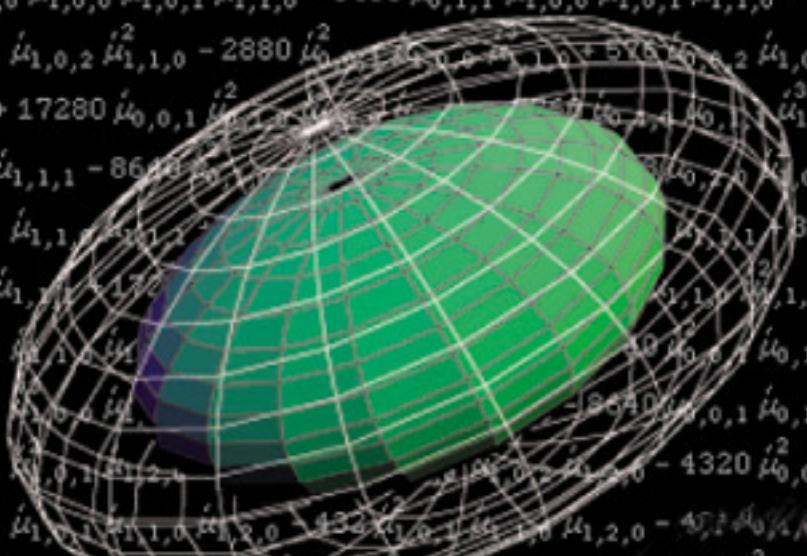


~~10320 $\mu_{0,0,1}^2 \mu_{0,1,0}^3 \mu_{1,0,0}^4 - 5040 \mu_{0,0,2} \mu_{0,1,0}^3 \mu_{1,0,0}^4 - 30240 \mu_{0,0,1} \mu_{0,1,1}^2 \mu_{1,0,0}^4 + 4320 \mu_{0,1,0}^2 \mu_{0,1,2} \mu_{1,0,0}^4 - 15120 \mu_{0,0,1} \mu_{0,1,0} \mu_{0,2,0} \mu_{1,0,0}^4 + 2160 \mu_{0,0,2} \mu_{0,1,0} \mu_{0,2,0} \mu_{1,0,0}^4 + 360 \mu_{0,1,2} \mu_{0,2,0} \mu_{1,0,0}^4 + 1320 \mu_{0,0,1} \mu_{0,1,0} \mu_{0,2,1} \mu_{1,0,0}^4 - 720 \mu_{0,1,1} \mu_{0,2,1} \mu_{1,0,0}^4 - 360 \mu_{0,1,0}$~~
SPRINGER TEXTS IN STATISTICS

MATHEMATICAL STATISTICS

with **Mathematica**



COLIN ROSE

MURRAY D. SMITH

Index

A

abbreviations 25
absolute values 41, 59, 284, 422
accuracy
 numerical 116, 230–231, 423–425
 symbolic 421–422
admissible estimator 302
Ali–Mikhail–Haq 212, 249
ancillary statistic 337
animations
 approximation error 286
 bivariate Exponential pdf (Gumbel Model II)
 11
 bivariate Gamma pdf (McKay) 248
 bivariate Normal pdf 217
 bivariate Normal quantiles 219
 bivariate Normal–Uniform pdf 214
 bivariate Uniform pdf 213
 conditional mean and variance 215
 contours of bivariate Normal component-mix
 249
 contours of the trivariate Normal pdf 227
 limit distribution of Binomial is Poisson 281
 Lorenz curve for a Pareto distribution 44
 non-parametric kernel density estimate 183
 Pearson system 150
 pmf of sum of two dice (fair vs shaved) 87
 Robin Hood 223
arbitrary-precision numbers 423–424
Arc–Sine distribution 6
ARCH model 384–392
assumptions technology 8–9
asymptotic distribution 282–286
 definition 282
 of MLE (invariance property) 369–371
 of MLE (maximum likelihood estimator) 367
 of MLE (multiple parameters) 371–374
 of MLE (with hypothesis testing) 393–394
 of sample mean 287
 of sample sum 287
asymptotic Fisher Information 375, 376
asymptotic theory 277–300
asymptotic unbiased estimator 366
asymptotic variance-covariance matrix 395–399,
 404, 407, 410, 415, 418–419
augmented symmetric function 272–276
Azzalini’s skew-Normal distribution 80, 225

B

bandwidth 181
Bates’s distribution 139, 289–290
Bernoulli distribution 89–91
 cumulant generating function 271
 distribution of sample sum 141
 likelihood 352
 Logit model 90–91
 method of moments estimator 184
 pmf 89
 sample mean vs sample median 309–310
 sufficiency in Bernoulli trials 337
Berry–Esseen Theorem 453
best unbiased estimator (**BUE**) 325, 335–336,
 362, 364
Beta distribution
 as defining Pearson *Type I(J)* 185
 as member of Pearson family 158
 cumulants 64
 fitted to censored marks 353–354
 MLE 363
 pdf 64
Beta–Binomial distribution 106
bias 306
Binomial distribution 91–95
 as limiting distribution of Ehrenfest urn 95
 as sum of n Bernoulli rv’s 91, 141
 cdf 92
 kurtosis 93
 limit distribution 280, 281
 mgf 141, 281
 Normal approximation 93, 281, 299
 pmf 91
 Poisson approximation 95, 280, 300
 product cumulant 270
biology 107, 380
Birnbaum–Saunders distribution
 cdf, pdf, quantiles 38–39
 pseudo-random number generation 78
bivariate Cauchy distribution 237
bivariate Exponential distribution
 Gumbel Model I, 204
 Gumbel Model II, 11–13
bivariate Gamma (McKay) 248
bivariate Logistic distribution (Gumbel) 248, 249
bivariate Normal distribution 216–226
 cdf 216, 217, 229–231

