

Index

- 2½-dimensional sketch, 243
- 3D room, 625
- aberrations, 11–12
 - astigmatism, 11
 - chromatic aberration, 12
 - circle of least confusion, 11
 - coma, 11
 - distortion, 11
 - radial, 47
 - field curvature, 11
 - primary aberrations, 11
 - spherical aberration, 11
- absolute
 - conic, 295
 - dual quadric, 295
- acceleration, 433
- accumulator array, *see* fitting
- active sensors, 467
- active vision, 250, 251
- affine
 - camera, *see* camera model, affine
 - projection matrix, *see* projection matrix, affine
 - projection model, *see* projection model, affine
- affine coordinates, 255, 259, 279
- affine geometry, 253–258
- affine shape, 252, 258
- affine space, 253
- affine subspace, 254
 - dimension, 254
- affine transformation, 28, 252
 - as coordinate change, 255
 - as mapping, 257
- coordinate system, 254–256
 - definition, 255
- coordinates
 - affine, 255
 - barycentric, 256
 - ratio, 257
- affine invariants, 411
- affine motion model, 365
- affine structure from motion
 - affine structure of affine images, 263
 - ambiguity, 252
 - definition, 252
 - Euclidean upgrade, 266–269
 - multiple views, 267–269
 - from binocular correspondences
 - algebraic, 260–263
 - geometric, 259–260
 - from multiple images
 - factorization, 263–266
 - motion segmentation, 269–272

- affine structure from motion (*cont.*)
 - reduced row-echelon form, 269
 - shape interaction matrix, 271
- affine structure-from-motion theorem, 260, 634
- affinity measures, *see* clustering
- AIC, *see* model selection
- airlight, *see* sources
- albedo, 65
 - definition, 65
 - of a Lambertian surface with constant BRDF, 65
 - low dynamic range, 119
 - reflectance, 101
 - spectral albedo, 101
 - spectral reflectance, 101
- algebraic, 337
- algebraic distance, 220. *See also* fitting
- algebraic surface, 457, 490
- aliasing, *see* sampling
- alignment, *see* model-based vision
- ambient illumination, 79
 - constant value, 79
 - value based on visible area, 80
- ambiguity
 - affine, *see* affine structure from motion
 - Euclidean, 269, 293
 - projective, *see* projective structure from motion
- analysis, *see* image pyramid
- analyzing orientation, *see* image pyramid
- apparent curvature, 438, 442
- appearance matching, 603
- applications
 - digital libraries, *see* digital libraries
- arc length, 433, 436, 437, 439
- area source, 75
 - expression for radiosity due to an, 77
 - radiosity does not change with distance, 76
- aspect, 446, 459
- aspect graph
 - construction
 - approximate, 461
 - exact, 456–460
 - example
 - Flatland, 446
 - squash, 460
- assembly, *see* matching on relations
- assimilation, *see* color perception
- astigmatism, 11
- asymptotic
 - bitangent, 456
 - curve, 449–450
 - red and blue, 449
 - directions, 435, 439, 442, 470
 - spherical image, 452
 - spherical map, 447, 450–451
 - tangent, 449, 451, 452, 455, 458
- attached shadow, 427
- augmented reality, 630
- Bézier
 - curve, 621
 - patch, 622
- background subtraction, 309–312
 - using EM, 367
- backprojection, *see* model-based vision
- backpropagation, *see* classifier
- backward pass, 533
- backward variable, 556
- Bakis model, *see* matching on relations
- band-pass filter, 199
- barycentric
 - combination, 254, 622
 - coordinates, 256
- baseline, 216
- Bayer patterns, 17
- Bayes classifier, *see* classifier
- Bayes information criterion, 370
- Bayes risk, *see* classifier
- beak-to-beak, 451, 452
- beat frequency, 468
- bed-of-nails function, 152
- Bernstein polynomials, 622
- between-class variance, 513
- bidirectional reflectance distribution function, 61
 - bounds, 62
 - computing radiance leaving a surface, 61
 - constraints on values, 61
 - definition, 61
 - Helmholtz reciprocity principle, 61
 - spectral BRDF, 98
 - units, 61
- bin picking, 460
- binocular fusion, *see* stereopsis, binocular fusion
- binormal
 - line, 432
 - vector, 433, 434, 438
- bitangent, 453
 - direction, 458
 - line, 445, 446, 455
 - asymptotic, 456
 - limiting, 455, 457
 - plane, 455, 460
 - ray manifold, 447, 453–455
- black body, 98
 - color temperature, 98
- blind spot, 14
- block matrix multiplication, 26
- blooming, 17
- Blum ribbon, *see* ribbon
- Blum transform, *see* ribbon
- blurring, *see* smoothing

- boosting, 530
- bootstrapping, *see* classifier
- brightness, *see* color spaces, *see* color perception
- Brooks ribbon, *see* ribbon
- bundle adjustment, 292
- camera
 - CCD, *see* CCD camera
 - obscure, 3, 15
 - photographic, 15
 - pinhole, *see* pinhole camera
 - vidicon, 16
- camera calibration
 - linear, 45–47
 - camera parameters, 45–46
 - degeneracies, 46–47
 - projection matrix, 45
 - photogrammetry, 50–51
 - with radial distortion, 47–50
 - camera parameters, 48–49
 - degeneracies, 49–50
 - projection matrix, 48
 - weak, *see* weak calibration
- camera model
 - affine, 32–35
 - extrinsic parameters, 34
 - intrinsic parameters, 34
 - projection equation, 6, 7, 34
 - perspective, 28–32
 - extrinsic parameters, 30–31
 - intrinsic parameters, 29–30
 - projection equation, 30
- canal surface, 570
- canonical frame, *see* model-based vision
- canonical variates, *see* classifier
- cast shadow, 427
- cast shadow boundaries, 78
- catadioptric optical systems, 8
- catastrophe theory, 446
- CCD camera, 16–17
 - Bayer patterns, 17
 - bias, 18
 - blooming, 17
 - charge coupling, 16
 - dark current, 18
 - line jitter, 18
 - photo-conversion, 16
 - potential well, 16
 - quantum efficiency, 17
 - shot noise, 17
- cell-decomposition algorithm, 459
- center of curvature, 430
- central limit theorem, 474
- central perspective, *see* projection model, pinhole perspective
- charge coupling, 16
- chromatic aberration, 12
- chromatic adaptation, *see* color perception
- CIE u'v' space, *see* color spaces
- CIE XYZ color space, *see* color spaces
- CIE LAB, *see* color spaces
- circle of curvature, 430
- circle of least confusion, 11
- class-based grouping, *see* object-outline relations
- class-conditional densities, 497
- classifier, 495
 - Bayes classifier, 497, 498
 - Bayes risk, 497
 - bootstrapping, 502
 - cost of misclassification, 496
 - decision boundary, 496
 - chosen to minimize total risk, 496, 497
 - definition, 496
 - estimating performance, 501
 - classifier, 502
 - cross-validation, 502
 - generalizing badly, 501
 - leave-one-out cross-validation, 502
 - overfitting, 501
 - receiver operating curve, 503, 505, 529
 - selection bias, 501
- examples
 - finding faces using a neural network, 520–522
 - finding faces with naive Bayes, 506
 - finding numbers using a neural network, 522–524
 - finding pedestrians with SVM's, 529
 - finding skin using class histograms, 503
 - identifying individuals with principal component analysis, 508, 510, 511
- feature selection, 505
 - by canonical variates, 512–515
 - by principal component analysis or PCA, 507–509
 - for SVM example, 527
 - problems with principal component analysis, 509
- for relational matching, 538
- from class histograms, 502
 - skin finding examples, 503–505
- general methods for building, 497
 - directly determining decision boundaries, 499
 - plug-in classifier, 498
- linearly separable, 499
- Mahalanobis distance, 499
- naive Bayes
 - for finding faces, 505, 506
 - general discussion, 504
- nearest neighbors, 500, 501
 - k -nearest neighbor classifier, 500

