

# Index

- Abilene network 157, 159, 207, 216–17
- Access Control Lists (ACLs) 248–50
- access routers 80–1, 85–6
- ACF *see* autocorrelation function
- ACK *see* acknowledgements
- acknowledgements, TCP 22
- ACLs *see* Access Control Lists
- ACM SIGCOMM 11
- ACM SIGMETRICS 10–11
- active measurement
  - concepts 118–24, 252, 255–6, 412–13
- active monitoring 252, 254–5
- active queue management 109
- addresses
  - see also* IP addresses
  - dark aspects 388–90
  - MAC 388
  - registries 80, 94–7
  - space hijacking 386
  - translators 117
- administrative issues 117, 426
- Advanced Research Project Agency (ARPA)
  - 14–15
- aggregated variance method 227
- algebra 7, 45–8, 67, 151
- alias resolution, traceroute 120–2
- aliasing, IP addresses 325–6
- all-pairs paths, graphs 66–70
- alpha traffic 231, 235
- analytic background 45–77
  - graphs 7, 64–70
  - linear algebra 7, 45–8, 67
  - metrics 70–3
  - models 208–11
  - probability 7, 46, 48–58
  - statistics 7, 58–63
- ANEMOS 396–7
- anonymization 355–78
  - see also* sensitive information
  - alternatives 377–8
  - application-level data 362, 373–4
  - attacks against 359–60, 374–6
  - concepts 9, 397
  - configuration data 369–70
  - data categorizing 360–5
  - data sharing 357–60, 365
  - definitions 356–7
  - motivation 357–8
  - packet-level traces 366, 370–3
  - processes 365–7
  - router-level data 369–70
  - success metrics 376–7
  - techniques 367–9
- anycast 250–1
- Apache Web server 287, 298–9, 307
- application protocol layer
  - see also* DNS; FTP; HTTP; P2P; SMTP
  - concepts 19–24, 31, 37–42
  - data gathering 103–4
  - instrumentation 103
  - measurement 37–42
- applications 4, 6–7, 13, 19–22, 42–4, 241–352
  - see also* DNS; emails; file sharing; FTP; multimedia; online games; P2P; Web
  - anonymizable data 362
  - concepts 4, 6–7, 13, 19–22, 42–4, 242–4, 362, 421–2, 429
  - dynamic characteristics 4
  - emerging questions 429
  - historical background 421–2
  - measurement area 6–7, 42–4
  - mix 242–4
  - sockets 22
  - types 6–7, 20–2, 42–4
- approximation, independent models 219–20
- architecture
  - see also* infrastructure; protocols

- concepts 13–44, 319–20, 425–6
  - core simplicity 425
  - games 334–5, 341–3
  - Internet 4–5, 13–44
  - measurement difficulties 425–7
  - P2P tools 319–20
- ARPA *see* Advanced Research Project Agency
- ARPANET
  - concepts 14–16, 43, 217, 419–20
  - history 14–16
  - measurement capabilities 16
  - router graphs 157–8
- arrival processes
  - packets 172–4
  - stochastic processes 55–6
- AS graphs 412–13
- ASes *see* autonomous systems
- asymmetry, paths 119
- Asynchronous Transfer Mode (ATM) 421
- ATM *see* Asynchronous Transfer Mode
- ATMEN 88, 398, 417
- attacks
  - against anonymization 359–60, 374–6
  - applications 394–5
  - backbones 82–4
  - DoS 303–4, 379, 381, 383, 387–8, 391
  - gateways 384–6
  - honeypots 388–90
  - inter-domain attacks 386
  - intranet 382–3
  - Man-In-The-Middle 381, 386
  - security 380–2
  - wide area measurement 387–94
- audio 349, 351–2
- authorities *see* hubs
- autocorrelation
  - concepts 54–8, 60–3
  - confusions 58
  - dependence structures 211–12
  - self-similarity 224–5
  - time scales 219–21
- autocorrelation function (ACF), concepts 60–1
- autocovariance, concepts 53–8
- autonomous systems (ASes)
  - see also* backbones; Border Gateway Protocol
  - anonymization 361, 364, 369, 377
  - CDN 295
  - concepts 15, 26, 28–31, 111–12, 160–1, 386, 412–13, 426
  - connection points (peering/exchange points) 26
  - graphs 111–12, 125–6, 154–61
  - honeypots 388–90
  - Internet growth 160–1
  - network entry points 84–5
  - numbers 364, 369, 377
  - passive measurement 124–6
  - routing 28–31, 95, 97, 156–7, 159–61, 412–13
  - security 386
  - static graphical properties 154–7
  - top-level systems 426
  - traceroute 122–3
- availability
  - bandwidth 128, 131–2
  - DNS 246
  - peers 325
- backbones
  - see also* autonomous systems; Internet Service Providers
  - concepts 15–17, 25–6, 27, 36, 71–2
  - default backbone 15–16
  - historical background 15–17
  - measurement locations 80–4
  - networks 177, 297
  - routers 80–1, 153
- backscatter technique 387, 391
- bandwidth
  - bulk transfer capacity (BTC) 135–6
  - concepts 67–70, 83, 127–36, 159, 293, 322, 350, 396–7
  - ISP allocations 83
  - multimedia streaming 350
  - network/traffic interaction 169
  - P2P 322
  - packet-pair methods 129–32
  - router graphs 159
  - self-induced congestion 134–5
  - size-delay methods 132–4
  - Web performance 293
- basic packet sampling 196–8
- benchmarks, mobile clients 286
- best-effort service, IP 21
- best-landmark method 144
- beta traffic 231, 235

- betweenness measure, vertex 65–6
- BGP *see* Border Gateway Protocol
- bias, sampling 71–3, 158
- BIND 98, 255–6, 262, 267
- biscaling behaviour 232
- BitTorrent 42, 310–12, 317, 328–30, 429
- blackhats 379, 390
- blackhole lists 268
- blogistan 306–7
- blogs 305–9, 365
- Bloom filters 199–201, 215
- Bluetooth 27, 110
- Boolean algebra 48, 151
- Border Gateway Protocol (BGP) 30–1, 35, 80, 85, 398–9, 400–2, 406–7
  - anonymizable data 362–3
  - Beacon System 407
  - control traffic 238–9
  - packet capture 190
  - passive measurement 125–6
  - security 386
  - system instability 163–164
- botnets 381
- bottleneck links 128–30
- Box, George 74
- bprobe* 415
- Bro intrusion detection tool 385
- broadband 352
- browsers 6, 15–16, 43–4
- BTC *see* Bulk Transfer Capacity
- building blocks, Internet 3–4
- Bulk Transfer Capacity (BTC) 70–1, 129, 135–6, 408–9
- bundling 298–9
- bytes 172–3, 184, 216–33
  
- cable modem 16, 27
- cached/non-cached responses, DNS 39
- caching
  - DNS 39, 98, 247, 266–8
  - P2P 313, 319–20
  - Web 272, 275, 280–1, 289
- CAIDA (Cooperative Association for Internet Data Analysis) 404, 410–14
- campus study, P2P 330–1
- capabilities, measurement 16–17
- capacity
  - awareness 319
  - bandwidth 128–32, 135
  - BTC 129, 135–6
    - planning 82
- capturing data 99–102
  - see also* packet capturing
- case studies 9, 395–417
  - ANEMOS 396–7
  - CAIDA 404, 409–14
  - Click 397–400
  - dss* 398, 400–3
  - High Energy Physics community 404, 407–9
  - individual toolsets 397–404
  - large-scale measurement projects 404–17
  - low-level monitoring tools 395–7
  - PlanetLab 404, 414–17
  - RIPE NCC 405–7
  - software tools 397–400
  - Windmill 397–9
- categorical datasets
  - concepts 58–63
  - Zipf's law 62–3
- CDF *see* cumulative distribution function
- CDMA cellular phone system 91–2
- CDNs *see* Content Distribution Networks
- cell phones 91–2, 284
- cellular telephony 24–5
- Central Limit Theorem, concepts 51–2, 62
- central tendency, concepts 51–2, 59–60, 62
- centralized games architecture 334, 341
- changes
  - Internet 7, 424
  - technology 419
  - Web 275, 301
- characteristic path length, graphs 65–6
- characterization
  - DNS 252–6, 258–61
  - games 333–4, 342–3
  - P2P 311–12, 318–19, 321–5, 327–30
  - Web 270–1, 278–81, 286–8
- cheating, games 332, 341
- chunk sizes, P2P 327, 328–30
- circuit-switching networks 17–18, 24
- Cisco 369–70, 393, 400–3
- Click 399–402
- client/server roles, endsystems 25–6, 39–40, 43–4
- clients
  - see also* users

