

## Index

- $L^p$ -space, 538
- $\ell^0$ -norm, 106
- $\ell^2$ -minimization, 113, 535
- $\ell^p$ -norm, 528
- $\ell^p$ -space, 538
- $\ell^{2,1}$ -minimization, 67
- $\ell^1$ -minimization, 112
  - weighted, 268
- $\ell^2$ -loss, 439
- $\ell^p$ -minimization, 98
- activation function, 432
- adjoint of a matrix, 530
- adjoint operator, 539
- ADMM, 163
- ADMM-CSNet, 519
- ADMM-Net, 519
- adversarial attack, 446
  - blackbox, 457
  - targeted, 457
  - whitebox, 457
- adversarial perturbation, 446
  - defences, 452
  - transferrable, 450
  - universal, 450
- adversarial training, 493
- AlexNet, 445
- algorithm
  - arithmetic, 175
  - general, 175
- almost surely, 542
- alternating minimization, 94
- analog signal recovery, 346
- analysis operator, 541
- anisotropic sampling, 77
- Arrow–Hurwicz method, 164
- artificial neural network, *see* neural network
- attenuation coefficient, 58
- AUTOMAP, 466, 469
- back-projection, 38
- backpropagation, 441
- balancing property, 339
- Banach space, 538
- basis pursuit denoising, 139
- Bayes’ rule, 543
- beam hardening, 59
- Bear, *see* test images
- Beer’s law, 59
- Bernoulli model, 256
- Bernoulli random matrix, 108
- Bernstein’s inequality, 286
  - matrices, 286
  - vectors, 286
- best  $s$ -term approximation, 107, 223
- Bezout’s theorem, 203
- biconjugate function, 549
- binary sampling, 6
- BM3D, 468
- bounded operator, 539
- bounded orthonormal system, 265
- bounded variation, 225
- BP, 113
- BSS machine, 175, 186
- C-LASSO, 129
- calibration, 69, 99
- canonical basis, 529, 541
- cartoon-like function, 234
- Cauchy–Schwarz inequality, 528, 538, 539, 545
- Chambolle–Pock algorithm, *see* primal–dual iteration
- change-of-basis matrix, 337
- circulant matrix, 535
- classification
  - binary, 431
  - multiclass, 431
- closed ball, 537
- closure, 537
- CNN, 437
- coarse scale, 190
- coded aperture, 66
- coherence
  - collection, 259
  - cross, 128
  - family, 259
  - local, 261
  - local, relative to  $\Delta$ , 269
  - matrix, 110

- mutual, 128
- collection
  - jointly isotropic, 253
  - nondegenerate, 314
- commuting property, 412
- composite  $\ell^1$ -minimization, 90
- compressibility, 8, 107
- compressive imaging, 3
- Compressive Sampling Matching Pursuit (CoSaMP), 127
- compressive video imaging, 74
- computational cost, 177
- computational imaging, 5
- concentration inequality, 121
- conditional probability, 543
- consistency, 496
- convex conjugate function, 549
- convex function, 546
- convex optimization problem, 548
- convex quadratic program, 146
- convex relaxation, *see* biconjugate function
- convex set, 546
- convolution, 215, 535
- cosparsity, 128
- cost function, 439
- coupon collector's effect, 256
- covering, 321
- covering number, 321
- CS SENSE, 69
- curvelets, 88, 219
- D-RIP, 128
- DAGAN, 466, 469
- Dantzig selector, 140
- data fidelity parameter, 347
- Daubechies wavelet, 202
  - boundary-corrected, 213
  - periodized, 213
  - smoothness, 206
- decoder, 112
- Deep MRI, 466, 469
- DeepFool, 446
- denoiser network, 459
- detail space, 194
- DFT, 555
- DHT, 44, 562
- dictionary learning, 93
  - patch-based, 95
- digital micromirror device, 63
- dilation, 192
- discrete gradient operator, 403
- discretization, 31
- Douglas–Rachford splitting, 163
- downsampling, 438
- dual certificate, 123
- dual vector, *see* dual certificate
- Dudley's inequality, 322
- DWT, 215
- dyadic anisotropic partition, 358
- dyadic expansion, 40
- dyadic isotropic partition, 358
- dyadic partition, 358
- Ell 50, 466, 469
- empirical risk, *see*  $\ell^2$ -loss
- encoder, 112
- epoch, 440
- exact recovery, 11, 112
- existence theorem, 436
- expectation, 544
- exploding gradients, 442
- eyeball metric, 33
- false structure phenomenon, 452
- fan beam geometry, 60
- fast gradient sign method, 456
- FBPCovNet, 462
- Fenchel's inequality, 549
- Fenchel–Rockafeller dual, 152
- Fermat's optimality condition, 548
- FFT, 555
  - nonuniform, 58, 71
- FHT, 562
- filter, 194, 437
  - high-pass, 216
  - length, 437
  - low-pass, 216
  - stride, 437
- filtered back-projection, 39
- fine scale, 190
- finite section, 347
- first-order method, 146
- FISTA, 151
- fixed point
  - equation, 150
  - iteration, 150
- flip test, 245
- forward–backward splitting, 148
- Fourier
  - basis, 554
  - coefficients, 554
  - continuous reconstruction problem, 33
  - discrete reconstruction problem, 36
  - matrix, 35
  - series, 554
  - transform, continuous, 553
  - transform, discrete, 555
- Fourier-slice theorem, 38
- FPC, 71
- frame, 88
  - bounds, 88
  - tight, 88
- frequency estimation, 347