- classifier (*cont.*)
 - neural network, 516
 - backpropagation, 519, 531
 - building a classifier with, 517
 - finding faces using, 520–522
 - finding numbers using, 522–524
 - fully connected layer, 516
 - layers, 516, 517
 - logistic function, 516
 - minimizing error, 518
 - minimizing error by stochastic gradient descent, 518
 - partially connected layer, 516
 - sigmoid function, 516
 - squashing function, 516, 518
 - threshold function, 516
 - plug-in classifier
 - example, 499, 500
 - risk function, 496
 - support vector machine, 524
 - finding pedestrians with SVM's, 527–529
 - for linearly separable datasets, 524–527
 - for not linearly separable datasets, 534
 - solving the constrained extremisation problem, 526
 - total risk, 496
- closure, *see* segmentation
- clustering, 304, 313
 - as a missing data problem, *see* missing data problems
 - complete-link clustering, 314
 - dendrogram, 314
 - graph theoretic, 317
 - affinity measures, 319, 320
 - basic terminology, 317
 - eigenvectors as clusters, 321–324
 - graph as a matrix, 318
 - normalized cuts, 323, 325
 - group average clustering, 314
 - grouping and agglomeration, 304, 313
 - image pixels by EM, 359–362
 - image pixels using agglomerative or divisive methods, 314
 - image pixels using K-means, 315, 316
 - image pixels, as a missing data problem, 355
 - partitioning and division, 304, 313
 - single-link clustering, 314
- clutter, 404, *see* model-based vision
- CMY space, *see* color spaces
- coarse-to-fine matching, 162
- collections of images, browsing, 604
 - desiderata for systems, 604
- color bleeding, 91, 131
- color constancy, 120
 - finite-dimensional linear model, 125
 - recovering surface color by gamut mapping, 128
 - recovering surface color from average reflectance, 127
 - human color constancy, 122, 123
 - lightness computation, 123
 - lightness constancy, 122
- color correlograms, *see* digital libraries
- color histogram, *see* digital libraries
- color matching functions, *see* color spaces
- color, modeling image, 115
 - color cameras, 115
 - color depends on surface and on illuminant, 116–118
 - complete equation, 116
 - diffuse component, 116
 - finite-dimensional linear model, 125, 126
 - computing receptor responses, 126
 - recovering surface color by gamut mapping, 128
 - recovering surface color from average reflectance, 127
 - gamma correction, 115
 - illuminant color, 117
 - interreflections ignored, 118
- color perception, 103
 - assimilation, 115
 - brightness, 122
 - chromatic adaptation, 114
 - cones, 105
 - contrast, 115
 - Grassman's laws, 104
 - human competence at color constancy, 123
 - lightness, 122
 - computing lightness, 123
 - lightness constancy, 122
 - photometry does not explain, 122
 - primaries, 103
 - principle of univariance, 105
 - rod, 105
 - subtractive matching, 103
 - surface color, 122
 - surface color perception, 122
 - test light, 103
 - trichromacy, 104
- color photography, 15
- color spaces, 106
 - brightness, 111
 - by matching experiments, 107
 - CIE u' v' space, 114
 - CIE $u'v'$ space, 113
 - CIE XYZ color space, 108
 - CIE xy , 109–111
 - CIE LAB, 114
 - CMY space, 110
 - mixing rules, 110
 - use of four inks, 111
- color differences, 113

- color matching functions, 107
 - negative values, 107
 - obtaining weights from, 107
 - cyan, 110
 - HSV space, 112
 - hue, 111
 - imaginary primaries, 107
 - just noticeable differences, 113
 - lightness, 111
 - Macadam ellipses, 113
 - magenta, 110
 - RGB color space, 109
 - RGB cube, 109
 - saturation, 111
 - uniform color space, 113, 114
 - uniform color spaces, 113, 114
 - value, 111
 - yellow, 110
 - color temperature, *see* black body
 - coma, 11
 - comb function, 152
 - common fate, *see* segmentation
 - common region, *see* segmentation
 - compact support, 144
 - complete data space, 356
 - complete graph, 557
 - component video, 17
 - compound lenses, 12
 - computational molecules, 474
 - computed tomography imaging, *see* medical imaging
 - concave point, 441
 - plane curve, 432
 - surface, 435
 - condition equations, 231
 - cones, 14, 569
 - conjugate symmetry, 572
 - conjugated directions, 439, 442
 - connected, 317
 - connected components, 317
 - connected graph, 317
 - content based image retrieval, *see* digital libraries
 - continuity, *see* segmentation
 - contour
 - image, *see* image contour
 - occluding, *see* occluding contour
 - contrast, *see* color perception, 172
 - control polygon, 622
 - convex hull, 464, 639
 - convex point
 - planar curve, 432
 - surface, 435
 - convolution, 136
 - associative, 145
 - continuous, 142, 144
 - ID derivation, 143
 - 2D derivation, 144
 - impulse response, 144
 - point spread function, 145
 - properties, 144
 - discrete, 136
 - convention about sums, 136
 - effects of finite input datasets, 145
 - examples
 - finite differences, 138–140, 168, 169, 171–173
 - local average, 135
 - ringing, 136, 137
 - smoothing, *see* smoothing
 - weighted local average, *see* smoothing
 - gives response of shift invariant linear system
 - discrete 1D derivation, 141
 - discrete 2D derivation, 142
 - kernel, 136, 145
 - like a dot product, 157, 158
 - notation, 142
 - separable kernel, 174
 - symmetric, 145
- convolution theorem, 147
 - convolutional neural network, *see* classifier
 - coordinate frame, *see* coordinate system
 - coordinate system
 - affine, *see* affine geometry
 - Euclidean, *see* Euclidean geometry
 - local, *see* differential geometry
 - projective, *see* projective geometry
 - coplanarity condition equation, 231
 - corner detection, 181
 - by analysis of gradient field, 183–185
 - correspondence problem, *see* stereopsis, binocular fusion
 - $\cos^4 \alpha$ fall-off, 63
 - covariant constructions, *see* model-based vision
 - Craig's notation, 23
 - cross-ratio, 275, 280
 - of 4 collinear points, 280
 - of 4 lines in a planar pencil, 281
 - of 4 planes in a pencil, 281
 - cross-validation, *see* model selection, *see* classifier
 - crust algorithm, 490
 - CUBIC SPLINE, 340
 - curvature, 431, 438, 440
 - curve, 430, 432, 472
 - apparent, 438
 - sign, 432
 - surface
 - Gaussian, 437, 440–442
 - normal, 434, 437, 442
 - principal, 435, 437
 - curve-tracing algorithm, 458
 - cusp, 427, 430, 435, 438, 446–453, 456, 460
 - crossing, 455, 456

- of the first kind, 430
 - of Gauss, 448, 450, 451
 - point, 427, 440
 - of the second kind, 430
- cyan, *see* color spaces
- cyclopean retina, 239
- cylinder, 569

