

# INDEX

## Symbols

+ (addition operator) methods, 231  
;, ;;, :::, etc. (array concatenation operators), 143  
#= (begin multiline comment), 59  
& (bitwise AND), 31  
# (comment line), 59  
~ (distribution assertion), 414  
÷ (division operator), 28  
;; (double semicolon), 191  
.. (ellipsis operator), 453  
=# (end multiline comment), 59  
± (error operator), 281  
: (expression quotation), 168  
== (generic equality operator), 31  
> (greater-than operator), 31  
>= (greater-than-or-equal-to operator), 31  
=== (identity operator), 31  
oo (infinity), 393  
⊆ (issubset operator), 136  
⊇ (issuperset operator), 136  
\ (left division operator), 398  
< (less-than operator), 31  
<= (less-than-or-equal-to operator), 31  
&& (logical AND), 31  
|| (logical OR), 31  
∈ (membership operator), 43  
% (modular arithmetic operator), 29  
∉ (not-a-member operator), 43  
π (pi, mathematical constant), 218–219, 245  
--> (plot recipe assignment), 256  
:= (plot recipe assignment), 256  
: (range operator), 35  
// (rational operator), 28  
; (semicolon), 29  
-p (startup flag), 480  
-t (startup flag), 469  
<: (subtype operator), 233–234  
:: (type assertion or declaration), 225–229

## A

abmplot() function, 374  
abmvideo() function, 375–376  
AbstractFloat type, 234  
abstract types, 223, 229  
  creating, 234  
Action() Javis function, 205  
act!() Javis function, 204  
Adams, Ansel, 83  
add\_edge!() Luxor function, 193, 196  
addition operator (+)  
  methods, 231  
adjacency matrix, 196  
adjoint() function, 145  
agent-based modeling, 362–379  
@agent macro, 364  
Agents package, 363  
  multiple agent types, 367  
  spaces, 363  
allagents() function, 368  
all() function, 166  
allowmissing() function, 331  
animation, 198–208  
  with Reel, 206  
anim\_rotate\_around()  
  Javis function, 204  
anim\_rotate() Javis function, 205  
ANSI color codes, 23  
any() function, 166  
Any type, 221–224  
APL, 10  
Aquinas, Thomas, 153  
arbitrary precision arithmetic,  
  216–218  
args property, 264  
arguments  
  keyword, 96–97  
  optional, 96–97  
Arizona, 430  
array comprehensions, 125–127  
array concatenation operators  
  (;;, :::, etc.), 143

- arrays, 33–35
  - adjoints and transposes, 144–146
  - concatenation, 142–143
    - using a newline, 142
    - using semicolons, 143
  - Hermitian adjoint, 145
  - indexing, 34
  - initialization, 139–142
  - logical indexing, 143–144
  - multidimensional, 36
  - mutability with `fill()` and `repeat()`, 140–141
  - planes, 143
  - reshaping, 141–142
  - sparse, 196
- artificial life, 380
- as import keyword, 65
- atomic variables, 472–474
- automatic differentiation, 406–413
- Avengers, The*, 189
- AxisArrays package, 452–454
- Axis() function, 453

## B

- Background() Javis function, 204
- baseball, 312
- Base module, 62, 232
- batch\_size keyword argument for `pmap()`, 485
- begin...end block, 30–31
- begin multiline comment (`#=`), 59
- @belapsed macro, 470, 474
- BenchmarkTools package, 470, 474
- Bessel function, 207, 384–388, 393–395
  - series representation, 384
  - symbolic derivatives, 386–388
- Bessel's equation, 393–395
- Between() function, 339
- BigFloat type, 217–218
- big() function, 217
- BigInt type, 217–218
- bimodal distribution, 320
- binary operators, 159
  - defining custom, 159–161
- @bind macro, 208–209
- binomial coefficient, 313, 317
- binomial() function, 313
- bioinformatics, 361

