

Index

- C^n -continuous, 738
- L_1 -norm minimization, 150
 - ML-type estimation as L_1 ., 148
- L_{12} -norm minimization, **148**, 755, 764
- S^1 , 214, 215
- S^2 , 199, 200, 242, 243
- S^3 , 242, 333
- S^5 , 243
- Π , **300**
- $\Pi(\mathbf{x})$, independent rows and columns, 319
- $\overline{\Pi}$, **301**
- Γ , 219
- $\Gamma(\mathbf{x})$, independent rows, 319
- $\overline{\Gamma}$, 233
- Ω , **84**
- χ distribution, 34
- χ^2 -square distribution, 33
- δ_0 , 131
 - for multi-dimensional test, 68, 130
 - for one-dimensional test, 66, 128
- $\ell(l'', l''')$, **625**
- D , 227
- \mathbb{P} , 231
- \mathbb{P}^0 , 215, 216, 231
- \mathbb{P}^1 , 214
- \mathbb{P}^2 , 200, 203, **206**, 207, 211, 215, 231
- \mathbb{P}^3 , **210**, 231
- \mathbb{P}^5 , 231
- \mathbb{P}^n , **215**
- \mathbb{P}^{*2} , **209**, 209
- \mathbb{P}^{*3} , **212**, 231
- \mathbb{T}^n , **345**
- \mathbb{T}^{*2} , 346
- \mathbb{T}^{*3} , 347
- $S(\mathbf{x})$, independent rows, 318
- ρ -function, 144
 - table of ρ ., 149
- $\varphi_2(\chi', l''')$, **631**
- $\varphi_3(\chi', l''')$, **631**
- x -parallax, 566, **589**, 601–604
- y -parallax, 561, 566, **589**, 590, 592, 602
- $2\frac{1}{2}$ D surface, 729
- 1D homography, 257
 - fixed entities of h., 276
- 1D point, 214
 - at infinity, 214
 - homogeneous coordinates of p., 214
- 2D affinity, 252
 - fixed line of a., 274
- 2D autocollineation, perspective a., 277
- 2D block adjustment
 - free b., 663
 - functional model of b., 651
 - gauge constraints in b., 665
 - gauge transformation in b., 668
 - inner precision of b., 666
 - mathematical model of b., 651
 - sparsity of matrices, 655
 - stochastic model of b., 652
 - theoretical quality of b., 670–674
- 2D circle, 237
- 2D homography, 250, **253**
 - algebraic solution for h., 389
 - closed form solution of h., 406
 - degrees of freedom of h., 321
 - fixed entities of h., 274
 - from uncertain point pairs, 425
 - minimal parametrization of h., 385
 - minimal solution of h., 321
 - orientedness of transformed entities, 355
 - uncertainty of points mapped with h., 387
- 2D line, 207
 - at infinity, **207**
 - centroid representation of l., 374
 - direction of l., 294, 348
 - distinct points of l., 318
 - from two points, 292
 - from uncertain centroid to Hessian form of l., 374
 - Hessian normal form of l., **207**, 374
 - Hessian normal form of uncertain l., 374
 - homogeneous coordinates of l., 207
 - null space of covariance matrix of l., 375, 392
 - optimal closed form solution for l., 397
 - oriented l., 346
 - Plücker coordinates of l., 223
 - point at infinity of l., 209, 294
 - point-direction form of l., 209
 - through two points, 221
 - transformation of l., 258
 - uncertain Hessian form to homogeneous coordinates of l., 375
 - uncertain Hessian parameters of l., 376
 - uncertain homogeneous coordinates to Hessian form, 377
 - uncertain l., 373–377
- 2D model block adjustment, 650–674
- 2D motion, 251
 - fixed entities of m, 274
- 2D point, 206
 - at infinity, 206
 - closest to conic, 295
 - covariance matrix of spherically normalized p., 393
 - degrees of freedom of p., 207
 - direct least squares solution of intersection p., 401
 - direct solution for intersection p., 401
 - distinct lines of p., 318
 - dual of p., 204
 - homogeneous coordinates of p., 206
 - null space of covariance matrix of p., 368, 393
 - oriented p., 345
 - Plücker coordinates of p., 223
 - reduced coordinates of p., 370
 - sign of intersection p., 353
 - spherical normalization of uncertain p., 368
 - uncertain p., 366–372
- 2D rotation, 251
 - fixed entities of r., 274
- 2D scaling, 251
- 2D shear, 252
- 2D similarity, 252
- 2D translation, 251
 - fixed entities of t., 274
- 3D affinity, 255
- 3D autocollineation, 280
- 3D circle, 241
- 3D conics, 241

- 3D homography, 256
 closed form solution of h ., 406
 fixed entities of h ., 275
 minimal solution of h ., 322
- 3D line
 and spatial triangle, 351
 approximating 6-vector of l ., 381
 at infinity, 219
 coplanarity of two l ., 304
 covariance matrix of reduced coordinates of l ., 381
 degrees of freedom of l ., 216, 227
 direct solution of l ., 412
 directed l ., 606
 direction of l ., 348, 353
 distinct planes of l ., 319
 distinct points of l ., 319
 dual l ., 233
 from two planes, 220
 moment vector of l ., **218**, 219, 220, 227
 oriented l ., 348
 parameters of l ., 216
 Plücker coordinates of l ., **218**, 226
 point at infinity of l ., 220
 point-direction form of l ., 220
 projection, 480
 reconstruction from two images, 605
 reduced coordinates of l ., 380–381
 spherical projection of l ., 481
 through four 3D lines, 302
 through two points, 300
 transformation, 259
 two-point form of l ., 220
 uncertain l ., 379–381
- 3D model block adjustment, 649
- 3D motion, 255
 fixed entities of m ., 276
- 3D point, 210
 at infinity, 210
 degrees of freedom of p ., 211
 direct least squares solution of intersection p ., 402
 direct solution for line intersection p ., 401
 distinct planes of p ., 319
 from several images, 602
 from two rays, normal case of image pair, 601
 homogeneous coordinates of p ., 210
 oriented p ., 346
 Plücker coordinates of p ., 225
 quality of p ., 526
 triangulation of p . from several images, 602
 uncertain p ., 372–373
- 3D points, collinearity of p ., 306
- 3D rotation, *see* rotation
- 3D similarity, 255
- 3D translation, 255
 fixed entities of t ., 275
- a posteriori probability density, 77
- a priori probability density, 76
- absolute orientation, 549, **552**, 607, 609
 direct solution of a . with three points, 515
 of calibrated cameras, 552
 of uncalibrated cameras, 552
 redundancy of a ., 613
 within two-step procedure, 612
- absolute points, 241
- acceptability
 of a covariance matrix, 120
 of bundle adjustment result, 688
 of configuration, 495, 516
 of precision, 117, 120
- accuracy, **116**, 490
 empirical a ., 117
 identification a ., 117, **490**, 706
 of the mean, 116
- adaptive least K th order squares, 146
- additional parameters, 123, 464
 choice of a ., 509, 684
 elimination, 695
 evaluation, 693
 evaluation of a ., 699
- adjacency graph, 654, 660
- adjugate matrix, 770
- adjustment, *see* estimation
- adjustment, block a ., 643
- ADS 80, Leica, 443, 445, 446
- aerotriangulation, 707, **718**, 721
- affinity
 2D a ., 252
 3D a ., 255
 chirality of transformed configurations, 357
 minimal solution of a ., 320
 sign of entities transformed with a ., 357
- algebraic solution, 178
 covariance matrix of a ., 180
 for 2D homography, 389
 for 2D line, 396
 for 2D line intersection, 401
 for 3D line intersection, 401
 for plane, 396
 for projection matrix, 494
 with eigenvalue decomposition, 179
 with SVD, 179
- algorithm
 K, R, Z from P , 500
 b, R from essential matrix, 583
 3D circle from its image, 536
 direct LSE 2D line from points, 401
 direct LSE 3D line from points, 414
 direct LSE 3D similarity from point pairs, 411
 direct LSE mean axis, 405
 direct LSE mean direction, 404
 direct LSE point from lines, 403
 direct LSE rotation from point pairs, 408
 DLT for projection matrix, 496
 Gauss–Helmert model with reduced coordinates, 416
- Gauss–Markov model with constraints, 108
- Gauss–Markov model, linear, 91
- homography from point pairs, 389
- model with constraints between the observations only, 171
- optimal P from image points, 498
- RANSAC, 156
- reweighing constraints, 169
- robust a . for Gauss–Helmert model with constraints, 168
- sequential similarity transformations, 710
- sequential spatial resection, 709
- triangulation, 600
- algorithmic complexity, 452
- analysis model, 7, 448
- angle
 between 2D direction and coordinate axes, 206
 between 3D direction and coordinate axes, 210
 between two 2D lines, 298
 direction a ., 298
 parallactic a ., 420, 421
 tilt a . of plane, 212
 zenith a ., 210
- antiparallel, 343
- antipodal
 line, 348
 plane, 347
 point, 344–346
- approximate residuals, 164
- approximate values, 145, 452
 for bundle adjustment, 707–715
 for bundle adjustment, direct solutions, 711
 for bundle adjustment, sequential solutions, 708
 for relative orientation, 583
 for relative orientation, normal case, 589
- AR-process
 AR(P), 52
 AR(1), 53
 AR(2), 53
 for modelling profiles, 748
 integrated A ., 54, 752
 observed A ., 749
- area camera, 444
- area of triangle, 222
- astigmatism, 379
- asymmetric weight function, 756
- attitude of camera, 456
- autocollineation, 248, 256
 2D a ., 277
 fixed elements of a ., 272
 perspective a ., **277**
- automatic image matching, 563
- autoregressive process, *see* AR process
- axis and angle
 from rotation matrix, 331
- axis, closed form solution of mean a ., 405
- back projection, 482