- dark current, 18
- data association, *see* tracking
- data mining, *see* digital libraries
- daylight, *see* sources
- de Casteljeau algorithm, 639
- decision boundary, *see* classifier
- degree elevation, 624, 640
- degree matrix, 324
- Delaunay triangulation, 490
- delta function, *see* convolution
- dendrogram, *see* clustering
- dense depth map, 82
- depth map, 82, 463, 467
- depth of field, 10
- depth of focus, 10
- derivative of Gaussian filters, *see* finite differences
- derivatives, estimating
 - differentiating and smoothing with one convolution, 169
 - using finite differences, 138
 - noise, 139, 140, 168, 169
 - smoothing, 169, 171–173
- derivatives, using finite differences, 474
- Descartes' law, *see* Snell's law
- deviance, *see* model selection
- dielectric surfaces, 102
- differential geometry, 486
 - analytical, 469–471
 - descriptive, 429–438
 - plane curves, 429–432
 - concave point, 432
 - convex point, 432
 - curvature, 430, 431, 472
 - cuspid of the first kind, 430
 - cuspid of the second kind, 430
 - Gauss map, 431
 - Gaussian image, 431
 - inflection, 430, 431
 - local coordinate system, 429
 - normal line, 429
 - normal vector, 429
 - regular point, 430
 - singular point, 430
 - tangent line, 429
 - tangent vector, 429
 - space curves, 432–434
 - binormal line, 432
 - binormal vector, 433
 - curvature, 432
 - Frénet frame, 432
 - Gauss map, 432
 - normal plane, 432
 - osculating plane, 432
 - parametric curve, 443
 - principal normal line, 432
 - principal normal vector, 433
 - rectifying plane, 432
 - tangent line, 432
 - tangent vector, 433
 - torsion, 433
- surfaces, 434–438
 - asymptotic directions, 435
 - concave point, 435
 - conjugated directions, 439, 442
 - convex point, 435
 - differential of the Gauss map, 436, 470
 - elliptic point, 435, 441
 - first fundamental form, 470
 - Gauss map, 435
 - Gaussian curvature, 437, 441
 - Gaussian image, 435
 - hyperbolic point, 435
 - local coordinate system, 435
 - Monge patch, 470
 - normal curvature, 434
 - normal line, 434
 - normal section, 434
 - normal vector, 434
 - parabolic point, 435
 - principal curvatures, 435
 - principal directions, 435, 439
 - second fundamental form, 437, 470
 - second-order model, 435
 - tangent plane, 434
- differential of the Gauss map, 436, 470
- diffraction, 8
- diffuse reflectance, 65, *see* albedo
- diffuse+specular model
 - see* Lambertian+specular model, 66
- diffusion equation, 163
- digital libraries, 599
 - appearance matching, 603
 - applications, 600
 - browsing, 604
 - clustering, 614, 616, 617
 - desiderata for systems, 604
 - layout with EMD, 607, 608
 - color correlograms, 606
 - data mining, 599
 - EMD or earth-mover's distance, 607, 608
 - evaluation, 601
 - news search example, 601
 - patent search example, 601
 - precision, 601

- recall, 601
 - web filtering example, 601
- iconic matching
 - applications, 603
- information retrieval, 601
- main search strategies
 - iconic matching, 603
- search by matching templates, 613
 - faces, 613
 - parts, 613–615
- semantic matching, 603
- summary representations, 604, 605
 - correlograms, 606
 - histograms, 605
 - layout, 606, 607
 - texture, 607
 - texture of textures, 608, 610
- user needs, 602
- using text and image data
 - for clustering, 614, 616, 617
 - for queries, 611, 612
- video, 617, 618
 - search by motion matching, 617
 - skims, 619
- dihedral vertex, *see* model-based vision
- dioptr, 14
- directed graph, 317
- directional-hemispheric reflectance, 64
 - computing from BRDF, 64
 - definition, 64
- disparity, 234
- distance minimization
 - algebraic, 220
 - geometric, 220
- distortion, 11
- dominant orientation, 196
- dual, 279, 280
- dual photometric stereo, 463
- dual problem, 526
- duality, 279
- dynamic programming, 243, *see* matching on relations

- E-step, *see* missing data problems
- earth-mover's distance, *see* digital libraries
- ecologically valid, 307, 309
- edge
 - detection, 469
 - roof edges, 473
 - step edges, 472–473
- edge detection, 175
 - gradient based, 176
 - edge following, 180
 - examples, 181–183
 - finding maxima of gradient magnitude, 176, 178
 - hysteresis, 181
 - nonmaximum suppression, 177, 179
- Laplacian of Gaussian, 175, 176
 - effects of scale, 177
 - in disfavor, 175
 - strange behavior at corners, 178
- poor behavior at corners, 181
 - rectifying, *see* corner detection
- roof edges, 187
- step edges, 187
- edge-preserving smoothing, 163
- edges, 165
- egg-shaped, *see* differential geometry, surfaces, elliptic
- EGI, *see* extended Gaussian image
- ego-motion, 395
- eigenfaces, *see* classifier
- eigenpictures, *see* classifier
- eigenvalue problem, 41
 - generalized, 41
- eight-point algorithm, *see* weak calibration
- elliptic point, 435, 441
- EM, *see* missing data problems
- entropy coding, 637
- envelope, 450
- epipolar
 - geometry, 216, 629, 634
 - line, 216, 235, 236, 243, 246, 283
 - plane, 216, 283
 - transformation, 219, 283
- epipolar constraint, 215, 216, 227
 - affine fundamental matrix, 260–262
 - parameterization, 262
- essential matrix, 215
 - characterization, 218
 - parameterization, 217
- fundamental matrix, 215, 219
 - characterization, 219
 - parameterization, 219, 283–284
- Longuet–Higgins relation
 - calibrated, 217
 - instantaneous, 218
 - uncalibrated, 218
- epipoles, 216, 224, 226, 283, 287
- essential matrix, *see* epipolar constraint
- Euclidean coordinates, 21
- Euclidean geometry, 20–28
 - coordinate system
 - change, 23–28
 - orthonormal, 21
 - right-handed, 21
- Euclidean coordinates
 - homogeneous, 22
 - nonhomogeneous, 20
- Euclidean shape, 269, 293
- rigid transformation
 - as coordinate change, 26
 - as mapping, 27

- Euclidean geometry (*cont.*)
 - homogeneous form, 27
 - nonhomogeneous form, 26
 - rotation matrix
 - about the k axis, 25
 - definition, 24
 - Euler angles, 53
 - exponential representation, 218, 232
 - properties, 26
 - quaternions, 478
 - Rodrigues formula, 53
 - Euclidean upgrade, 293
 - from affine structure, 266–269
 - multiple views, 267–269
 - from projective structure, 292
 - partially-calibrated cameras, 293
 - Euler angles, 53
 - exitance, 72
 - of a source with known radiance distribution, 72
 - spectral exitance, 97
 - expectation-maximization, *see* EM
 - exponential representation of matrices, 232
 - extended Gaussian image, 463
 - exterior orientation, 50, 231
 - exterior product, 37
 - extrinsic parameters
 - affine camera, 34
 - perspective camera, 30–31
 - f number, 10, 241
 - Façade, 627
 - familiar configuration, *see* segmentation
 - feature selection, *see* classifier, *see* model selection
 - feature tracking, 162
 - field curvature, 11
 - field of view
 - camera, 10
 - human eye, 13
 - figure-ground, *see* segmentation
 - filtering, *see* linear filtering
 - finite difference, 138, 139
 - choice of smoothing, 171–173
 - derivative of Gaussian filters, 169, 171–173
 - differentiating and smoothing with one convolution, 169
 - noise, 168, 169
 - smoothing, 169, 171
 - finite-dimensional linear model, *see* color, modeling image
 - first fundamental form, 470
 - first-order geometric optics, *see* paraxial, geometric optics
 - fitting, 301. *See also* segmentation, missing data problems
 - as an inference problem, 341
 - generative model, 341
 - log-likelihood, 341
 - curves, 337
 - algebraic distance, 338
 - normalizing, 339
 - implicit curves, 337
 - approximating distance from point to, 338
 - distance from point to, 337, 338
 - examples of, 337
 - parametric curves, 340
 - parametric curves, distance from a point to, 340
 - parametric curves, examples of, 340
 - example using EM, 362–364
 - fundamental matrix, 303
 - using EM, 368
 - using RANSAC, 348
 - Hough transform, 329, 407, 408
 - accumulator array, 330
 - implementation guidelines, 330
 - for lines, 330–332
 - practical difficulties, 330, 332, 333, 408
 - identifying outliers with EM, 365, 367
 - layered motion models with EM, 363, 365, 366
 - least squares, 333, 334
 - as an inference problem, 341
 - outliers, 342
 - sensitivity to outliers, 342, 343
 - lines, 303. *See also* missing data problems
 - as a missing data problem, 356
 - as an inference problem, 341
 - by least squares, 333, 334
 - by total least squares, 334, 335
 - example using EM, 362–364
 - identifying outliers with EM, 365, 367
 - incremental line fitting, 335
 - k -means, 335
 - which point is on which line, 335, 341
 - which point is on which line with EM, 362–364
 - outliers, *see* robustness
 - robust, *see* robustness
 - tokens, 302, 333
 - total least squares, 334, 335
 - using k -means, 335
- Flatland, 444
 - flecnodal
 - curve, 451, 452, 455, 460
 - point, 450, 451, 453
 - fluorescence, 60
 - FM beat, 468
 - focal length, 10
 - focal points, 10
 - focus of expansion, 218