- BioJulia, 361
- biology, Julia ecosystem, 361
- BitArray type, 144
- bitwise AND (`&`), 31
- BLAS, 404, 468
- blood, counting cells, 442–449
- blue() function, 443
- Bool type, 31
- break keyword, 124–125
- broadcasting, 51
- BSD, 4, 5
- bugs, 357
- byte array literal, 130–131

## C

- C, xxi, 25
- C++, xxii, 20
- cactus ferruginous pygmy owl, 430
- CairoMakie package, 376
- California, 213
- call stack, 179–181
- canny() function, 447
- cartesian indices, 459–464
- cdf() function, 417
- central limit theorem, 417
- Chain package, 174–175
- characters, 44–46
- Chesapeake Bay, 193–195
- Chocolately, 9
- closure, 199–200
- coalesce() function, 330
- @code\_warntype macro, 243–245
- coding environments, 23
- coin, fairness, 413
- collect() function, 36, 128
- collection
  - defined, 123
  - flattening, 369
  - and loops, 123
    - as parametric type, 248
    - type of elements, 221
- cols() function, 340
- cols() function, 345
- combinations, 313
- combinatorics, 312
- combine() function, 346–347, 350
  - renamecols() function, 347
- comment line (`#`), 59
- comments, 59

- complex numbers, 27
  - plotting, 264
- composite types
  - creating, 234–236
  - immutable, 236
  - mutable, 236
  - properties of, 235
- comprehensions, array, 125–127
- computer algebra, 382–395
- computer languages, 26
- concatenation, 41–43
- concrete types, 222
- concurrency, 467–486
- conj() function, 146
- const keyword, 52
- constructors, 235
  - inner, 240
  - methods, 235–236
  - outer, 240
- continue statement, 125
- ContinuousAgent notation, 364
- contour plots, 110–112, 116
- converting units, 272–274
- cooperative multitasking, 477
- core, CPU, 468
- Core module, 62
- correlation, 357
  - and crime, 354, 357
  - Pearson, 354
- corrplot() plotting function, 357
- counting, 312
- COVID-19, 334
  - models, 359
- crime, 352–353
- cryptography, 307
- CSV files, 332
- CSV package, 332, 334
  - normalizenames() function, 334

**D**

- data
  - noisy, 421
  - out of core, 358
- dataframe, 333–337
  - Between() function, 339
  - columns
    - mutating, 341
    - references and copies, 341
    - display, 335
    - filtering, 337, 339
    - grouping, 349–350
    - indexing, 336–337
      - Cols() function, 340
      - using regular expressions, 340
    - missing values, 337
    - names function, 342
    - Not() function, 339
    - plotting, 338–339
    - show() function, 335
    - summary statistics, 348
    - transposing, 342–343
  - DataFrames package, 333–337
  - Dawkins, Richard, 361
  - DefaultSymbols submodule, 271
  - dependency hell, 11
  - describe() function, 348, 355
  - destructuring, 96, 157–159
    - struct keyword arguments, 158–159
  - determinant, 399
  - det() function, 399
  - @df macro, 335, 353
  - Dict() function, 134–135
  - dictionaries, 134–135
    - indexing, 134–135
  - diff() (SymPy differential operator), 394
  - DifferentialEquations package,
    - 294–303, 362, 408–413
    - combining with Measurements,
      - 302–303
    - controlling error, 301, 412
    - plotting solutions, 297–298
    - time-dependent parameters,
      - 299–301
  - differential equations with SymPy,
    - 393–395
  - Differential() function, 387
  - Dijkstra, Edsger, 213
  - dimensions, 270
  - directed graph, 193
  - disallowmissing() function, 331
  - @distributed macro, 484–485
  - Distributed package, 480
  - distribution, 321–322
    - bimodal, 320
    - empirical, 322
    - Gaussian, 324–326
    - normal, 324–326
    - theoretical, 322