- bandwidth of matrix, 662
- barycentric coordinates, 213, 349
- base line, 551, 563
- base vector, 553, 578, 582
 - estimation from 2 points, given rotation, 578
- base-to-height ratio, 604
- basis functions
 - monomials as b., 733
 - of collocation, 735
 - radial b., 735
 - splines as b., 736
 - trigonometric b., 734
- Bayer pattern, 444
- Bayesian estimation, 76–78
 - in Gauss–Markov model, 93
 - surface reconstruction as B., 742
- Bayesian factor, 64
- Bayesian information criterion, 139, 686
- Bertrand’s paradox, 22
- best linear unbiased estimate, 79
- best unbiased estimate, 79
- bi-partite graph, 646
- bias, **116**
 - induced by linearization, 44
 - of estimated variance factor, 137
 - of estimates, 79, 141
 - of normalization, 45
 - of product, 44
 - of the mean, 45
 - of the variance, 45
 - of variance of image points and lines, 493
- bicubic interpolation, 738
- bilinear interpolation, 738
- bilinearity of coplanarity constraint, 553
- binomial distribution, 28
- bivector, 235
- block, 643
- block adjustment, 643
 - 2D model b., 651
 - adjacency graph in b., 660
 - bundle adjustment as b., 648
 - free b., 663
 - linear planar b., 711–714
 - mathematical model of b., 647
 - model b., 645
- block matrix, inverse of b., 769
- blunder, *see* outlier
- boundary of region, 442
- break down point, 145
- bundle adjustment, 450, 609, **648**
 - acceptability of accuracy of b., 692
 - acceptability of design of b., 691
 - acceptance criteria for results of b., 688
 - approximate values, 707–715
 - as block adjustment, 648
 - Cramer–Rao bound of b., 683
 - empirical accuracy of b., 682
 - Euclidean b., 649
 - evaluation of b., 687
 - factorization method for b., 714
 - for camera calibration, 696
 - for image pair, 610
 - for image triplet, 638
 - for relative orientation, 585
 - functional model of b., 675
 - gauge constraints in b., 665
 - linear estimation of rotations in b., 713
 - linearized model of b., 676
 - MAP estimate for b., 648
 - nonlinear model of b., 675
 - outlier detection, 707–715
 - projective, 676
 - projective b., 649
 - redundancy of image pair, 611
 - self-calibrating b., 450, 674–696
 - sensitivity of b., 701
 - spherical camera b., 686
 - variance component estimation in b., 679
 - view planning for b., 715–722
 - with lines, 676
 - with points, 610, 649
- bundle of rays, 461, 559
- calibrated camera, **460**, 555–557, 607, 622
 - for the image pair, 556
- calibration
 - laboratory c., 697
 - of camera, 449
 - self-c., 697
 - stability of c., 702
 - test field c., 697
 - with unknown testfield, 698
- calibration matrix, 471
 - differential c., 501
 - from projection matrix, 499
- camera, 460
 - absolute orientation of calibrated c., 552
 - absolute orientation of uncalibrated c., 552
 - affine c., **464**
 - area c., 444
 - calibrated c., 452, **460**, 607, 622
 - calibrated perspective c., 555–557
 - calibration, 449
 - calibration, bundle adjustment for c., 696
 - calibration, laboratory c., 697
 - calibration, test field c., 697
 - catadioptric c., 487
 - central c., **446**, 456, 465, 622
 - computational c., 444
 - coordinate system, **463**, 465, 602
 - coplanarity constraint for images of calibrated c., 555–557
 - coplanarity constraint for images of spherical c., 556–557
 - digital c., 465
 - distortions of perspective c., 505
 - essential matrix of normalized c., 559
 - Euclidean c., **464**
 - fish-eye c., 485
 - generic c., **446**, 460
 - geometric c. model, 443
 - ideal c., **465**, 561
 - ideal perspective c., 468
 - ideal unit c., 465
 - line c., 444
 - matrix, 281
 - metric c., **460**, 460
 - model, 441, **445**, 479
 - model of central c., 468
 - model of perspective c., 462, 464, 470
 - model of real c., 461
 - model of spherical c., 462, 468
 - moving c., 568
 - normalized c., **465**, 472, 713
 - orientation, 449
 - partially calibrated c., **460**
 - perspective c., 248, **446**, 456, 460, 464, 607
 - perspective c. for the image pair, 550
 - perspective c. for the image triplet, 622
 - perspective c. with distortions, **464**
 - pinhole c., 253, 281, 464, 465
 - planes, 554
 - point c., 444
 - pose, 456
 - principal planes of c., 474
 - ray, 469
 - real c., 456
 - relative orientation, 552
 - spherical, 582
 - spherical c., **446**
 - spherical c. for the image pair, 555, 556
 - spherical c. for the image triplet, 622
 - stellar calibration of perspective c., 496
 - systems, 488
 - uncalibrated, **461**
 - uncalibrated c., 452, 490, 550, 622
 - with affine sensor, 470
 - with distortion, 462
 - with Euclidean sensor, 531
- Canon PowerShot A630, 443, 445
- catadioptric camera, 487
- catadioptric optics, 446
- caustic, 445, 446
- Cayley representation of rotation, 336
- central camera, **446**, 456, 465
 - model of, 468
- central limit theorem, 30
- central projection, **456**, 467, 481, 485, 487, 490
- centroid representation, 490, 492
 - of 2D line, 374
 - of plane, 377
- Chasles’ theorem, 272
- check of linearization, 104
- check points, 683, 700
- checkability, 117, 453
 - of coordinates in absolute orientation, 411
 - of parameters, 133

- checking the implementation, 139
- chirality, 357
 - effect of affinity, 357
 - effect of homography on c., 356
 - of 2D line and point, 349
 - of four 3D points, 350
 - of plane and point, 350
 - of three 2D points, 349
 - of two 3D lines, 350, 355
- choice of additional parameters, 509, 684
- Cholesky decomposition, 86, 661, 776
- circle, 237
 - 2D, 237
 - 3D, 241
- circle fitting, 177
- close range applications, 452
- closed form estimation, 176–183
- closed form solution, *see* direct solution
- clustering, 157
- cofactor matrix, 369, 556, **769**
 - as dual transformation matrix, 259
 - for line conic, 239
 - for plane quadric, 240
 - for polarity, 238
 - for transformation of hyperplanes, 258
- collinearity
 - equations, 470
 - of 3D points, 306, 602
 - of projection centres, 622
 - of three 2D points, 296
 - projective c. equations, 472
- collineation, 247, **277**
 - 1D c., 257
 - perspective c., 248, 277, 278
 - projective c., 248
- collocation, 174–176
 - basis functions of c., 735
- colour image, 569
- coplanarity, *see* coplanarity
- complete search, 151
- complete space U , 231
- complex numbers, 651
- computational camera, 444
- concatenation
 - of displacements, 262
 - of homographies, 261
 - of transformations, 261
- concurrence
 - of planes, 307
 - of three 2D lines, 296
- condition number, **118**, 286, 537, 574, 659
- conditional probability, 23
- conditioning, **286**
 - effect of c. on normal equations, 657
 - of point coordinates, 321, 465, 494, 571, 603, 606
 - of projection matrix, 537
- confidence
 - ellipse, 32, 369
 - hyperbola, 374
- conformal geometric algebra, 236
- conic, 236
 - central form of c., 237
 - closed form solution for c., 182
 - dual c., 239
 - general form of c., 236
 - orientation of c., 348
 - parametric form of c., 237
 - point closest to c., 295
 - point of symmetry of c., 237
 - tangent at c., 238
 - transformation of c., 260
- conjugate
 - rotation, 281–282, 321
 - transformation, 278
 - translation, 279
- consensus set maximization, 143, 157
- constraints
 - between corresponding image features, 451
 - coplanarity c. for image of calibrated cameras, 555
 - coplanarity c. for images from uncalibrated cameras, 552
 - coplanarity c. for normal case, 562
 - crisp c., 96
 - epipolar c. for image triplet, 639
 - for essential matrix, 557
 - for fundamental matrix, 553
 - for groups of observations, 167
 - for three image points, 623
 - gauge c., 110
 - weak c., 102
- constructions
 - in 2D, 292–295
 - in 3D, 300–304
- continuous random variables, 26
- continuous, C^n -c., 738
- control
 - feature, 647
 - full c. point, 608
 - horizontal c. point, 609
 - line, 493, 548, 609
 - plane, 609
 - planimetric c. point, 609
 - point, 450, 493, 527, 548
 - points of image pair, 608
 - stochastic c. point, 610
- convolution, 42
- Cook's distance, 127
- coordinate axes, 244
- coordinate system
 - camera c., 461, **463**, 465, 602
 - elements of c., 243
 - image c., 463
 - normalized camera c., 466
 - object c., **462**, 465
 - of photogrammetric model, 559
 - scene c., 462
 - sensor c., 463
- coordinate transformation, 109, 262–266
 - interpretation of c., 249
- coordinates
 - barycentric c., 213, **349**
 - homogeneous c., 45, **195**, 205
 - image c., 469
- coplanarity
 - condition, 228
 - of 3D points, 602
 - of four 3D points, 307
 - of two 3D lines, 304
- coplanarity constraint, **550**, 564
 - for normal case, 561, 562
 - from projection rays, 554
 - of images of calibrated cameras, 555–557
 - of images of spherical cameras, 556–557
 - of images of uncalibrated cameras, 552, 553
 - table, 562
- corrections, 82
- correctness, 116
 - of covariance matrix, 140
 - of variance factor, 140
- correlation, 248
 - coefficient, 31, 37
 - function, 50
 - matrix, 38
 - of parameters of spatial, 522
 - projective c., 282
 - singular, 564
- correspondence, 548
- correspondence problem, 9
- corresponding
 - image lines, 568
 - image points, 561, 563, 568, 569
 - points and lines, 621
- covariance, 37
 - function, **49**, 121, 736, 739, 741
 - intersection, 98
 - operator, 38
- covariance matrix, 37
 - acceptability of c., 120
 - correctness of c., 140
 - effect of wrong c., 135
 - eigenvalue decomposition of c., 667
 - empirical c., 118
 - evaluation of c., 669
 - metric for c., 121
 - of algebraic solution, 180
 - of centroid, 410
 - of estimated observations, 86
 - of estimated parameters, 86, 96
 - of estimated residuals, 87
 - of five-point solution, 588
 - of homography from four points, 388
 - of image coordinates, 569
 - of matrix, 32
 - of mean direction, 403
 - of parallaxes, 569
 - of parameters, relative orientation, 591
 - of projection matrix, 495
 - of quaternion, 383
 - of quaternion from directions, 408
 - of reduced 2D line coordinates, 376
 - of reduced coordinates \mathbf{x}_r , 371