- fold
 - of the Gauss map, 432, 436, 440
 - plane curve, 432
 - surface, 436, 440
 - point, 427, 440
- foreshortening, 55
 - different receivers that appear the same from
 - the source receive the same power, 56
 - different sources that appear the same from
 - the receiver have the same effect, 55
 - definition, 55
- form factors, 90
- forward pass, 533
- forward variable, 556
- Fourier transform, 145, 146
 - as change of basis, 146
 - of a band pass filter, 199
 - basis elements as sinusoids, 146, 147
 - definition for 2D signal, 146
 - inverse, 147
 - is linear, 146
 - local version, 200
 - of a low pass filter, 199
 - pairs, 147
 - phase and magnitude, 147
 - magnitude spectrum of image
 - uninformative, 148, 149
 - of a sampled signal, 152
 - sampling, *see* sampling
 - understanding image pyramids with, 199, 200
- fovea, 14
- Frénet frame, 432
- frame grabber, 17
- frame group, *see* model-based vision
- frame pair, 421
- free-form surface, 486
- Frobenius norm, 264, 290, 294
- fronto-parallel plane, 6
- fully connected layer, *see* classifier
- fundamental matrix, *see* epipolar constraint
 - fitting using RANSAC, 348
 - correspondence as noise, 348
 - fitting error, 348
 - starting using seven points, 349
 - fitting using seven points, 349
- fundamental points, 277
- Gabor filters, 200
- gamma correction, *see* color, modeling image
- gating, *see* tracking
- Gauss map
 - differential of the, 436, 470
 - fold, 432, 436, 440
 - plane curve, 431
 - space curve, 432
 - surface, 435
- Gauss–Newton, *see* nonlinear least squares
- Gauss sphere, 435, 484
- Gaussian curvature, 437, 440–442, 470
- Gaussian image
 - curve, 431, 440
 - surface, 435, 438
 - extended, 463
- Gaussian smoothing, 472
- generalized canal surfaces, 577
- generalized cylinder, 577
- generalized cylinders, 576, *see* ribbons
 - may appear in the image as ribbons, 579
 - operationalized as generalized canal surfaces, 577
 - operationalized as swept plane curves, 577
- generalized eigenvalue problem, 41, 291, 514
- generalized eigenvector, 41
- generalizing badly, *see* classifier
- generating curve, 570
- generative model, 355
- generator, 569. *See also* ribbon
- generic
 - curve, 446
 - surface, 446, 449
- geometrical modes, 93
- geometry
 - affine, *see* affine geometry
 - differential, *see* differential geometry
 - Euclidean, *see* Euclidean geometry
 - projective, *see* projective geometry
- gestalt, *see* segmentation
- Global Convergence Theorem, 291
- global shading model, 86
 - color bleeding, 91, 118
 - comparing black and white rooms, 87
 - derivation, 88
 - distant surfaces, 90
 - form factors, 90
 - governing equation, 88
 - interreflection kernel, 88
 - qualitative effects, 90
 - reflexes, 91
 - smoothing effect of interreflection, 90
 - solution in terms of constant patches, 89
- gradient, estimating
 - differentiating and smoothing with one
 - convolution, 169
 - using finite differences, 138
 - noise, 139, 140, 168, 169
 - smoothing, 169, 171–173
- graph, 317
- Grassman’s laws, *see* color perception
- group, *see* matching on relations
- grouping, *see* segmentation
- gutterpoint, 448
- gzip, 637

- heavier tails, 366
- height map, 82
- Helmholtz reciprocity principle, 61
- Hessian, 44
- hidden Markov model, *see* matching on
 - relations, *see* tracking
- highlights, *see* specularity
- homogenous, *see* texture
- homogeneous coordinates
 - affine, 256
 - Euclidean, 22–23
 - projective, 276–278
 - projection matrices, 31
- homogeneous Markov chain, *see* matching on
 - relations
- homography, *see* projective geometry,
 - projective transformation
- homotopy continuation, 457, 464
- horopter, 238
- Hough transform, *see* fitting
- HSV space, *see* color spaces
- hue, *see* color spaces
- human
 - eye, 13–15
 - blind spot, 14
 - cones, 14
 - fovea, 14
 - Helmoltz’s schematic eye, 14
 - macula lutea, 14
 - receptive field, 15
 - rods, 14
 - stereopsis, 237–240, 248
 - cyclopean retina, 239
 - horopter, 238
 - monocular hyperacuity threshold, 238
 - random dot stereogram, 238
- hyperbolic point, 435, 441
- hyperplane
 - affine, 254
 - duality, 279
 - equation, 280
 - at infinity, 278
 - projective, 278
- hypothesis, *see* matching on relations
- hypothesize and test, *see* model-based vision
- hysteresis, *see* edge detection

- iconic matching, 603
 - applications, 603
- ICP algorithm, *see* iterated closest-point
 - algorithm
- ideal diffuse surfaces, 65. *See also* Lambertian
 - surfaces
- illusory contour, 309. *See also* segmentation
- image-based rendering, 620
- image center, 5
- image contour, 427
 - convexities and concavities, 441
 - curvature, 441
 - cusp, 427, 439, 440
 - inflection, 439, 440
 - Koenderink’s Theorem, 441–442
 - T-junction, 427
- image plane, 4
- image pyramid, 159. *See also* scale
 - analysis, 196
 - analysis of textured images, 196
 - coarse scale, 160
 - Gaussian pyramid, 159–161
 - analysis, 160
 - applications, 161, 162
 - as a low pass filter, 199
 - synthesis, 199
 - Laplacian pyramid, 197
 - analysis, 197, 198
 - as a band pass filter, 199, 200
 - synthesis, 199
 - oriented pyramid, 196, 202
 - analysis, 204
 - as a band pass filter, 200
 - example, 204
 - synthesis, 205
 - understanding using Fourier transform, 199, 200
- image rectification, 236–237, 240
- image search, *see* digital libraries
- image structure graph, 459
- implicit curves, 337. *See also* fitting
- impulse response, 142. *See also* convolution
- incomplete data space, 356
- incremental fitting, *see* fitting
- index of refraction, 9, 12
- inertia
 - axis of least, 42
 - second moments, 42
- inflection, 430, 431, 435, 448, 451–453
- information retrieval, *see* digital libraries
- integer programming, 324
- integrability, 85
 - in lightness computation, 125
 - in photometric stereo, 85
- interest points, *see* matching on relations
- interior orientation, 50, 231
- internal boundaries, 569
- interpretation tree, *see* model-based vision
- interreflection, 86
- interreflection kernel, 88
- intrinsic parameters
 - affine camera, 34
 - perspective camera, 29–30
- invariant bearing groups, 414
- invariant local jets, *see* matching on
 - relations