- bivariate Normal distribution (*cont.*)
 characteristic function 221
 component-mixture 249
 conditional distribution 220
 contour plot 218
 marginal distributions 220
 mgf 220
 orthant probability 231
 pdf 216, 217
 pseudo-random number generation 232–234
 quantiles 218–219
 truncated bivariate Normal 224–226
 variance-covariance matrix 220
 visualising random data 234
- bivariate Normal–Uniform distribution 213–215
- bivariate Poisson 243–248
 mgf 246
 moments 246–248
 pgf 244
 pmf 244–245
- bivariate Student's t 237–238
- bivariate Uniform (à la Morgenstern) 212–213
- Black–Scholes option pricing 70–71, 447
- Brownian motion 70
- C**
- Cauchy distribution
 as a stable distribution 58
 as ratio of two Normals 134
 as transformation of Uniform 119
 characteristic function 143
 compared to Sinc² pdf 35–36
 distribution of sample mean 143
 mean 36
 pdf 35, 143
 product of two Cauchy rv's 148
- cdf** (cumulative distribution function)
 definitions
 - continuous multivariate 191
 - continuous univariate 31
 - discrete multivariate 194
 - discrete univariate 81
- limit distribution 279
- numerical cdf 39
- of Arc–Sine 7
- of Binomial 92
- of Birnbaum–Saunders 39
- of bivariate Exponential
 - Gumbel Model I, 204
 - Gumbel Model II, 12
- of bivariate Normal 216, 217, 229–231
- of bivariate Normal–Uniform 214
- of bivariate Uniform 213
- of half-Halo 75
- of Inverse Triangular 13
- of Levy 74
- of Maxwell–Boltzmann 32
- of Pareto distribution 38
- of Pascal 10
- of Reflected Gamma 33
- of stable distribution 59
- of trivariate Normal 229–231
- see also* inverse cdf
- censored data 354
- censored distribution 68–69
 and option pricing 70–71
 and pseudo-random number generation 114
 censored Lognormal 71
 censored Normal 69
 censored Poisson 327
- Central Limit Theorem 286–292, 365
 Generalised Central Limit Theorem 56
 Lindeberg–Feller 453
 Lindeberg–Lévy 287, 366, 368, 373
- central moment 45, 200
- characteristic function** 50–60
 definition
 - multivariate 203
 - univariate 50
 inversion of cf
 - numerical 53, 55, 60
 - symbolic 53–60
 Inversion Theorem 53
 of bivariate Normal 221
 of Cauchy 58, 143
 of Levy 58
 of Lindley 51
 of Linnik 54
 of Normal 50, 57
 of Pareto 51
 of stable distribution 56–57
 relation to pgf 84
 transformations 131
 Uniqueness Theorem 52
- Chebyshev's Inequality 295–296
- Chi-squared distribution
 as square of a Normal rv 129, 131, 299
 asymptotic distribution of sample mean 283
 distribution of sample sum 142
 mean deviation 41, 421–422
 method of moments estimator 283
 mgf 131
 mode 36
 pdf 36, 41
 ratio of two Chi-squared rv's 135
 relation to Fisher F 135
 van Beek's bound 284–285
 see also noncentral Chi-squared
- coefficient of variation 40
- complete sufficient statistic 343, 346
- component-mix distribution 102–104
 bivariate Normal component-mixture 249
 estimating a Poisson two-component-mix 405–411

- conditional expectation $E[X | a < X \leq b]$ 66–67
 odd-valued Poisson rv 97–98
 truncated Normal 67
- conditional expectation $E[X | Y=y]$ 197–199
 definitions: continuous 197, discrete 199
 deriving conditional mean and variance
 - continuous 198, 215
 - discrete 199
 Normal Linear Regression model 221–222
 Rao–Blackwell Theorem 342
 regression function 197, 221–222
- conditional pdf $f(X | a < X \leq b)$ 65–67
- conditional pdf $f(X | Y=y)$ 197
 of bivariate Exponential (Gumbel Model II)
 12
 of bivariate Normal 220
 of bivariate Normal–Uniform 215
 Normal Linear Regression model 221–222
- conditional pmf $f(X | Y=y)$ 199
- conditional probability 65, 97
- confidence interval 394–395
- consistency 292–294, 367, 457
- consistent estimator 294, 297
- Continuous Mapping Theorem 366, 456
- contour plot 188, 218, 227
- convergence
 in distribution 278–282, 293
 in probability 292–298
 to a constant 294
- copulae 211–215
- correlation 201
 and independence 125, 211
 and positive definite matrix 228
 between k-statistics 268
 between order statistics 314
 definition 201
 trivariate example 202
 visualising correlation 212–213
 see also covariance
- covariance 201
 between sample moments 266
 definition 201
 derived from central mgf 205
 in terms of raw moments 206
 of bivariate Exponential (Gumbel Model II)
 12
 trivariate example 202
 see also correlation
- Cramér–Rao lower bound 333–335
 for Extreme Value 336
 for Inverse Gaussian 334–335
 for Poisson 334
- cumulant generating function
 definition 60, 203
 of Bernoulli 271
 of Beta 64
 of Poisson 96
- cumulants 60
 in terms of moments 62, 206–207
- of Bernoulli 271
 of Beta 64
 of k-statistics 267–271
 of Poisson 96
 product cumulant 209–210, 269
 unbiased estimator of cumulants 256–260
- cumulative distribution function (*see* cdf)
- D**
- data**
 censored 354
 population vs sample 151
 raw vs grouped 151
 —
 American NFL matches 260
 Australian age profile 239
 Bank of Melbourne share price 384
 censored student marks 354
 death notices 405
 grain 153
 income and education 396
 medical patients and dosage 90
 NB1, NB2 418
 nerve (biometric) 380, 418
 psychiatric (suicide) 412
 sickness 155
 snowfall 181
 student marks 151, 162, 170, 177, 354
 Swiss bank notes 19, 185
 US stock market returns 185
 word count 418
- degenerate distribution 103, 238, 280
- delta method 456
- density estimation
 Gram–Charlier 175–180
 Johnson 164–174
 non-parametric kernel density 181–183
 Pearson 149–163
- dice 84–87
- differentiation with respect to powers 326
- Discrete Uniform distribution 115
- distributions**
 asymptotic
 censored
 component-mix
 degenerate
 elliptical
 empirical
 limit distribution
 mixing
 parameter-mix
 piecewise
 spherical
 stable family
 stopped-sum
 truncated
 zero-inflated