- of reduced coordinates of 3D line, 381
- of rotation, 435
- of rotation from directions, 407
- of rotation matrix, 435
- of the residuals, relative orientation, 591
- reference c., 517
- singular c., 33
- sparsity of c., 663
- specification of c., 121
- theoretical c., 517
- Cramer–Rao bound, **86**, 118, 648
 - of bundle adjustment, 683
- crisp constraints, 96
- criterion matrix, 120
- critical configuration, **452**, 452
 - DLT with points, 495
 - estimation of trifocal tensor, 636
 - image pair, 614
 - line prediction, 626
 - prediction in image triplet, 635
 - spatial resection, 515, 521
- critical cylinder of spatial resection, 515, 517
- critical surface
 - estimation of essential matrix, 588
 - estimation of fundamental matrix, 571
 - relative orientation, 588
- cross ratio
 - of collinear points, 268
 - of concurrent lines, 270
- cumulative distribution, 26
- cumulative distribution, inverse c., 40
- curvature
 - as fictitious observations, 747
 - as prior, 745
 - for regularization, 747
- curve, flatness of c., 739
- Cuthill–McKee algorithm, 662
- d.o.f., *see* degrees of freedom
- datum, *see* gauge
- decision theory tasks, 19
- decomposition
 - Cholesky d., 661, 776
 - LU d., 661
 - of projection matrix, 498
 - QR d., 776
- definition accuracy, 117
- degenerate configuration, 517
- degrees of freedom
 - of 2D point, 207
- degrees of freedom, 360
 - 3D rotation, **327**
 - in χ^2 -distribution, 33
 - in t -distribution, 35
 - in Fisher distribution, 35
 - in noncentral χ^2 distribution, 34
 - in Wishart distribution, 34
 - of 2D elation, 278
 - of 2D homography, **251**, 253, 321
 - of 2D line, 375
 - of 2D perspective, 278
 - of 2D point, 368
 - of 3D elation, 281
 - of 3D homography, 255
 - of 3D homology, 281
 - of 3D line, **216**, 227, 264
 - of 3D point, 211, 373
 - of 3D rotation, 327, 382
 - of collineations, 285
 - of essential matrix, 556
 - of fundamental matrix, 553
 - of general homography, 249
 - of general rotation, 326
 - of image pair, 550
 - of plane, 212
 - of projection matrices from
 - fundamental matrix, 594
 - of projection matrix, 472
 - of test w.r.t. ground truth, 119
 - of test on bias, 141
 - of test on correctness of covariance matrix, 141
 - of test on groups of outliers, **129**, 129, 131
 - of test on noise level, 140
 - of test on systematic errors, 134
 - of tests on geometric relations, 393, 395
 - of transformations, 253
 - of trifocal tensor, 622
 - of variance factor, 90, 98
- Delaunay triangulation, 732
- delta function, 26
- Denavit–Hartenberg parameters, 264
- density
 - a posteriori d., 77
 - function, 26
- dependent images, 558, 595
 - general parametrization, 558
- design matrix, 82
 - reduced d., 95
- detectability
 - ellipse, 130
 - factor, 125, 129, 131
 - of gross errors, relative orientation, 591
 - of groups of gross errors, 129
 - of single gross errors, 125
- detectable gross error, 125
- detectable outliers during relative orientation, 592
- diagnostics, 142
 - external d., **115**, 119
 - internal d., **115**, 115, 117, 118
- differential
 - angles, 337, 338
 - calibration matrix, 501
 - rotation, 336
 - rotation vector, 337
 - similarity transformation, 111
- differential GPS, 683, 721
- DigiCAMx4, IGI, 683
- digital elevation model, 728
- digital surface model, 728
- direct linear transformation (DLT), 247, **249**
- direct LS estimation
 - 2D lines from points, 401
 - 3D line from points, 414
 - 3D similarity from point pairs, 411
 - mean axis, 405
 - mean direction, 404
 - point from lines, 403
 - rotation from point pairs, 408
- direct solution, 176, 178, 452
 - minimal d., 178
 - minimum norm solution, 179
 - of 2D intersection point, 401
 - of 3D homography, 406
 - of 3D intersection point, 401, 402
 - of 3D line, 411
 - of absolute orientation with three points, 515
 - of algebraic surface, 183
 - of best fitting 2D line, 397
 - of best fitting mean axis, 405
 - of best fitting mean direction, 403
 - of best fitting plane, 400
 - of best fitting rotation from directions, 406
 - of best fitting similarity, 408
 - of bundle adjustment, 711
 - of circle fitting, 177
 - of conic, 182
 - of ellipse fitting, 182
 - of estimation a 3D line, 412
 - of homography, 406
 - of quadric fitting, 183
 - of spatial resection, 513
 - of spatial resection with > 3 points, 518
 - of trifocal tensor, 636
- directed
 - 3D line, 606
 - prediction of d. image lines in image triplet, 627
- direction
 - angle, 298
 - angle between 2D d. and coordinate axes, 206
 - angle between 3D d. and coordinate axes, 210
 - closed form solution for mean d., 403
 - cosine matrix for rotation, 328
 - interpolation of d., 341
 - of 2D line, 294
 - of camera ray, 467, **469**
 - of intersection of two planes, 353
 - of join of two points, 352
 - of line segment, 352
 - of lines and planes, 346–348
 - vector of image point, **469**, 553, 556
- discrete random variables, 26
- dispersion operator, 38
- displacements, 262
 - concatenation of d., 262
- distance
 - between two 2D points, 298
 - between two 3D lines, 310
 - between two 3D points, 309
 - from origin in 2D, 297
 - Mahalanobis d., 84

- of 2D entities, 297–298, 310
- of 2D point from 2D line, 298
- of 2D point from line, 298
- of 3D entities, 308
- of 3D line from origin, 308
- of 3D line to origin, 218
- of 3D point from line, 309
- of 3D point from origin, 308
- of 3D point from plane, 310
- of plane from origin, 308
- of two covariance matrices, 121
 - signed d., 354
- distinct entities defining
 - 2D line, 318
 - 2D point, 318
 - 3D line, 319
 - 3D point, 319
 - plane, 319
- distortion
 - lens d., 464, 507
 - nonlinear d., 452, 477
 - of perspective mapping, 479
 - radial, 506
 - radial d., 506–508
 - tangential d., 506
- distortion model, 476
 - phenomenological d., 508
 - physical d., 506
- distribution, 24, 28–35
 - χ d., 34
 - χ^2 -square d., 33
 - t -d., 35
 - binomial d., 28
 - cumulative d., 26
 - exponential d., 29
 - Fisher d., 35
 - Gaussian d., 29
 - inverse cumulative d., 40
 - Laplace d., 29
 - mixed d., 143
 - multi-dimensional normal d., 31
 - normal d., 29
 - quantiles of d., 40
 - Rayleigh d., 29
 - Student's t -d., 35
 - uniform d., 28
 - Wishart d., 34
- DLT, 247, **249**, 480, 622
 - algebraic solution for d., 494
 - direct estimation of d., 494
 - explicit form of D., 472
 - for uncalibrated cameras, 472
 - from 3D lines, 504
 - precision of d. compared to spatial resection, 523
 - theoretical precision of d., 522
 - two d. for image pair, 611
- DMC, Intergraph, 683
- double points, 523, 590, 592
- doubly integrated white noise process, 53
- driving process, 52, 749
- dual
 - 3D line, 233
 - conic, 239
 - entities, 231
 - of 2D point, 204
 - oriented projective plane, 346
 - oriented projective space, 347
 - Plücker coordinates, 233
 - Plücker matrix, 233
 - projective plane \mathbb{P}^{*2} , **209**, 209
 - projective space \mathbb{P}^{*3} , **212**, 231
 - transformation, 259
- duality, 203, 229–236, 283
 - of 2D point and 2D line, 234
 - of 3D lines, 235
 - of 3D point and plane, 234
 - of transformations, 259
- dualizing matrix, 227
- effect
 - of intrinsics and extrinsics on image coordinates, 502
 - of random errors on estimation, 117
 - of wrong covariance matrix, 135
- ego-motion determination, 644
- eigenvalue
 - decomposition of covariance matrix, 667
 - generalized e. problem, 517
- eigenvalues, 773–774
- elation
 - definition of e., 278
- elementary rotation, 328
 - angles from rotation matrix, 330
 - concatenation of e., 329
- ellipse, 237
 - confidence e., 32
 - detectability e., 130
 - fitting, 182
 - sensitivity e., 130
 - standard e., **31**, 366, 369
- empirical
 - accuracy, 117, **118**
 - accuracy of bundle adjustment, 682
 - covariance matrix, 118
 - precision, 117, **118**
 - sensitivity, 126, 130, 134
 - standard deviation, 118
- empty projective space \mathbb{P}^0 , 231
- endlap, 700, **718**, 721
- epipolar
 - axis, 563, 564
 - constraints, 639
 - geometry, 562–565
 - line, 248, 563–565, 623
 - line, curved e., 564
 - line, oriented e., 564
 - plane, 563
- epipolar line, 573–574
- epipole, 563, 565, 594
- equidistant projection, 487
- equisolid projection, 487
- equivalence of uncertain homogeneous vectors, 390
- equivariant function, 267
- error in variables model, 161
- error propagation, *see* variance propagation
- error, quasi-systematic, 667
- essential matrix, 556–557, 562, 575–583, 613, 623
 - degrees of freedom of e., 556
 - dependent images, 558
 - from ≥ 7 points, 575
 - from 2 points, given rotation, 578
 - from 4 coplanar points, 577
 - from 5 points, 575
 - normalized cameras, 559
 - parametrizations of e., 557
 - projection matrices from e., 595
 - singular values of e., 557
- estimable quantities, 109, 666
- estimate
 - Bayesian e., 76–78, 93
 - best linear unbiased e., 79
 - best unbiased e., 79
 - least squares e., 79
 - maximum a posteriori e., 77
 - maximum likelihood e., 78
- estimated
 - covariance matrix of e. observations, 86
 - covariance matrix of e. parameters, 86
 - covariance matrix of e. residuals, 87
 - observations, 86
 - parameters, 84
 - residuals, 84
 - size of gross errors, 131
 - size of group of gross errors, 128
 - size of single gross error, 124
 - variance factor, 89
- estimation
 - Bayesian e., 93
 - Bayesian e. in Gauss–Markov model, 93
 - bias of e., 141
 - evaluation of e., 117
 - in Gauss–Helmert model with constraints, 163–170
 - in Gauss–Markov model with constraints, 99–102
 - in linear Gauss–Markov model, 81–102
 - in model with constraints between observations only, 170
 - in nonlinear Gauss–Markov model, 102–107
 - of 2D intersection point, 417
 - of 3D similarity transformation, 607
 - of variance components, 91–93, 493
 - on curved manifolds, 415
 - robust e., 141
 - sequential e., 96
 - statistically optimal e., 452
 - stochastic model of e., 76, 83
 - with implicit functions, 160
 - with reduced coordinates, 415
 - with two group, 96
- estimation theory, 75–81
- tasks, 19