- invariants, 282
 - affine
 - affine coordinates, 257
 - barycentric combinations, 257
 - ratio of collinear points, 257
 - projective
 - cross-ratios, 283
 - projective coordinates, 283
- irradiance, 60
 - definition, 61
 - of a patch illuminated by radiance, 61
 - spectral irradiance, 98
- isotropy, *see* texture
- iterated closest-point algorithm, 479–481
- Jacobian, 43, 457
- k-d* trees, 479
- k*-means, *see* clustering
- k*-nearest neighbor classifier, *see* classifier
- Kalman filtering, *see* tracking
- kernel, *see* convolution
- key frame, *see* shot boundary detection
- Koenderink's Theorem, 441–442
- Lambertian surfaces, 65
- Lambertian+specular model, 66
 - body reflection, 119
 - image color model, 119–121
 - surface reflection, 119
- language model, *see* matching on relations
- Laplacian, 175
- Laplacian pyramid, *see* image pyramid
- layered motion, *see* fitting, *see* missing data problems
- layers, *see* classifier
- least squares, 39–44, *see* fitting
 - linear, *see* linear least squares
 - homogeneous, 480
 - nonhomogeneous, 485
 - nonlinear, *see* nonlinear least squares
- leave-one-out cross-validation, 371. *See also* classifier
- left-right model, *see* matching on relations
- lenses
 - depth of field, 10
 - f* number, 10
 - focal length, 10
 - relative aperture, 63
 - vignetting, 63
- level set, 481
- Levenberg–Marquardt, *see* nonlinear least squares
- light at surfaces, 60
 - fluorescence, 60
 - local interaction model, 60
 - scattering, 60
- light field, 620, 636
- light slab, 636
- light source, 71
- lightness, *see* color spaces, *see* color perception
- lightness computation, 123
 - algorithm, 124, 125
 - assumptions and model, 123
 - constant of integration, 125
- lightness constancy, *see* color perception
- limiting bitangent developable, 455
- line
 - affine, 254
 - fitting, 41–42
 - projective, 278
- line geometry
 - coordinates
 - in the plane, 23
 - exterior product, 37
 - line equation
 - in the plane, 23
 - preimage, 223
 - projection equation, 640
- line jitter, 18
- line source, 75
 - radiosity goes down as reciprocal of distance, 75
- line space, 330
- linear, *see* properties
- linear combinations of models, *see* model-based vision
- linear dynamic models, *see* tracking
- linear features, 507
- linear filtering, *see* convolution, *see* linear systems, shift invariant
- linear least squares, 39–42
 - homogeneous, 40–42
 - eigenvalue problem, 41
 - generalized eigenvalue problem, 41
 - nonhomogeneous, 39–40
 - normal equations, 39
 - pseudoinverse, 40
- linear systems, shift invariant
 - convolution like a dot product, 157, 158
 - filtering as output of linear system, 136
 - filters respond strongly to signals they look like, 157
 - impulse response, 144
 - point spread function, 145
 - properties, 140
 - scaling, 141
 - superposition, 140
 - response given by convolution, 142
 - 1D derivation, 143
 - 2D derivation, 144
 - discrete 1D derivation, 141
 - discrete 2D derivation, 142
- linearly separable, *see* classifier

- lines of curvature, 465
- lip, 451
- local shading model, 77
 - area sources, 79
 - shadows, 79
 - for point sources, 77
 - at infinity, 78
 - not at infinity, 78
 - shadows, 78
 - radiosity is a function of surface normal, 92
 - reflectance map, 92
- local shading models
 - ambient illumination, 79
 - constant value, 79
 - value based on visible area, 80
 - area sources
 - shadows, 79
 - point sources
 - shadows, 79
- local symmetry, 573
- local visual events, 447, 451–453
- logistic function, *see* classifier
- Longuet–Higgins relation, *see* epipolar constraint
- loss, 496
- low-pass filter, 199

- M-estimator, *see* robustness
- M-step, *see* missing data problems
- macula lutea, 14
- magenta, *see* color spaces
- magnetic resonance imaging, *see* medical imaging
- magnification, 6
- magnitude spectrum, *see* Fourier transform
- Mahalanobis distance, *see* classifier
- manifold, 455
- marching cubes, 483
- Markov chain, *see* matching on relations
- Markov models, hidden, *see* matching on relations, *see* tracking
- matching on relations
 - hidden Markov models, 550
 - application to sign language understanding, 559, 562
 - application to finding people, 563, 566
 - Bakis model, 559
 - definitions, 550
 - dynamic programming, 553
 - dynamic programming, algorithm, 555
 - dynamic programming figure, 553
 - dynamic programming, formal details of, 554
 - example of Markov chain, 551
 - fitting a model with EM, 555, 557–559
 - homogeneous Markov chain, 550
 - language model, 559
 - language models, bigram, 561
 - language models, independent word, 560
 - left-right model, 559
 - Markov chain, 550
 - model topologies, 557, 558
 - node value, 553
 - person as an HMM, 564, 565
 - state transition matrix, 551
 - stationary distribution, 551
 - trellis, 552
 - trellis model, 552
 - Viterbi algorithm, 553, 555
- probabilistic models and correspondence
 - search, 542
 - detection and stopping search, 544
 - example: finding faces, 545, 546
 - example: finding people and horses, 548, 549
 - formulating search, 544
 - key issues in structuring search, 544
 - probability model requires search, 543
 - pruning using classifiers, 546, 547
 - search by incremental assembly, 543
 - voting, 538
 - applied to 3D objects, 542
 - as a classifier, 538
 - assembly, 543
 - derived from a generative model, 539
 - derived from a more elaborate generative model, 540
 - example, 539
 - group, 543
 - hypothesis, 543
 - interest points, 538
 - invariant local jets, 538
 - on relations between patches, 541, 542
 - patches, 538
 - pattern, 538
- matrix
 - nullspace, 46
 - range, 39
 - rank, 39
- MDL, *see* model selection
- medial axis, *see* ribbon
- medical imaging
 - applications of registration, 420–422
 - imaging techniques, 419
 - computed tomography imaging, 419
 - magnetic resonance imaging, 419
 - nuclear medical imaging, 419
 - ultra-sound imaging, 419
- metric shape, *see* Euclidean geometry, Euclidean shape
- Meusnier’s theorem, 437
- Mie scattering, *see* sources
- minimum description length, *see* model selection

- missing data problems, 354, 355
 - complete data likelihood, 356
 - EM algorithm, 357, 358
 - background subtraction example, 367
 - E-step, 358
 - fitting HMM with, 555, 557–559
 - for mixture models, 358
 - fundamental matrix example, 368
 - general case, 359
 - incomplete data log-likelihood increases at each step, 358
 - line fitting example, 362–364
 - M-step, 358
 - motion segmentation example, 363, 365, 366
 - outlier example, 365, 367
 - practical difficulties, 368
 - in practice, 359
 - segmentation example, 359–362
 - formal statement, 356
 - image segmentation, 355
 - incomplete data likelihood, 357
 - iterative reestimation strategy, 357
 - line fitting, 356
 - mixture model, 358
 - mixing weights, 355
 - mixture, 355
- mixing weights, *see* missing data problems
- mixture, *see* missing data problems
- mixture models, *see* missing data problems
- mobile robot
 - localization, 51–53
 - navigation, 234, 251
- model selection, 369
 - AIC, 369
 - Bayesian, 370
 - BIC, 370
 - cross-validation, 370
 - deviance, 369
 - MDL, 370
 - minimum description length, 370
 - selection bias, 369
 - test set, 369
 - training set, 369
- model-based stereopsis, 628
- model-based vision
 - alignment, 403, 404
 - for curved surfaces, 422, 423
 - application in medical imaging, 418–422
 - backprojection, 402
 - clutter, 408
 - fitting a projective camera using a
 - correspondence, 406
 - fitting an affine camera using a
 - correspondence, 405, 406
 - frame group, 403
 - dihedral vertex, 404
 - three points, 404
 - trihedral vertex, 404
 - hypothesize and test, 401
 - interpretation tree, 402
 - linear combinations of models, 406
 - modelbase, 401
 - pose, 402
 - pose clustering, 407, 408
 - practical difficulties, 408
 - pose consistency methods, 403
 - using invariants, 410
 - affine invariants for plane points, 411
 - canonical frame, 415, 416
 - covariant constructions, 415, 416
 - general discussion of invariants, 410
 - general plane curves, 415
 - geometric hashing, 413
 - indexing, 413, 414
 - plane affine transformations, 410
 - projective invariants for plane algebraic curves, 411
 - projective invariants for plane points and lines, 411
 - typical system, 414, 415
 - verification, 402, 416
 - alternative strategies, 418
 - by edge proximity, 416
 - and orientation, 417
 - is unreliable, 417
 - verification score, 402
- modelbase, 401
- Monge patch, 80, 470
- motion field, 218, 617
- moving trihedron, *see* Frénet frame
- Muller–Lyer illusion, 305
- multilinear constraints
 - epipolar, *see* epipolar constraint
 - quadrifocal, *see* quadrifocal constraints
 - trifocal, *see* trifocal constraints
- multilocal visual events, 447, 455–456
- multiple-view stereo, *see* stereopsis, multiple views
- Munsell chips, 130
- N-cut, *see* clustering
- naive Bayes, 504, *see* classifier
- nearest neighbor classifier, *see* classifier
- needle map, 461, 463
- neural network, *see* classifier
- Newton’s method
 - convergence rate, 43
 - nonlinear equations, 43, 458, 624
 - nonlinear least squares, 43–44
- node value, *see* matching on relations
- noise, 166
 - additive stationary Gaussian noise, 166, 168
 - choice of smoothing filter, 171