- distributions – Continuous**
- α -Laplace (*see* Linnik)
 - Arc–Sine
 - Azzalini's skew-Normal
 - Bates
 - Beta
 - Birnbaum–Saunders
 - Cauchy
 - Chi-squared
 - Double Exponential (*see* Laplace)
 - Exponential
 - Extreme Value
 - Fisher F
 - Gamma
 - Gaussian (*see* Normal)
 - half-Halo
 - half-Normal
 - Hyperbolic Secant
 - Inverse Gamma
 - Inverse Gaussian
 - Inverse Triangular
 - Irwin–Hall
 - Johnson family
 - Laplace
 - Levy
 - Lindley
 - Linnik
 - Logistic
 - Lognormal
 - Maxwell–Boltzmann
 - noncentral Chi-squared
 - noncentral F
 - Normal
 - Pareto
 - Pearson family
 - Power Function
 - Random Walk
 - Rayleigh
 - Rectangular (*see* Uniform)
 - Reflected Gamma
 - semi-Circular (*see* half-Halo)
 - Sinc²
 - stable
 - Student's *t*
 - Triangular
 - Uniform
 - Weibull
- distributions – Discrete**
- Bernoulli
 - Beta–Binomial
 - Binomial
 - Discrete Uniform
 - Geometric
 - Holla
 - Hypergeometric
 - Logarithmic
 - Negative Binomial
 - Pascal
 - Poisson
- Pólya–Aeppli
- Riemann Zeta
- Waiting-time Negative Binomial
- Waring
- Yule
- Zero-Inflated Poisson
- Zipf (*see* Riemann Zeta)
- distributions – Multivariate**
- bivariate Cauchy
 - bivariate Exponential (Gumbel Model I and II)
 - bivariate Gamma (McKay)
 - bivariate Logistic (Gumbel)
 - bivariate Normal
 - bivariate Normal–Uniform (à la Morgenstern)
 - bivariate Poisson
 - bivariate Student's *t*
 - bivariate Uniform (à la Morgenstern)
 - Multinomial
 - multivariate Cauchy
 - multivariate Gamma (Cherian and Ramabhadran)
 - multivariate Normal
 - multivariate Student's *t*
 - Trinomial
 - trivariate Normal
 - truncated bivariate Normal
- domain of support 31, 81–85
- circular 191
 - non-rectangular 124, 125, 190–191, 314
 - rectangular 124, 190
 - triangular 191, 314, 317
- dominant estimator 302
- Dr Faustus 421
- E**
- economics and finance 43–45, 56, 70–72, 108–109, 117, 121, 384
- Ehrenfest urn 94–95
- ellipse 218, 236
- ellipsoid 227
- elliptical distributions 234
- empirical pdf 73, 77, 154, 381, 383
- empirical pmf 16, 110, 111, 112
- engineering 122
- entropy 15
- Epanechnikov kernel 182
- estimator**
- admissible 302
 - asymptotic unbiased 366
 - BUE (best unbiased) 325, 335–336, 362, 364
 - consistent 294, 297
 - density (*see* density estimation)
 - dominant 302
 - estimator vs estimate 357
 - Fisher estimator 395–396, 397, 404