- Euclidean
 - bundle adjustment, 649
 - camera, 464
 - normalization, 196, 198
 - normalization of matrix, 285
 - normalization of vector, 199
- Euclidean part
 - of 1D point, 214
 - of 2D line, 207
 - of 2D point, 206
 - of 3D line coordinates, 218
 - of 3D point, 210
 - of plane, 211
- Euler's rotation theorem, 326
- evaluation
 - w.r.t. groups of gross errors, 128
 - w.r.t. single gross errors, 124
 - w.r.t. systematic errors, 133
 - of acceptability of precision, 120
 - of additional parameters, 699
 - of block adjustment, 662
 - of bundle adjustment, 687
 - of calibration model, 684
 - of checkability of parameters, 133
 - of covariance matrix of block adjustment, 669
 - of detectability of groups of gross errors, 129
 - of detectability of single gross errors, 125
 - of effect of errors, 122
 - of empirical accuracy, 118
 - of empirical precision, 118
 - of estimation, 115
 - of theoretical precision, 117
 - of uncertain relations, 393
- expectation, 36, 38
 - of function of stochastic vector, 44
 - operator, 38
- exponential ρ -function, 149
- exponential distribution, 29
- exterior orientation, **460**, 460, 629, 634
 - model of e., 465
 - of camera systems, 488
 - of image pair, 550, 610
 - of image triplet, 622, 623
- exterior parameters, 460
- external diagnostics, **115**, 119
- external precision, 116
- extrapolation during transformation, 389
- extrinsic parameters, *see* exterior parameters
 - from spatial resection, 513
- factor graph, **654**, 659, 661
- factorization
 - of matrix, *see* decomposition
- factorization for bundle adjustment, 714
- feature
 - control f., 647
 - image f., 646
 - scene f., 646
- fictitious observations, 78, 750
 - for profile reconstruction, 746
- field of view, 445, 446, **458**, 459, 468, 484
- field-based representation, 8
- field-based scene description, 442
- fill-in, 662–665
- filtering, 730, 736, 762
 - Kalman f., 96, 98
 - Wiener f., 93
- FinePix REAL 3D W1, Fuji, 443, 445
- fish-eye, 444
 - camera, 485
 - lens, 459, 485
 - optics, 478
- Fisher
 - distribution, 35
 - information matrix, 86
- fitted observations, 86
- fixed entities, 272–277
 - of 1D homography, 276
 - of 2D affinity, 274
 - of 2D homography, 274
 - of 2D motion, 274
 - of 2D rotation, 274
 - of 2D translations, 274
 - of 3D affinity, 276
 - of 3D homography, 275
 - of 3D motion, 276, 282
 - of 3D translation, 275
 - of planar motion, 275
 - of spatial motion, 276
- flatness
 - of a curve, 739
 - of a surface, 739–741
- flight direction, 558
- flight plan, 452
- flying height, 605
- focal length, 256, 461
- focal point, 461
- foot point
 - of 2D origin on line, 295
 - of origin on 3D line, 323
- forward motion, 589
 - image pair, quality, 593
- free adjustment, 109
 - inner precision of f., 666
 - minimum trace solution of f., 111
 - of block, 663
 - reduced normal equations of f., 114
- free network, 109
- Fuji FinePix REAL 3D W1, 443, 445
- function
 - ρ -f., 144
 - delta f., 26
 - density f., 26
 - multi-dimensional probability f., 27
 - of a random variable, 40
 - of two random variables, 42
 - separable f., 28
 - step f., 25
- functional model, 75, 490
 - algebraic structure of f., 161
 - invertibility of f., 144
 - nonlinear – linear f., 161
 - of 2D block adjustment, 651
 - of block adjustment, 647
 - of bundle adjustment, 675
 - table with f., 171
- fundamental matrices of image triplet, 623
- fundamental matrix, 553–555, 570–574, 612, 622, 629
 - as singular correlation, 564
 - degrees of freedom of f., 553
 - from ≥ 7 points, 571
 - from ≥ 8 points, 570
 - from camera planes, 554
 - from projection matrices, 554
 - from projection matrix for lines, 564
 - singular values of f., 554
- Gamma-matrix, 219
 - dual G., 233
- gauge, **108**, 703
 - constraints, 110
 - constraints in bundle adjustment, 665
 - definition of g. of coordinate system, 109
 - definition of g. of covariance matrix, 109
 - in bundle block, 645
 - linear g. constraints, 112
 - minimal control in block adjustment for g., 664
 - nonlinear g. constraints, 111
 - transformation, 108–114
 - transformation in block adjustment, 668
 - transformation, regular g., **112**, 121
 - transformation, singular g., 112
 - unspecified g., 669
- Gauss–Helmert model, 160, **162**, 162, 163, 174, 414, 415
 - for 2D intersection point, 418
 - for homography estimation, 424, 425
 - for relative orientation, 586
 - for total least squares, 161
- Gauss–Helmert model with constraints, **163**, 174
 - estimation in G., 163–170
 - linear G., 163
 - nonlinear G., 163
 - normal equations of G., 165
 - redundancy of G., 165
 - robust algorithm for G., 168
- Gauss–Markov model, 162, 173, 414, 415, 497
 - Bayesian estimation in G., 93
 - for homography estimation, 424, 427
 - for image triplet, 638
 - for self-calibrating bundle adjustment, 675, 678
 - for surface reconstruction, 743, 746
 - linear G., 81–102
 - nonlinear G., 102–107
 - nonlinear G. with constraints, 104

- Gauss–Markov model with constraints,
 99–102, 162, 173
 estimation in G., 100
 linear G., 162
 nonlinear G., 162
- Gauss–Newton method, 103, 105
- Gaussian distribution, 29
- general weighted least squares, 80
- generative model, 83
- generic camera, **446**, 460
 relative pose, 581
- geometric algebra, 236
- geometric image model, 447
- geometric relations
 in 2D, 295–299
 in 3D, 304–308
- geometry
 epipolar g., 562–565
 image pair, 549–568
 image triplet, 622–632
 of single image, 456
 single image, 488
- global test, 90
 bundle adjustment, 689
- GPS, 450, 452, 493, 647, 653
 differential G., 683, 721
- Gram–Schmidt orthogonalization, 511
- graph
 adjacency g., 654, 660
 bi-partite g., 646
 factor g., **654**, 659, 661
- graph surface, **729**, 739
- Grassmann–Cayley algebra, 234
- gross error, *see* outlier
 detection, 452
 estimated size of g., 124, 131
 lower bound for detectable g., 125, 131
 model of g., 123
 test statistic for g., 131
- gross errors, 452
- ground sampling distance, **457**, 590, 683, 716, 720
- ground truth, 115, 119, 429, 683
- groups of observations, 86
 constraints for g., 167
 detectable gross errors of g., 129
 diagnostics of g., 130
 evaluation of g., 128
 in sequential estimation, 96
 in variance component estimation, 91, 92
 normal equations for g., 96
 outlier model of g., 123
 sensitivity factor of g., 130
- Gruber
 points, 590
 position, 590
- GSD, *see* ground sampling distance
- Hadamard product, 137, **776**
- harmonic homology, 280
- harmonic points, 270
- hat function, 736
- hat matrix, 86
- Helmert point error, 366
- Hessian matrix, 44, 106
 of log-likelihood function, 78
 of surface function, 741
- Hessian normal form, 207
 uncertain, 374
- hierarchy of transformations, 285
- homogeneous
 uncertainty, 396
- homogeneous entities, notation of h., 196
- homogeneous coordinates, 45, **195**, 490
 of 1D point, 214
 of 2D line, 207
 of 2D point, 206
 of 3D point, 210
 of plane, 211
- homogeneous part
 of 1D point coordinates, 214
 of 2D line coordinates, 207
 of 2D point coordinates, 206
 of 3D line coordinates, 218
 of 3D point coordinates, 210
 of plane coordinates, 211
- homogeneous representation, 195
- homogeneous stochastic process, 51
- homogeneous uncertain vectors,
 equivalence of h., 390
- homogeneous uncertainty, 121, 371
- homogeneous vectors, normalization of h., 198, 241
- homography, **249**, 247–249, 253, 254, 256
 1D h., 257
 2D h., 250, **253**
 2D h. between images, 567, 578
 3D h., 255, 256, 613, 622
 concatenation of h., 261
 constraint of two 3D lines, 316
 cross ratio, 268
 depth and parallax map, 602
 effect of h. on chirality, 356
 fixed entities of 1D h., 276
 fixed entities of 2D h., 274
 fixed entities of 3D h., 275
 from point pairs, 389
 from uncertain point pairs, 425
 general h., 248
 image to map plane, 526
 image to scene plane, 524, 525
 invariants of h., 268
 minimal parametrization of uncertain h., **384**, 426
 quasi-affine h., 357
 table of constraints with h., 316
 uncertain h., 384–386
 uncertainty of h. from uncertain points, 387
 uncertainty of points mapped with h., 387
 vector form of h., 315
- homologous, *see* corresponding
- homology, **277**, 280, 284, 568
 between images, 567
 harmonic h., 280
 singular values of h., 568
- homology, *see also* perspective
 autocollineation, 277
- horizon, 208, **458**, 468, 474, 482
 as 3D control line, 494, 504
- horizon line, 458, 459
- horizontal view, 456
- horopter, 521
- Hough transformation, 158, **283**
- Huber estimator, **148**, 150
- human stereo vision system, 561
- hyperbola, 237
 standard h., 374
- hyperplane, 221, 224, 226, 283
 at infinity, 215
 transformation of h., 258
- ideal
 camera, 465
 image point, 463
 lens, 256
 perspective camera, 468
 unit camera, 465
- ideal point, *see* point at infinity
- identification accuracy, 117, 706
 of features, 490
- identity
 of two 2D entities, 296
 of two 3D entities, 306
- IGI DigiCAMx4, 683
- ill-posed, 82
- image
 coordinate system, 463
 coordinates, 469
 coplanarity constraint of i. from uncalibrated cameras, 552
 distortion model, 476
 distortions, 505
 feature, 646
 geometry, 456
 geometry of nadir i., 459
 geometry of slanted i., 459
 matching, 402, 563
 model, 7, 441
 orientation of single image, 489
 oriented i. line, 482
 pair, *see* image pair
 perspective i., 456
 point, *see* image point
 pyramid, 491
 rectified i., 477
 reduced i. coordinates, **468**, 470
 relative orientation, 552
 scale, 457
 sequence, 647, *see* image strip
 straight line-perturbing i. errors, 464
 theoretical precision of i. block, 673
 theoretical precision of i. strip, 670–673
 triplet, *see* image triplet
 two-step procedure of i. orientation, 549
- image pair
 bundle solution for i., 610
 comparison of procedures for i., 614