- classification 297–9
- connectivity 296–9
- customer–provider relationships 156
- flash crowds 304
- mobile clients 240, 284–6, 292–3, 330–1, 336, 345–6
- proximity assumption 263–4
- representative populations 274–5
- tailoring responses 297–9
- Web servers 274–5, 297
- clocks 90–4
- clustering
  - coefficient 65
  - dimensionality reduction 204–5
  - graph neighbours 65–6, 69–70
  - network–aware clustering 283–5, 295, 297–8, 303–5, 307, 319–21
  - small world phenomenon 156
- CNAME 262
- Code Red worm 304, 391, 413
- CoDeen 416–17
- codes, anonymization 378
- CoDNS 416
- coefficient of variation, concepts 59–60
- commercial issues 5–6, 15–17, 269, 276, 283–4, 289, 332, 364–5, 393–4
  - see also* electronic commerce
  - anonymization 364–5
  - caching 289
  - games 332
  - measurement reasons 5–6
  - NSF networks 15
  - performance issues 5
  - security products 393–4
  - Web measurement services 269, 276, 283–4
- Common Log Format 279
- communication media 24, 27
- complex networks 423, 429
- components, vectors 45–8
- Computer Communication Review* journal 11
- Computer Networks* journal 11
- conditional distribution, concepts 51–8
- conditional expectation, concepts 51–8
- conditional probability, concepts 50–8
- confidence intervals 185–7
- configuration
  - anonymization 369–70
  - DNS 247
  - P2P 312
  - Web 271–2, 288
- congestion 113–14, 134–6, 150–1, 166–7
  - TCP properties 21–2
- connected graphs, concepts 65–70
- connection points (peering/exchange points), autonomous systems 26
- connections
  - ASes 155
  - interdisciplinary connections 423–4
  - networks/traffic 114–15
  - P2P 312–13
  - TCP 21–2
  - Web 296–9
  - wireless networks 109–11
- connectivity issues 5, 16, 22–4, 26
- console games 337, 343
  - see also* online games
- constancy, traffic stability 185
- constant rate sampling 196–7
- constraint–based method, geolocation 144
- constructive data models, concepts 73–5
- Content Distribution Networks (CDNs) 42, 257–8, 263, 266, 287, 294–6, 348, 416
  - DNS 257–8, 263, 266
  - multimedia 348
  - Web 287–8, 294–6
- content modification, Web 276, 286
- continuous random variables, concepts 49–58
- continuous–time stochastic processes, concepts 52–5
- control traffic 176, 190, 238–9
- cookies 374
- core simplicity 115–16, 177, 425
- Cossack system 387
- count–min* sketch 202
- Counter–Strike 342–4
- counting 172–3, 184, 193–4, 200–1, 203
- counting Bloom filters 200–1
- covariance, concepts 46, 50–8
- crawling
  - P2P 318, 321–2
  - Web 279, 281–2, 291–2, 299–302, 306
- credit card numbers 363
- critical path analysis 290
- cross traffic 131–2, 134–5
- crossover statistics 182–3
- cryptographic techniques 372

- cumulative distribution function (CDF) 49–63
- curse of dimensionality 188
- customer–provider relationships 156
- dark addresses 388–90, 393
- data
  - see also* modeling
  - anonymization 360–5
  - capture 99–102
  - DNS 250
  - games 337–8
  - gathering 103–4, 290–3
  - management 191–2
  - models 73–7
  - P2P 315–17
  - sensitivity 356
  - sharing 178–9, 357–60, 365
  - volume 178, 424
  - Web 274–6
- data reduction
  - counters 193–4
  - dimensionality 203–7
  - flow capture 194–6
  - probabilistic models 207–12
  - sampling 196–9
  - summarization 199–203
  - traffic 192–212
- databases 79–80, 94–9, 146–7, 255–6, 398, 403–4
- datagrams, UDP transport protocol 19–23, 34–5, 41
- datasets
  - concepts 58–63, 74–7, 400–3
  - modeling 74–7
- DDoS *see* denial of service attacks
- de-identification 357, 376
- dead links 302–3
- decentralization
  - design principles 22–3
  - games architecture 334, 341
  - Internet 426
- decoys 314, 316, 320
- default backbone, concepts 15–16
- degree, vertex 65–70
- degree distributions 67–70, 154–5, 158–60
- delay-based geolocation 144–6
- delays 67–70, 94, 112–13, 129–36, 144–50, 153, 166–7, 282, 338–9, 343–4
  - games 338–9, 343–4
  - internal to networks 147–50
  - multimedia 351
  - one-way delays 118
  - packets 94, 112–13, 129–36, 153, 166–7
  - Web 270
- demographic aspects
  - concepts 5, 164–5, 274–5
  - geographic location 164–5
  - Web clients 274–5
- denial-of-service attacks (DoS) 303–4, 379, 381, 383, 387–8, 391, 411, 413
- dependence
  - distributional models 211–12
  - long range 187, 218–21, 224–6, 228–32
  - short range 220, 224, 229
- dependent variables, concepts 50–8
- descriptions, sets of measurement 59–60
- descriptive data models, concepts 73–5
- descriptive statistics, concepts 58–63
- design principles
  - decentralization 22–3
  - end-to-end argument 24–5
  - inference measurement 150–2
  - Internet 13, 17–25
  - IP hourglass design principle 23–4
  - stateless switching 24
- detection methods, attacks 382, 384–6, 392–3
- deterministic delays 166
- deterministic sampling 196–7
- DEW *see* DNS-Enhanced Web
- DHT *see* distributed hash table
- dial-up connectivity 5, 16
- diameter, small world phenomenon 156
- dig* (Domain Internet Groper) 98, 252, 267
- digital divide, High Energy Physics
  - community 409
- digital subscriber line (DSL) 16, 27
- dimensionality, traffic statistics 188, 203–7
- DirectConnect 42, 324, 327, 331
- directed graphs, concepts 64–70
- discrete random variables, concepts 49–58
- discrete-time stochastic processes,
  - concepts 53–5
- dispersion
  - see also* variance
  - concepts 59–63
- distance 141, 237
  - see also* paths
- distributed data gathering 103–4

- distributed games architecture 341
- distributed hash table (DHT) 41
- distributed internetworking 177
- distributional models 181, 208–11
- distributions
  - concepts 46, 51–8, 62, 208–11, 415–16
  - skewness 62–3
  - tails 56–8, 62–3, 179–83, 210–11, 225–31, 234
  - types 52, 56–8
- DLLs (dynamically loaded libraries) 401–3
- DNS (Domain Name System) 6, 20–2, 37–9, 42, 241, 244–69, 360, 362–4, 397, 402–3, 405–7, 412–13, 416–17
  - see also* applications
  - anonymization 360, 362–4
  - cached/non-cached responses 39
  - caching 39, 98, 247, 266–8
  - CDN 257–8, 263, 266, 294–5
  - challenges 248–51
  - characterization 252–3, 258–61
  - concepts 6, 20–2, 37–9, 42, 245–56, 258–69, 397, 402–3, 405–7, 412–13, 416–17
  - databases 94–5, 97–8
  - Internet growth 162–3
  - King 139
  - location databases 146
  - measurement 37–9, 397, 402–3, 405–7, 412–13, 416–17
  - other applications 256–8, 262–9
  - properties 245–8
  - resource records 98
  - servers 38–9, 244–69, 294–6, 360
  - tools 251–6
- DNS-Enhanced Web (DEW) 265–6
- dnscache* 267
- dnschecker* 255–6
- dnsstat* 254
- dnstop* 254–5
- domain squatters 267
- dominant congested links 150–1
- DoS *see* denial-of-service attacks
- download times, Web pages 5
- downloading 312–14, 316–17, 321, 327–30
- drop events 113
- drop-tail service discipline 109
- dsc* 255
- DSHIELD 392
- DSL *see* digital subscriber line
- dss* 398, 400–3
- duplicate blogs 307
- duplicate packets 168
- duration, packet train rate 236
- dynamic characteristics, Internet 4
- ECHO packets 35, 118, 121, 135
- ECHO REPLY message 35
- edges, graphs 64–70
- eDonkey 41–2, 310–11, 326–9
- educational multimedia 351–2
- eigenvalues 48
- eigenvectors 48
- eighty-twenty rule 182
- electrical links 190
- electronic commerce 3
  - see also* commercial issues
- ‘elephants and mice’ phenomenon 183, 234
  - see also* size-count disparity
- emails 15, 17, 43, 268, 390, 394
  - see also* SMTP
- embedded content, Web 295, 297–9
- embedding-based methods, latency 137, 139–42
- empire, evil 281, 326
- empirical distributions, concepts 58–63
- eMule 310–12, 317
- encryption 366, 372
- end-to-end argument 24–5, 116
- end-to-end protocols
  - see also* application protocol layer; transport protocol layer
  - concepts 20
- endsystems
  - client/server roles 25–6, 39–40, 43–4
  - concepts 18–22, 24–7, 39–40, 161–3
- enterprise networks
  - see also* autonomous systems
  - concepts 15–16
- entertainment multimedia 351–2
- entities
  - DNS 246, 249, 251, 259–61
  - P2P 310, 314–15, 319, 324
  - Web 271–2, 277–8, 288
- entropy rate, concepts 54–8
- entry points, networks 84–6
- Erdős-Rényi random graph, concepts 67–70
- Erlang, A.K. 219