- noise (*cont.*)
 - central limit theorem, 173, 174
 - effect of scale, 173
 - efficiency, 173
 - formal criteria, 172
 - optimal looks like a Gaussian, 172
 - separability, 174
 - virtues of Gaussian kernel, 172
- dead pixels, 168
- linear filter response, 167
- smoothed noise, 170
- smoothing to improve finite difference estimates, 169, 171
- why finite differences respond to it, 168, 169
- nonlinear least squares, 42–44
 - Gauss–Newton, 44
 - convergence rate, 44
 - Levenberg–Marquardt, 44
 - Newton, *see* Newton’s method
- nonmaximum suppression, *see* edge detection
- non-square pixels, 150
- normal
 - curvature, 434
 - line, 429, 434
 - plane, 432
 - principal, 432
 - section, 434
 - vector, 429, 434
- normal equations, *see* linear least-squares, nonhomogeneous
- normal section, 435
- normalized affinity matrix, 326
- normalized correlation, 158, 240, 488
- normalized cut, *see* clustering, 324
- normalized image plane, 29
- NTSC, 17
- nuclear medical imaging, *see* medical imaging
- Nyquist’s theorem, 153

- object model acquisition, from range images, 481–483
- object recognition, *see* template matching
 - by relations, *see* matching on relations
 - from range images, 483–490
 - modelbase, 401
 - pose, 402
- object–outline relations, 568. *See also* ribbons
 - canal surfaces, 570
 - grouping constraint, 571
 - class-based grouping, 575
 - cones, 569
 - grouping constraint, 569
 - cylinders, 569
 - grouping constraint, 569
 - generalized cylinders may appear in the image as ribbons, 579
 - linked using explicit geometric reasoning, 588, 590
 - outline of deduction process, 590, 591
 - polyhedra, 569
 - PRCGC’s or planar right constant
 - cross-section generalized cylinders, 574
 - grouping constraint, 575
 - straight homogeneous generalised cylinders, 573
 - grouping constraint, 574
 - surfaces of revolution, 571
 - grouping constraint, 573
- occluding contour, 427
 - cusp point, 427, 440
 - fold point, 427, 440
- octree, 639
- optic flow, 617
- optical axis, 5, 8
- optical flow, 639
- ordering constraint, 243
- orientation selective, 200
- oriented pyramid, *see* image pyramid
- orthographic projection, *see* projection model, affine, orthographic
- orthonormal coordinate system, 21
- osculating plane, 432
- outliers, *see* robustness
- outline, *see* image contour
- overfit, 370
- overfitting, *see* classifier

- PAL, 17
- parabolic curve, 447–451, 460
- parabolic point, 435, 440, 441, 450, 452, 457
- paraboloid, 435
- parallel projection, *see* projection model, affine, parallel
- parallel symmetric, 575
- parallelism, *see* segmentation
- parameterized image variety (PIV), 633
- parametric curve, 340, 443. *See also* fitting
- parametric surface, 469
- paraperspective
 - projection matrix, *see* projection matrix, affine, paraperspective
 - projection model, *see* projection model, affine, paraperspective
- paraxial
 - geometric optics, 8–9
 - refraction equation, 9
- partially connected layer, *see* classifier
- parts, application in digital libraries, 613–615
- patches, *see* matching on relations
- pattern, *see* matching on relations
- PCA, *see* classifier

- pencil
 - of coplanar lines
 - cross-ratio, 281
 - of hyperplanes, 280
 - of lines, 280
 - of planes, 280
 - cross-ratio, 281
- penumbra, 79
- perceptual organization, *see* segmentation
- perspective
 - camera, *see* camera model, perspective
 - effects, 5
 - projection matrix, *see* projection matrix, pinhole perspective
 - projection model, *see* projection model, pinhole perspective
- phase spectrum, *see* Fourier transform
- phases, 191
- Phong model, 66
- photo-conversion, 16
- photogrammetry, 50, 215, 231, 234, 629
- photometric stereo, 80
 - depth from normals, 84
 - dual, 463
 - formulation, 82
 - integrability, 85, 125
 - normal and albedo in one vector, 82
 - recovering albedo, 83
 - recovering normals, 83
 - zeroing contributions from shadowed regions, 83
- pinhole, 3
 - camera, 4–6
 - perspective, *see* projection model, pinhole perspective
- pixel, 17
- Plücker coordinates, 640
- planar right constant cross-section generalized cylinder, 574
- plane
 - affine, 254
 - equation, 22
 - projective, 278
- plane affine transformations, 410
- plane projective transformation, 410
- planes, representing orientation of
 - slant, 208, 209
 - tilt, 208, 209
 - tilt direction, 208, 209
- plenoptic function, 636
- point source, 72
 - choice of model, 74
 - general considerations, 73
 - nearby point source, 74
 - dark corners in rooms, 75
 - dependency on distance, 74
 - point source at infinity, 74
 - radiosity due to a, 74
 - source vector, 74
- point source at infinity, 74
- point spread function, *see* convolution
- points at infinity, 275
- polarity, 196
- pose, *see* model-based vision
- pose consistency methods, *see* model-based vision
- potential well, 16
- precision, *see* digital libraries
- primaries, *see* color perception
- primary aberrations, 11
- principal
 - curvatures, 435, 471
 - directions, 435, 439, 470
- principal component analysis, *see* classifier
- principal points, 11
- principle of univariance, *see* color perception
- probabilistic data association, *see* tracking
- probability distributions
 - normal distribution
 - important in tracking linear dynamic models, 380
 - integral identities for 1D Gaussians, 380
- projection equation
 - affine, 34
 - orthographic, 7
 - weak-perspective, 6
 - pinhole perspective, 6
 - points, 30
- projection matrix
 - affine, 34
 - characterization, 34–35
 - paraperspective, 34
 - weak-perspective, 34
 - pinhole perspective
 - characterization, 31–32
 - explicit parameterization, 31
 - general form, 30
- projection model
 - affine, 6–7, 32–33
 - orthographic, 7, 32
 - parallel, 32
 - paraperspective, 32, 33
 - weak-perspective, 6, 32, 632
 - pinhole perspective
 - planar, 4–6
- projective coordinates, 276, 280
- projective geometry, 275–284
 - affine space embedding, 278–279
 - hyperplane at infinity, 278
 - projective closure, 278
 - projective completion, 278
 - coordinate system, 276–278
 - fundamental points, 277
 - unit point, 277

- projective geometry (*cont.*)
 - duality, 279
 - projective coordinates
 - cross-ratio, 275, 280
 - homogeneous, 277
 - nonhomogeneous, 280
 - projective shape, 275, 284
 - projective space, 275
 - projective subspace, 276
 - projective transformation, 28, 275
- projective structure from motion
 - ambiguity, 275
 - definition, 274
 - Euclidean upgrade, 292
 - partially-calibrated cameras, 293
 - from binocular correspondences
 - algebraic, 285–287
 - geometric, 284–285
 - from multilinear constraints
 - fundamental matrix, 288
 - trifocal tensor, 288–289
 - from multiple images
 - bundle adjustment, 292
 - factorization, 289–292
- properties, linear systems, shift invariant
 - linear, 136
 - shift-invariant, 136, 141
- proximity, *see* segmentation
- pseudoinverse, 40
- pulse time delay, 468