- distribution assertion (~), 414
- Distributions package, 324–326
- DivideError, 179
- division, 27
- division operator ( $\div$ ), 28
- DNA, 361
- do blocks, 166–167
- docstrings, 67
- documentation
  - with docstrings, 67–68
  - and Markdown, 68–69
- doit() function, 393
- double semicolon (;), 191
- drugs, 362
- drum, modes of vibration, 206–207
- dsolve() SymPy function, 394
- DSP package, 435–437
- duration() function, 432

## E

- e* (Euler’s number), 219
- eccentricity in the Ptolemaic system, 201
- editors, 5, 14–15
- eigenvalues, 399
- eigenvectors, 399
- eigvals() function, 399–400
  - of symmetric matrix, 401
  - of triangular matrix, 402
- eigvecs() function, 399
- Einstein, Albert, 381
- Elixir, 169
- ellipsis operator (...), 453
- eltype() function, 221
- Emacs, 15
  - REPL interaction, 15
- end multiline comment (=), 59
- entropy sources, 307
- enumerate() function, 147–148
- epicycles, 201–205
- Eq() SymPy function, 394
- erf() (error function), 393
- error operator ( $\pm$ ), 281
- error propagation, 280–284
- errors, 178–186
  - combining with units, 283
- Euler’s number, 219
- @everywhere macro, 480
- evolution, simulated, 362–379

- EvolutionaryModelingTools package, 362
- exceptions, 178–186
  - types of, 178–179
- executive process, 480
- expand\_derivatives() function, 387
- expint() function, 264
- exponential integral, 264
- expression, 26
  - from string, 168
- expression objects, 168–170
  - interpolation of values, 169–170
- expression quotation (:), 168
- Expr type, 168
- :extra\_kwargs entry, 257

## F

- f0 numerical suffix, 281
- factorial, 216
- factorial() function, 217, 313
- factorization, matrix, 402–403
- factorize() function, 402–403
- factor trees, 197–198
- @fastmath performance macro, 176–177
- FedEx, 61
- fetch() function, 476
- fill() function, 139
- fillrange plotting attribute, 257
- filter() function, 163–164
- finally keyword, 186
- findFirst() function, 131–132
- findlast() function, 131–132
- findnext() function, 132
- fir() function, 435–437
- fish, 193
- flattening a collection, 369
- Float16 type, 215
- Float32 type, 215, 281
- Float64 type, 27, 214
- floatmax() function, 216
- floatmin() function, 216
- fluid dynamics, 284–294
- foldl() function, 164
- foldr() function, 164
- Folds package, 469–470
- football fields, 270
- force from potential energy, 408–413
- Fortran, xxi–xxii, 404, 454
- ForwardDiff package, 406–413
- Fourier transform, 433

Fox, Professor L., 395  
 framerate() function, 432  
 France, 350  
 FreeUnits Unitful type, 272  
 frequency analysis, 433–441  
 frequency filtering, 435–441  
 function, 48–51
 

- anonymous, 51
- composing, 50
- difference from macros, 172
- extending, 232
- higher-order, 161
- keyword arguments
  - concise syntax, 154
  - return value, 50

 functional languages, 229  
 fundraising, 269

**G**

gas, 306  
 Gaston plotting backend, 116, 278  
 Gaussian distribution, 109, 324–326, 392–393  
 generator expression, 127–128  
 generic equality operator (==), 31  
 gingerbread man, 95–96  
*Glaucidium brasilianum cactorum*, 430  
 GLMakie package, 376  
 global keyword, 226–227  
 global variables, 52  
 gnuplot, 116, 278  
 goats, 310  
 gradient, 406  
 graphplot() Luxor function, 195–198  
 GraphRecipes package, 193  
 graphs (node-edge diagrams), 192–199  
 Graphs package, 193–198
 

- layout methods
  - :buchheim, 198
  - :tree, 198
- layout quality, 195

 Gray() function, 443  
 greater-than operator (>), 31  
 greater-than-or-equal-to operator (>=), 31  
 Greek letters, 13  
 green() function, 443  
 grid() function, 118

GroupedDataFrame type, 349–350  
 GR plotting backend, 115, 277–278  
 gui() function, 86