- errors
  - inference 358
  - metrics 70
- estimation
  - latency 136–42
  - traffic matrices 212–15
- Ethereal 349
- Ethernet 19, 23–4, 27, 136, 172, 189, 414
- Euclidean space 46–7, 140–1, 166
- eValid Test Suite 283
- event averages 71–3
- EverQuest 331–2, 335
- exchange points 26, 86–7
- expectation paradox 181
- expected value, concepts 49–58
- exponential distribution 52, 56–8, 183
- exponential growth
  - Internet 163
  - traffic 217–18
- external time sources 91
- extreme distribution, concepts 52
  
- false edges, paths 119–20
- FastTrack 323–4
- fault detection 67–70
- FIFO queuing 131
- file sharing 5–6, 25, 40–2
- file transfers 20, 23, 40, 42–4
  - see also* FTP
- filtering
  - anonymization 372–4
  - AS connections 126
  - Bloom filters 199–201, 215
  - multistage filters 201
  - packets 86
  - security 394
- fingerprinting 356–7
- firewalls 116, 268–9, 381–2, 384–5, 392, 399, 413
- First Person Shooter (FPS) games 332, 335–7, 340, 342, 344–5
- first-order stationarity, stochastic processes 54–8
- flash crowds 272–3, 303–5, 330
- flooding protocols, routers 30, 41
- flows
  - see also* netflow
  - anonymization 375
  - data reduction 194–6
  - intranet security 383
  - IPFIX 195–6
  - packets 101–2
  - RTFM 196, 254
  - sampling 283
  - traffic 175–7, 194–6, 214–15, 236–8
- Flowscan 403
- Flowtools 195–6
- forward secrecy 356
- forwarding decisions, routers 28
- forwarding engines 108–9
- fpdns* 255
- FPS *see* First Person Shooter games
- freeriding 313, 320, 322
- FTP (File Transfer Protocol) application
  - protocol 23, 40, 42–3, 242–3
  - concepts 42–3
  - TCP usage 43
- fused measurements 127
  
- games *see* online games
- Gamespy 340–1
- gamma distribution, concepts 52
- Ganglia 417
- gateways
  - see also* Border Gateway Protocol
  - concepts 14–15, 26, 30
  - protocols 85
  - routers 80–1, 84
  - security 384–6
- Gaussian distributions *see* Normal
- GAV (GPL Arcade Volleyball) 336, 345
- generalized random graph, concepts 67–70
- generic top-level domains, DNS 253, 262
- Genii 388
- geographic location 164–5
- geolocation 142–7, 412–13
- GIF images, CND 295
- Gigascope 191–2, 398, 403–4
- Gilbert model 167
- Global Positioning System (GPS) 91–2
- GNP embedding approach 139–41
- GNU Zebra 190
- Gnutella 41, 310–12, 321–5
- Gomez 283
- goodness-of-fit tests 208–11
- goodput 115
- GPS *see* Global Positioning System
- graphs

- see also* incidence matrix
- ASes 111–12, 125–6, 154–7, 159–61
- cliques 65
- commonly encountered models 67–70
- concepts 7, 64–70
- interface graphs 111–12
- measurement issues 66–70
- netflow* data 259–61
- P2P traffic 319
- router graphs 111–12, 157–61
- small world graphs 69–70, 156
- structure characterization 65–6
- Web graph modeling 280, 300
- ‘ground–zero’ hosts 413–14
- group–based characterization, DNS 259–61
- growing network model 68–70
- growth
  - Internet 155, 160–3
  - traffic 217–18
  - Web sites 288
- GSM 27
- GSQ 191–2
- GTrace 411
- H.323 standard 347, 351
- Half–Life 340, 342–5
- hardware 79, 82, 92
- hashing strings 369–70
- headers
  - concepts 20–2, 32–4, 123, 370–2, 396–7
  - IP (Internet Protocol) 32–3
  - nested headers 20–1
  - TCP (Transmission Control Protocol) 34
  - UDP 35
  - Web example 21
- heavy–tails 57–8, 62, 179–83, 225–31, 234
- heuristic notions, sampling 71
- hidden factors
  - DNS 250–1
  - games 337–9
  - P2P 315–17
  - Web 274–8
- hierarchical routing
  - AS graphs 156–7
  - concepts 28–31, 37–8
  - P2P nodes 319, 322–3
- high dimensionality, time series 188
- High Energy Physics (HEP) community 404, 407–9
- high variability
  - infrastructure 154–6, 158–60
  - Internet measurements 61–2
  - statistical issues 425
  - traffic 179–83, 237
- high–speed connectivity 5
- histograms, concepts 59–63
- historical background, Internet 3–4, 14–17, 419–24
- hit rates, Web caches 289
- honeypots 387–90
- hop–by–hop protocols
  - see also* link protocol layer;
  - network protocol layer
  - concepts 20–2, 25–6
- host ID information, IP addresses 21–2, 37–8
- Hostcount project, RIPE NCC 405
- hosts 21–2, 25, 37–8, 161–3, 259, 263, 268
- Host.txt file 37–8
- hourglass design principle, IP 23–4, 116, 178, 425
- HTTP (HyperText Transfer Protocol)
  - application protocol
  - see also* Web
  - CDN 294–5
  - concepts 20–2, 39–40, 42–4, 270–1, 276, 282, 398–403, 417
  - crawlers 282
  - DNS 257, 264–6
  - measurement 39–40, 398–403, 417
  - popularity 42–3
  - request–response pair 39–40
  - streaming multimedia 346
  - TCP usage 40, 42–4, 257
  - transport layer 320–1
- HTTP/1.0 6, 39–40, 43
- HTTP/1.1 6, 39–40, 43
- httperf* 291, 298–9
- hubs 280, 300–1, 327
- Human Pacman 334–5, 345
- Hurst parameter (*H*) 221–4, 227–30
- hybrid games architecture 334–5, 341
- IANA *see* Internet Assigned Numbers Authority
- ICFA *see* International Committee for Future Accelerators
- ICMP (Internet Control Message Protocol)
  - active measurement 118–19, 121

- concepts 16, 35–6
  - ECHO packets 118, 121, 135
  - measurement 35–6
  - TIME EXCEEDED packets 118–21, 133
- identity aspects 356, 361–3, 375–6
- IDMaps 139
- IDS *see* intrusion detection systems
- IEEE *see* Institute of Electrical and Electronics Engineers
- IEEE/ACM Transactions on Networking* journal 11
- IEPM–BW project, High Energy Physics community 409
- IETF *see* Internet Engineering Task Force
- ifEntry 193–4
- Iffinder 411
- IGPs 239
  - see also* IS-IS; OSPF
- ill-posed problems, traffic 212–13
- IMC *see* Internet Measurement Conference
- IMPs *see* Interface Message Processors
- incidence matrix
  - see also* graphs
  - concepts 65–6
- indegree, vertex 65–6
- independent models 213–14, 218–21
- independent variables, concepts 50–8
- indexers 281
- inference 147–52
  - anonymization 358, 360
  - attacks 360
  - errors 358
  - searching 302–3
  - statistical 423
  - traffic tools 212–15
- Infocom conference 10–11
- information resources 10–11
- information sharing 392–3, 426–8
- infrared 25
- infrastructure 3–4, 6–10, 17–22, 25–6, 107–69
  - see also* architecture; links; routers
  - challenges 115–17
  - changes 102–3
  - concepts 3–4, 6–10, 17–22, 25–6, 107–69
  - measurement area 6–7
  - properties 107–15
  - tools 117–52
- instability, routing 238–9
- instantaneous RTT 137–8
  - see also* round-trip time
- Institute of Electrical and Electronics Engineers (IEEE) 110
- instrumentation changes 102–3
- inter-AS (domain) routing, concepts 28–31, 35
- interarrival process, stochastic processes 55–6
- interception proxies 277–8
- interdisciplinary connections 423–4
- interface graphs 111–12
- Interface Message Processors (IMPs) 420
- interfaces
  - concepts 21–2
  - traceroute 120–1
- International Committee for Future Accelerators (ICFA) 407–9
- Internet
  - see also* applications; infrastructure; traffic
  - architecture 4–5, 13–44
  - building blocks 3–4
  - builders 3–4
  - changes 7
  - commercial issues 5–6, 15–17
  - concepts 3–10, 14–17
  - databases 94–9
  - definition 3, 15
  - design principles 13, 17–25
  - directories 94–9
  - dynamic characteristics 4
  - growth 155, 160–3
  - historical background 3–4, 14–17, 419–24
  - measurement concepts 3–10, 16–17
  - operation details 25–30
  - optimization issues 413
  - organization 14–22, 25–30
  - practical issues 79–104
  - security issues 4, 9, 380–2, 397, 411–12
  - uses 3, 16
  - versatility 3
- Internet Assigned Numbers Authority (IANA) 95–6
- Internet Engineering Task Force (IETF) 17, 36, 42
- Internet Exchange Points 86–7
- Internet Measurement Conference (IMC) 10
- Internet Motion Sensor 393

