Index

a

acid-resistant rhodamine probes 190
acid-resistant rhodamine spirolactams 189
AIE dots 205, 207
AIEgens 207
algebraic algorithms 78–79
Au NP 218

b

backpropagation 141–143
balanced SOFI algorithm 96
Bayesian analysis of blinking and bleaching (3B) 99–100
Bayesian information criterion (BIC) 81
Bayesian statistical algorithm 81
biological neural networks 136
bioorthogonal HM-SiR probe 189
blind SIM 113–116
BODIPY-based polymer dots 216, 218
boron dipyrromethene (BODIPY) dyes 194–198

c

cationic carbon quantum dot (cQD) 209, 210
centroid method 78, 79
classic SIM 118, 230
CM2P 181
coherent optical adaptive techniques (COAT) technology 29
compressive sampling MP (CoSaMP) 83
confocal fluorescence microscopy 5
confocal laser scanning microscopy (CLSM) 8, 108, 229
confocal microscopes 3–5, 121, 123, 231
conventional grating-based SIM 111–113
converging lens 2
convex relaxation method 82, 83
convolutional neural networks (CNN) 145–149
  convolutional layer 146–147
  output layer 145
  pooling layer 147
  properties 147–148
  SR image reconstruction 148–149
CS theory 82
cyanine dyes 56, 182, 185, 191–194

d

DAOPHOT 81
DAOSTORM 81
deconvolution networks 156
deep learning-based SR microscopy
  challenges 153
    data limitations 154
    result reliability 155–156
    training obstacles 154–155
  deep networks 135–136
  image reconstruction 144
    2D reconstruction methods 145–152
    3D reconstruction methods 153
deep networks, fundamental of
  loss functions 144

Super Resolution Optical Imaging and Microscopy: Methods, Algorithms, and Applications, First Edition. Edited by Junle Qu and Zhigang Yang.
© 2024 WILEY-VCH GmbH. Published 2024 by WILEY-VCH GmbH.

deep networks, fundamental of (*contd.*)
test set data 143
training set 143
validation set data 143
deep networks, fundamentals of 135–136
activation function and layers 137
rectified linear unit 139–140
sigmoid 138–139
softmax function 139
neural networks 136–137
training and data 141
backpropagation 142–143
gradient descent optimization 141–142
Deep-STORM 148, 149
DeepSTORM3D 153
diazoindanone-based probe 190
diffraction 3, 6–8, 15, 26, 32–37, 39, 42, 51, 52, 56, 67, 68, 107, 110–113, 118–120, 124
digitally enhanced STED (DE-STED) 26
direct laser writing (DLW) lithography 43
direct stochastic optical reconstruction microscopy (dSTORM) 52, 56, 57
DNA-based PAINT approach (DNA-PAINT) 76–78, 232
donor-acceptor organic fluorophores 209
double helix PSF method 66
Dronpa 19, 20, 169, 172, 176
dual channel RESOLFT imaging 37
dual-channel RESOLFT nanoscopy 169
dual-color STED imaging 20
dual-color STED system 19
dual-color STORM imaging of microtubules 192
dynamic STED super-resolution imaging of mitochondria 31

e

entropy-based super-resolution imaging (ESI) 93, 101
ER-Tracker Red 196
exchange-PAINT 77–78
extended-depth 3D prSTORM imaging 64

f

far-field SRM methods 163
far-field super-resolution microscopy 8–9
Fast localization based on a continuous-space formulation (FALCON) 84
feed-forward multilayer neural network 137
f-HM-SiR 189
finite rate of innovation (FRI) sampling theory 84
FLASR 41
fluctuation-enhanced Airyscan technology 176
fluorescence carbon dots (FNCDs) 209
fluorescence emission difference (FED) super-resolution imaging technique 26
fluorescence fluctuation-based super-resolution microscopy methods 99
applications 102–103
Bayesian analysis of blinking and bleaching (3B) 99–100
comparison results 103
entropy-based super-resolution imaging 101
MUSICAL 102
super-resolution radial fluctuations 100–101
VISion 99
fluorescence photoactivation localization microscopy (fPALM) 72
fluorescent metal complexes
for SIM 204
for SMLM 203–204
for STED 202–203
fluorescent nanomaterials 204
for SIM 216–218
for SMLM 213–216