- h-statistic 253–256
 Hessian estimator 395–396, 398, 404
 inadmissible 302, 321–322
 k-statistic 256–261
 maximum likelihood estimator (*see* MLE)
 method of moments 183–184, 283
 minimax 305
 minimum variance unbiased 341–346, 364
 non-parametric kernel density 181–183
 ordinary least squares 385
 Outer-product 395–396, 398
 sample central moment 360
 sample maximum 320–321
 sample mean (*see* sample mean)
 sample median 309–310, 318–320
 sample range 320–321
 sample sum 277, 287
 unbiased estimator of parameters 325–347
 unbiased estimator of population moments
 251–261
 expectation operator
 basic properties 32
 definitions
 - continuous 32
 - discrete 83
 - multivariate 200
 when applied to sample moments 263
- Exponential distribution
 bivariate 11–13, 204
 difference of two Exponentials 139–140
 distribution of sample sum 141–142
 likelihood 351
 MLE (numerical) 381
 MLE (symbolic) 358
 order statistics 313–314
 pdf 141, 313, 344, 358
 relation to Extreme Value 121
 relation to Pareto 121
 relation to Rayleigh 122
 relation to Uniform 121
 sufficient statistic 344
 sum of two Exponentials 136
 Exponential regression 375–376, 396
 Extreme Value distribution
 Cramér–Rao lower bound 336
 pdf 336, 377
 relation to Exponential 121
- F**
- factorial moment 60, 206–207, 247
 factorial moment generating function 60, 203,
 247
 factorisation criterion 339–341
 families of distributions
 Gram–Charlier 175–180
 Johnson 164–174
 Pearson 149–163
- stable family 56–61
 fat tails 56, 108–109
 see also kurtosis
 first-order condition 21, 36, 357–361, 363
 Fisher estimator 395–396, 397, 404
 Fisher F distribution 135
 Fisher Information 326–332
 and MLE (regularity conditions) 367–368,
 372–373
 asymptotic Fisher Information 375, 376
 first derivative form vs second derivative 329
 for censored Poisson 327–328
 for Gamma 331–332
 for Inverse Gaussian 18
 for Lindley 326
 for Normal 330–331
 for Riemann Zeta 329
 for Uniform 330
 Frank 212
 frequency polygon 73, 77, 151, 154, 380
 see also plotting techniques
 Function Form 82
 functions of random variables 117–148
 fundamental expectation result 274
- G**
- games
 archery (Robin Hood) 222–224
 cards, poker 101
 craps 87–89, 115
 dice (fair and unfair) 84–87
- Gamma distribution
 as member of Pearson family 157, 185
 as sum of n Exponential rv's 141–142
 bivariate Gamma (McKay) 248
 Fisher Information 331–332
 hypothesis testing 392–394
 method of moments estimator 184
 mgf 142, 456
 MLE (numerical) 382–383
 multivariate (Cherian & Ramabhadran) 208
 pdf 73, 142
 pseudo-random number generation 73
 relation to Inverse Gamma 147
- Gamma regression model 419
 gas molecules 32
 Gaussian kernel 19, 182
 generating functions 46–56, 203–205
 Geometric distribution
 definition 98
 distribution of difference of two rv's 148
 pmf 98
 Gini coefficient 40, 43–45
 gradient 357–361
 Gram–Charlier expansions 175–180
 graphical techniques (*see* plotting techniques)
 Greek alphabet 28

H

h-statistic 253–256
 half-Halo distribution 75, 80
 half-Normal distribution 225
 Helmert transformation 145
 HELP 5
 Hermite polynomial 175, 179, 449
 Hessian estimator 395–396, 398, 404
 Hessian matrix 358, 360
 histogram 18, 155 (*see also* plotting techniques)
 Holla’s distribution 105, 112
 Hyperbolic Secant distribution 80
 Hypergeometric distribution 100–101

I

inadmissible estimator 302, 321–322
 income distribution 43–44, 121
 independence
 correlation and dependence 125, 211
 mutually stochastically independent 210
 independent product space 124, 190
 Invariance Property 360, 369–371, 401, 410, 417
 inverse cdf
 numerical inversion 38–39, 75–77, 109
 symbolic inversion 37–38, 74–75
 of Birnbaum–Saunders 38–39
 of half-Halo 75
 of Levy 74
 of Pareto 38, 43
 Inverse Gamma distribution
 as member of Pearson family 185
 pdf 365
 relation to Gamma 147, 365
 relation to Levy 58
 Inverse Gaussian distribution
 Cramér–Rao lower bound 334–335
 Fisher Information 18
 pdf 18, 334
 relation to Random Walk distribution 147
 Inverse Triangular distribution 13–14
 Inversion Theorem 53
 Irwin–Hall distribution 55, 139
 isobaric 272

J

Jacobian of the transformation 118, 123, 130, 223
 Johnson family 164–174
 as transformation of a Logistic rv 185
 as transformation of a Normal rv 164
 Types and chart 164
 - S_r (Lognormal) 165–167
 - S_U (Unbounded) 168–172
 - S_B (Bounded) 173–174

K

k-statistic 20, 256–261
 kernel density (*see* non-parametric kernel density)
 Khinchine’s Theorem 298
 Khinchine’s Weak Law of Large Numbers 278, 296–298, 366
 Kronecker product 437
 kurtosis
 building your own function 446
 definition 40–41
 of Binomial 93
 of Poisson 446
 of Weibull 42
 Pearson family 149–150

L

Laplace distribution
 as Linnik 54
 as Reflected Gamma 33
 order statistics of 23, 315–317
 relation to Exponential 139–140
 latent variable 353, 412
 Lehmann–Scheffé Theorem 346
 Levy distribution
 as a stable distribution 58
 as an Inverse Gamma 58
 cdf, pdf, pseudo-random number 74
 likelihood
 function 21, 350–357
 observed 22, 351–357
 see also log-likelihood
 limit distribution
 definition 279
 of Binomial 280, 281
 of sample mean (Normal) 279
 limits in *Mathematica* 278
 Lindley distribution
 characteristic function 51
 Fisher Information 326–327
 pdf 51, 327
 linear regression function 221
 linex (linear-exponential) loss 322
 linguistics 107
 Linnik distribution 54
 List Form 82, 111
 log-likelihood
 concentrated 361, 382–383, 418
 function 21, 357–376, 381
 observed log-likelihood
 - ARCH model (stock prices) 387
 - Exponential model (nerve data) 381
 - Exponential regression (income) 396
 - Gamma model (nerve data) 382–383
 - Logit model (dosage data) 90
 - Ordered Probit model (psychiatric data) 414–415