- Internet Official Protocol Standards* 17
- Internet Routing Registry (IRR) 95–7
- Internet Service Providers (ISPs)
  - address registries 95–6
  - administrative barriers 117
  - anonymization 361
  - concepts 15–17, 26, 30–1, 117, 361, 414, 422–3
  - historical background 15–16
  - IDS 384
  - information sharing 426
  - measurement locations 80–3
  - network management 422–3
  - permissions 23
  - policy routing 30
  - routing 30–1
  - spam 394
  - top-level ISPs 17
  - types 16, 26
- Internet Sink (iSink) project 393, 399–400
- Internet2 414
- interpretable parameters, modeling 75–6
- intra-AS (domain) routing, concepts 28–31, 35
- intranets 382–3
- intrusion detection systems (IDS) 382, 384–6, 392–3
- invariants, traffic 215–16
- inverse matrices 46–7
- InXs *see* Internet Exchange Points
- IP addresses
  - aliasing 325–6
  - anonymization 361–3, 367, 369, 370–7
  - concepts 21–2, 26, 28, 37–9, 325–6, 361–3, 367, 369, 370–7, 411–13
  - DNS 37–9, 259–61, 263
  - network-aware clustering 283–4, 295, 308
  - P2P 319, 325–6
  - sockets 22
- IP Flow Information Export effort (IPFIX) 195–6
- IP Identifications (IP IDs) 121
- IP (Internet Protocol)
  - see also* network protocol layer
  - anonymization 371–2
  - concepts 14–15, 19–24, 26, 28, 31–3, 37–9, 325–6, 361–3, 367, 369–77, 398–9, 405–7, 411–13
  - firewalls 399
  - headers 32–3, 123, 371–2
  - hourglass design principle 23–4, 116, 178, 425
  - IP addresses 21–2, 26, 28, 37–9, 325–6, 361–3, 367, 369–77, 411–13
  - IPv4 32, 407, 412, 428–9
  - IPv6 32, 123, 407, 428
  - measurement 31–3, 37, 398–9, 405–7, 411–12
  - Record Route option 33
  - segments 22
  - traffic flows 175, 195–6
  - TTL values 32–3, 118
  - unreliability 21, 24–5
- IP multicast, concepts 37
- iperf* 409
- IPFIX *see* IP Flow Information Export effort
- IRR *see* Internet Routing Registry
- IS-IS intra-domain routing protocol 29, 35
- ISDN 27
- ISPs *see* Internet Service Providers
- jitter
  - games 340, 343–4
  - multimedia 348, 350–2
  - packets 114, 168
  - video 348, 350
- joint entropy, concepts 54–8
- joint probability, concepts 50–8
- journals 10–11
- k-anonymity* 376–7
- Kademlia 309
- KaZaa 6, 41–2, 310–11, 313, 316, 326, 429
- kernel 396–7
- Keynote 283
- King 139, 263–4, 344
- lag, concepts 54–8
- lame delegations, DNS 256
- landmarks
  - geolocation 144–6
  - latency 137, 139, 141
  - window model 203
- LANS *see* local area networks
- large ISPs 16
  - see also* Internet Service Providers
- large observations, statistics 179–82

- large-scale measurement projects, case studies 404–17
- ‘last mile’ providers 16
- latency 136–42, 412–13
  - DNS 247, 250
  - embedding-based methods 137, 139–42
  - estimation 136–42
  - games 335–6, 343–4
  - King 263
  - latency radius 340
  - mirror sites 295–6
  - proxy-based methods 137–9
  - sensitivity 83, 86
  - user-perceived latency 293, 295–7, 299
  - Web 270, 272
- layers
  - hidden layers 116, 251, 276–7, 316–17, 338–9
  - overview 18–22
  - protocols 18–22, 31–42
- leechers, BitTorrent 328–30
- legal aspects
  - BitTorrent 330
  - data sharing 359
- libpcap* 188–9, 254, 371
  - see also* packet capturing
- Limewire 42
- linear algebra
  - concepts 7, 45–8, 67
  - notation list 46
- link protocol layer
  - see also* Ethernet; MPLS; Sonet; WiFi
  - concepts 18–22, 23–6, 29
- link state advertisements (LSAs) 30–1, 126, 153, 403
  - see also* routing
- link state protocol 29–30
  - see also* routers
- link weights, paths 30
- link/structure preserving transformation 368
- links
  - see also* infrastructure; routers
  - backbones 84
  - bandwidth 129–32, 135–6
  - common technologies 25–6, 27
  - concepts 15, 18–26, 27, 108
  - data sharing risks 360
  - dead links 302–3
  - diagrammatic overview 18
  - dominant congested links 150–1
  - inference 151
  - packet capture 189–90
  - speeds 25–6, 27
  - traffic matrices 212
  - Web 280–1
- Linux Operating System 328, 329
- Lipschitz embedding 141–2
- live multimedia streaming 326, 350–2
- LLCD *see* log-log complementary distribution
- local area networks (LANs) 14–15, 21, 24, 27, 82, 110, 189
- local clocks, routers 35
- local data gathering 103–4
- local scaling 232
- locality, flows 237
- location
  - databases 146–7
  - DNS servers 247
  - geolocation 142–7
  - measurements 80–9
  - peers 325
  - Web functions 271, 280, 288
- log-log complementary distribution (LLCD) 209–10, 226
- logging 102, 252, 394
- lognormal distribution, concepts 52
- logscale diagram method 227–8
- long tails 56–8, 62–3, 179–83, 231
- long time scales 216–18
- long-range dependence 187, 218–21, 224–6, 228–32, 425
- lookups 248, 266
- loss
  - see also* packet loss
  - inference 147–50
- lossless transformation 367–8
- lossy transformation 368
- low-level monitoring tools, case studies 395–7
- lower-level protocol data 99–100
- LSAs *see* link state advertisements
- MAC addresses 370, 388
- malicious traffic 176, 388, 390–2
- malware 390–2
- Man-In-The-Middle attacks 381, 386
- management, middleboxes 116
- management information base (MIB) 36, 193–4