- full rank matrix, 530
- fully trained, *see* learn-the-physics
- Gaussian distribution, *see* normal distribution
- Gaussian random matrix, 108
- Gaussian random variable, 544
- generalization, 432
- generalized sampling, 338
- Generative Adversarial Networks (GANs), 493
- Gibbs phenomenon, 54
- global minimizer, 548
- GLPU phantom, 32
- golfing scheme, 292
- gradient descent, 147, 440
  - acceleration, 148
  - memory, 148
  - with momentum, 441
- Gray code, 560
- gridding, 39, 71
- group  $\ell^1$ , 70
- GSPR, 71
- Hölder
  - continuity, 224
  - piecewise, 225
  - space, 224
- Hölder's inequality, 528, 538, 539, 545
- Hadamard matrix, 43
- Hausdorff distance, 471
- helium atom scattering, 72
- Hilbert space, 538
  - separable, 540
- Hoeffding's inequality, 300
- homotopy method, 163
- Huber function, 160
- hyperbolic tangent function, 432
- hyperparameter, 440
- i.i.d., 544
- image, 30
  - continuous, 30
  - discrete, 30
  - greyscale, 30
- image-domain learning, *see* denoiser network
- ImageNet Large Scale Visual Recognition Challenge (ILSVRC), 445
- incoherence, 110, 259
  - asymptotic, 249
- independence, 543, 544
- indicator function, 547
- inexact input, 144, 174
- inner product, 538
  - Euclidean, 528
- input class, 174
- instance optimality, 121
- integral transform, 5
- interior point methods, 146
- inverse crime, 86
- inverse problem triple, 471
- isotropic family, 252
- isotropic sampling, 76
- ISTA, 151
- Iterative Hard Thresholding (IHT), 127
- iterative reweighting, 90
- iteratively re-weighted least squares, 163
- JPEG-2000, 9, 221
- Khinchine's inequality, 325
- Kronecker product, 535
- 11-magic, 71
- Lagrangian, 152
- LASSO
  - constrained, 129
  - LAD, 141
  - square-root, 130
  - unconstrained, 10, 129
- law of total probability, 543
- layer, 433
  - convolutional, 437
  - hidden, 434
  - input, 434
  - output, 434
  - pooling, 438
- learn-the-physics, 461
- learning rate, 440
- learning rate schedule, 441
- Least Absolute Deviations (LAD), 141
- Least Angle Regression (LARS), 163
- least-squares loss, *see*  $\ell^2$ -loss
- least-squares problem, 533
- Legendre–Fenchel identity, 550
- lensless imaging, 63
- lexicographical ordering, 30
- limited-angle tomography, 72
- linear approximation, 222
- linear classifier, 432
- linear programming, 143
- Lipschitz
  - constant, 147
  - continuous, 147
- local minimizer, 548
- loss function, *see* cost function
- lossy compression, 9
- low-rank matrix recovery, 98
- lower semicontinuous, 547
- Maurey's lemma, 325
- mean, 544
- mean-squared loss, *see*  $\ell^2$ -loss
- measurable function, 543
- measurement matrix, 11, 108
- Med 50, 466, 469
- metric space, 537
  - complete, 537
- minimal phase solution, 204
- minimizer, 548