- control points of i., 608
- critical configuration of i., 614
- degrees of freedom of i., 550
- exterior orientation of i., 550
- geometry of i., 549
- interior orientation of i., 550
- normal case of i., 465, 561
- object points, 608
- orientation of i., 549, 608
- triangulation for normal case of i., 601
- triangulation for perspective i., 600
- two-step procedure for i., 612
- image point
 - direction, 556
 - ideal i., **463**, 469
 - observable i., 461, **463**
 - uncertainty of i., 491
- image triplet
 - geometry of i., 622
 - nonlinear observation equations for i., 638
 - orientation of i., 632
 - predicting directed lines in i., 627
 - relative orientation of i., 633, **636**
- images, dependent i., 595
- implicit functions, estimation with i., 160
- implicit variance propagation, **43**, 516
- IMU, 653
- incidence
 - of 2D entities, 295
 - of 2D line and 2D point, 295
 - of 3D line and plane, 305
 - of 3D point and line, 306
 - of 3D point and plane, 304
 - of two 3D lines, 304
- independence
 - stochastic i., 28
- independent events, 23
- independent images, **558**, 581, 589
- independent random variables, 31
- influence function, 147
 - table of i., 149
- information matrix, 86
- inner
 - geometry, 110
 - precision, 110, 666
 - precision of free block, 667
- inner product, 767
- INS, 452, 647
- integrated AR-process, 54
- integrated white noise process, 53
- Intergraph DMC, 683
- interior and exterior orientation
 - from projection matrix, 500
- interior orientation, **460**, 464, 610, 629
 - of image pair, 550
 - of image triplet, 622
- interior parameters of camera, **460**
- interior parameters of camera system, 488
- internal
 - diagnostics, **115**, 115, 117, 118
 - precision, 116
- interpolation, 730
 - bicubic i., 738
 - bilinear i., 738
 - linear i., 737
 - precision of i., 734
- interpolation during transformation, 389
- interpolation of directions, 341
- interpolation of rotations, 341
- interpretation, 9
- interpretation model, 7, 448
- interpretation of line drawings, 523
- intersection, 549
 - of 2D line and conic, 293
 - of 3D line and plane, 301
 - of three planes, 302
 - of two 2D lines, 202, 292
 - of two planes, 220, 301
- intersection of planes, direct LS solution of i., 403
- intrinsic parameters, *see* interior parameters
- intrinsic parameters of a camera, 463
- invariant, 266
 - number of independent i., 271
 - of affinities, 268
 - of five 2D points, 272
 - of homography, 268
 - of perspective mappings, 268
 - of polygon, 267
 - of projective mapping, 266
 - of rectangle, 266, 271
- inverse cumulative distribution, 40
- inverse depth, 257
- inverse perspective, 489, 523
- inversion of transformation, 261
- invertibility of functional model, 144
- isocentre, 459
- isometric parallel, 459
- isotropic stochastic process, 51
- isotropic uncertainty, 121
 - of directions, 367, **371**, 403, 413
 - of points, **368**, 396, 399, 406, 408, 412
- iterative estimation, 92, **103**, 414, 452
 - of spatial resection, 520
 - on curved manifolds, 415
- iterative solution, 452
- Jacobian
 - of DLT, 501
 - of DLT for nadir view, 501
 - of Hessian form to homogeneous 2D line, 375
 - of homogeneous to Euclidean 3D coordinates, 373
 - of homogeneous to Euclidean coordinates, 371
 - of homogeneous to Hessian form of 2D line, 377
 - of reduction of 3D line coordinates, 380
 - of reduction of point coordinates, 370
 - of spherical normalization, 368, 376
- of spherical normalization of 3D point, 373
- within estimation, 161
- within variance propagation, 43
- join
 - of 3D point and line, 302
 - of three 3D points, 302
 - of two 2D points, 202, 293
 - of two 3D points, 300
- K-transformation, 109
- Kalman filter, 96, 98
- keypoint detector
 - uncertainty, 491
- Kronecker product, 137, 555, 775
- laboratory calibration, 697
- Ladybug 3, Pointgrey, 443–445
- lag, 49
- Laplace distribution, 29
- Laplacian development theorem, 768
- law of cosines, 514
- least squares
 - estimate, 79
 - general weighted l., 80
 - ordinary l., 80
 - weighted l., 79
 - with regularization for profile reconstruction, 747
- leave-one-out test, 124, 128
- Legoland scene, 529
- Leica ADS 80, 443, 445, 446
- lens
 - distortion, 461, 464, **507**
 - fish-eye l., 459
 - narrow-angle l., 459
 - normal l., 459
 - thin l. projection, 256
 - ultra-wide angle l., 459
 - wide-angle l., 459
 - zoom l., 459
- levels of reasoning, 7
- leverage point, 127
- Lie group, 284
- likelihood function, 77
- line
 - antipodal l., 348
 - at infinity, 203, 345
 - direction of l. segment, 352
 - segment, 352
 - vanishing l., 529
- line at infinity, 208
 - of plane, **208**, 212, 220
- line camera, 444
- line drawing interpretation, 523
- line segment, uncertainty of l., 492
- linear substitute model, 103
- linearization, check of l. within Gauss–Markov model, 104
- linearized model of bundle adjustment, 676
- linearized models, table with l., 171
- loop closing, 672
- lower bound
 - for detectable deviation, 66
 - for detectable gross error, 125, 131
- LS, *see* least squares

- LU-decomposition, 661
- M-estimation, 609
- MAD, **40**, 146
- Mahalanobis distance, **69**, 84, 361
- Manhattan scene, 529
- MAP estimate, 77
 - bundle adjustment, 648
 - profile reconstruction, 744
- Maple, 522
- mapping, 644
 - affine m., 357
 - as coordinate transformation, 249
 - as displacement, 249
 - general m. 3D to 2D, 479
 - of general lines, 484
 - of quadrics, 484
 - perspective m., 277
 - quasi-affine m., 357
- matching, 9
- matrix
 - block, inverse of b., 769
 - correlation m., 38
 - covariance m., 37
 - Euclidean normalization of m., 285
 - exponential, 781
 - exponential for homography, 384
 - exponential for motion and similarity, 384
 - exponential for rotation, **326**, 326, 337, 338, 382
 - exponential for transformations, 382
 - normally distributed m., 32
 - precision m., 83
 - product, eigenvalues of m., 773
 - random m., 27
 - representation of 2D entities, 312
 - representation of 3D entities, 313
 - skew symmetric m., 336
 - sparse m., 86
 - sparse structure of m., 655
 - spectral normalization of m., 286
 - Toeplitz m., 53
 - weight coefficient m., 89
 - weight m., 83, 89
- maximum a posterior estimate, 77
- maximum likelihood estimation, 78–79
- maximum likelihood type estimation, 147
- mean, 36
 - accuracy of the m., 116
 - bias of m., 45
 - of ratios, 46
 - operator, 38
 - precision of the m., 116
 - vector, 38
- median, 40
- median absolute difference, 40, 146
- meta model, 6, 441
- method of modified weights, 147
- metric camera, **460**, 696
- metric for covariance matrices, 121
- minimal parametrization
 - of 2D homography, 385
 - of uncertain homography, 384
 - of uncertain motion, 383
 - of uncertain quaternions, 383
 - of uncertain rotation, 382
 - of uncertain similarity, 383
 - of uncertain transformations, 381
- minimal representation
 - of 2D uncertain point, 369
- minimal solution, 178
 - of 2D affinity, 320
 - of 2D homography, 321
 - of 3D homography, 322
 - of basis of image pair, 578
 - of essential matrix, 575
 - of fundamental matrix, 571
 - of image orientation, 489
 - of projection matrix, 494
 - of relative orientation from mirror images, 579
 - of relative orientation of three images, 636
 - of relative orientation, iterative m., 585
 - of spatial resection, 513
 - of trifocal tensor, 636
 - with QR decomposition, 179
- minimum norm solution, 179
- minimum trace solution, 111
- minimum-volume estimate, 146
- mirroring
 - at y -axis, 251, 279
 - at a plane, 281
 - transformation in 2D, 279
- mixed distribution, 143
- ML-type estimation, 147
 - L_1 -norm minimization as, 148
- model
 - functional m., 75
 - generative m., 83
 - geometric m. of camera, 443
 - geometric m. of scene, 442
 - linear substitute m., 103
 - mathematical m., 75
 - notion of m., 7
 - of analysis, 7
 - of camera, 441, **445**
 - of constraints between observations only, **162**, 162
 - of distortion, 476
 - of image, 7, 441
 - of interpretation, 7
 - of projection, 449
 - of scene, 7, 441
 - of sensor, 7
 - of world, 7
 - phenomenological m. of distortion, 505
 - photogrammetric, *see* photogrammetric model
 - physical m. of distortion, 505
 - stochastic m., 76, 83
 - thin plate m., 741
 - thin rod m., 741
 - weak membrane m., 740
 - weak string m., 739
 - with constraints between the observations only, 173
- model block adjustment
 - 2D, 650
 - 2D m., 651–674
 - 3D m., 649
 - projective m., 649
- modified weights, 147
- moment vector of a 3D line, **218**, 219, 220, 227
- moments, 36
 - central m., 37
 - general m., 36
 - of normal distribution, 39
- mono-plotting, 526
- monomials, 733
- motion
 - 2D m., 260
 - 3D m., 260
 - fixed entities of planar m., 275
 - fixed entities of spatial m., 276
 - forward m., 589
 - from object to camera, 466
 - from structure, 449
 - planar, 251
 - rigid body m., 255
 - rotational m., 337
 - sideward m., 588
 - spatial m., 255
 - uncertain m., 383
- moving object, 568
- moving camera, 568
- multiple solutions, 452
 - of relative orientation, E-matrix, 582
 - of relative orientation, F-matrix, 571
 - of spatial resection, 515
- nadir
 - direction, 528
 - point, 346, 458
 - view, 456, 521
- narrow-angle lens, 459
- negative point, 344
- net area of model, 719
- Newton–Raphson method, 105
- noncentral χ^2 distribution, 34
- noncentrality parameter, 65, 131
- nonlinear
 - distortions, 452, 477
 - Gauss–Markov model, 102
 - Gauss–Markov model with constraints, 104
 - model of bundle adjustment, 675
- nonmetric camera, uncalibrated n., 697
- nonrejection region, 63
- normal case
 - of image pair, 561
 - of image pair, iterative relative orientation, 588
 - of single image, 465
 - triangulation for n. of image pair, 601
- normal cases, 453
- normal distribution, 29
 - in best unbiased estimation, 81