- maps, routers 29–30, 399–400
- MAPS (Mail Abuse Prevention System)
  - project 268
- marginal distribution, traffic 230–1
- Markov models 167
- matrices 46–7
- matrix–vector multiplication 47–8
- maximum likelihood methods 149, 215
- MDS *see* multidimensional scaling
- means
  - concepts 46, 49–58, 61–2, 179–80
  - sampling 179–80
- measurement
  - see also* metrics; passive measurement
  - absence 3–4
  - active measurement 118–24, 252, 255–6
  - application protocol layer 37–42
  - areas 6–7, 16–17
  - ARPANET 16
  - building platforms 426–7
  - capabilities 16–17
  - case studies 9, 395–419
  - collection difficulties 4
  - concepts 3–10, 16–17, 23–4, 31–42, 73–6, 80–9, 118–24, 252, 255–6, 395–419
  - descriptions 59–60
  - difficulties 3–4, 424–6
  - DNS 37–9, 397, 402–3, 405–7, 412–13, 416–17
  - emerging questions 428–30
  - games 332–6
  - HTTP 39–40, 398–403, 416–17
  - ICMP 35–6
  - information sharing 427–8
  - Internet concepts 3–10
  - IP 31–3, 37, 398–9, 404–7, 411–12
  - large–scale measurement projects 404–17
  - load 122, 141
  - location 80–9
  - low–level monitoring tools 395–7
  - metrics 70–3
  - modeling 73–7
  - network protocol layer 31–3, 37
  - operational measurement 420–1
  - P2P 40–2, 397
  - practical issues 79–104
  - probability issues 52–8, 76–7
  - progress 4–5
  - protocol layers 31–42, 99–104
  - reasons for measuring 5–6
  - routing 35, 397–400
  - sampling uses 16–17, 70–3
  - security 379–95
  - SNMP 36
  - statistical issues 58–63
  - stochastic processes 52–5, 76–7
  - TCP 31, 33–4, 71, 398–9, 415–17
  - tools 4–5, 7, 9, 16–17, 395–417
  - traffic 421–3
  - transport protocol layer 31, 33–4
  - trends 419–24
  - UDP transport protocol 31, 34–5, 198–9, 244–5, 259–60, 413
- memory 60–1, 185–7
- Mercator crawler 291, 301
- messages 153, 238–9
- metric–induced topology 150–1
- metrics
  - see also* measurement; sampling
  - concepts 70–3, 150–1
  - errors 70
  - event averages 71–3
  - instability 179–81
  - success 376–7
  - time averages 71–3
  - uncertainty 70–1
- MIB *see* management information base
- Microsoft Media Server (MMS) 346–8
- mid–size ISPs 16
  - see also* Internet Service Providers
- middleboxes 116–17, 153
- MINC inference method 148
- minimum RTT (minRTT) 137–9, 166
  - see also* round–trip time
- mirror sites 86–7, 293, 295–6, 301
- mirrored server games architecture 334
- mmdump*, multimedia tool 349
- MMORPG (Massive Multiplayer Online Role Playing Games) 332–4
- MMS *see* Microsoft Media Server
- mobile clients
  - games 336, 345–6
  - P2P 330–1
  - traffic 240
  - Web 284–6, 292–3
- Mockapetris, Paul 37

- modeling
  - concepts 73–7
  - distribution models 181, 208–11
  - graph modeling 280, 300
  - independent models 213–14, 218–21
  - multifractal processes 233
  - ON/OFF models 234–5
  - over-fitting problems 75
  - parameters 74–7
  - parsimonious models 74–5
  - probability models 76–7, 180–1, 207–12, 230–1
  - queuing models 180
  - self-similarity 227–8, 230
  - statistical difficulties 181
  - types 73–4
  - uses 74–7
  - validation 74–5
  - ‘what if’ questions 76, 403
- modular querying mechanisms 397–404
- Mohonk project 389–90
- monitoring 252, 254–5, 283, 392–3
- monofractal processes 232
- Morris worm 391
- Mosaic 16
- MPLS, link protocol layer 23
- MRT format files 400–3
- multi-session games 336
- multi-site measurements 87–8
- multicast 37, 123, 149–50, 152, 327
- multidimensional scaling (MDS) 141
- multidimensional time series 188
- multifractal processes 232–3
- multilateration 144–5
- multimedia 44, 326, 346–52
  - see also* applications
  - categories 351–2
  - challenges 348
  - properties 347–8
  - streaming 326, 346–52
  - tools 349
- multiplayer games 331–4, 339–40, 342, 345
- multipoint communication 321
- multistage filters 201
  
- name-based geolocation 143
- NAPs *see* network access points
- Napster 6, 40–1, 244, 309–11, 321–3, 326–7
  - see also* P2P
  
- narrow links 129–32
- National Institute of Standards and Technology (NIST), US 91
- National Science Foundation (NSF) 15
- NATS *see* network address translators
- neighbours, graphs 64–70
- nested headers, concepts 20–1
- netflow* 84–85, 101, 400, 402–403
  - anonymization 361, 366, 370, 377
  - DNS 253–4, 259–61
  - P2P 318, 323
- NETFLOW method, *dss* 402
- NeTraMet (Network Traffic Flow Measurement Tool) 196, 254, 262, 411
- nettimer* 325
- network access points (NAPs) 81, 85
- network address translators (NATs) 117
- network effects, games 343–4
- network engineering 171, 184
- network ID information, IP addresses 21–2, 30–1
- network latency 137, 141
- Network News Transport Protocol (NNTP) 243
- network protocol layer
  - see also* IP
  - concepts 19–24, 31–3, 37
  - measurement 31–3, 37
- network proximity assumption 262–3, 295
- network telescopes 388, 412–14
- Network Time Protocol (NTP) 93–4
- network tomography 66–70, 147–52, 213
- network-aware clustering 283–5, 295, 297–8, 303–5, 307, 319–21
- network-defined flows 175–6
- network-internal delays 147–50
- network-level support, P2P 320–1
- network-oriented traffic measurement 422
- networked games 337–40
- networks
  - see also* individual networks; network; SNMP
  - backbones 177, 297
  - complex networks 423, 429
  - concepts 21–2, 25–6, 28–33, 40–2, 147–52, 213, 320–1, 337–44, 422
  - core simplicity 115–16
  - entry points 84–6
  - exchange points 86–7

- LANs 82, 110, 189
  - management 422–3
  - traffic 112–15, 165–9
  - wide area networks 87–9
- ninety–ten rule 182
- NIST *see* National Institute of Standards and Technology
- NNTP *see* Network News Transport Protocol
- nodes 64–70, 131–2, 155, 160, 214–15, 260–1, 316, 319–20, 324–6
  - ARPANET 420
  - availability 325–6
  - DNS 260–1
  - fanouts 214–15
  - infrastructure 131–2, 155, 160
  - P2P 316, 319–20, 324–6
- noise 216–17
- norm, vectors 47
- Normal (Gaussian) distributions, concepts 46, 51–8, 62, 73–4, 230–1
- NSF *see* National Science Foundation
- NSFNET, concepts 15–16
- NTP *see* Network Time Protocol
- numerical datasets, concepts 58–63
- objectivity 209
- observability 115–16, 177–8
- Occam’s razor 75
- OD *see* origin–destination flow
- OFF times 234–5
- off–the–shelf hardware 395–7, 403–4
- offline processes 366, 376–7
- offset, clocks 90–1, 93–4
- ON/OFF processes 173–4, 234–5
- one–way packet delays 94, 118
- online games 6, 20–2, 44, 331–45
  - see also* applications
  - anonymization 362–5
  - attacks 382
  - challenges 337–40
  - characterization 333–4, 342–3
  - commercial value 332
  - concepts 6, 20–2, 44, 331–45
  - future aspects 429
  - measurement 332–6
  - networked games 337–40
  - tools 339–40
  - types 332–3
- online processes, anonymization 366–7, 376
- operation details, Internet 25–30
- operational measurement 420–1
- optical fibers 24, 25, 27
- optimization issues, Internet 413
- optimizations, measurement load 122
- organization, Internet 14–22, 25–30
- organization specific information 363–4
- origin servers, HTTP requests 40
- origin–destination flow (OD) 66, 175–6
- OSPF (Open Shortest Path First) intra–domain routing protocol 29, 31, 35, 126–7, 153, 403
- outdegree, vertex 65–6
- over–fitting problems, modeling 75
- overhead, Web servers 276
- overlays 80, 104
- Overnet 41, 235, 309
- overview 6–10
- ownership 313–14
- P2P (peer to peer) 6–7, 20–2, 40–3, 309–31, 397
  - see also* application; Napster
  - anonymizable data 362
  - applications mix 244
  - BitTorrent 328–30
  - challenges 314–17
  - characterization 311–12, 318–19, 321–5, 327–30
  - concepts 6–7, 20–2, 40–3, 314–31, 397
  - eDonkey 327–9
  - games 341–2
  - legal considerations 40
  - measurement 40–2, 397
  - other applications 325–7
  - overlays 104
  - peer location 325–6
  - properties 310–14
  - protocols 40–2
  - tools 317–21
  - Web traffic study 292–3
  - wireless networks 330–1
- packet capturing
  - see also* libpcap; passive measurement
  - low–level monitoring tools 395–7
  - traffic 177–8, 188–90
- packet delays 94, 112–13, 118, 129–36, 153, 166–7
- packet drops 113