- QR decomposition, 40, 41
- quadratic programming, 527
- quadrature pairs, 201
- quadric
 - surface, 23, 457
 - equation, 23
- quadrifocal constraints, 227–230
 - 1 point, 3 lines, 229
 - 4 lines, 229
 - 4 points, 228
- quadrifocal tensor, 215, 229
 - characterization, 229
 - estimation, 229
- quadrilinear constraints, *see* quadrifocal constraints
- qualitative radiometry, 70
 - Lambert's wall, 71
- quantum efficiency, 17
- quaternions, 478, 480, 485, 490
- QuickTime VR, 639

- radial
 - alignment constraint, 48
 - curvature, 441
 - curve, 441
 - distortion, 47
- radiance, 58
 - proof that it is constant along straight lines, 58
 - definition, 58
 - spectral radiance, 97
 - units, 58
- radiometry, 55
- radiosity, 63
 - definition and units, 63
 - of a surface of constant radiance, 64
 - of a surface whose radiance is known, 64
- radius of curvature, 430
- random dot stereogram, 238
- range finders, 467–469
 - acoustico-optical, 469
 - time of flight, 468
 - triangulation, 467
- range image, 467
- RANSAC, *see* robustness
- ratio
 - of 3 collinear points, 257
 - of signed distances between collinear points, 257
- ray, 275
- ray tracing, 459, 465, 630
- Rayleigh scattering, *see* sources
- recall, *see* digital libraries
- receiver operating curve, *see* classifier
- receptive field, 15
- rectifying plane, 432
- reduced row-echelon form of a matrix, 269
- reflectance, *see* albedo
- reflectance map, 92
- reflexes, 91
- region growing, 477
- regional properties, 91
- registration
 - from planes, 484–485
 - from points, 479–481
- regular point, 430
- relational matching, *see* matching on relations
- relations, *see* matching on relations
- relations between object and outline, *see* object-outline relations
- relative aperture, 63
- representing orientation, *see* image pyramid
- Retinex, 130
- RGB, 17
- RGB color space, *see* color spaces
- RGB cube, *see* color spaces
- ribbons, 579
 - Blum ribbon, 579
 - Blum transform, 580
 - Brooks ribbon, 579
 - capacity to represent, 584, 586
 - generator, 579
 - grassfire transform, 580

- interpretation, 580
- matching, 583, 584
- medial axis, 580
- segmentation, 581, 583
- spine, 579
- right circular cone, 569
- right circular cylinder, 569
- right-handed coordinate system, 21
- rigid transformation, *see* Euclidean geometry
- rim, *see* occluding contour
- ringing, *see* convolution
- risk, *see* classifier
- robustness, 341, 342
 - identifying outliers with EM, 365, 367, 368
 - M-estimator, 344–346
 - influence function, 343
 - M-estimators, 343, 344
 - scale, 344
 - outliers
 - causes, 342
 - sensitivity of least squares to, 342, 343
- RANSAC, 346
 - example, fundamental matrix, 348
 - how many points need to agree?, 347
 - how many tries?, 346
 - how near should it be?, 347
 - searching for good data, 346
- ROC, *see* receiver operating curve
- Rodrigues formula, 53
- rods, 14
- roof, 472
- roof edge, 187
- rotation matrix, *see* Euclidean geometry
- RREF, *see* reduced-row echelon form of a matrix
- ruled surface, 451

- saddle-shaped, *see* differential geometry, surfaces, hyperbolic
- sampling, 148, 150
 - aliasing, 149, 152–156
 - formal model, 150–152
 - Fourier transform of sampled signal, 152
 - illustration, 150, 151
 - non-square pixels, 150
 - Nyquist's theorem, 153
 - poorly causes loss of information, 149
- saturation, *see* color spaces
- scale, 159, *see* image pyramid, 201
 - anisotropic diffusion or edge preserving smoothing, 163
 - applications, 161
 - coarse scale, 160
 - effects of choice of scale, 173
 - efficient smoothing, 173, 174
 - of an M-estimator, 344
- scale ambiguity, *see* ambiguity, Euclidean
 - scale space, 471, 472
 - scale-restraint condition equations, 231
 - scaled orthography, *see* weak perspective
 - scaling, *see* linear systems, shift invariant
 - scan conversion, 487
 - SECAM, 17
 - secant, 429
 - second fundamental form, 437, 470
 - segmentation, 301. *See also* clustering, fitting
 - application in digital libraries, 611
 - as a missing data problem, 355. *See also* missing data problems
 - background subtraction
 - using EM, 367
 - by graph theoretic methods, *see* clustering
 - clustering, *see* clustering
 - example applications, 302, 309
 - background subtraction, 309–312
 - shot boundary detection, 310
 - fundamental matrix fitting, 303
 - gestalt, 305
 - goals, 302
 - human, 304
 - closure, 306
 - common fate, 306
 - common region, 306
 - continuity, 306
 - examples, 302, 306–309
 - factors that predispose to grouping, 305–309
 - familiar configuration, 306, 307
 - figure and ground, 305
 - gestalt quality or gestaltqualität, 305
 - illusory contours, 309
 - parallelism, 306
 - proximity, 306
 - similarity, 306
 - symmetry, 306
 - line fitting, 303
 - model problems, 303
 - range data, 469–477
 - regions, 303
 - segmentation by EM, 359–362
 - tokens, 302
 - useful in semantic matching, 604
 - selection bias, *see* model selection, *see* model selection, *see* classifier
 - self-calibration, 295
 - self-loop, 317
 - self shadow boundaries, 78
 - semantic matching, 603
 - semilocal constraints, 542
 - semilocal surface representation, 486
 - separable kernels, 174
 - shading model, 70

- shading primitive, 94
- shadows, 78
 - area sources, 79
 - cast shadow boundaries, 78
 - penumbra, 79
 - point sources, 78
 - self shadow boundaries, 78
 - umbra, 79
- shape
 - affine, *see* affine geometry
 - Euclidean, *see* Euclidean geometry
 - projective, *see* projective geometry
- shape interaction matrix, 271
- SHGC, 573
- shift invariant linear system, *see* linear systems,
 - shift invariant
- shift-invariant, *see* properties
- shot boundary detection, 302, 309–311
 - key frame, 311
 - shots, 310
- shot noise, 17
- shots, 304, *see* shot boundary detection
- sigmoid function, *see* classifier
- signal, 166
- silhouette, *see* image contour
- similarity, 269, *see* segmentation
- singular point, 430
- singular value decomposition, 40, 41, 221, 265, 290
 - definition and properties, 264
- singularity theory, 446
- skeleton, 578
- skylight, *see* sources
- slack variables, 534
- slant, 208
- smoothing, 136
 - as high pass filtering, 153, 155, 156
 - Gaussian kernel, 136
 - discrete approximation, 137, 174
 - Gaussian smoothing, 136–138
 - avoids ringing, 136, 137
 - central limit theorem, 173, 174
 - discrete kernel, 137, 174
 - effects of scale, 137, 173
 - efficiency, 173
 - separability, 174
 - standard deviation, 137
 - suppresses independent stationary additive noise, 139
 - virtues of, 172
 - response to noise, 167
 - to reduce aliasing, 153, 155, 156
 - weighted average, 135
- Snell's law, 8
- solid angle, 56
 - analogy with angle, 56
 - definition, 56
 - in terms of angular coordinates on a sphere, 58
 - in terms of subtended area, 57
 - units, 57
- SOR, 571
- source vector, 74. *See also* point source
- sources
 - airlight, 98
 - black body, 98
 - daylight, 98
 - fluorescent light, 99
 - incandescent light, 99
 - mercury arc lamps, 101
 - Mie scattering, 99
 - Rayleigh scattering, 98
 - skylight, 98
 - sodium arc lamps, 101
 - source colors, 117
- space carving, 639
- spatial frequency, *see* Fourier transform
- spatial frequency components, 146
- spectral albedo, *see* albedo
- spectral BRDF, *see* bidirectional reflectance distribution function
- spectral exitance, *see* exitance
- spectral irradiance, *see* irradiance
- spectral locus, 109
- spectral quantities, 97
- spectral radiance, *see* radiance
- spectral reflectance, *see* albedo
- spectral specular albedo, *see* specular
- spectral units, 97
- specular, 65
 - dielectric surfaces, 102
 - metal surfaces, 102
 - Phong model, 66
 - spectral specular albedo, 101
 - specular albedo, 66
 - specular lobes, 66
 - specularity, 66
 - finding, 119
- specular direction, 65
- specularity, 66, *see* specular
- spherical aberration, 11
- spin
 - coordinates, 486
 - images, 486–490
 - map, 486
- spine, *see* ribbon
- spline
 - curve, 621
 - surface, 621, 622
- squashing function, *see* classifier
- standard deviation, *see* smoothing
- state transition matrix, *see* matching on relations
- stationary distribution, *see* matching on relations