- multi-dimensional n., 31
- normal equation
 - components, 85
 - for groups, 96
 - for system for two groups of observations, 96
 - in Gauss–Helmert model with constraints, 165
 - in Gauss–Markov model, 84
 - in Gauss–Markov model with constraints, 100
 - partitioned n., 94
 - profile of n. matrix, 662
 - reduced n., **94**, 660
 - reduced n. of free adjustment, 114
 - sparsity of n. matrix, 657–661
 - table with n., 171
- normal lens, 459
- normal line
 - through 2D point, 294
 - through the 2D origin, 294
- normalization
 - bias of n., 45
 - Euclidean n., 242
 - Euclidean n. of matrix, 285
 - Euclidean n. of vector, 199
 - of homogeneous matrices, 285
 - of homogeneous vectors, 198, 241
 - spectral n. of matrix, 286
 - spherical n., 45, 199, **242**
 - spherical n. of matrix, 286
- normalized
 - camera, **465**, 472, 713
 - camera coordinate system, 466
 - definition of n. residuals, 144
 - residuals, 152, 170
 - trifocal tensor, 628
 - variance of n. residuals, 145
- notation of homogeneous entities, 196
- null space
 - for estimating homography, 389, 496
 - of covariance matrix of 2D line, 375, 392
 - of covariance matrix of 2D point, 368, 393
 - using QR decomposition, 179
- numerical differentiation, 453
- NURBS, mapping of N., 484
- object
 - coordinate system, **462**, 465
 - moving o., 568
 - point, 563
 - points, image pair, 608
- object-based representation, 8
- object-based scene description, 442
- oblique view, 456
- observable image point, 463
- observation equations, 82
 - linearized o. for normal case of relative orientation, 589
 - nonlinear o., 173
 - nonlinear o. for image triplet, 638
- observation process, 25
- observational errors, 83
- observations
 - fictitious o., 78
 - uncertain o., 490
- observed AR-process, 749
- One Shot 360, 443, 445, 446
- operator
 - covariance o., 38
 - dispersion o., 38
 - mean o., 38
- optical axis, 461
- optical ray, 528
- optics, 456
 - catadioptric o., 446
- optimal estimation
 - of intrinsics and extrinsics, 501
 - of projection matrix, 496
- oracle, robust estimation as o., **142**, 167
- ordinary least squares, 80
- orientation
 - absolute o., 549, **552**, 607
 - absolute o. within two-step procedure, 612
 - also see direction, 352
 - exterior o., **465**, 610
 - exterior o. of camera systems, 488
 - exterior o. of image pair, 550
 - interior o., 610
 - interior o. of image pair, 550
 - of cameras, 449
 - of conics and quadrics, 348
 - of image pair, 549, 608
 - of image triplet, 632
 - of join of 3D line and point, 353
 - of plane, 354
 - parameters from essential matrix, 581
 - quality of o. procedures, 453
 - relative o., 450, 551
 - relative o. of image triplet, 633
 - relative o. within two-step procedure, 612
- orientation-preserving transformation, 355
- oriented
 - 2D line, 346
 - 2D point, 345
 - 3D line, 348
 - 3D point, 346
 - epipolar line, 564
 - image line, 482
 - plane, 347
 - point, 344
 - projective geometry, 343
 - projective plane, 345
 - projective space, **345**
- orthogonal
 - projection, 487
- orthogonality
 - of 2D lines, 297
 - of 3D line and plane, 308
 - of 3D lines, 307
 - of planes, 307
- outlier, *see* gross error, 609
 - asymmetric distribution of o., 755
 - detection, 142
 - detection in bundle adjustment, 707–715
 - model, 143
- P3P problem, 513–518
- panorama, 644
- Panoscan Mark III, Rolleiflex, 443, 445, 446
- parabola, 237
- parallactic angle, 420, 421, **548**, 549, 550, 596, 598, 599, 601, 604, 717
- parallax
 - x*-p., 569, **589**, 601–604
 - y*-p., 561, **589**, 590, 592, 602
 - accuracy of p., 569
 - covariance matrix, 569
 - map, 602
 - vertical p., 561
- parallel line
 - through 2D point, 294
 - through the 2D origin, 294
- parallel projection, 545
- parallelepiped, 553
- parallelism
 - of 2D lines, 297
 - of 3D line and plane, 308
 - of 3D lines, 307
 - of planes, 307
- parameters
 - additional p., 123, 464
 - extrinsic p., 460
 - interior p. of camera system, 488
 - intrinsic p. of a camera, 460
- parametrization of relative orientation, 557–559
 - singularity, 559
- partially calibrated camera, 460
- partitioning of normal equation matrix, 94
- PCA of covariance matrix, 667
- pencil of planes in epipolar geometry, 563
- percentile, 40
- perspective
 - 2D autocollineation, 277
 - 3D autocollineation, 280
 - autocollineation, 277
 - calibrated p. camera, 555–557
 - camera, 248, **446**, 456, 460, 464, 607, 622
 - camera for the image pair, 550
 - camera model, 462, 470
 - collineation, 248, **277**, 277, 278
 - distortion, 503
 - distortions of p. camera, 505
 - image, 456
 - inverse p., 523
 - mapping with distortions, 479
 - model of p. camera, 464
 - projection, 467, **470**, 486
 - projection of 3D line, 480
- perspectivity, 277, 278
- phenomenological distortion model, 505, 508
- photo collection, 644

- photogrammetric model, **549**, 612–613, 708–711, 719
 absolute orientation of p., 607
 coordinate system definition, 559
 coplanarity constraint, 551
 net area of p., 719
 of image triplet, 622–633
 of images of calibrated cameras, 552
 of images of uncalibrated cameras, 552
 parameters of p. for given projection matrix P' , 560
 scale of p., 559, 607, 634, 714
 photogrammetric models
 mutual scale of p., 621
 physical distortion model, 505, 506
 Pi-matrix, 300
 Pi-matrix, dual P., 301
 pinhole camera, 253, 257, 281, 464, 465
 pixel distance, 465
 Plücker
 constraint, 218
 enforcing P. constraint, 381
 matrix, 219
 Plücker constraint, 227
 Plücker coordinates, 221–229, 768
 definition of P., 223
 dual P., 233
 Euclidean part of P. of 3D line, 218
 homogeneous part of P. of 3D line, 218
 of 2D line, 223
 of 2D points, 223
 of 3D line, **218**, 226
 of 3D line from points, 217
 of 3D points, 225
 of plane, 225
 Plücker matrix, 227
 dual P., 233
 planar homography
 fixed entities, 274
 planar motion, 251
 planar object
 critical configuration of DLT, 495
 plane, 211
 antipodal p., 347
 at infinity, 212
 centroid representation of p., 377
 degrees of freedom of p., 212
 distinct points of p., 319
 homogeneous coordinates of p., 211
 horizon of p., 208
 intersection, 301
 joining 3D point and line, 302
 line at infinity of p., **208**, 212, 220
 optimal direct solution of p., 400, 436
 orientation of p., 348, 354
 oriented p., 347
 parameters of p. through three points, 225
 Plücker coordinates of p., 225
 point-direction form of p., 213
 quadric, 240
 slope of p., 212
 three-point representation of p., 213
 transformation of p., 258
 uncertain p., 377–379, 403
 planes, concurrent p., 306
 PnP problem, 513–521
 point
 antipodal p., 344–346
 control p. of image pair, 608
 in tetrahedron, 351
 negative p., 344
 of symmetry, 462
 oriented p., 344
 positive p., 344
 tie p. of image pair, 608
 uncertainty of transformed p., 387
 vanishing p., 210, 529–534
 point at infinity, 472, 493, 550
 1D p., 214
 2D p., 206
 3D p., 210
 of 2D line, 209, 294
 of 3D line, 220
 point camera, 444
 point of symmetry
 of conic, 237
 of quadric, 240
 Pointgrey Ladybug 3, 443–445
 polar of a point, 233
 polarity, 233, 283, 285
 at conics, 238
 at the unit circle, 233
 on the sphere, 200
 pole of a line, 233
 polycamera, 445
 pose, 456
 of camera, 6, 456, **460**
 theoretical precision of p., 522, 523
 positive definite function, 50
 positive point, 344
 power function, 65
 power of test, 62
 PowerShot A630, Canon, 443, 445
 pre-image of line at infinity, 355
 precision, **116**, 453
 acceptability of p., 117
 and accuracy, 116
 empirical p., 117
 external p., 116
 inner p., 110
 internal p., 116
 matrix, **43**, 83, 367
 of interpolation, 734
 of the mean, 116
 singular p. matrix, 367
 theoretical p., 117
 prediction, 730
 in image pair, image point, 562–565
 in image triplet, points and lines, 623–625
 of points, lines and planes, 451
 prediction errors, 97
 prediction operator
 $\ell(l'', l''')$, 625
 $\varphi_2(\chi', l''')$, 631
 $\varphi_3(\chi', l''')$, 631
 principal
 distance, 457, **462**, 464, 465, 471
 distance from two vanishing points, 531
 line, 458
 plane of optics, 256, **461**
 planes of camera, 474
 point, 458, **462**, 464, 465, 470, 471
 point from projection matrix, 475
 point from three vanishing points, 532
 prior
 for profiles and surfaces, 745–748
 variance component estimation of p., 750
 prior, see also a priori, 76
 probability
 a posteriori p. density, 77
 a priori p. density, 76
 axiomatic definition of p., 22
 axioms of p., 23
 conditional p., definition, 23
 density function, 26
 distribution, 24
 notion of p., 21
 total p., 23
 von Mises' definition, 22
 process
 doubly integrated white noise p., 53
 integrated white noise p., 53
 stochastic p., 49
 profile of normal equation matrix, 662
 profile reconstruction
 fictitious observations for p., 746
 LS with regularization, 747
 MAP estimate for p., 744
 outlier detection in p., 755
 projection
 central p., 481, 485, 487
 equidistant p., 487
 equisolid p., 487
 line, **483**, 564
 matrix, see projection matrix
 model, 449
 not straight line-preserving p., 564
 of 3D lines, 480
 of lines, 564
 orthogonal p., 487
 parallel p., 545
 perspective p., 467, **470**, 486
 perspective p. of 3D line, 480
 plane, 482, 483
 ray, 445
 spherical p., 467
 spherical p. of 3D line, 481
 stereographic p., 346, 487
 thin lens p., 256
 uncertainty of p. ray, 524
 projection centre, 248, 254, **457**, 460–466, 474–475, 563
 collinear, 622