- packet flows 101–2, 195–6
- packet jitter 114, 168
- packet loss
  - games 335–6, 343
  - infrastructure 113–14, 123, 167–8
  - multimedia 348, 351
- packet pairs 129–32, 134, 150
- packet reordering 168
- packet size distributions 233
- packet switching 420
  - concepts 14–22, 24, 26, 28
  - diagrammatic overview 18
  - stateless switching 24
- packet tracing
  - anonymization 366, 370–3
  - backbones 82–3
  - data capture 101–3
  - data gathering 103
  - DNS 252–3
  - Web 276–8, 292, 301
- packet trains
  - autocorrelation 225
  - flow capture 194–5
  - heavy tails 225–7
  - ON/OFF processes 174
  - self-similarity 225–7
  - sessions 174–5
  - traffic structure 234–6
- packets 172–3
  - see also* packet; traffic
  - concepts 6, 14–22, 26, 28, 395–400
  - duplication 168
  - ECHO 118, 121, 135
  - filtering 86
  - headers 20–2, 32–4, 396–7
  - paths 28–31
  - routers 108–9
  - segments 22
  - TIME EXCEEDED 118–21, 133
  - time scales 216–33
  - window size 22
- pages, Web 280–2, 300–3, 305–9
- Palm calculus 73
- parallel processes, anonymization 366–7
- parameters, modeling 74–7
- Pareto distribution, concepts 52, 57–8
- Passive and Active Measurement workshop (PAM) 10
- passive measurement 124–7, 188–90, 252–4, 256, 322–4, 411–14
  - see also* packet capturing
  - BGP 124–6
  - DNS 252–4, 256
  - games 340
  - OSPF 126–7
  - P2P 322–4
  - traffic 188–90
  - Web 290, 293, 297
- path vectors 30–1
- pathchar* 415
- paths
  - bandwidth 67–70, 133, 396–7
  - concepts 28–31, 65–70
  - graphs 65–70
  - jitter 339
  - length 237
  - link weights 30
  - matrices 176
  - router graphs 160
  - traceroute 119–20
- patterns
  - anonymization 365–6
  - attack 359–60
- PCA *see* principal component analysis
- PCs
  - endsystems 18, 25–6
  - PC-based clocks 92
- PDA's 25
- PDF *see* probability density function
- Peakflow 393
- peer sets, BitTorrent 328–9
- peering 26, 81, 84–5, 126, 156–7
- peering/exchange points, autonomous systems 26
- peers, concepts 25
- percentiles, concepts 59–60
- perception
  - games players 338–9
  - multimedia users 348
- performance issues
  - commercial issues 5
  - DNS 256, 261–2
  - measurement reasons 5–6, 36
  - middleboxes 116
  - traffic 171, 184
  - Web 273, 276, 282–3, 293–9
- permission, data sharing 358–9

- personal-sensitive data 361, 363
- personalized crawlers 291
- physical devices, infrastructure 107–11
- piggybacking 257, 264–6, 285
- ping* 118, 162, 325, 339, 415
- PingER project, High Energy Physics
  - community 408
- pipelining, Web 43–4
- PlanetLab 404, 414–17
- PlanetSeer 416
- players, games 338–9, 342
- points of presence (PoPs) 82–3, 111–12, 237
- Poisson distribution 56, 68, 72–3, 219
- policy routing, ISPs 30
- polling techniques 100
- PoPs *see* points of presence
- popularity
  - DNS 266–8
  - games 331–6, 341–2, 345
  - P2P 312
  - Web 273, 279–81, 290, 303, 376
- ports
  - concepts 22, 189
  - mirroring 189
- Postel, Jon 95
- power laws 69–70, 155–6, 300–1
- predictable variation, traffic 217–18
- preferential attachment graph, concepts 67–70
- prefixes, IP addresses 21–2, 371–2, 375, 377, 411–13
- principal component analysis (PCA) 205–7
- privacy 143, 179
  - see also* anonymization
- PRO-COW compliance study 299
- probabilistic counting 203
- probability
  - see also* stochastic processes
  - concepts 7, 46, 48–58, 76–7, 180–1, 207–12, 230–1
  - measurement issues 52–8, 76–7
  - notation list 46
- probability density function (PDF), concepts 46, 49–58
- probability models 76–7, 180–1, 207–12, 230–1
  - concepts 76–7
  - real data 75–7
  - uses 76–7
- probing 122–3, 131–2, 133
- propagation delay 113, 132–3, 166
- properties
  - DNS 245–8
  - games 332–7
  - infrastructure 107–15
  - measurement areas 6–7
  - multimedia 348
  - P2P 310–15
  - traffic 172–6
  - Web 270–3, 286–9
- protocols 3–4, 6, 11, 18–22, 28–42, 80, 93–4
  - see also* architecture; individual protocols
  - anonymizable data 362
  - concepts 13–15, 18–22, 28–42
  - gateways 85
  - headers 20–2, 32–3
  - hidden layers 116, 250–1, 276–7, 316–17, 339–40
  - layers 18–22, 31–42
  - measurement 31–42
  - measurement across layers 99–104
  - overview 18–22
  - routing 28–31, 80
  - standards 299
  - time information 93–4
  - types 14–15, 18–22, 28–42, 93–4
- provisioning 83
  - see also* bandwidth
- proxies
  - anonymization 374
  - games 338, 341
  - interception proxies 277–8
  - middleboxes 116
  - mobile clients 285
  - network-aware clustering 283–4
  - P2P 313, 318
  - Web 102, 277–8, 284–7, 374
- proximity assumption 262–3, 295
- proxy-based latency estimation 137–9
- QQ *see* quantile-quantile plots
- qstat* 340
- Quagga 190, 407
- Quake games 342–5
- quality, games 339–40
- quantile-quantile (QQ) plots 209–10
- quantiles, concepts 59–60, 209–10
- queries

- DNS 248–9, 254–6, 259, 261–5, 267
- P2P 309, 310–12, 315–17, 323–4
- queuing
  - delay 112, 129, 132, 153, 167–8, 186–7
  - FIFO queuing 131
  - management 108
  - models 180
  - self-similarity 229
- RADbs *see* Routing Assets Databases
- random additive sampling 72–3
- random graphs, concepts 67–70
- random sampling 196–7
- random variables, concepts 49–58, 61–2
- rates
  - clocks 90
  - packet trains 235–6
  - sampling 196–8
- re-identification 357, 375–6
- real data, probability models 75–7
- Real Time Flow Metering (RTFM) 196
- real-time requirements, games 335–6
- Real-time Streaming Protocol (RTSP) 347–8, 350
- Real-time Transport Protocol (RTP) 347
- Realtime Traffic Flow Measurement (RTFM) 253–4
- RealTracer tool 349–50
- Record Route option 33, 121
- records 98, 146
- redirector devices 289
- references, blogs 308–9
- regional networks, concepts 15–16
- registries 79–80, 94–7
- regularization methods 213–15
- relationships, ASes 156–7
- relative variability, concepts 51–8
- remote data gathering 103–4
- reordering packets 168
- representativeness
  - client populations 274–5
  - sampling 71–2
  - wide area networks 88–9
- request counts 304–5
- request–response pair, HTTP 39–40
- Requests for Comments* (RFCs) 10, 17, 31, 39–40
- research 379, 421, 426–30
- residual capacity 128
- resolution, clock 90–1
- resources
  - ownership 313–14
  - P2P 313–14, 315–16, 320
  - records 98, 146
  - segmentation 320
- responses 264–5, 296–9, 346–7
- reverse blacklisting 390
- reverse engineering 349, 357, 359, 366, 375
- reverse proxies 288
- RFCs *see* Requests for Comments
- ‘rich get richer’ phenomenon 155, 302
- RIPE NCC 405–7
- risks, data sharing 358–60
- Riverhead 393
- RMX (reverse MX) 268
- Rocketfuel project 369
- root server study, DNS 261
- root servers 261, 412–14
- round-trip time (RTT) 118, 133, 137–9, 166–7, 232, 396–7, 415–16
  - latency estimation 137–8
  - packet delay 166–7
  - ping* 118
  - size–delay methods 133
  - very short time scales 232
- routers 6, 13, 15, 18–22, 24, 25–30, 71–2, 108–9, 152–3, 397–400
  - see also* infrastructure; links
  - anonymization 369–70
  - BGP 30–1, 35, 398–402, 407
  - concepts 15, 18–22, 24, 25–30, 108–9, 152–3, 397–400
  - configuration 369–70
  - core simplicity 177
  - decision-making 26, 28, 29–31
  - diagrammatic overview 18
  - flooding protocols 30, 41
  - forwarding decisions 28
  - graphs 111–12, 157–60, 412–13
  - Internet growth 161–3
  - local clocks 35
  - maps 29–31, 399–400
  - measurement locations 80–1, 84–6
  - peering 80–1, 84–5
  - prime function 25
  - sampling uses 71–2
  - sizes 25
  - stateless switching 24

