 Ranger 7, 5 Rayleigh noise. See Noise Real numbers, set of, 104 Redundancy, 596 coding, 596, 597

relative data, 596 spatial and temporal, 596, 599 Region adjacent, 762 border, 65 boundary, 65 contour, 65 definition, 64 descriptors. See Description disjoint, 762 Region descriptors circularity, 982 compactness, 982 connected components, 986 contrast, 993 co-occurrence matrix, 991 correlation, 992 eccentricity, 983 effective diameter, 983 entropy, 993 Euler number, 986 holes, 986 homogeneity, 993 major and minor axes, 982 moments, 988 polygonal networks, 987 principal axes, 983 roundness, 982 texture (spectral), 997 texture (statistical), 988 topological, 985 uniformity, 990, 993 Region of interest (ROI), 130 Regularization, defined, 929 Relation antireflexive, 80 binary, 80 ordering, 80 transitive, 80 Remote sensing, 13 LANDSAT, 13 thematic bands 13 Resampling. See Image: resampling Reseau marks, 5, 89 Resolution, 55 dots per inch (dpi), 55 intensity, 55 line pairs, 55 spatial, 55 Root-mean-squared (rms) error, 408, 604 Rubber-sheet distortions, 985 Run-length encoding (RLE), 622 Run-length pairs, 599, 622

S

Salt-and-pepper noise. *See* Noise Sample, 116. *See also* Population bias, 116 difference from population, 115 excess kurtosis, 117 mean, 116 unbiased estimates of parameters, 117 variance, 116 Sampling, 47, 261, 279. *See also* Quantization aliasing. *See* Aliasing critically-sampled signal, 263

()

Index 1167

limitations of human eye, 282 Nyquist rate, 265 of printed material, 284 over-sampled signal, 263 rate, 261, 263, 269, 278 relationship to frequency intervals, 274 theorem, 263, 277, 282 undersampled signal, 267 units of sampling rate, 261 Saturation, 53 Scalar field, 889 Scale-invariant feature transform. See SIFT Scale space. See SIFT Scaling geometric. See Geometric transformations intensity, 75 Scaling functions, 493 coefficients of, 495 Haar, 493 refinement equation for, 495 scale and translation of, 493 separable, 508 Self-adaptive networks. See Neural networks Sensors acquisition and, 41 arrays, 45 single, 42 strips, 44 sequency, 485 Sets, 75, 77 complement, 76 difference, 76 fuzzy, 217 intersection, 76 mutually exclusive, 76 on grayscale images, 78 partially-ordered, 80 sample space, 76 set universe, 76 strict-ordered, 80 union, 76 Sets and set operations, 702 reflection, 694 translation, 695 Shading correction, 74, 743. See also Background flattening using lowpass filtering, 197 Shannon's first theorem, 602 Sharpening frequency. See Filtering (Frequency domain) spatial. See Filtering (Spatial domain) Shepp-Logan phantom. See Image reconstruction from projections Shrinking. See Image: resampling SIFT algorithm, 1036 curvature estimation using Hessian matrix, 1031 examples of image matching, 1036-1039 Hessian matrix, 1030 keypoint descriptors, 1034 keypoint locations accuracy, 1029 keypoint orientation, 1032 keypoints, 1024 local extrema, 1027 octaves, 1025 scale parameter, 1025

()

scale space, 1025 subpixel accuracy, 1030 Sifting property. See Impulse Signal-to-noise ratio, 408 Signatures, 968 Signed distance functions. See Active contours (level sets) Sinc function, 258. See also Function Sinogram. See Image reconstruction from projections Skeletons, 970. See also Morphological image processing defined, 971 via the distance transform, 970 Slant transform, 488 Sliding inner product, 466 Slope density function, 969 Slope overload, 664 **SMPTE**, 607 Snakes. See Active contours (snakes) Sobel gradient operators. See Spatial filtering Softmax function, 1093. See also Neural networks Space constant, 786 Spaghetti effect, 789 Spatial coordinates, 50 definition 2 transformation of, 84 Spatial domain convolution. See Convolution correlation. See Correlation definition, 133 filtering. See Spatial filtering Spatial filtering. See Filtering (Spatial domain) masks. See Spatial filters Spatial filters. See also Spatial filtering Spatial operations, 83 Spatial variables, 50 Spectrum. See Discrete Fourier transform (DFT); See Fourier transform Statistical moments, See Moments Step edges. See Edges Strict ordering, 80 Structured light, 15 Structuring element. See Morphological image processing Subband coding, 505 Subpixel accuracy, 62, 789, 939, 943, 1030 Subspace analysis tree, 515 Successive-doubling. See Fast Fourier transform Sum of absolute distortions (SAD), 656 Sum of products, 178, 183, 259 Superpixels as graph nodes, 842 defined. 834 SLIC algorithm, 837 Superposition, 398 Supervoxels, 839 Symlets, 513, 671 Symmetry antihermitian, 291 conjugate, 291 conjugate antisymmetry, 291 even, 295, 412 hermitian, 291 odd, 295