- Poisson two-component-mix model 405–406
- see also* likelihood
- Logarithmic distribution 115
- Logistic distribution
 - as base for a Johnson-style family 185
 - bivariate 248, 249
 - pdf 23, 318
 - order statistics of 23
 - relation to Uniform 147
 - sample mean vs sample median 318–320
- Logit model 90–91
- Lognormal distribution
 - and stock prices 71
 - as member of Johnson family 165–167
 - as transformation of Normal 120, 165
 - censored below 71
 - moments of sample sum 276
 - pdf 71, 120
- Lorenz curve 43–44
- loss function 301–305
 - asymmetric 303–304
 - asymmetric quadratic 322, 323
 - linex (linear-exponential) 322
 - quadratic 306

M

- machine-precision numbers 423–425
- marginal distribution 195–196
 - and copulae 211
 - joint pdf as product of marginals 210, 211, 351, 355
 - more examples 12, 126, 133–137, 146, 204, 214, 220, 224–225, 237–238, 244
- Markov chain 94, 447–448
- Markov's inequality 295–296
- Mathematica*
 - assumptions technology 8–9
 - bracket types 27
 - changes to default behaviour 443–445
 - differentiation with respect to powers 326
 - Greek alphabet 28
 - how to enter μ_r 30
 - kernel (fresh and crispy) 5, 425
 - limits 278
 - lists 428–429
 - matrices 433–437, 445
 - notation (common) 27
 - notation entry 28–30
 - packages 425
 - replacements 27
 - subscripts 429–432
 - timings 30
 - upper and lower case conventions 24
 - using Γ in Input cells 443
 - vectors 438–443
 - see also* plotting techniques

mathStatica

- Basic vs Gold version 4
- Continuous* distribution palette 5
- Discrete* distribution palette 5
- HELP 5
- installation 3
- loading 5
- registration 3
- working with parameters 8
- maximum likelihood estimation (*see* MLE)
- Maxwell–Boltzmann distribution 32
- mean 35–36, 45
 - see also* sample mean
- mean deviation 40, 41, 299, 421–422
- mean square error (*see* MSE)
- median 37
 - of Pareto distribution 37–38
 - see also* sample median
- medical 90–91, 155, 380, 405, 412
- method of moments estimator 183–184
 - for Bernoulli 184
 - for Chi-squared 283
 - for Gamma 184
- mgf** (moment generating function)
 - and cumulant generating function 60
 - and independence 210
 - central mgf 93, 203, 205, 247
 - definition 46, 203
 - Inversion Theorem 53
 - Uniqueness Theorem 52
 - of Binomial 93, 141, 281
 - of bivariate Exponential (Gumbel Model I) 204
 - of bivariate Exponential (Gumbel Model II) 12
 - of bivariate Normal 220
 - of bivariate Poisson 246
 - of Chi-squared 131
 - of Gamma 142, 456
 - of Multinomial 239, 241–242, 242–243
 - of multivariate Gamma 208
 - of multivariate Normal 249
 - of noncentral Chi-squared 144
 - of Normal 47
 - of Pareto 49
 - of sample mean 141
 - of sample sum 141
 - of sample sum of squares 141
 - of Uniform 48
- MGF Method 52–56, 130–132, 141–147
- MGF Theorem 52, 141
 - more examples 281, 364–365
- minimax estimator 305
- minimum variance unbiased estimation (*see* MVUE)
- mixing distributions 102–109
 - component-mix 102–104, 249, 405–411
 - parameter-mix 105–109

- MLE** (maximum likelihood estimation) 357–376
 asymptotic properties 365–366, 371–376
 general properties 362
 invariance property 369–371
 more than one parameter 371–374
 non-iid samples 374–376
 numerical MLE (*see Chapter 12*)
 - ARCH model (stock prices) 387
 - Exponential model (nerve data) 381
 - Exponential regression model (income) 396
 - Gamma model (nerve data) 382–383
 - Logit model (dosage data) 90
 - Normal model (random data) 418
 - Ordered Probit model (psychiatric data) 414–415
 - Poisson two-component-mix model 405–406
 regularity conditions
 - basic 367–369
 - more than one parameter 371–372
 - non-iid samples 374–375
 small sample properties 363–365
 symbolic MLE (*see Chapter 11*)
 - for Exponential 358
 - for Normal 359–360, 418
 - for Pareto 360–361
 - for Power Function 362–363
 - for Rayleigh 21
 - for Uniform 377
 mode 36
 moment conversion functions
 univariate 62–64
 multivariate 206–210
 moment generating function (*see mgf*)
 moments
 central moment 45, 200
 factorial moment 60, 206–207
 fitting moments (*see Pearson, Johnson, method of moments*)
 negative moment 80
 population moments vs sample moments 251
 product moment 200, 266
 raw moment 45, 200
 moments of moments 261–271
 introduction 20
 moments of sampling distributions 251–276
 monomial symmetric function 273
 Monte Carlo 290
 see also pseudo-random number generation
 see also simulation
 Morgenstern 212
MSE (mean square error)
 as risk 306–311
 comparing h-statistics with polyachies 264–266
 of sample median and sample mean (Logistic) 318–320
 of sample range and sample maximum (Uniform) 320–321
 weak law of large numbers 296–297
 multinomial coefficient 451
 Multinomial distribution 238–243
 multiple local optima 400
 multivariate Cauchy distribution 236
 multivariate Gamma distribution (Cherian and Ramabhadran) 208
 multivariate Normal distribution 216–235
 multivariate Student's *t* 236
 mutually stochastically independent 210
MVUE (minimum variance unbiased estimation) 341–346, 364
- N**
- Negative Binomial distribution 99, 105, 418
 noncentral Chi-squared distribution
 as Chi-squared–Poisson mixture 105
 derivation 144
 exercises 299
 noncentral F distribution 135
 non-parametric kernel density 181–183
 with bi-weight, tri-weight kernel 182
 with Epanechnikov kernel 182
 with Gaussian kernel 19, 182
 non-rectangular domain 124, 125, 190–191, 320–321
Normal distribution
 and Gram–Charlier expansions 175
 as a stable distribution 57
 as limit distribution of a Binomial 93, 281, 299
 as member of Johnson family 164–165, 167
 as member of Pearson family 150, 158
 asymptotic distribution of MLE of (μ, σ^2) 372–374
 basics 8
 bivariate Normal 216–226
 censored below 69
 central moments 265
 characteristic function 50, 57
 characteristic function of $X_1 X_2$ 132
 conditional expectation of sample median, given sample mean 342–343
 distribution:
 - of product of two Normals 132, 133
 - of ratio of two Normals 134
 - of X^2 129, 131
 - of sample mean 143, 294–295
 - of sample sum of squares 144
 - of sample sum of squares about the mean 145
 estimators for the Normal variance 307–308
 finance 56, 108–109
 Fisher Information 330–331
 limit distribution of sample mean 279