## H

hardware requirements, 4  
 HDF5 plotting back end, 116  
 heatmaps, 110  
 Hermitian adjoint, 145  
 higher-order functions, 161  
 high-performance computing, 485–486  
 high school, bad memories, 197  
 histogram2d() function, 355  
 histograms, 322, 353
 

- bins, 323
- 2D, 355
- using :scatterhist, 325

 Hopper, Grace, 467  
 hough\_circle\_gradient() function, 446  
 Hough transform, 446–449  
 hyperthreading, 469  
 hypothesis testing, 358  
 HypothesisTests package, 358

## I

identity matrix, 399  
 identity operator (===), 31  
 IDEs, 20–22  
 idxs plotting keyword, 297  
 if blocks, 33  
 ImageBinarization package, 444  
 image blurring, 463  
 ImageFeatures package, 446–449  
 image processing, 442–464  
 image reduction, 463  
 Images package, 442–449
 

- RGB type, 442

 ImageView package, 442  
 import statement, 63–64  
 imshow() function, 442  
 @inbounds performance macro, 176  
 indexing of arrays, 34, 38–39
 

- with arrays, 39–41

 InexactError, 179  
 Inf type, 215  
 Inf16 type, 215  
 Inf64 type, 215

- infinity, 28, 215
- infinity (∞), 393
- infix operators, 159
  - defining custom, 159–161
- in membership operator, 43
- inner constructors, 240
- instability, 288
- installation, 3–5
  - on BSD, 6–7
  - on Docker, 9
  - on Linux, 6–7
  - on macOS, 7–8
  - on Windows, 8–9
- Int16 type, 226
- Int32 type, 27, 247
- Int64 type, 27, 215, 247
- Int128 type, 216
- Integral() SymPy function, 393
- InteractiveDynamics package, 373
- interprocess communication, 483
- Int type, 247
- inverse, matrix, 398
- inv() function, 398
- irrational numbers, 218–219
- Irrational type, 218–219, 233
- isa() function, 216
- isascii() function, 163
- ishermitian() function, 400
- issubset() function, 136
- issubset operator ( $\subseteq$ ), 136
- issuperset operator ( $\supseteq$ ), 136
- issymmetric() function, 400
- iterated map, 95–96

## J

- Java, 20
- JavaScript, 25, 211
- Javis package, 198–205
  - motions, 205
- Johns Hopkins, 334
- join() function, 58
  - optional delimiter, 132
- Julia, features of
  - big, 151
  - composability, 303, 383–385, 388
  - introduction, xxi
  - no classes, 241
  - not functional, 229

- not object oriented, 229
  - unusual, 213
- JuliaDB package, 358
- julia-emacs, 15
- julia-repl, 15
- Julia versions, 5
- julia-vim, 14–15
- Jupyter, 16, 17
  - plotting with, 17

## K

- keyword arguments, 96–97
- kill\_agent() function, 372
- @kwdef macro, 241–242

## L

- LAPACK, 404
- LaTeX, 13, 274
  - strings, 129
- latexify() function, 274
- Latexify package, 274–276, 385
- LaTeXStrings package, 104–105
- lava lamps, 307
- Lederman, Leon M., 269
- left division operator ( $\setminus$ ), 398
- Leibniz, 245
- lens() function, 106–107
- less-than operator ( $<$ ), 31
- less-than-or-equal-to operator ( $\leq$ ), 31
- Let's Make a Deal*, 310
- liblastrampoline package, 404
- linear algebra, 233, 395–403
- LinearAlgebra package, 399–400
- linear equations, system, 397–399
- linear regression, 105
- LinearSolve package, 404
- line plot, 86
- Linux, 5, 404
- Lisp, 25, 169
- load balancing, 479
- local keyword, 226–227
- logic, 31
  - three-valued, 331
- logical AND ( $\&\&$ ), 31
- logical indexing, 143–144
- logical OR ( $\|\|$ ), 31
- looping, 46–47
  - over strings, 48