- from projection matrix, 498
 - quality of p. from spatial resection, 516, 517
- projection matrix, **472**, 607, 629
 - algebraic solution for p., 494
 - covariance matrix of p., 495
 - decomposition of p., 498
 - direct estimation of p., 494
 - DLT with p., 494
 - for 3D lines, 480, 626
 - for 3D points, 626
 - from essential matrix, 595
 - from fundamental matrix, 594
 - general p., 479
 - interior and exterior orientation
 - from, 500
 - optimal estimation of p., 496
 - proper p., 468, 474, 482, 483
 - properties of p., 473
 - properties of p. for 3D lines, 481
 - uncertainty of p., 475
- projective
 - bundle adjustment, 649
 - collination, 248
 - correlation, 282
 - line IP, 231
 - model, 480
 - model block adjustment, 649
 - oriented dual p. plane, 346
 - oriented p. plane, 345
 - oriented p. space, 345
 - plane \mathbb{P}^2 , 200, 203, **206**, 231
 - 3D points at infinity, 211
 - partitioning of p., 215
 - representation as unit sphere, 215
 - point \mathbb{P}^0 , 215, 216, 231
 - space \mathbb{P}^1 , 214
 - space \mathbb{P}^3 , **210**, 231
 - space \mathbb{P}^n , 215
 - transformation, 611
- projective bundle adjustment, 676
- projectivity
 - 2D p., 253
 - 3D p., 256
 - pure p., 254
 - singular p., 473
- propagation of uncertainty, 386
- proper
 - projection matrix, 468, 474, 482, 483
 - rotation matrix, 499
- pseudo-inverse, 101, 779
 - rectangular matrix, 779
 - symmetric matrix, 779
- pseudo-likelihood function, 144
- QR decomposition, 776
 - for minimal solution, 179
 - for null space, 179
- quadratic variation, **741**, 760
- quadric, 239
 - fitting, 183
 - mapping of q., 484
 - orientation of q., 348
 - point of symmetry of q., 240
 - tangent plane at q., 240
- transformation of q., 260
- quality
 - checkability of the observations, 609
 - criteria, 609
 - of 3D point from two images, 603
 - of 3D points, 526
 - of parameters, 452
 - of relative orientation, 590
 - precision, 609
- quantile, 40
- quasi-affine projective mapping, 357
- quasi-systematic errors, 667
- quaternion, 332–335
 - as hyper-complex numbers, 333
 - covariance matrix of q., 383
 - uncertain q., 383
- R (software package), 115
- radial basis function, 735
- radial distortion, 506–508
- random
 - matrix, 27
 - number generation, 55
 - vector, 27
- random perturbations, 452
- random sample consensus, *see* RANSAC
- random variables, 24–28
 - continuous r., 26
 - discrete r., 26
 - independent r., 31
 - transformation of r., 41
 - uncorrelated r., 31
- RANSAC, 153–157, 609
- ray direction, 467, **469**, 514
 - sign of r., 492
 - uncertainty of r., 492
- Rayleigh distribution, 29
- reasoning levels, 7
- reconstruction
 - of point on plane, 524
 - of points and lines, 596–606
 - quality of r. procedures, 453
- rectangle, invariants of r., 271
- reduced
 - design matrix, 95
 - normal equations, 660
- reduced coordinates, 393
 - covariance matrix of r., 371
 - of 2D point, 370
 - of 3D line, 380–381
- redundancy, **82**, 609
 - matrix, **87**, 669
 - numbers, **88**, 145
 - numbers, relative orientation, 592
 - of absolute orientation, 613
 - of bundle adjustment image pair, 611
 - of Gauss–Helmert model with constraints, 165
 - of Gauss–Markov model, 82
 - of Gauss–Markov model with constraints, 100
 - of two DLTs, 611
 - of two spatial resections, 612
- relative r., 145
 - table with r., 171
- reference covariance matrix, 517
- refraction, 477
- regression model, 81
- regularization, 82, 747
- regularizing observations, 746
- rejection region, 63
- relative orientation, 450, 551, 634
 - epipolar geometry of r., 562
 - iterative r., 585–594
 - iterative r. for ideal forward motion, 593
 - iterative r. for normal case, 588
 - of image pair, 622
 - of image triplet, 636
 - of images of calibrated cameras, 552
 - of images of generic cameras, 581
 - of images of uncalibrated cameras, 552
 - planar object, 567
 - quality of r., 590
 - theoretical precision of r., 590
 - theoretical reliability of r., 590
 - with known plumb line, 581
 - within two-step procedure, 612
- relative redundancy, 145
- relief displacement, 459
- representation of uncertain points and lines, minimal r., 369–371
- residual of coplanarity constraint, 555, 562
- residuals, 82
 - approximate r., 164
 - covariance matrix of r., 87
 - normalized r., 144, 152, 170
 - standardized r., 125
 - variance of normalized r., 145
- resolution, 442
- reverse Cuthill–McKee algorithm, 662
- rho-function, *see* ρ -function
- rigid body motion, 255
- RMSE, 119
- robust estimate
 - of standard deviation of normalized residuals, 146
 - of variance factor, 146
- robust estimation, 141–185
 - as oracle, 142
 - maximum likelihood-type estimation, 147
 - of variance factor, 145–146
 - strategies, 158
 - with L_1 -norm minimization, 150
 - with clustering, 157
 - with complete search, 151
 - with RANSAC, 153
- robustness, 142
 - evaluation of r. with influence function, 147
- Rollei Panoscan Mark III, 443, 445, 446
- root mean square error, 119
- rotating slit camera, 485
- rotation, 325, 460
 - 2D r., 251

- 3D r ., 255
 - averaging, 713
 - axis and angle from r . matrix, 331
 - axis angle representation of r ., 331
 - Cayley representation of r ., 336
 - closed form solution for r . from directions, 406
 - concatenation of elementary r ., 329
 - concatenation of r . with quaternions, 337
 - conjugate r ., 281, 321
 - differential equation for r ., 337
 - differential r . vector, 337
 - direction between planes, 353
 - direction cosine matrix for r ., 328
 - eigenvalues of r . matrix, 327
 - elementary r ., 328
 - Euler's theorem for r ., 326
 - interpolation, 341
 - matrix, *see* rotation matrix
 - minimal r . between two vectors, 340
 - quaternion representation of r ., 332, 335
 - relations between representations for r ., 338
 - representations in 3D: overview, 326
 - Rodriguez representation of r ., 335
 - singularity of r ., 330
 - skew-symmetric matrix representation of r ., 336
 - uncertain r ., 382–383
 - vector, 336–338
 - with Euler angles, 328
 - rotation matrix, 326, 466
 - as local coordinate system, 378
 - direction cosine r ., 328
 - exponential form of r ., 326, 337
 - from corresponding vectors, 339
 - from projection matrix, 499
 - from three image lines, 531
 - representation, 327
 - rotational motion, 337
 - rounding error, 26, 29, 39
 - S-matrix, 112
 - S-transformation, 109, 113
 - in block adjustment, 668
 - regular S -, **112**, 121
 - singular S -, 112
 - sampling
 - in RANSAC, 154
 - of distributions, 56
 - scale
 - factor, 604
 - mutual s . of photogrammetric models, 621, 639
 - number, **457**, 591, 604, 720
 - of photogrammetric model, 551, **559**, 607
 - scale difference, 464
 - of image coordinate system, 471
 - scale transfer, 634, 639
 - scaling in 2D, 251
 - scene
 - coordinate system, 462
 - feature, 646
 - field-based s . description, 442
 - geometric model of s ., 442
 - model, 7, 441
 - object-based s . description, 442
 - reconstruction, 450
 - Schur complement, 660
 - search, complete s ., 151
 - segment, line s ., 352
 - selecting independent constraints, 317
 - self-calibrating bundle adjustment, 450, 674–696
 - self-calibration, 492, 697–699
 - self-diagnosis, 452
 - sensitivity, 115
 - w.r.t. groups of outliers, 130
 - w.r.t. single outliers, 126–128
 - w.r.t. systematic errors, 134–135
 - analysis, 592, 609, 695, 699
 - ellipse, 130
 - factor, 126–128, 130, 132, 692–694, 701, 705–706
 - of bundle adjustment, 691, 693, 701
 - of relative orientation, 589
- sensor coordinate system, 463
- sensor model, 7
- separable function, 28
- sequential estimation, 96
- shear, 464, 470, 471
- shear in 2D, 252
- sidelap, **718**, 721
- sideward motion, 588
- sign
 - constraints for points in image triplet, 624
 - effect of affinity on s . of entity, 357
 - of distance, 354
 - of intersection of 3D line and plane, 353
 - of intersection point of two 2D lines, 353
 - of ray direction, 492
- significance level, 62
- significance number, 62
- similarity
 - 2D s ., 252
 - 3D s ., 255, 613, 622
 - closed form solution of s ., 408
 - minimal solution of s ., 320
 - transformation, 611
 - uncertain s ., 383
- simulating data, 55
- single image, normal case of, 465
- single viewpoint, 445
- singular
 - correlation, 564
 - dual conic, 241
 - line conic, 241
 - precision matrix, 367
 - projectivity, 473
 - value decomposition, 777
 - values of essential matrix, 557
 - values of fundamental matrix, 554
 - values of homology, 568
 - vector, right s ., 571
- skew matrix, 336, **770**
 - product with matrix, 772
 - properties, 770
- SLERP, *see* spherical linear interpolation
- slope of curve, 739
- slope of plane, 212
- smoothness
 - of a function, 740
 - of a surface, 740–742
- SO(n), 326
- solution
 - direct s ., 452
 - iterative s ., 452
 - minimal direct s ., 178
- space
 - complete s ., 231
 - empty s ., 231
- sparse
 - covariance matrix, 86, 663
 - design matrix, 656, 657
 - matrix, 86
 - normal equation matrix, 657–661
 - reduced normal equation matrix, 660
 - structure of matrices, 655
- spatial resection, 513–521, 533, 623
 - critical configuration of s ., 515
 - direct solution of s ., 513
 - direct solution with > 3 points, 518
 - iterative solution, 520
 - quality of projection centre from s ., 516
 - theoretical precision of s ., 523
 - two s . for image pair, 612
 - with observed scene lines, 521
- spectral normalization
 - of matrix, 286
 - variance propagation, 783
- spherical
 - linear interpolation, 341
 - normalization, 45, 198, 199, **242**
 - normalization of matrix, 286
 - normalization of uncertain 2D point, 368
 - projection, 467
 - projection of 3D line, 481
- spherical camera, **446**, 456, 462, 468, 555, 582
 - bundle adjustment, 686
 - calibrated s . for the image pair, 556
 - triangulation for s ., 597
- spherically normalized homogeneous coordinates, 490
- spline, 736
 - one-dimensional s ., 736
 - two-dimensional s ., 737
- SPSS (software package), 115
- stable configuration, 452
- standard deviation, 37
 - empirical s ., 118