- limit Normal distribution 362, 367
 - examples 369, 392–395
- mgf 47
- mgf of X^2 131
- MLE of (μ, σ^2) 359–360, 418
- MVUE of (μ, σ^2) 346
- Normal approximation to Binomial 93, 281, 299
- pseudo-random number generation
 - approximate 291–292
 - exact 72–73, 418
- QQ plot 291
- raw moments 46
- relation to Cauchy 134
- relation to Chi-squared 129, 131
- relation to Lognormal 120
- risk of a Normally distributed estimator 303–304
- sample mean as consistent estimator of population mean 294–295
- standardising a Normal rv 120
- sufficient statistics for (μ, σ^2) 340–341
- trivariate Normal 226–228
- truncated above 65–66, 67
- working with σ vs σ^2 326, 377, 455
see also Invariance Property
- Normal linear regression model 221–222, 385, 457
- notation**
- Mathematica* notation
 - bracket types 27
 - Greek alphabet 28
 - how to enter μ_r 30
 - notation (common) 27
 - notation entry 28–30
 - replacements 27
 - subscripts 429–432
 - upper and lower case conventions 24
 - using Γ in Input cells 443
 - statistics notation
 - abbreviations 25
 - sets and operators 25
 - statistics notation 26
 - upper and lower case conventions 24
- O**
- one-to-one transformation 118
- optimisation
- differentiation with respect to powers 326
 - first-order condition 21, 36, 357–361, 363
 - gradient 357–361
 - Hessian matrix 358, 360
 - multiple local optima 400
 - score 357–361
 - second-order condition 22, 36–37, 357–360
 - unconstrained vs constrained numerical optimisation 369, 379, 388–389, 401, 414
- optimisation algorithms 399–405
- Armijo 408
 - BFGS (Broyden–Fletcher–Goldfarb–Shanno) 399–400, 403, 405–411, 459
 - DFP (Davidon–Fletcher–Powell) 403
 - direct search 400
 - genetic 400
 - Golden Search 401
 - Goldstein 408
 - gradient method 400, 401–405
 - line search 401
 - Method → Newton 390–391, 397, 403, 415, 459
 - Method → QuasiNewton 403, 406–407, 419, 459
 - NR (Newton Raphson) 390–391, 397, 399–400, 403, 412–417, 458–459
 - numerical convergence 404–405
 - Score 403–404
 - simulated annealing 400
 - taboo search 400
- option pricing 70–72
- order statistics 311–322
- distribution of:
 - sample maximum 312, 321
 - sample minimum 312
 - sample median 318–320
 - sample range 320–321
 - for Exponential 313–314
 - for Laplace 23, 315–317
 - for Logistic 23
 - for Uniform 312
 - joint order statistics 23, 314, 316, 320
- Ordered Probit model 412–417
- ordinary least squares 385
- orthant probability 231
- Outer-product estimator 395–396, 398
- P**
- p*-value 393–394
- parameter identification problem 414
- parameter-mix distribution 105–109
- Pareto distribution
- characteristic function 51
 - median 37–38
 - mgf 49
 - MLE 360–361
 - pdf 37, 49, 51, 360
 - quantiles 38
 - relation to Exponential 121
 - relation to Power Function 147
 - relation to Riemann Zeta 107
- Pascal distribution 10, 99
- pdf** (probability density function)
- definition 31, 187
 - see also* Distributions
 - see also* pmf (for discrete rv's)