- lowered form, 243
- lscpu command, 469
- LuaLaTeX, 274, 279
- Luxor package, 190–192, 239, 251, 285, 294
  - coordinate system, 192
  - defaults, 191
  - fonts, 192
  - scale factor, 191

## M

- machine file, 481
- macOS, 4–5
- @macroexpand macro, 177
- macros, 170–177
  - adding syntax to Julia, 171–173
  - for broadcasting, 173–174
  - for chaining functions, 174–175
  - collision avoidance, 171
  - creating, 171
  - difference from functions, 171
  - for information, 177
  - invocation syntax, 171
  - for performance, 175–177
  - for string formatting, 177
  - for timing, 175
- map() operator, 161–163
  - and broadcasting, 162–163
- mapreduce() operator, 166
- marginalhist() plotting function, 356
- Marx, Groucho, 123
- MathJax, 274–275, 389
- math symbols, 13
- MATLAB, xxii
- matrix, 37
  - identity, 399
  - special types, 400–402
  - triangular, 401
- matrix factorization, 402–403
- matrix inverse, 147
- matrix multiplication, 146–147
- maximum() function, 166
- mean() function, 319–321
- measurement() function, 282
- Measurements package, 280–284
  - combining with
    - DifferentialEquations, 302–303
- median() function, 319
- membership, 43

- membership operator ( $\in$ ), 43
- Meta.parse() function, 168
- metaprogramming, 167–177
- MethodError, 179
- methods, 229–233
- methods() function, 231
- minimum() function, 166
- missing() function, 330
- Missings package, 331
- missing type, 328–330
  - and logic, 331
  - and Plots, 329
- MIT, xxi
- mode() function, 320
- modular arithmetic operator (%), 29
- module paths, 66
- modules
  - creating, 65–67
  - current, 66
  - exported names, 63
  - naming, 63
  - paths and dots, 66–67
  - renaming imported, 65
- Monk, Thelonious, 462
- Monty Hall problem, 310–311
- mosaicview() function, 443
- MP3, 430
- multiple dispatch, xxii, 229–233, 241
- multiplication by juxtaposition, 29–30
- multiprocessing, 468, 479–485
- multithreading, 468–479
- mutable keyword, 236
- mutation, 55–59
  - arrays, 55–56
  - by functions, 56–57
  - strings, 58
- mutually assured destruction, 457
- myid() function, 483

## N

- Nof8 type, 442
- named tuples, 138–139
- names() function, 342
- namespaces, 62, 66
- NASA, 191, 270
- native types, 216
- Netflix, 406
- networked computing, 481–482, 484
- nframes() function, 432

Node, 10  
 nonstandard string literals, 128–129  
 normal distribution, 324–326  
 Normal() function, 324  
 not-a-member operator ( $\notin$ ), 43  
 notebooks
 

- Jupyter, 16–17
- Pluto, 17–20

 Not() function, 339  
 nouns, 213, 234  
 nsolve() SymPy function, 392  
 nthreads() function, 469  
 numbers, 26
 

- complex, 27
- irrational, 218–219
- rational, 28
- types of, 26–27

 Number type, 222  
 numerical precision, 216  
 numeric-symbolic modeling, 384  
 numeric types, 214  
 nworkers() function, 480

**O**

Object() Jarvis function, 204  
 object-oriented programming, 213, 229, 240  
 occursin() function, 131  
 Oceananigans, 284–294
 

- boundary conditions, 286
- computational grid, 285
- diffusivities, 286
- equation of state, 287
- initial conditions, 288
- the model, 287
- precompiling, 284
- running a simulation, 287–290
- visualization, 290, 292, 294

 Octave, xxii  
 ODEProblem() function, 296  
 OffsetArrays.center() function, 458  
 OffsetArrays package, 454–459  
 ones() function, 141  
 OpenStreetMap, 363  
 operating systems, 4–5  
 optional arguments, 96–97  
 OSCAR, 404  
 outer constructors, 240