- of exterior orientation with spatial resection, 523
- of height, 604
- of image coordinates, 527
- of parameters
- relative orientation, 591
 - robust estimator of s. of normalized residuals, 146
- standard ellipse, **31**, 366, 369
- standard hyperbola, 374
- standardized residuals, 125
- stationary, 49
- statistically best fitting
 - 2D line, 397
 - mean axis, 405
 - mean direction, 403
 - plane, 400
 - rotation from directions, 406
 - similarity, 408
- Steiner's theorem, **37**, 116
- stellar calibration, **496**, 533
- step function, 25
- stereo vision, human s., 561
- stereographic projection, **243**, 346, 487
- stitching, 644
- stochastic independence, 28
- stochastic process, 48–55
 - homogeneous s., 51
 - isotropic s., 51
 - stationary s., 49
- stochastical model, 76
- for surface reconstruction, 743
- of 2D block adjustment, 652
- of block adjustment, 647
- of estimation, 83
- straight line segments, 480
- straight line-preserving, 249, 470
- structure from motion, 450, 568
- structure tensor, 402, 569
- Student's *t*-distribution, 35
- suboptimal test for gross errors, 126
- substitute model, 103
- substitute parameters, 177
- subsymbolic level of real world, 7
- surface, 442
 - $2\frac{1}{2}$ D s., 729, 733–742
 - flatness of s., 739–741
 - graph s., **729**, 739
 - reconstruction, 727, 730
 - reconstruction as Bayesian estimation, 742
 - reconstruction, outlier detection in s., 755
 - smoothness of s., 740–742
- surfel, 442
- SVD
 - for algebraic solution, 179
 - for consistency of essential matrix, 575
 - for consistency of rotation matrix, 531
 - for estimation of 3D line, 606
 - for estimation of 3D point, 603
 - for estimation of base vector, 579
 - for estimation of fundamental matrix, 571
 - for estimation of projection matrix, 495
 - for partitioning of essential matrix, 581
 - for partitioning of fundamental matrix, 595
 - of essential matrix, 557
 - of fundamental matrix, 553
- swing angle, 459
- symbolic image description, 448
- symbolic level of world model, 7
- systematic error, 116
 - in bundle adjustment, 683
 - model of s., 123
 - quasi-s., 667
- systems of cameras, 488
- taking position, **457**, 469, 550, 563
- tangent
 - line at conic, 238
 - plane at quadric, 240
- tangent space, 370
- tangential distortion, 485, 506
- telelens, 459
- tensor notation, 782
- test
 - for 3D line through triangle, 351
 - for coplanarity constraint, 555
 - for estimated parameters, 133
 - for gross error, 131
 - for point in tetrahedron, 351
 - of point in triangle, 349
 - of prediction errors, 98
 - one-sided t., 67
 - suboptimal t. for gross errors, 126
 - two-sided t., 65
 - within sequential estimation, 98
- test field calibration, 697, 698
- testability, 66
 - of mean, 65
 - of mean vector, 67
 - of observations, relative orientation, 592
- testing, 393
 - approximate t., 393
 - geometric relations in 2D and 3D, 393
 - uncertain relations, 393
- tetrahedron
 - chirality of t., 350
 - point in t., 351
 - sign of volume of t., 225
 - volume of t., 225
- theoretical
 - precision, 117
 - sensitivity, 127, 135
- theoretical covariance matrix, 517
- theoretical precision
 - of 3D point, 526
 - from two images, 603
 - of bundle adjustment, 683
 - of DLT, 522
 - of image blocks, 673
 - of image strips, 671
 - of point on horizontal plane, 527
 - of pose estimation, 521
 - of relative orientation, 590
 - of spatial resection, 523
 - of strips and blocks, 670–674
 - of surface interpolation, 761
- theoretical reliability
 - of absolute orientation, 411
 - of relative orientation, 590
- thin plate model, 741
- thin rod model, 741
- tie points of image pair, 608
- tilt angle, 459
- tilt angle of a plane, 212
- Toeplitz matrix, 53
- torsion, 741
- total least squares, 161
- total probability, 23
- traffic light decision, 63
- transformation, 247
 - 1D t., 257
 - 2D affinity, 252
 - 2D homography, 253
 - 2D mirroring at *y*-axis, 251
 - 2D projectivity, 253
 - 2D rotation, 251
 - 2D scaling, 251
 - 2D shear, 252
 - 2D translation, 251
 - 3D affinity, 255
 - 3D homography, 256, 552, 613
 - 3D homography, image pair, 611
 - 3D projectivity, 256
 - 3D rotation, 255
 - 3D similarity, 255, 551, 613, 622
 - 3D similarity, image pair, 611
 - 3D translation, 255
 - concatenation of t., 261
 - conjugate t., 278
 - coordinate t., 262
 - direct solution of similarity t., 408
 - dual t., 259
 - extrapolation during t., 389
 - group, 284
 - hierarchy, 285
 - interpolation during t., 389
 - inversion of t., 261
 - of 2D line, 258
 - of 2D point, 250
 - of 3D line, 259
 - of 3D point, 255
 - of conic, 260
 - of coordinates w.r.t. fixed reference, 263
 - of coordinates w.r.t. transformed reference, 264
 - of hyperplane, 258
 - of object w.r.t. fixed reference, 262
 - of object w.r.t. transformed reference, 263
 - of oriented entities, 355
 - of plane, 258
 - of quadric, 260
 - of random variable, 41
 - orientation-preserving t., 355
 - planar motion, 251
 - similarity t., 252
 - spatial motion, 255

- translation
 - 2D t., 251
 - 3D t., 255
 - conjugate t., 279
- triangle
 - area of t., 222
 - chirality of t., 349
 - spatial t. and 3D line, 351
- triangular irregular network, 732
- triangulation, 549, 552, 595, **596**
 - algebraic t. from multiple images, 602
 - Delaunay t., 732
 - for normal case of image pair, 601
 - for perspective image pair, 600
 - for spherical camera, 597
- trifocal matrices, 625–626
- trifocal plane, 623
- trifocal tensor, 622, **625**, 625, 629
 - degrees of freedom of t., 622
 - direct estimation for t., 636
 - from projection matrices, efficient computation, 626
 - iterative solution for t., 637
 - minimal solution of t., 636
 - normalized t., 628
- trigonometric basis functions, 734
- true value, 79
- truncated L_2 -norm minimization, 148
- Tschebyscheff polynomials, 510
- twisted cubic, 495

- ultra-wide lens, 459
- Ultracam, Vexcel, 443–445, 683
- uncalibrated camera, **461**, 490, 622
- uncertain
 - 2D line, 373–377
 - 2D point, 366–372
 - 3D line, 379–381
 - 3D point, 372–373
 - Euclidean coordinates, 371
 - geometric entities, 359
 - geometric relations, 359
 - Hessian parameters of 2D line, 376
 - homogeneous coordinates, 367, 375
 - homography, 384–386
 - matrix, 32
 - minimal representation of u. 2D point, 369
 - motion, 383
 - observations, 490
 - plane, 377–379, 403
 - quaternion, 383
 - rotation, 382–383
 - rotation matrices, 382
 - scene points and lines, 493
 - similarity, 383
 - spherical normalization of u. 2D point, 368
- uncertainty
 - homogeneous u., 121, 371, 396
 - isotropic u., 121, 396
 - isotropic u. of directions, 367, **371**, 403, 413
 - isotropic u. of points, **368**, 369, 399, 406, 408, 412
 - of directions in the camera, 492
 - of estimated 3D line, 413
 - of extrinsics and intrinsics from projection matrix, 500
 - of feature identification, 490
 - of image points, 491
 - of key point, 491
 - of line segments, 492
 - of projection matrix, 475
 - of projection ray, 524
 - of ray direction, 492
 - of transformed points, 387
 - propagation, 386
- uncorrelated random variables, 31
- uniform distribution, 28
- unit camera, 465
- unit circle
 - S^1 in \mathbb{R}^2 , 214, 215
- unit sphere
 - S^2 in \mathbb{R}^3 , 199, 200, 242, 243
 - S^3 in \mathbb{R}^4 , 242
 - S^5 in \mathbb{R}^6 , 243
- unscented transformation for variance propagation, 47

- vanishing line, 529
- vanishing point, 208, 210, 459, 529–534
 - estimation, 417
- variance, 37
 - bias of v., 45
 - of normalized residuals, 145
 - of ratio, 46
 - of residual of coplanarity constraint, 555
 - of scale of similarity from points, 410
- variance component estimation, 91–93, 493
 - bundle adjustment, 679
 - profile reconstruction, 750
- variance factor, 716
 - correctness of v., 140
 - estimated v., **89**, 680–685, 700–701
 - initial, 89
 - interpretation of v., 498
 - robust estimation of v., 145–146
 - test of v., 90
- variance propagation, **42**, 42–48
 - implicit v., **43**, 154, 180, 516
 - nonlinear v., 43
 - of bilinear forms, 387
 - of linear functions, 42
 - of nonlinear functions, 43
 - of spectral normalization, 783
 - unscented transformation, 47
 - with weight matrices, 43
- vec operator, 775
- vech operator, 775
- vector representation
 - of conics and quadrics, 316
 - of transformations, 315
- vertical parallax, 561
- vertical view, 456
- Vexcel Ultracam, 443–445, 683
- view
 - horizontal v., 456
 - nadir v., 456
 - oblique v., 456
 - perspective v., 459
 - vertical v., 456
 - zenith v., 456
- view planning, 715–722
 - for flat areas, 718
 - of buildings and rooms, 721
 - rules of thumb for v., 716
- viewing angle, 371, **458**
- viewing direction, 458, 462
 - from projection matrix, 475
 - normal case of image pair, 561
- viewing position, **457**, 469, 550
- viewing sphere, 423, 447
- viewline, 445
- viewpoint of camera, 445
- visual odometry, 644
- volume of tetrahedron, 225

- weak configuration, 698
- weak constraints, 102
- weak membrane model, 740
- weak string model, 739
- weight, 83
 - coefficient matrix, 89
 - matrix, **43**, 83, 89
 - table of w. functions, 149
- weight function
 - asymmetric w., 756
- weighted
 - least squares, 79
 - sum of the squared residuals, 84
- weights
 - in least squares estimation, 81
 - modified w., 147
- whitening, 41
- wide-angle lens, 459
- Wiener filter, 93
- Wishart distribution, 34
- Woodbury identity, 769
- world model, 7

- Yule–Walker equations, 184

- zenith
 - angle, 210
 - point, 346
 - view, 456
- zoom lens, 459