- peakedness 40–41, 108–109
 Pearson family 149–163
 animated tour 150
 Pearson coefficients in terms of moments 159–160
 Types and chart 150
 - *Type I*, 17, 156, 158, 185
 - *Type II*, 158
 - *Type III*, 154, 157, 185
 - *Type IV*, 151–153, 157
 - *Type V*, 158, 185
 - *Type VI*, 158
 - *Type VII*, 157
 unimodal 179
 using a cubic polynomial 161–163
 penalty function 400, 407, 415
pgf (probability generating function)
 definitions 60, 84, 203
 deriving probabilities from pgf 85, 85–86, 86, 104, 245
 of bivariate Poisson 244–245
 of Hypergeometric 100
 of Negative Binomial 99
 of Pascal 11
 of Zero-Inflated Poisson 104
 physics 32, 94–95
 piecewise distributions
 Bates's distribution 289–290
 Inverse Triangular 13
 Laplace 23, 315–317
 order statistics of 23
 Reflected Gamma 33
plotting techniques (some examples)
 arrows 37, 81, 280
 contour plots 188, 218, 227
 data
 - bivariate/trivariate 233–235
 - grouped data 18, 155
 - raw 151
 see also frequency polygon
 - scatter plot 397
 - time-series 384
 see also empirical pdf/pmf
 domain of support (bivariate) 125, 138, 140
 empirical pdf 73, 77, 154, 381, 383
 empirical pmf 16, 110, 111, 112
 filled plot 44, 68
 frequency polygon 73, 77, 151, 154, 380
 graphics array 32, 38, 68, 109, 118, 124, 168, 174, 218
 histogram 18, 155
 Johnson system 170
 non-parametric kernel density 19, 182–183
 parametric plot 167
 pdf plots 6, 139, *etc.*
 - as parameters change 8, 14, 32, 145, 165, 225, 313, 315
 - 3D 11, 188, 198, 213, 214, 217, 316
 Pearson system 17, 152
 pmf plots 10, 83, 98, 101, 103
 - as parameters change 87, 92, 96
 - 3D 190
 QQ plots 291
 scatter plot 397
 superimposing plots 34, 35, 37, 42, 54, 55, 69, 91, 133, 219, 302, 306
 text labels 32, 37, 54, 145, 302, 306, 313
 wireframe 228
 see also animations
pmf (probability mass function)
 definitions 82, 189
 see also Distributions – Discrete
 see also pdf (for continuous rv's)
 Poisson distribution 95–98
 as limit distribution of Binomial 95, 280, 300
 bivariate Poisson 243–248
 censoring 327–328
 Cramér–Rao lower bound 334
 cumulant generating function 96
 distribution of sample sum 137
 kurtosis 446
 odd-valued Poisson 97–98
 pmf 16, 95, 110, 334
 Poisson two-component-mix 102–103, 406
 pseudo-random number generation 16, 110
 sufficient statistic for λ 340
 zero-inflated Poisson 104
 poker 101
 Pólya–Aeppli distribution 105
 polyache 255–256
 polykay 257–259
Power Function distribution
 as a Beta rv 185, 363
 as defining Pearson *Type I(J)* 185
 MLE 362–363
 relation to Pareto 147
 sufficient statistic 363–364
 power sum 252, 272–276
 probability
 conditional 65, 97
 multivariate 191–194
 orthant probability 231
 probability content of a region 192–193, 230–231
 throwing a die 84–87
 see also cdf
 probability density function (*see* pdf)
 probability generating function (*see* pgf)
 probability mass function (*see* pmf)
 probit model 412–413
 product moment 200, 266
 products/ratios of random variables 133–136
 see also:
 - deriving the pdf of the bivariate t 237–238
 - product of two Uniforms 126–127
 Proportional-hazards model 412
 Proportional-odds model 412

pseudo-random number generation
 methods
 - inverse method (numerical) 75–77,
 109–115
 - inverse method (symbolic) 74–75
 - *Mathematica's Statistics package* 72–73
 - rejection method 77–79
 and censoring 114
 computational efficiency 113, 115
 List Form 111
 of Birnbaum–Saunders 78
 of Gamma 73
 of half-Halo 75–77
 of Holla 112
 of Levy 74
 of multivariate Normal 232–234
 of Normal 291–292, 418
 of Poisson 16, 110
 of Riemann Zeta 113
 visualising random data in 2D, 3D 233–235

Q

QQ plot 291
 quantiles 37
 of Birnbaum–Saunders 38–39
 of bivariate Normal 218–219
 of bivariate Student's t 237
 of Pareto 38
 of trivariate Normal 227–228

R

random number (*see* pseudo-random number)
 random variable
 continuous 31, 81, 187
 discrete 81–82, 189
 see also Distributions
 Random Walk distribution 147
 random walk with drift 355, 384–386
 Rao–Blackwell Theorem 342
 raw moment 45, 200
 Rayleigh distribution
 MLE 21
 relation to Exponential 122
 rectangular domain 124, 190
 reference computer 30
 Reflected Gamma distribution 33–34
 registration 3
 regression 384–392
 regression function 197, 221–222
 regularity conditions
 for Fisher Information 329–330
 for MLE
 - basic 367–369
 - more than one parameter 371–372
 - non-iid samples 374–375

relative mean deviation 299
 re-parameterisation 369, 388–389, 401, 406, 410, 414
 Riemann Zeta distribution
 area of application 107
 Fisher Information 329
 pmf 113, 329
 pseudo-random number generation 113
 risk 301–305
 Robin Hood 222–224

S

sample information 332, 338, 376
 sample maximum 311, 312, 320–321, 377
sample mean
 as consistent estimator (Khinchine) 298
 as consistent estimator (Normal) 294–295
 as MLE (for Exponential parameter) 358
 as MLE (for Normal parameter) 359–360
 asymptotic distribution of sample mean 287
 definition 277
 distribution of sample mean
 - for Cauchy 143
 - for Normal 143
 - for Uniform 139, 288–292
 Khinchine's Theorem 298
 limit distribution of sample mean (Normal) 279
 mgf of 141
 variance of the sample mean 264
 vs sample median, for Bernoulli trials 309–310
 vs sample median, for Logistic trials 318–320
sample median
 conditional expectation of sample median,
 given sample mean 342–343
 vs sample mean, for Bernoulli trials 309–310
 vs sample mean, for Logistic trials 318–320
 sample minimum 311, 312
sample moment
 sample central moment 251, 360
 - covariance between sample central
 moments 266
 - in terms of power sums 252
 - variance of 264
 sample raw moment 251
 - as unbiased estimators of population raw
 moments 253
 - in terms of power sums 252
 sample range 320–321
sample sum
 asymptotic distribution of sample sum 287
 definition 277
 distribution of sample sum
 - for Bernoulli 141
 - for Chi-squared 142