- RouteViews project 124–6, 407
- routing
  - ASes 95, 97, 156–7, 159–61
  - concepts 26, 28–31, 35, 397–400, 412–13
  - control traffic 238–9
  - delays 112, 166–7
  - hierarchical routing 28–31, 37–8
  - instability 163–164, 238–9
  - levels 28–31
  - loops 29, 33, 85
  - measurement 35, 397–400
  - overlays 104
  - protocols 28–31, 35, 80
  - registries 95–7
  - tables 124
- Routing Assets Databases (RADBs) 96
- Routing Information Service (RIS) project, RIPE NCC 405, 407
- routing matrix, graphs 66–70
- RTCP (RTP Control Protocol) 347
- RTFM *see* Real Time Flow Metering
- RTP *see* Real-time Transport Protocol
- rtpmon* multimedia tool 349
- RTSP *see* Real-time Streaming Protocol
- RTT *see* round-trip time
- S Statistical language 397
- S-Net 397
- sampled router graphs 412–13
- sampling 16–17, 58, 70–3, 179–80, 196–9, 424–5
  - see also* metrics
  - bias 71–3, 157–8
  - concepts 16–17, 58, 71–3, 179–80, 196–9, 424–5
  - data reduction 196–9
  - event averages 72–3
  - flow data 283
  - intranet security 383
  - packet traces/flows 101–2
  - random additive sampling 72–3
  - representative measurements 71–2
  - sample means 179–80
  - time averages 72–3
  - unbiased 71–3
  - uses 16–17, 71–3
- satellite communications 24, 27
- scalars 45–8
- scale-free graphs 69
- scaling issues 45–8, 69, 218–32, 335, 342, 419
- SCIC *see* Standing Committee on International Connectivity
- scriptroute* 415
- searching
  - anonymization 363, 375
  - search engines 281–2, 326
  - Web 281–2, 300–3
- second-order property, autocovariance 53–8
- second-order stationarity, stochastic processes 53–8
- security issues 4, 9, 110, 116, 246, 268–9, 379–95, 397, 411–14
  - applications 394
  - DNS 246
  - DoS attacks 411, 413–14
  - firewalls 116, 268–9, 381–2, 384–5, 392
  - gateways 384–6
  - inter-domain attacks 386
  - Internet 380–2
  - intranets 382–3
  - measurement 379–95
  - network telescopes 412, 413–14
  - wireless LANs 110
  - worms 411, 413
- seeds, BitTorrent 328
- segments, concepts 22
- selection, peers 325
- self-induced congestion 134–5
- self-references 309
- self-similarity 221–30, 232, 421
  - asymptotic self-similarity 224–5, 230
- semi-log plots 162–3
- semi-lossy transformation 368
- sensitive information 9
  - see also* anonymization
- sensitivity, data 356, 361, 363
- sensor networks 428–9
- sequential inferencing 360
- servers
  - CDN 293–294
  - DNS 38–9, 244–69, 294–6, 360
  - eDonkey 327
  - endsystems 18, 25–6, 39–40
  - games 337–40, 343
  - HTTP requests 39–40
  - performance issues 6
  - Web 274–7, 279, 288, 294–9, 360

- service level agreements (SLAs) 86
- service providers
  - see also* Internet Service Providers
  - permissions 23
- sessions
  - games 343
  - packet trains 174–5
  - traffic structure 236
- settings, DNS parameters 248–9
- sharing data 357–60
- shingling 301
- short tails, distributions 56–8, 62–3
- short time scales 218–33
  - heavy-tails 225–30
  - long-range dependence 218–21, 224–6, 228–31
  - self-similarity 221–30
  - very short time scales 232–3
- short-range dependence 220, 224, 229
- signalling 216–17, 323
- similarity
  - see also* self-similarity
  - clustering 204
- SimMud proposal 341
- single-session games 336
- size-count disparity 182–3
  - see also* ‘elephants and mice’ phenomenon
- size-delay methods 132–4, 136
- sketches 201–2, 204
- skew, clocks 90–1, 94
- skewed distributions, concepts 62–3
- Skitter project 411–13
- Slammer worm 391, 413
- SLAs *see* service level agreements
- sliding window model 203
- smacq* 191
- small world graphs, concepts 69–70, 156
- SMTP (Simple Mail Transfer Protocol)
  - application protocol 20, 40, 43, 243
  - see also* emails
- SNMP (Simple Network Management Protocol) 16–17, 36
  - backbones 82
  - concepts 16–17, 36
  - data capture 100
  - historical background 420
  - instrumentation 102
  - intranet security 383
  - measurement 36
  - MIB 36, 193–4
  - spam 394
  - traffic counters 193–4
  - versions 36
- Snort intrusion detection tool 385
- sockets, TCP 22
- software
  - case studies 397–404
  - clocks 92
  - DNS 247
  - malware 390–2
  - mobile clients 284
  - packet tracing 102
  - requirements 79
  - viruses 379, 381–3, 390–2
  - Web 290–2
  - worms 381–2, 388, 390–3
- Sonet, link protocol layer 23
- space-code Bloom filters 201, 215
- spam 43, 268, 390, 394
- spatial distribution, wireless traffic 240
- special purpose systems, packet capture 189–90
- speed
  - anonymization 377
  - link capacity 25–7, 136
  - packet capture 190
  - packet train rate 235–6
  - traffic 421
  - worms 391–3
- spider programs 43, 279, 284–5
- SQL 404
- SRI *see* Stanford Research Institute
- stability 61, 163–4, 183–5, 238–9, 425
- standard deviation, concepts 50–63, 75
- Standing Committee on International Connectivity (SCIC) 408–9
- Stanford Research Institute (SRI) 14
- statelessness 24, 115
- static properties, AS graphs 154–60
- stationarity condition 53–8, 183–5, 224–5
  - see also* wide-sense stationarity
- statistics
  - see also* graphs; probability; sampling; tails; variability
  - autocorrelation 185–7, 211–12, 219–21, 224–5

- concepts 7, 58–63, 179–88, 231, 423, 425, 429
  - difficulties 179–88, 425
  - dimensionality 188, 203–7
  - inference 423
  - measurement difficulties 425
  - measurement issues 58–63, 425
  - memory 185–7
  - stability 183–5
  - stationarity 183–5, 224–5
  - statistical physics 423, 429
  - traffic 179–88
- Steam 340–1
- stochastic delays 166–7
- stochastic processes, concepts 52–8, 60, 76–7, 166–7, 217–18
- stochastic variation, traffic 217–18
- stored multimedia streaming 350–1
- storms of instability 238–9
- stratified sampling 196–7
- stratum levels, synchronized clocks 93
- streaming multimedia 20–2, 326, 346–52
- STREAMS system 191
- strictly–stationary condition,
  - stochastic processes 53–8
- strings 363, 369–70, 373, 375
- strongly connected graphs, concepts 65–70
- students, P2P 312, 331
- stupid network 115
- subexponential distribution, concepts 56–8, 62
- subgraphs, concepts 65–70
- success metrics 376–7
- summarization 199–203
- supercomputers 25
- supernodes, P2P 41–2
- surveys 349
- switching
  - see also* packet switching
  - ATM 421
  - Ethernet 189
  - infrastructure 115
  - Web 278
- SYN flags 34, 411
- synchronized time 93–4
- synthetic traffic 228, 344–5
- systems 73–4, 123–4, 185–7, 191
- tails 56–8, 62–3, 179–83, 210–11, 225–31, 234
  - heavy tails 57–8, 62, 179–83, 225–31, 234
  - long tails 56–8, 62–3, 179–83, 231
- TCP (Transmission Control Protocol)
  - see also* protocols; transport protocol layer
  - acknowledgements 22
  - BTC 129, 135
  - concepts 1–5, 19–24, 31, 33–4, 38, 40–2, 71, 398–9, 415, 417
  - congestion 21–2
  - connections 21–2, 114–15, 312–13
  - distributional models 209–11
  - DNS 245, 254, 257, 259–61, 265
  - FTP 43
  - games 335, 338
  - header contents 34
  - HTTP 40, 42–4, 257
  - measurement 31, 33–4, 71, 398–9, 415, 417
  - P2P 312–13
  - packet reordering 168
  - packet trains 235–6
  - piggybacking 265
  - popularity 42
  - reliability function 21–2
  - segments 22
  - self–similarity 228
  - sockets 22
  - SYN flags 34
  - tcpdpriv* 371–2, 375
  - tcpdump* 254–5, 327–8, 339, 349, 416
  - Web 276–8
- TCP/IP
  - see also* protocols
  - concepts 14–15
  - historical background 14–15
  - tcpdpriv* 371–2, 375
  - tcpdump* 254–5, 327–8, 339, 349, 416
  - DNS 254–5
  - eDonkey 328
  - games 339
  - multimedia 349
- technical factors 4–6, 16
- telephone traffic analysis 219–20
- telescopes, networks 388
- Test Traffic Measurement (TTM) project,
  - RIPE NCC 406–7
- think time 234–5, 314, 339