Т

Taylor series, 764 Texture. See also Region descriptors spectral, 997 statistical, 988 Thickening. See Morphological image processing Thinning. See Morphological image processing Threshold. See also Thresholding coding, 640 Thresholding adaptive, 805 basics, 805 document, 825 dynamic, 805 global, 808 hysteresis, 794, 821 illumination, role of, 807 local, 805 multiple, 819 multivariate, 578 noise, role of, 806 Otsu's method, 809 predicate, 824 reflectance, role of, 807 regional, 805 using edges, 815 using smoothing, 814 variable, 823 Tie (control) points, 89 Time-Frequency Plane, 467 Token, 628 Tomography, 416. See also Image reconstruction from projections magnetic resonance imaging (MRI), 422 single photon emission, (SPECT), 422 X-ray computed tomography, 418 X-ray CT scanner generations, 420 Training defined, 1051 epoch, 1083, 1104 neural networks. See Neural networks over-fitting. See Neural networks patterns. See Pattern perceptrons. See Perceptrons test set, 1051 training set, 1051 validation set, 1051 vanishing gradients, 1134 Training by backpropagation, 1099, 1120 Transformation affine, 85 geometric (rubber-sheet). See Geometric transformations kernel, 455 matrix, 456 matrix dual, 462 rotate, 86 scale, 86 sheer, 86 translate, 86 Transformation functions bit-plane slicing, 145 Transforms cosine, 475, 633 Fourier, 633. See Fourier transform

1168 Index

Transforms (*cont.*) Haar, 490 Hartley, 473 Hough. *See* Hough transform matrix-based, 454 morphological. *See* Morphological image processing orthogonal, 458 sine, 480 slant, 488 Walsh-Hadamard, 484, 633 wavelet, 492. *See also* Wavelets Tuple, 166

U

Uniform. See Noise Unitary matrix, 461 space, 452 transform, 461 universality approximation theorem universality approximation theorem, 1133 Uppermost leftmost point, 957 Upwind derivatives. See Active contours (level sets)

V

()

Vanishing gradient, 1134 Vanishing moments, 512 Variable thresholding. See Thresholding Variance of intensity. See Moments Vector field, 889. See also Scalar field gradient flow field, 896 image, 889, 898 unit normal, 906 Vector operations angle between vectors, 453 dot (scalar) product, 452 inner product, 452 integral inner product, 452 norm, 452 orthogonal complement, 496

Vertex concave, 964 convex, 964 degenerate, 964 Video compression standards, 660 Vision. See also Visual perception high-level, 2 inspection, 15 low-level, 2 machine, 2 mid-level, 2 Visual perception, 32 blind spot, 33 brightness adaptation, 35 brightness discrimination, 35 human eye structure, 32 image formation in eye, 34 Mach bands, 37 optical illusions, 38 photopic vision, 33 scotopic vision, 33 simultaneous contrast, 38 subjective brightness, 35 Voxels, 559

W

Walsh functions, 484 Walsh-Hadamard transform (WHT), 484 Hadamard (natural) ordering, 484 sequency ordering, 486 Watermarking digital images, 680 block diagram for, 684 reasons for, 680 Watermarks, 680 attacks on, 683 fragile invisible, 682 insertion and extraction, 683 invisible, 681 private (or restricted key), 683 public (or unrestricted key), 683 robust invisible, 683 visible, 681 Wavelength, 40 of EM spectrum, 40 required to get image, 41

Wavelet coding, 670 decomposition level selection, 672 quantizer design for, 673 selection of wavelets for, 671 Wavelet functions, 495 coefficients of, 496, 513 Haar, 497 Wavelet packets, 514 filter bank for, 517 subspace analysis tree, 515 Wavelets, 467, 470 and edge detection, 512 and multiresolution analysis, 494 packets, 514 scaling functions, 493. See also Scaling functions series expansions, 498 wavelet functions, 495. See also Wavelet functions Weber ratio, 36 White noise. See Noise Windowing, 303. See also Apodizing, Filtering windows Wraparound error, 302, 303, 308, 312, 317, 346

X

XOR classification problem definition, 1088 solution using neural nets, 1105 solution using perceptrons, 1089

Z

Zero crossing, 202 Zero crossings, 774, 786, 788 Zero-memory source, 602 Zonal coding implementation, 640 Zone plate, 214 Zooming, *See* Image: zooming $(\blacklozenge$