- mismatch, 2, 86
- modReLU function, 505
- Moreau's identity, 552
- MRA, 192
- MRI, 51
  - parallel, 68
- MRI-VN, 466, 469
- MSE, 33
- multiple measurement vector problem, 73
- multiresolution space, 192 *see* MRA,
- multivariate function approximation, 346
- neighbourhood, 537
- Nemirovski's surface-following method, 183
- NESTA, 159
- Nesterov's method, 157
- neural network, 433
  - architecture, 434
  - biases, 433
  - complex-valued, 459
  - convolutional, 437
  - deep, 434
  - expressivity, 442
  - feedforward, 433
  - fully connected, 435
  - neuron, 433
  - parameters, 434
  - recurrent, 465
  - shallow, 434
  - trainability, 442
  - unit, 433
  - weights, 433
- NMR, 72
- noiselets, 73
- nonincreasing rearrangement, 107
- nonlinear approximation, 223
- nonnegative definite, 531
- nonuniform recovery, 114
- norm, 528
  - $L^p$ , 538
  - $\ell^p$ , 528
  - $\ell^{p,q}$ , 532
  - dual, 529
  - Frobenius, 532
  - induced matrix, 531
  - matrix  $\ell^p$ , 531
  - unit ball, 529
- normal distribution, 544
- normed vector space, 538
- NSP, 115
- null space of a matrix, 530
- off-the-grid compressed sensing, 347
- open ball, 537
- optical imaging, 62
- optimal map, 471
- oracle, 174
- oracle class, 174
- oracle estimator, 125
- orthogonal, 529, 540
- orthogonal complement of a subspace, 540
- Orthogonal Matching Pursuit (OMP), 127
- orthogonal matrix, 530
- orthogonal projection, 531, 540
- orthonormal basis, 529, 540
- over-relaxation, 153
- overcomplete, *see* redundant
- overfitting, 443
- parallel beam geometry, 60
- parameter tuning, 50, 98
- PDHG method, 164
- perceptron, 432
- periodic function, 554
- phase retrieval problem, 72
- phase transition, 73
- PhaseLift, 72
- pixel basis, 31
- Plancherel's theorem, 553
- Plug-and-Play Prior ( $P^3$ ) method, 469
- Poincaré's inequality
  - Haar-incoherent measurements, 417
  - one-dimensional, 413
  - strengthened, 416
  - two-dimensional, 414
- Poisson noise, 64
- polynomial time, 177
- positive definite, 530
- primal–dual gap, 154
- primal–dual iteration, 151
- prior information, 98
- probability space, 542
- projected gradient method, 149
- projection onto a convex set, 549
- proper function, 546
- proximal gradient method, *see* forward–backward
  - splitting
- proximal mapping, 551
- proximal point algorithm, 149
- pseudoinverse, 534
- PSNR, 33
- QCBP, 9, 113
  - analysis, 49
  - synthesis, 49
  - uniform recovery property, 306
  - weighted, 90, 268
- quotient,  $\ell^1$ , 140
- Rademacher process, 321
- Rademacher sequence, 297
- radio interferometry, 72
- Radon
  - continuous reconstruction problem, 37
  - discrete reconstruction problem, 40
  - projection, 38
  - transform, 37