**P**

-p (julia startup flag), 480  
 packages, 69–81
 

- privacy, 9

 pairs() function, 148–150  
 pandemic
 

- simulation, 313, 316–318
  - boundary conditions, 317

 parametric instability, 300–302, 422–426  
 parametric plots, 86, 93–94
 

- 3D, 112–113

 parametric types, 214, 248–252  
 PCM, 430  
 pdf() function, 325  
 @pdf Luxor macro, 192  
 Pearson correlation, 354  
 Peel, Emma, 189  
 pendulum, 294–302, 408–409, 422–426
 

- finite angle, 298–299
- parametric instability, 300–302, 422–426

 performance and type stability, 242–247  
 Perl, 133  
 permode keyword argument, 275–276  
 permutations, 313  
 permutedims() function, 145–146, 343  
 petaflop club, xxii  
 PGFPlots plotting backend, 116  
 PGFPLOTSX plotting backend, 116, 279  
 physics, 269–304  
 pi, mathematical constant ( $\pi$ ), 218–219, 245  
 PI, SymPy constant, 393  
 pixel type from Images package, 442  
 plot
 

- aspect ratio, 101
- attributes, 98–99
  - fonts, 100
  - frame styles, 100
- color palette, 109
- components of, 98
- contour, 110–112
  - filled, 111–112
  - labeled, 111



- current, 91
- of a damped oscillator, 91
- with errors, 284
- functions, 88–89
- gnuplot, 116
- inset, 106–107, 121
- interactive, 116
- label position, 103–104
- labels, 102
- layout, 117–121
- legend position, 102–103
- mutating, 92
- parametric, 93–94
  - 3D, 112–113
- polar, 86
- polar coordinates, 86, 94–95
- for publication, 277–280
- recipes, 252–264
  - pipeline, 254–255
  - plot, 259–260
  - series, 255–258
  - type, 260–262
  - user, 262–263
- saving, 106
- scatter, 95–96
  - with singularities, 89
  - 3D, 114–115
- subplot, 100
- surface, 108–109
  - settings, 108
- in the terminal, 115
- vector, 113
- for the web, 116
- plotlyjs plotting backend, 116
- plot recipe assignment (-->), 256
- Plots, 84
  - backends, 84, 115–116
    - activation, 84
    - and dependencies, 86
    - Gaston, 116
    - GR, 115
    - HDF5, 116
    - installation, 84
    - names of, 85
    - PGFPlots, 116
    - PlotlyJS, 116
    - PyPlot, 116
    - UnicodePlots, 115
    - closing windows, 86
    - displaying from programs, 86
    - plot settings, 98
    - plotting pipeline, 254–255
    - plot\_title plotting argument, 102
    - plumbing, 406
    - Pluto, 16–18, 20, 23, 191
      - dependency graph, 18–20
      - interactive controls, 208–210
      - interface, 18–20
      - and LaTeX math, 274
      - and MathJax, 274–275
      - module files, 20
      - with SymPy, 388–395
    - PlutoUI package, 208–209
    - pmap() function, 480–481, 484
    - @png Luxor macro, 191
    - point (unit), 191
    - polar plots, 94–95
    - power spectral density, 433–435
    - precision() function, 218
    - prediction, 322
    - prerequisites, xxiii
    - prime factorization, 197–198
    - prime numbers, 125
    - @printf macro, 177, 214
    - Printf package, 177, 214
    - println() function, 32
      - multi-argument, 124
    - privacy with the package system, 9
    - probabilistic programming, 413–426
    - probabilistic simulation, 310–313, 316–318
    - probability, 306
      - combining, 317
      - frequency interpretation, 306
      - philosophy of, 414
    - probability density function, 325
    - probability theory, 359
    - prod() function, 165
    - psd() function, 433–435
    - pseudorandom numbers, 307
      - normally distributed, 326–327
    - Ptolemy, 201
    - Pumas package, 362
    - p-values, 358
    - pyplot plotting backend, 116
    - Python, xxii, 10, 25, 240, 388