- three-way handshake 34
- thresholds, interarrivals 174
- throughput 114, 169
  - see also* bandwidth
- tight links 129, 132
- time averages 71–3
- TIME EXCEEDED message 33, 35, 118–21, 133
- time information 89–94
  - background 90–1
  - measurement 79, 89–94
  - sources 91–2
  - synchronized time 93–4
  - terminology 90
- time scales 216–33
  - long time scales 216–18
  - scaling behaviour 218–32
  - short time scales 218–33
  - traffic 216–33, 422
  - very short time scales 232–3
- time series 113, 172–3, 188
  - concepts 55–6, 60–2
  - memory 60–1
  - stability 61
- time series of counts, stochastic processes 55–6
- Time Stamp Counter (TSC) register 92, 94
- ‘time to glass’ 273, 293
- timers, segments 22
- TIMESTAMP message 35
- TIMESTAMP REPLY message 35
- TiVo 373–4, 376
- TLDs *see* top-level domains
- tomography, networks 66–70, 147–52, 213
- tools 117–52, 188–215
  - see also* individual tools
  - active measurement 118–24
  - anonymization 365
  - bandwidth measurement 127–36
  - case studies 9, 395–417
  - data management 191–2
  - data reduction 192–212
  - DNS 251–6
  - fused measurements 127
  - games 339–40
  - geolocation 142–7
  - IDS 385
  - inference 147–52, 212–15
  - infrastructure 117–52
  - large-scale measurement projects 404–17
  - latency 136–42
  - low-level monitoring tools 395–7
  - measurement 4–5, 7, 9, 16–17, 118–42, 395–417
  - multimedia 349
  - P2P 317–21
  - packet capture 188–90
  - passive measurement 124–7
  - security 385
  - traffic 188–215
  - Web 278–86
- top-level domains (TLDs) 38, 253, 405–7
- top-level ISPs 17
  - see also* Internet Service Providers
- topology 111–12, 154–65
  - AS graphs 154–7
  - dynamic aspects 160–4
  - geographic location 164–5
  - inference methods 151–2
  - router graphs 157–61
- traceroute 16–17, 71, 410, 412, 416
  - DNS 263–4
  - historical background 420–1
  - infrastructure 112, 118–23
  - sampling bias 158
  - Web 280
- tracing *see* packet tracing
- traffic 3–4, 6–7, 16–17, 67–70, 171–240, 333–4, 342–3, 395–417, 421–3
  - backbones 83
  - bytes 216–33
  - challenges 176–88
  - concepts 3–4, 6–7, 16–17, 67–70, 171–240, 395–417, 421–3
  - data reduction 192–212
  - DNS 245–6, 254, 258–9
  - flows 254
  - games 333–4, 342–3
  - growth 217–18
  - intranet security 382–3
  - matrices 176, 212–15, 236–7
  - networks 112–15, 165–9
  - P2P 319
  - packets 216–33
  - properties 172–6
  - RTFM 254
  - self-similarity 221–30

- shapers 116
- statistical difficulties 179–88
- synthetic traffic 228, 344–5
- time scales 216–33
- tools 188–215
- volume 184
- Web 270–3, 287, 289–93
- trajectory sampling 198–9
- transactions
  - DNS 249, 261
  - Web 270, 290
- transfer size, packet trains 236
- transformation techniques 367–9
- transmission delay 113, 129, 132, 166
- transport layer support, P2P 320–1
- transport protocol layer
  - see also* TCP; UDP
  - concepts 19–24, 31, 33–4, 40
  - measurement 31, 33–4
- transposed matrices 46–7, 67–70
- trees 149, 151–2, 327
- trends 215–18, 419–24
- tries 202
- trust 365, 393
- TSC *see* Time Stamp Counter register
- TTL (time-to-live) field
  - DNS 247, 249–50, 262, 296–7
  - IP (Internet Protocol) 32–3, 118
  - traceroute 118, 121–2
- tuples 376–7
- UDP transport protocol
  - see also* protocols; transport protocol layer
  - concepts 19–23, 31, 34–5, 38, 41–2, 119, 198–9, 244–5, 259–60, 413
  - header contents 35
  - measurement 31, 34–5, 198–9, 244–5, 259–60, 413
  - popularity 42
  - Slammer worm 413
  - unreliability 34–5
- unbiased sampling 71–3
- uncertainty, metrics 70–1
- uncongested bandwidth 128
- undirected graphs, concepts 64–70
- unicast-based inference methods 149
- Uniform Resource Identifier (URI) 39–40
- University of California, Los Angeles (UCLA) 14
- University of California, San Diego (UCSD) 412
- University of California, Santa Barbara (UCSB) 14
- UNIX 397–8, 400–3
- Unreal Tournament 342, 344
- unstable paths 119–20
- unweighted graphs, concepts 64–70
- uploading 313, 328–30
- URI *see* Uniform Resource Identifier
- URLs 38
- user-perceived latency 293, 295–7, 299
- users
  - see also* clients
  - cancellation rates 293
  - mobility 240
  - multimedia 348–9
  - populations 89, 165
  - surveys 349
  - wireless access 239–40
  - workload models 271–2, 288–9
- UTC 36
- validation, modeling 74–5
- variability 50–8, 61–2, 154–6, 158–60, 179–83, 237, 425
  - high variability 61–2, 154–6, 158–60, 179–83, 237, 425
  - random variables 50–8, 61–2
  - relative variability 51–8
- variance
  - see also* dispersion
  - concepts 46, 50–63
  - confusions 58
- vectors 45–8
- verification issues, anonymization 373
- vertices
  - see also* nodes
  - graphs 64–70
- very short time scales, traffic 232–3
- video 348–50, 351–2
- viruses 379, 382–3, 390–2
- volume
  - data 424
  - traffic 184
- vulnerability testing 385

- weak stationarity, concepts 53–4
- Web 5, 6–7, 15–16, 20–2, 25, 38–40, 43–4, 243–4, 269–308, 397
  - see also* applications; HTTP
  - anonymization 361–2, 374
  - applications 299–308
  - challenges 273–8
  - characterization 270–1, 278–81, 286–8
  - client/server roles 25, 39–40, 43–4
  - concepts 5, 6–7, 15–16, 20–2, 25, 38–40, 43–4, 270–308, 397
  - crawling 279, 281–2, 291–2, 299–302, 306
  - download times 5
  - heavy-tails 182
  - historical background 15–16, 43–4, 421–2
  - nested headers 20–1
  - pages 280–2, 300–3, 305–9
  - performance 273, 276, 283–4, 293–9
  - pipelining 43–4
  - ports 22
  - properties 270–3, 286–9
  - proxies 102, 278–9, 284–8, 374
  - research 429
  - search engines 326
  - servers 274–7, 279, 288, 294–9, 360
  - static structure 300
  - tools 278–86
  - URLs 38
- Web sites
  - anonymization 363, 376
  - content/access dynamics 289
  - flash crowds 303–5
  - growth 288
  - latency 293
  - mirror sites 293, 296, 301
  - monitoring 283
  - popularity 273, 280–1, 289, 376
  - references 308
  - World Cup 1998 288
- weblogs *see* blogs
- Weibull distribution, concepts 52
- weighted graphs, concepts 64–70
- well-known ports 22
- wget* 291
- ‘what if’ questions, modeling 76, 403
- whitehats 379, 390
- whois database 146–7
- wide area networks 87–9
- Wide project 372
- wide-area security measurement 386–94
- wide-sense stationarity
  - see also* stationarity
  - concepts 53–4
- WiFi 19, 23–4, 27, 136
- WiMAX 110
- Windmill 397–9
- window size, concepts 22
- wireless networks 5, 25–6, 109–11, 239–40, 287, 330–1, 336, 345–6, 428
  - connectivity 109–11
  - games 336, 345–6
  - measurement 428
  - P2P 330–1
  - traffic 239–40
  - Web devices 287
- Witty worm 414
- workload models 271–2, 288
- workshop papers 10
- World Cup 1998 Web site 288
- World Wide Web *see* Web
- worms 304, 382, 388, 390–3, 411, 413–14
- Zebra 407
- zero skew, clocks 90
- zing* 118
- Zipf’s law 62–3, 289
- zombies 260, 380–1