for STED 205
inorganic nanoparticles 211–213
organic nanoparticles 205–211
fluorescent nanoparticle systems 231
fluorescent probes
for RESOLFT microscopy
application in writing and manufacturing at nanoscale 43–44
fluorescent protein 38–39
improvement based on fluorescence dynamics 39
life science application 42
organic fluorophores 41
for super-resolution imaging 163
for super-resolution microscopy 9–10
fluorescent proteins (FPs) 54, 164
for RESOLFT nanoscopy 167–169
for SIM 176
for SMLM-based SRM 169–176
for STED nanoscopy 164–167
fluorophore-switch dyad 39
Fourier interpolation 96–97
4Pi method 17
frequency domain localization method 79
fSOFI algorithm 97

g

generative adversarial networks (GAN) 149
architecture 150
game theory 150
SR image reconstruction 151–152
training 150–151
genetic algorithm-based STED (GA-STED) imaging technology 29
genetically encoded labeling method 54
GMars-Q 169
GMars-T-based bimolecular fluorescence complementation (BiFC) biosensors 39
gradient descent optimization 141–142
graphene quantum dots for SMLM 215
grazing incidence SIM 116–117
green FPs (GFPs) 164
ground state depletion microscopy 32
advantages and disadvantages 33
applications 34
principles 32–33
GSDIM 34

h

HaloTag-modified Rh-Gly 187
Hessian-SIM 117–118
high-density environmentally sensitive (HIDE) membrane probes 189
HoeSR 188
hybrid fusion method 54
HyPer2 166

i

image analysis algorithms 10, 230
image scanning microscopy (ISM) 118, 119, 230
incoherent wavefront adjustment method 17
inseparable sparse measures 83
Instant-MSIM 124
inverted microscopes 4
in vivo STED microscopy technique 32

k

Kohinoor 41
in RESOLFT nanoscopy 169
Köhler illumination 2, 3, 107, 109

l

laser scanning confocal microscope (LSCM) 5, 118
leaky ReLU 138, 140, 152
least squares (LS) method 80
lens-based super-resolution fluorescence microscopy 34
lipid droplet (LD) dynamics 181
live-cell SRM studies 163, 168, 194, 216, 232

live-cell STED nanoscopy 164–166, 178
live cell STORM imaging 69–72
local connectivity of convolutional layers 147
LysoPB Yellow 185
lysosome 565, 199, 200
LysoTracker Red 196

m

matching pursuit (MP) method 82
maximum a posteriori (MAP) calculation 100
maximum likelihood estimation (MLE) methods 80
MB-S_n 201
mean square error (MSE) loss function 144
MINFLUX 233
minimal photon fluxes (MINFLUX) localization method 84
MitoPB Yellow 184
Mito-RealThiol (MitoRT) 201
model interpretability 156
modified enhanced squaraine variant dye, (MitoESq-635) 182
modulated STED system 28
Moiré effect 108, 110
monomeric green RSFP 169
monomeric NIR FP variants (miRFPs) 167
MSIM based on helical phase engineering (MSIMH) 126, 230
m-STED 26
multi-color STED 18–20, 42
multi-color STORM imaging 59, 61
multi-emitter fitting algorithm 80–81
multi-focal plane imaging method 67–68
multifocal SIM (MSIM) 122
multilayer perceptrons 137
multi-photon excitation technology 18
multi-photon STED 18–20
multiphoton upconversion super-resolution microscopy 18
multiple measurement vector (MMV) model-based sparse Bayesian learning (MSBL) algorithm 230
multiple signal classification algorithm (MUSICAL) 93, 102

n

nanographenes 215
near-field scanning optical microscopy (NSOM) 7, 8
negative log-likelihood loss function 144
negative switching RSFPs 168
NeuN-specific probe 181
neural networks 136–137
non-genetically encoded labeling method 54
Nyquist–Shannon sampling criterion 58