- random convolution, 64
- random sign assumption, 297
- random variable, 543
- random vector, 544
- range of a matrix, 530
- rank of a matrix, 530
- reconstruction map, 2
- reconstruction problem, 2
- recovery guarantee, 11, 114
- redundant, 88
- regridding, *see* gridding
- Regularization by Denoising (RED), 469
- ReLU function, 432
  - leaky, 433
- ResNet, 438
- resolution, 30
- resolvent, 552
- Restricted Eigenvalue Condition (REC), 127
- RIC, 118
  - G-adjusted, 307
  - in levels, 307
- RIP, 118
  - G-adjusted, 307
  - in levels, 307
  - weak, 127
- rNSP, 116
  - in levels, 308
- Robust Width Property (RWP), 127
- saddle-point problem, 152
- sampling bandwidth, 338
- sampling levels, 257
- sampling map, *see* sampling scheme
- sampling pattern, *see* sampling scheme
- sampling scheme, 75
  - block, 266
  - Cartesian, 78
  - DAS, 360
  - DIS, 360
  - DS, 360
  - Gaussian multilevel, 77
  - half-half, 76
  - inverse linear law, 76
  - inverse square law, 76
  - multilevel random, 77, 257
  - Poisson disc, 99
  - power law, 76, 355
  - radial, 78
  - spiral, 78
  - uniform random, 75
  - variable density, 76
- sampling strategy, *see* sampling scheme
- saturation, 257, 258
- scaling function, 192
- scrambled orthogonal transform, 64
- self-adjoint matrix, 530
- self-adjoint operator, 539
- sensor-domain learning, 469
- shearlets, 88, 220
- Shepp–Logan phantom, 3, 32
- side information, *see* prior information
- sigmoid function, 432
- single-pixel camera, 62
- singular values, 533
- singular vectors, 533
- skip connections, 438
- smoothing, 158
- soft shrinkage, *see* soft thresholding
- soft thresholding, 150, 551
- SpaRSA, 71
- sparse and balanced, *see* sparse and distributed
- sparse and distributed, 265
- sparse coding, 94
- sparse corruptions problem, 141
- sparsifying transform, 8, 108
- sparsity, 8, 106
  - in levels, 250
    - asymptotic, 248
    - block, 70
    - group, 70
    - joint, 67
    - structured, 98, 128
- sparsity bandwidth, 338
- sparsity basis, 8, 108
- sparsity levels, 251
- sparsity ratio, 332
- SPGL1, 51, 163
- split-Bregman method, 163
- splitting, 148
- SR-LASSO, 130
  - uniform recovery property, 306
- staircasing effect, 89
- standard deviation, 545
- Stechkin’s inequality, 126
- steepest descent, *see* gradient descent
- Steinhaus sequence, 297
- stochastic gradient
  - mini-batch, 440
- stochastic gradients, 440
  - momentum, 441
- stochastic process, 321
- strong convexity parameter, 546
- strongly convex function, 546
- subdifferential, 547
- subgradient descent, 148
- subsampling Fourier matrix, 36
- subsampling unitary matrix
  - multilevel, 257
  - nonuniformly, 254
  - randomly, 109
- superresolution problem, 347
- supervised machine learning, 431
- support, 106

- SVD, 533
- symmetric matrix, 530
- symmetrization, 322
- synthesis operator, 541
- Talagrand's theorem, 329
- test images, 32
- test set, 432
- TGV, 89
- training, 439
  - data augmentation, 444
  - early stopping, 444
  - regularization, 443
  - weight decay, 456
- training error, 431
- training set, 431, 502
- transfer function, 195
- trigonometric polynomial, 554
- TV minimization, 17, 405
- TV semi-norm, 403
- U-LASSO, 129
- U-net, 462
- uncertainty principle, 110
- underfitting, 443
- uneven section, 347
- uniform recovery, 114
- union bound, 542
- union of subspaces, 106, 128
- unitary matrix, 530
- unitary operator, 540
- universal approximation theorem, 435
- universal instability theorem, 477
- universal interpolation theorem, 436
- universality, 122
- unpooling, 438
- unravelling, 464
- upsampling, 438
- validation set, 432
- vanishing gradients, 442
- variance, 545
- vectorization, 31
- Walsh
  - continuous reconstruction problem, 45
  - discrete reconstruction problem, 45
  - function, Paley ordering, 41
  - function, sequency ordering, 42
  - transform, continuous, 41
  - transform, discrete, 44
- wavelet
  - biorthogonal, 221
  - bivariate, 210
  - boundary corrected, 208
  - CDF, 221
  - compact support, 199, 200
  - crime, 217
  - DB2, 205
  - DB4, 202
  - decomposition formula, 216
  - discrete, 218
  - filter, 194
  - folded, 221
  - Haar, continuous, 188
  - Haar, discrete, 218
  - orthonormal, 188
  - periodized, 207
  - reconstruction formula, 216
  - smoothness, 200
  - tree model, 98
  - vanishing moments, 198
- weak RIP, 303
- X-lets, 221
- X-ray CT, 58
- YALL1, 71
- Young's inequality, 111
- zero padding, 61