sample sum (*cont.*)
 distribution of sample sum (*cont.*)
 - for Exponential 141–142
 - for Poisson 137
 - for Uniform 55, 139
 mgf of sample sum 141
 moments of sample sum 261–271, 276
 sample sum of squares
 distribution of (Normal) 144
 mgf of 141
 sampling with or without replacement 100
 scedastic function 197
 score 357–361
 second-order condition 22, 36–37, 357–360
 security (stock) price 70–72, 108–109, 384
 Sheather–Jones optimal bandwidth 19, 182
 signal-to-noise ratio 299
 Silverman optimal bandwidth 182
 simulation 87–89, 126–127, 298–299
 see also Monte Carlo
 see also pseudo-random number
 Sinc² distribution 35–36
 skewness
 definition 40
 of Weibull 42
 Pearson family 149–150
 Skorohod's Theorem 456
 small sample accuracy 289–292
 smoothing methods 181–183
 spherical distributions 234, 451
 stable distributions 56–61
 standard deviation 40, 45
 standard error 395, 399
 standardised random variable 40, 120, 281, 287
 statistic 251
 stopped-sum distribution 108
 Student's *t* distribution
 as member of Pearson family 157
 as Normal–InverseGamma mixture 105
 bivariate Student's *t* 237–238
 derivation, pdf 134
 sufficient statistic 337–341, 344, 362, 363–364
 sums of random variables 136–147
 deriving pmf of bivariate Poisson 244–245
 sum of Bernoulli rv's 141
 sum of Chi-squared rv's 142
 sum of Exponentials 136, 141–142
 sum of Poisson rv's 137
 sum of Uniform rv's 54–55, 138–139
 see also sample sum
 Swiss bank notes 19, 185
 symmetric function 253, 272–276
 systems of distributions (*see families*) 149–180

T

t distribution (*see* Student's *t*)
t-statistic 395, 399

theorems
 Berry–Esseen 453
 Central Limit Theorem 286–292
 Continuous Mapping Theorem 366, 456
 Inversion Theorem 53
 Khinchine 298
 Lehmann–Scheffé 346
 Lindeberg–Feller 453
 Lindeberg–Lévy 287
 MGF Theorem 52, 141
 Rao–Blackwell Theorem 342
 Skorohod's Theorem 456
 transformation theorems
 - univariate 118
 - multivariate 123
 - not one-to-one 127
 Uniqueness Theorem 52
 timings 30
 transformations 117–148
 MGF Method 52–56, 130–132, 141–147
 transformation method 118–130
 - univariate 118
 - multivariate 123
 - manual 130
 - Jacobian 118, 123, 130, 223
 - one-to-one transformation 118
 - not one-to-one 127
 Helmert transformation 145
 non-rectangular domain 124, 125
 transformation to polar co-ordinates 222–223
 see also:
 - products/ratios of random variables
 - sums of random variables
 Triangular distribution
 as sum of two Uniform rv's 55, 138–139
 Trinomial distribution 239
 trivariate Normal 226–228
 cdf 229–231
 orthant probability 231
 pseudo-random number generation 232–234
 visualising random data 235
 truncated distribution 65–67
 truncated (above) standard Normal 65–66, 67
 truncated bivariate Normal 224–226

U

unbiased estimators of parameters 325–347
 asymptotic unbiasedness 366
 unbiased estimators of population moments
 251–261
 introduction 20
 multivariate 259–261
 of central moments 253–254, 259–261
 of cumulants 256–258, 260
 of Normal population variance 307–308
 of population variance 253, 254
 of raw moments 253

Uniform distribution
 bivariate Uniform (à la Morgenstern) 212–213
 Fisher Information 330
 mgf 48
 MLE 377
 order statistics 312
 other transformations of a Uniform rv 122
 pdf 48, 122, 312, 320, 330
 product of two Uniform rv's 126–127
 relation to Bates 139, 289–290
 relation to Cauchy 119
 relation to Exponential 121
 relation to Irwin–Hall 55, 139
 relation to Logistic 147
 sample mean and Central Limit Theorem 288–292
 sample range vs sample maximum 320–321
 sum of Uniform rv's 54–55, 138–139
 unimodal 36, 179, 182–183
 Uniqueness Theorem 52

V

van Beek bound 283–285, 453
 variance
 definition 40, 45
 of sample mean 264
 of 2nd sample central moment 264
 variance-covariance matrix
 asymptotic variance-covariance matrix 395–399, 404, 407, 410, 415, 418–419
 definition 201

variance-covariance matrix (*cont.*)
 of bivariate Exponential
 - Gumbel Model I, 205
 - Gumbel Model II, 12
 of bivariate Normal 220
 of bivariate Normal–Uniform 215
 of bivariate Uniform 213
 of trivariate models 202, 211
 of truncated bivariate Normal 226
 of unbiased estimators 333–335

W

Waiting-time Negative Binomial distribution 99
 Waring distribution 418
 weak law of large numbers 296–298
 Weibull distribution 42

X

xenium (*see* book cover)

Y

Yule distribution 107

Z

zero-inflated distributions 103–104
 Zipf distribution (*see* Riemann Zeta) 107