o

objective lens 1, 2, 4, 5, 7–9, 17, 18, 53, 54, 113, 122
offline gated STED technology 22–23
optical diffraction limit 5–7, 15, 35, 103, 163
optical microscopy 1–3
optical photon reassignment microscopy (OPRA) 124, 230
optical shelving 32, 33
optical transfer function (OTF) 96, 108
optimization algorithms 80, 111, 141
optogenetics 44
organic fluorescent probes
  for SIM 199, 201
  for SMLM 185
    BODIPY and oxazine/spiropyran dyes 194–198
    cicyanodihydrofurans 198–199
    cyanine dyes 191–194
    2-dithienylethenes 198–199
    xanthene/rhodamine dyes 185–191
  for STED 176
    CM2P 181
    NeuN-specific probe 181
    phosphole-based fluorescent probes 183–185

rhodamine-based fluorescent probes 177–179
rhodamine-RNA aptamer probes 181
tetrazine-quenched cyanine probes 182
organic fluorophores 38, 41, 71, 163, 209
organic red-emitting carbon dots 213
organosilica nanohybrids 205
orthogonal MP (OMP) algorithm 83
oxazine 54, 56, 185, 194–198

p

PAmRFPs 172
parallelized RESOLFT microscopy 36–37
parameter sharing of convolutional layers 147
pattern estimation SIM (PE-SIM) 114
perylenemonoimide-dithienylethene (PMI-DTE) conjugates, photoswitching of 198, 199
phasor-plot analysis of STED-FLIM 23
phosphole-based fluorescent probes, for STED imaging 183, 185
photoactivatable boron-alkylated BODIPY probe 195
photoactivatable fluorescent proteins (PA-FPs) 72
photoactivatable FPs (PA-FPs) 169, 172
photoactivatable Zn-salen complex (J-S-Alk) 203
photo-activated localization microscopy (PALM) 52, 203
principles 72
single-particle tracking PALM 73–74
vs. STORM 72–73
photoblinking Pdots 216
photo-caged Q-rhodamines 188
photoluminescence of QDs 57
photon separation 23
photostable carbon dots 216
photostable silica-coated core-shell organic nanoparticles 205
photoswitchable FPs (PS-FPs) 169
photoswitchable variants, of enhanced green fluorescent protein (EGFP) 38
photoswitching 169
of Cy5 191
PhoxBright 430 (PB430) 184
2PISIM process 124
pixel reassignment 119
point accumulation for imaging in nanoscale topography (PAINT) 75
advantage 75–76
DNA-PAINT 76–78
exchange-PAINT 77–78
limitation 76
uPAINT 76
point accumulation topography (PAINT) 53
point-scanning SIM (PS-SIM) 118, 128
based on digital method 121–123
based on optical method 123–125
principle of 119–121
special 126–127
point spread function (PSF) engineering super-resolution imaging 15
polymer dots (Pdots) 210
probe-refresh STORM (prSTORM) 61
proposed a SOFI variant, variance imaging for super-resolution (VISion) 93
PSF engineering method 63–67
pSTED-SPLIT methods 24
pulsed 2P-STED microscope 19
pyronine fluorophores 190

q

QSTORM 57
QuickPALM 79
Quick-SIMBA 176

r

rectified linear unit (ReLU) 139–140
RE-scan confocal microscopy (RCM) 123

reversible photoswitching, in GFP probes 41
reversible saturable optical fluorescence transition (RESOLFT) microscopy 34
  dual channel RESOFT imaging 37
  fluorescent probes for 38–41
  mechanism 35
  parallelized 36–37
  three dimension imaging 37–38
  two-photon 37
reversibly photoswitchable fluorescent proteins (RSFPs) 167, 171
reversibly switchable variant of enhanced GFP (rsEGFP) 42, 168
Rh-Gly 187
rhodamine-based fluorescent probes 177–179
rhodamine-based N-Nitroso photo-cage system and NOR535 188
rhodamine-RNA aptamer probes 181
rsFP 41
RSFP Padron2 39
rsFusionReds 168