- step, 472
- step edges, 187
- steradians, 57
- stereo rig, 216
- stereolithography, 483
- stereopsis
 - binocular fusion, 240–245
 - dynamic programming, 243–245
 - multiscale matching, 242, 243
 - normalized correlation, 240–242, 628
 - constraints
 - compatibility, 239
 - continuity, 239
 - epipolar, 235
 - ordering, 243
 - uniqueness, 239
 - disparity, 234, 237, 238
 - multiple views, 247, 625
 - random dot stereogram, 238
 - reconstruction, 235–237
 - rectification, 236–237
 - trinocular fusion, 246
- stochastic gradient descent, 519
- straight homogeneous generalised cylinder, 573
- structured light, 467
- subtractive matching, *see* color perception
- superposition, *see* linear systems, shift invariant
- superquadrics, 490
- support maps, 365
- support vector machine, *see* classifier
- support vectors, 526
- surface color, *see* color perception
- surface of revolution, 571
- SVD, *see* singular value decomposition
- swallowtail, 451, 452
- symmetric, 144
- symmetric Gaussian kernel, *see* smoothing
- symmetry, *see* segmentation
- symmetry line, 573
- synthesis, *see* image pyramid
- system, *see* linear systems, shift invariant
- system identification, 397

- T-junction, 427, 440, 446, 447, 453, 455, 456, 460
- tails, 365
- tangent
 - crossing, 455
 - line, 429
 - plane, 434
 - vector, 429
- template matching, 495, *see* classifier
 - application in digital libraries, 613–615
 - filters as templates, 157
- templates, geometric, from spatial relations, 568
- tensor, 224
- tensor product, 174
- tensorial notation, 227
- test set, *see* model selection
- textons, 190
- texture
 - applications in digital libraries, 608, 610
 - examples, 189, 190
 - homogeneity, 205
 - isotropy, 208
 - representing with filter outputs, 191, 193
 - efficient computation with oriented pyramids, 196
 - typical filters, 191–193, 200–203
 - scale, 189
 - shape from texture, 207
 - for planes, 208–210
 - statistics of filter outputs, 193
 - choice of statistic, 195
 - example, 194
 - scale of windows, 196
 - synthesis, 202, 205, 206
 - textons, 190
 - texture map, 203
- texture mapping, 627, 630, 634, 637
- thick lenses, 11
 - principal points, 11
- thin lenses, 9–10
 - $\cos^4 \alpha$ fall-off, 63
 - equation, 10
 - focal length, 10
 - focal points, 10
 - radiance/irradiance equation, 63
- thin-plate energy term, 624
- third-order refraction equation, 11
- threshold function, 516
- tie points, 620, 629
- tilt, 208
- tilt direction, 208
- tokens, *see* segmentation
- torsion, 433, 434
- total least squares, *see* fitting
- tracking
 - applications
 - motion capture, 373
 - recognition, 373
 - surveillance, 373
 - targeting, 373
 - topics, 393
 - vehicle tracking example systems, 393–396
 - data association, 388
 - by global nearest neighbors, 389
 - by probabilistic data association, 390
 - clutter, 389
 - gating, 390
 - definition, 373
 - Kalman filters, 380
 - detailed derivation for 1D, 380

- tracking (*cont.*)
 - detailed derivation for 1D, prediction, 381, 382
 - equations for 1D, 382
 - equations for arbitrary dimension, 384
 - example of tracking a point on a line, 383, 384
 - forward–backward smoothing, 383, 386–388
 - integral identities for 1D Gaussians, 380
 - notation, 380
- as inference, 374
 - derivation, 375
 - derivation of correction step, 375
 - derivation of prediction step, 375
 - key assumptions, 374
 - main cases, 374
- linear dynamic models, 376
 - all conditional probabilities normal, 380
 - are tracked using a Kalman filter, *qv*, 380
 - constant acceleration, 377, 379
 - constant velocity, 377, 378
 - drift, 377
 - higher order models, 379
 - periodic motion, 379
- main problems
 - correction, 374
 - data association, 374
 - prediction, 374
- measurement
 - measurement matrix, 377
 - observability, 377
- smoothing, 383, 386–388
- training set, *see* model selection
- transfer, 215, 223, 229, 620, 629
- transformation groups
 - affine transformations, *see* affine geometry
 - projective transformations, *see* projective geometry
 - rigid transformations, *see* Euclidean geometry
 - rotations, *see* Euclidean geometry
 - similarities, 269
- trellis, *see* matching on relations
- triangular spline, 622
- trichromacy, *see* color perception
- trifocal
 - lines, 222
 - plane, 222
- trifocal constraints, 223–228, 230
 - 1 point, 2 lines, 225
 - 3 lines, 224
 - 3 points, 225
 - 3 points, 3 rays, 228
- trifocal tensor, 249
 - calibrated, 224
 - estimation, 226–227
 - uncalibrated, 226
- trihedral vertex, *see* model-based vision
- trilinear constraints, *see* trifocal constraints
- trinocular fusion, *see* stereopsis, trinocular fusion
- triple point, 455, 456
- tritangent, 456
- twisted cubic, 47
- twisted curves, *see* differential geometry, space curves
- ultra-sound imaging, *see* medical imaging
- umbra, 79
- undirected graph, 317
- undulation, 450
- unit point, 277
- unode, 454
- value, *see* color spaces
- variety, 632
- vector quantization, 637
- velocity, 433
- vergence, 238, 247
- verification, *see* model-based vision
- vertex, 569
- video formats
 - component video, 17
 - NTSC, 17
 - PAL, 17
 - RGB, 17
 - SECAM, 17
- viewing
 - cone, 427, 569, 621
 - cylinder, 427
- viewpoint
 - general, 440
- vignetting, 12, 63
- virtual image, 4
- virtual reality, 630
- virtualized reality, 625
- visual events, 445, 451
 - curves, 451
 - equations, 457, 466
 - local, 451–453
 - beak-to-beak, 451, 452
 - lip, 451
 - swallowtail, 451, 452
 - multilocal, 455–456
 - cusp crossing, 455, 456
 - tangent crossing, 455
 - triple point, 455, 456
- visual hull, 639
- visual potential, *see* aspect graph
- Viterbi algorithm, *see* matching on relations, 554
- voxel, 481

- wavelet coefficients, 527
- weak calibration, 219–221
 - eight-point algorithm
 - minimal, 219
 - normalized, 220
 - overconstrained, 220
 - nonlinear, 220
 - weak perspective
 - projection matrix, *see* projection matrix,
 - affine, weak-perspective
 - projection model, *see* projection model,
 - affine, weak-perspective
- weighted graph, 317
- within-class variance, 513
- yellow, *see* color spaces
- z-buffer, 461, 465, 631, 634
- zero crossings, 175
- zero-skew projection matrix, 31
- zippered polygonal mesh, 490