## Q

Quantity Unitful type, 272  
quiver() function, 113–114  
quote blocks, 168  
quoting expressions, 169

## R

R, 305, 358  
rand() function, 307–309, 323–324  
randn() function, 326–327  
random\_agent() function, 372  
random events  
  disjunction, 317  
  in programs, 309  
randomness and computers, 306  
random number generators, 359  
  seeding, 309  
random numbers, 307  
range operator (:), 35  
ranges, 35–36  
rational numbers, 28  
rational operator (//), 28  
raw strings, 129  
RCall package, 358  
readchomp() function, 482  
readline, 11  
readline() function, 124  
@recipe macro, 255–256  
RecipesBase package, 255–256  
red() function, 443  
reduce() function, 164–166  
  and non-associative operators,  
  164–165  
reducing functions  
  and empty collections, 165  
  init argument, 165  
  neutral element, 165  
Reel package, 206–208, 292  
regression lines, 357  
regular expressions, 132–133  
  nonstandard string literal, 132  
  for selecting dataframe  
  columns, 340  
religion, 269  
reltol parameter, 301, 412  
renaming imported modules, 65  
render() function, and LaTeX, 274  
repeat() function, 128, 139

## REPL

colors, 12–13  
command recall, 11  
entering Unicode characters, 13  
help mode, 11  
initialization, 12–13  
introduction, 10  
modes, 10, 12  
package mode, 11  
paste mode, 11  
  and readline, 11  
shell mode, 11  
tab completion, 12  
replace() function, 131–132  
reshape() function, 141–142  
RGB type from Images package, 442  
roll() Reel function, 206  
rotation matrix, 382–383  
run!() (Agents function), 373  
run() function, 481

## S

saving signals, 441  
scatterplots, 95–96, 354  
  3D, 114  
  voluminous, 355  
scientific communication, 210  
scientific machine learning, 405–427  
scientific notation, 27  
scientists, 23  
SciML, 405–427  
scope, 52  
  and begin blocks, 52  
  and if blocks, 52  
  and functions, 52–53  
  and loops, 54  
  modification in interactive  
  contexts, 54  
ScreenSend, 15  
secrets, 63  
semantic version strings, 129–130  
semicolon (;), 29  
@series macro, 257  
:series\_plotindex attribute, 257  
series recipes, 255–258  
setprecision() function, 218  
sets, 135–137  
  adding elements, 137  
  difference, 136

- intersection, 136
- subset, 136
- superset, 136
- Set type, 135–137, 221
- `sfilt()` function, 438–441
- `@shorthands` macro, 257
- Shostak, Seth, 429
- `show()` function for dataframes, 335
- SignalAnalysis package, 431–441
- `signal()` function, 431
- signal processing, 430–441
- signals, saving, 441
- significant digits, 281–282
- simulated evolution, 362–379
- simulation, probabilistic, 310–313, 316–318
- SI units, 271–273
- `skipmissing()` function, 330
- slurping, 156–157
- Smith, Frederick W., 61
- smooth plot setting, 105
- Socrates, 405
- solar system, 190
- `solve()` function
  - in `DifferentialEquations`, 296
  - in `SymPy`, 390
- source code for Julia, 6
- sparse array, 196
- `SparseArrays` package, 196, 233
- `@spawnat` macro, 483
- `@spawn` macro, 474–475
- `SpecialFunctions` package, 207, 264
- spectrogram, 433
- splatting, 154–155
- `split()` function, 58
- spreadsheet, 19
- `@sprintf` macro, 177
- standard deviation, 321
- standard library, 62
- statistics, 305, 322, 358–359
  - Julia packages, 359
  - standard library, 319
- `Statistics` package, common
  - functions, 320
- `StatsBase` package, 320
- `StatsPlots` package, 335, 356–357
- `std()` function, 321
- Steed, John, 189
- `string()` function, 128
- string interpolation, 133–134
- string literals, nonstandard, 128–129
- strings, raw, 129
- strings and characters, 44–46
- `struct`, 137–138
  - constructor, 137
  - mutable, 138
  - properties, 138
- `struct` keyword, 235
- `SubDataFrame` type, 349
- `substitute()` function, 383
- subtype, 222
- subtype operator (`<:`), 233–234
- `subtypes()` function, 224
- supertype, 222
- `supertype()` function, 222
- `supertypes()` function, 224
- surface plots, 108–109
- `@svg Luxor` macro, 192
- symbolic mathematics, 382–395, 404
- `Symbolics` package, 382–388
  - tracing to generate expressions, 386
- symbols, 167
  - defined, 170, 187
- `Symbol` type, 168
- `SymPy` package, 388–395
  - differential equations, 393–395
  - evaluating integrals, 392–393
  - numerical root finding, 391–392
  - with Pluto, 388–395
- `@syms` macro, 389
- `@sync` macro, 474–475