S

scanning near-field optical microscopy (SNOM) 7
separable sparse measures 83
SF-1 200
sigmoid activation function 138–139, 152
silicon rhodamine-based small-molecule fluorescent probe 189
simulated speckle blind-SIM 115
single-emitter fitting algorithm 79–80
single molecule-guided Bayesian localization microscopy (SIMBA) 100, 176
single-molecule localization algorithms 78
  algebraic algorithms 78–79
  CS algorithm 82
  multi-emitter fitting algorithm 80–81
  single-emitter fitting algorithm 79–80
single-molecule localization microscopy (SMLM) 51
  fluorescent metal complexes for 203–204
  fluorescent nanomaterials for 213
  future development of 85
  schematic illustration 52
  techniques 10, 230
single-particle tracking PALM (sptPALM) method 73–74
SiO_2-NPs 207
Skylan-NS 176
Skylan-S 173
small-molecule fluorescent probes
  organic fluorescent probes for STED 176, 185
SNIFP 167
softmax function 139
spatial filter SMLM (SFSMLM) method 70
spatial modulation STED 27
spatiotemporal cross-cumulants SOFI (XC-SOFI) algorithm 95–96
specialized optical microscopes 3
  confocal microscopes 4
  inverted microscopes 4
speckle pattern illumination SOFI (S-SOFI) 97–98
spin-RESOLFT microscopy 44
spiropyrans (SPs) 196
spontaneous emission 21, 35
spot-scanning SIM 118–127, 230
squaraine-based valuable fluorescent probes 183
SRRF-Deep approach 153
SR-SIM 110–111
STED super-resolution imaging with quantum dots 24, 26
stimulated emission depletion microscopy (STED) 229
  fluorescent metal complexes for 202–203
  fluorescent nanomaterials
    inorganic nanoparticles 211–213
    organic nanoparticles 205–211

live cell imaging 29
ground state depletion microscopy 32–34
multi-color and multi-photon 18–20
power reducing strategies 20
DE-STED 26
offline gated STED technology 22–23
phasor-plot analysis of STED-FLIM 23
STED super-resolution imaging based on adaptive optics 27
STED super-resolution imaging with quantum dots 24–26
temporal and spatial modulation STED 26–27
time-gated STED technology 21–22
principles of 15–16
schematic diagram of 16
three-dimensional 16–18
stochastic blueing, of QDs 214
stochastic gradient descent 142
stochastic optical fluctuation imaging (SOFI) 173
bSOFI 96
fSOFI 96–97
principle 94
speckle SOFI 97–98
XC-SOFI 95–96
stochastic optical reconstruction microscopy (STORM) 52, 203
consideration in 57–59
detecting and localizing single PSFs 55–57
labeling with photo-switchable fluorescent dyes 54–55
live cell STORM imaging 69–72
multi-color 59–61
setup 53–54
three-dimensional 61–62
structured illumination microscopy (SIM) 107
fluorescent metal complexes for 204
fluorescent nanomaterials for 216–218
future systems 128
point-scanning 118–127
wide-field 107–118
structured light illumination method 17
sulforhodamine fluorophore 188
super-resolution imaging techniques 7, 9–11, 34, 176, 229
super-resolution microscopy (SRM) 6, 7, 11, 93
far-field 8–9
fluorescent probes 9
super-resolution optical fluctuation imaging (SOFI) 9, 57, 93, 173
super-resolution radial fluctuation (SRRF) 93, 100–101, 153
supervised learning algorithms 143

t

TagRFP657 167
temporal modulation STED 27
tetrazine-quenched cyanine probes 182
3D, parallelized, reversible, saturable/switchable optical fluorescence transition (3D pRESOLFT) microscopy technique 37
3D reconstruction methods 153
three-dimensional SIM (3D-SIM) 108, 112, 201, 204
three-dimensional STED 16–18
three-dimensional STORM 61–62
fluorescence self-interference 68
multi-focal plane imaging 67–68
PSF engineering 63–67
time-correlated single-photon counting (TCSPC) technology 23
time-gated STED technology 21–22
time-lapse STED imaging 164, 165
total internal reflection-based SIM (TIRF-SIM) 111
triangulation method 78, 79
two-color RESOLFT microscopy 39
2D reconstruction methods
convolutional neural networks 145–149

2D reconstruction methods (*contd.*)
generative adversarial networks 149
two-photon excitation 18
two-photon RESOLFT 37
two-photon STED imaging system 18

u

ultra-fast SIM 117
UnaG 172, 173
unsupervised learning algorithms 143
upconversion nanoparticles (UCNPs) 24, 205

v

VISion 93, 99, 103

w

wide-field SIM 107–118
basics of 108–110
blind SIM 113–114
conventional grating-based SIM 111–113
grazing incidence SIM 116–117
Hessian-SIM 117–118
SR-SIM 110–111

x

xanthene/rhodamine dyes 185–191

z

ZnS-coated CdSe QDs 211, 214