## T

- `-t` (Julia startup flag), 469
- thermal convection, 288
- thermal diffusivity, 287
- `thickness_scaling` plot setting, 104
- `@threads` macro, 470–474
- 3D plot, 108–112
- `throw()` function, 183–185
- TikZ, 278
- `time()` function, 478
- timing, 475
- tracing
  - to generate `Symbolics` expression, 386
  - of a matrix, 399
- `transpose()` function, 145

- transposing dataframes, 342–343
- tr() function, 399
- triangular matrix, 401
- trigonometry, 160
- try...catch blocks, 181–182
- tuples, 42–43
  - named, 138–139
- turbulent convection, 292
- Turing package, 413–426
- twinx() function, 300
- 2D plot, 86
- two language problem, xxii
- type aliases, 247
  - for collections, 248
- type assertion, 224–228
- type assertion or declaration operator (::), 225–229
- type declaration, 224–228
  - of global variables, 226
  - purpose, 228
  - and scope blocks, 228
- typemax() function, 215
- typemin() function, 215
- typeof() function, 214, 222
- type piracy, 233
- type promotion, 27, 219–220
- type recipes, 260–262
- types, 26, 213–265
  - abstract, 223, 229
    - creating, 234
  - concrete, 222
  - creating composite, 234–236
  - irrational, 218–219
  - native, 216
  - numeric, 214
  - parametric, 214, 248–252
  - user-defined, 234–242
- typesetting units, 274–276
- type stability, 228, 242–247

**U**

- u (nonstandard string literal), 270
- uconvert() function, 273
- Ulm, 381
- uncertainty() function, 282
- undirected graph, 193
- Unicode characters, 13
  - code point, 130
  - entering in the REPL, 13
- unicodeplots plotting backend, 115
- uniform distribution, 309
- UnionAll type, 249
- Union types, 233–234
- unitformat plotting keyword, 278
- UnitfulLatexify package,
- Unitful package, 270–280
- unit() function, 274, 279
- units
  - combining with errors, 283
  - converting, 272–274
  - physical, 270–280
  - in plots, 276–280
  - stripping from Unitful expressions, 272–274
  - typesetting, 274–276
- uparse() function, 271
- upreferred() function, 273
- US Census, 351–353
- user-defined types, 234–242
  - performance, 242
- @userplot macro, 263–264
- user recipes, 262–263
- using keyword, 63
- ustrip() function, 273, 279

**V**

- value() function, 282
- var() function, 321
- @variables macro, 382
- variance, 321
- vector plots, 113
- vectors of vectors, 37
- verbs, 213, 234
- versions of Julia, 5–6
- @view macro, 395–396
- views, 395–397, 450–452
- @views macro, 395–396
- Vim, 14–15, 23
  - REPL interaction, 14–15
- viscosity, 287
- VS Code, 20–22

**W**

- wait() function, 476
- WAV file, 430
- WAV package, 441
- weather, 253

where keyword, 249  
while block, 32  
whitespace, 33  
Windows, 4–5  
worker processes, 480  
write() method from Reel, 208

## **Y**

yield() function, 477–479

## **Z**

zeros() function, 141  
zip() function, 150–151